



AGROFORESTRY HANDBOOK

for the **PACIFIC NORTHWEST**



A practical guide for planning and design



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A practical guide for planning and design

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U.S. DEPARTMENT OF AGRICULTURE



CONTENTS

	PAGE
CONTRIBUTORS	1
VIDEO SERIES	2
USER'S GUIDE TO THE HANDBOOK.	3
PART I INTRODUCTION TO AGROFORESTRY	
1 WHAT IS AGROFORESTRY?	6
2 AGROFORESTRY IN THE PACIFIC NORTHWEST	14
PART II ASSESSMENT	
3 GOAL SETTING FOR AGROFORESTRY FARMS	20
4 SITE ASSESSMENT	22
PART III PROJECT PLANNING	
5 DESIGN CONSIDERATIONS FOR ALL AGROFORESTRY FARMS	66
6 SYSTEM SELECTION	84
7 SPECIES SELECTION	91
PART IV AGROFORESTRY PRACTICES	
8 ALLEY CROPPING	99
<i>Case Study: Alley cropping at Raising Cane Ranch</i>	<i>107</i>
9 FOREST FARMING	111
<i>Case Study: Forest farming at Neil's Bigleaf Maple Syrup</i>	<i>121</i>
10 FOREST GARDENS	125
<i>Case Study: Forest gardens at Sweetwater Farm</i>	<i>141</i>
11 RIPARIAN FOREST BUFFERS	144
<i>Case Study: Riparian forest buffers at Nehalem River Ranch</i>	<i>153</i>
12 SILVOPASTURE	157
<i>Case Study: Silvopasture at Spencer Shadow Ranch</i>	<i>166</i>
13 WINDBREAKS & HEDGEROWS	171
<i>Case Study: Windbreaks & hedgerows at Heart Culture Farm</i>	<i>185</i>
PART V ECONOMIC CONSIDERATIONS	
14 ECONOMIC BUDGETING FOR AGROFORESTRY	191
15 MARKETING AGROFORESTRY PRODUCTS.	195
16 INCENTIVES FOR AGROFORESTRY	203

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Established in 1998, the Center for Agroforestry is one of the longest standing agroforestry institutions in North America. Their mission of research, education, and outreach works to stand up profitable and resilient new tree crop industries for family farms across the Midwest and Eastern United States.



Center for Agroforestry
University of Missouri



Learn more at
CenterForAgroforestry.org

VIDEO SERIES

A companion to this handbook, this ongoing **Agroforestry in the Pacific Northwest video series** highlights many of the projects and individuals working to advance agroforestry practices across the region.

Credits

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Supported by a grant from [Western Sustainable Agriculture Research and Education \(WSARE\)](#)

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5 Practices Transforming Agriculture in the Northwest

This introduction to the video series speaks to the foundations of agroforestry and provides a primer into five of the primary agroforestry systems.

How Urban Agroforestry Creates Biodiversity and Abundance

Duma Community forest garden is a wonderful example of how agroforestry can be applied in urban spaces to grow enormous amounts of food while also meeting ecological needs.

Restoring Rivers with Forest Farming

The Skykomish Biocultural Restoration Field Station is showing how land tending can be a catalyst for land regeneration and for reconnecting people to place.

Partnering with Livestock to Restore Endangered Ecosystems

Val Kime's silvopasture systems show that intentional and carefully timed integration of animals into oak savannas can help restore these endangered forest types.

West Coast Maple Syrup: A Forest Farming Innovation

Neil McLeod's systems for tapping bigleaf maples and producing tasty syrup from their sap has demonstrated how forest farming can reap unexpected yields in the Pacific Northwest.

This Farm Transformed Hay Fields Into a Food Forest

Raising Cane Ranch demonstrates how tree intercropping systems such as hedgerows, windbreaks, and alley cropping can add crop diversity while buffering climate impacts.

How Wildflowers are Bringing Biodiversity to Hazelnut Orchards

Marissa Lane-Massee shows how managing hazelnut orchards with wildflower cover crops significantly reduces inputs and creates a potential second crop of native wildflower seed.

This Food Forest is Also a Public Park and River Restoration Project

Carrie Brausieck explains how a food forest and riparian buffer in Snohomish is being used to restore a river while providing free food and medicine, all within a public park.

Using Sheep to Tend the Landscape: Silvopasture at CRL

At the Center for Rural Livelihoods, Drew Thomas' rotational grazing system provides forage and shade while managing understory vegetation, cycling nutrients, and reducing wildfire fuels.

How Combining Trees and Animals Can Make Farms Resilient

Kara Huntermoon of Heart Culture farm gives a tour of her site and discusses the potential of agroforestry to provide food security and economic resilience even on challenging ground.

USER'S GUIDE TO THE HANDBOOK

Farmers, ranchers, and other land stewards often face the challenge of balancing economic viability with environmental stewardship, resilience, and community values.

Agroforestry offers a unique set of tools for achieving these goals.

By intentionally integrating trees and shrubs with crops, livestock, and other land uses, agroforestry systems can provide multiple benefits from the same piece of land. These practices can diversify income, improve soil and water resources, enhance wildlife habitat, increase climate resilience, and contribute to the overall health and sustainability of working landscapes. Because agroforestry is highly adaptable, practices can be tailored to fit specific site conditions, management objectives, and operational needs.

When thoughtfully designed and managed, agroforestry can help reconcile goals that are often viewed as competing, creating opportunities to produce food, fiber, and other products while simultaneously delivering conservation and social benefits.

This handbook explores six core agroforestry practices and their applications across a variety of agricultural and forested settings. It is intended to support landowners and resource professionals in evaluating opportunities, selecting appropriate practices, and designing systems that effectively meet their objectives.

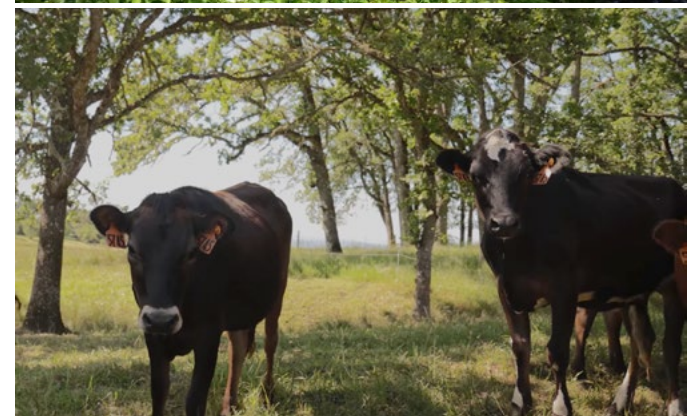
The handbook is written for agricultural and forest landowners, growers, conservation professionals,

extension educators, and others interested in managing trees for multiple functions on the landscape. It provides practical guidance and decision-making tools, but should not be considered a substitute for site-specific planning or professional advice.

Agroforestry is both a science and a practice that continues to evolve as new research, technologies, and management approaches emerge. As our understanding grows, so too do the opportunities for agroforestry to support productive, resilient, and sustainable working lands.

Outcomes of good agroforestry planning and design

- Improved quality of life
- Clean water
- Increased soil health
- Natural climate solutions
- Increased biodiversity
- Health
- Diverse farm income
- Healthy and local food supplies
- Livestock comfort



Planning process

The agroforestry planning process consists of five interconnected stages: **articulating goals**, **observing and assessing** existing conditions, developing a **design** informed by those conditions and goals, **implementing and managing** the system, and **evaluating** outcomes. The results of this final stage often lead to revised goals and the beginning of a new cycle of planning and action.

Agricultural planning processes are often portrayed as a linear sequence of steps. While this approach helps organize information and highlights the importance of completing certain tasks before others, planning is more accurately understood as an iterative process. New discoveries, changing site conditions, market opportunities, climate variability, and evolving landowner objectives can all influence the direction of a project.

Evaluation helps inform future decisions, and progress in one stage often reveals the need to revisit another. For example, implementation may uncover design challenges, design work may identify the need for additional assessment, and observations made on the ground may lead to refined goals. As a result, developing an agroforestry plan typically involves moving back and forth among the various stages as knowledge and experience grow.

This handbook focuses primarily on the first three stages of the planning cycle—articulating goals, assessing land and resources, and designing agroforestry systems. However, because successful agroforestry depends on effective implementation, management, and evaluation, these topics are also discussed throughout the handbook where relevant. Together, these stages provide a framework for developing agroforestry systems that are adaptable, resilient, and aligned with long-term landowner objectives.

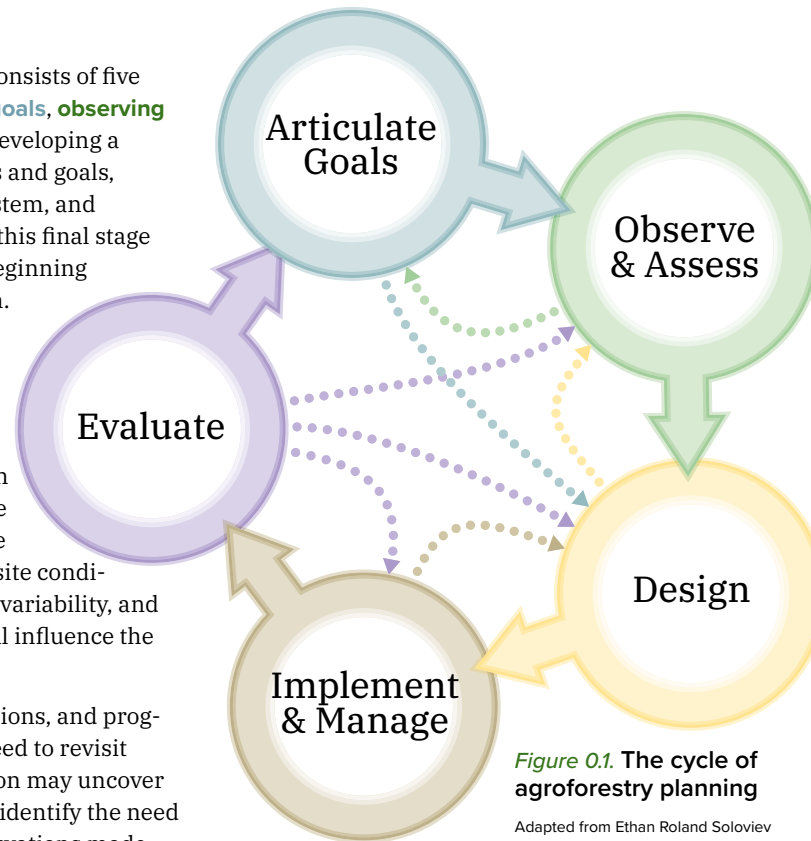


Figure 0.1. The cycle of agroforestry planning

Adapted from Ethan Roland Soloviev of Applesseed Permaculture.

Using this handbook

From meeting conservation goals to developing and marketing of specialty products, the information in this handbook is intended to support successful agroforestry planning and implementation. We hope it serves both as a practical guide and as a source of inspiration for integrating trees and shrubs into agricultural landscapes for multiple benefits.

Agroforestry practices can enhance the productivity, resilience, and ecological function of farms, forests, and ranches while generating benefits that extend beyond property boundaries. By sharing this handbook, our goal is to help landowners, managers, and communities create lasting value through the thoughtful stewardship of soil, water, air, forests, and wildlife.

How the handbook is organized

This handbook is organized into five main parts. It is designed for you to follow through these parts sequentially.

- **Part I** defines agroforestry and places it within its regional context.
- **Part II** focuses on the personal and site assessment phases.
- **Part III** addresses specific design considerations for all agroforestry farms, including guidance on the selection of systems and species based on the assessments completed in Part II.
- **Part IV** dives deeper into the design of the seven primary agroforestry systems most commonly applied in the Northwest: alley cropping, forest farming, forest gardening, riparian buffers, silvopasture, windbreaks, and hedgerows.
- **Part V** explores agroforestry markets and budgeting, and also includes a section on incentive programs and grants for planning and implementation.

- 1 WHAT IS AGROFORESTRY?
- 2 AGROFORESTRY IN THE PACIFIC NORTHWEST

INTRODUCTION TO AGROFORESTRY

The Pacific Northwest has great potential for agroforestry. As a regenerative land use system, agroforestry also presents hope at a critical time. The challenge of meeting local and global food demand while accounting for the impacts of agriculture and development on ecosystems, all in the context of an increasingly unstable climate, weighs heavily on the region's future.

As a corollary to these challenges, many critical habitats, including wet and upland prairies, oak woodlands and savannas, and riparian forests, are located on private land. These issues point to a need for an ecologically oriented agriculture capable of intensifying production while maintaining and increasing habitat in the region.

Agroforestry presents an opportunity to undertake a regenerative and just approach to addressing these interrelated factors. It has the capacity to increase food and other resource production on working landscapes while reintegrating ecosystem services and habitat. It offers a way to sequester significant amounts of carbon into soils and trees. And it presents an opportunity to revitalize and support Indigenous agroecosystems which have used agroforestry practices for time immemorial.

The following chapters both define and describe the potential of agroforestry for the Pacific Northwest.

Chapter 1 defines agroforestry and its application in the Northwest. It provides a set of ways to understand when agriculture or forestry systems may be considered agroforestry systems. It also differentiates or situates agroforestry within other common sustainable land use systems and provides a general overview of the most common types of agroforestry practices in the Northwest. Finally, it lists the benefits of agroforestry within the region.

Chapter 2 places Northwest agroforestry in a historical context from Indigenous practices to modern day applications. Looking toward the future, it also discusses priorities for increasing the regional adoption of agroforestry moving forward.

WHAT IS AGROFORESTRY?

By **Abel Kloster**,
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Author Note: This chapter is based in part on original narrative developed by Mike Gold and Andy Mason for the University of Missouri and used with permission. The chapter has been revised, expanded, and updated by Abel Kloster, Carrie Brausieck, and Patrick Shults for this publication.



Photos courtesy of Mitchel Davidovitz

Agroforestry is a new name for a series of ancient land stewardship practices applied worldwide that integrate trees with other crops and/or animals. Agroforestry is as diverse in its specific application as the landscapes and cultures that work with it.

However, the following definitions capture the essence of agroforestry:

“Agroforestry is an intensive land management system that optimizes the benefits from the biological interactions created when trees and/or shrubs are deliberately combined with crops and/or animals.”

—Association for Temperate Agroforestry, 1997

“Agroforestry projects and programs harness the full potential of agroforestry by ensuring that trees, crops, and livestock interact in mutually beneficial ways that sustain and better multiple ecosystem services.”

—CIFOR-ICRAF, *Agroforestry: A Primer*

“Agroforestry is a management system that combines agriculture and trees to address conservation needs and build more profitable and weather-resilient farms, ranches and communities.”

—USDA National Agroforestry Center

“Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately practiced on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence. In agroforestry systems there are both ecological and economical interactions between the different components”

—Lundgren and Raintree, 1982

From these definitions, one can derive a set of common characteristics. Agroforestry systems are intentionally managed to:

- include two or more species of plants (or plants and animals), at least one of which is a woody perennial;
- have two or more outputs;
- have crop cycles greater than one year;
- and are more complex, ecologically (structurally and functionally) and economically, than a monocropping system.^[1]

Key criteria

Agroforestry is recognized by meeting the qualifications of the “Four I’s”. These criteria help describe the core elements of agroforestry systems, emphasizing their purpose and separating them from other agricultural systems that may include woody perennials.

Agroforestry is intentional

Combinations of trees, crops, and/or livestock are intentionally designed, established, and/or managed to work together and yield multiple products and benefits, rather than as individual elements which may occur together or in proximity, but are managed separately. Agroforestry is neither monoculture farming nor is it a mixture of monocultures.

Agroforestry is intensive

Practices are created and intensively managed to maintain their productive and protective functions, and often involve cultivation, fertilization, irrigation, pruning and thinning. These systems are managed to reduce competition for light, nutrients and moisture between components. This occurs on a spectrum of intensiveness depending on the practice. Agroforestry systems often require fewer inputs than conventional agriculture over time, but are often managed more intensively for specific environmental and economic objectives.

Agroforestry is integrated

Components are structurally and functionally combined into an integrated management unit tailored to meet the objectives of the landowner or manager. Integration may be horizontal or vertical, above- or below-ground, simultaneous or sequential. Multiple crops and livestock are integrated to optimize the productive capacity and ecosystem services of the land and help balance economic production with resource conservation.

Agroforestry is interactive

It actively manages the interactions among components to reduce competition and optimize the yields of multiple harvestable products, while simultaneously providing numerous conservation and ecological benefits. Agroforestry can be simple, with few interactive components, but often naturally develops into complex systems that result in multiple interactive components above- and below-ground.

Related terms

Agroecology

Agroecology is the application of ecological concepts and principles to agricultural practices to create sustainable agroecosystems. It promotes agricultural systems that are environmentally sound, highly productive, and economically viable.

Agroecology is notable for its valuation of the local knowledge of farmers and recognizing the social, economic, and political factors that must be included when applying whole system thinking to agriculture and adoption of sustainable practices. Agroforestry is a key practice in agroecology, and research from the field of agroecology has contributed to our understanding of agroforestry today.

Perennial Agriculture

Perennial agriculture incorporates crops that are able to regrow and continue to reproduce grains, seeds, fruits, and biomass after at least one harvest. This can include trees and shrubs, as in agroforestry systems, but extends beyond to include perennial grains, oil seeds, legumes, and forages.

Perennial agriculture helps landowners meet productivity goals while improving ecosystem benefits and processes, such as soil health, compared to conventional agriculture.

Permaculture

Permaculture is a whole-systems and ethically based method of design that aims to organize strategies and techniques from agriculture, technology, architecture, economics, and other disciplines into mutually supportive relationships that lead to ecologically based human settlement.

Originally conceived as a conjunction of “permanent” and “agriculture” to capture a vision for perennialized agricultural system design, permaculture grew into a movement focused more broadly on the myriad facets leading to the design of sustainable places to live. As a strategy, agroforestry is foundational in permaculture as a key practice and concept for the design of agriculture and forestry systems.

Regenerative Agriculture

Regenerative agriculture describes a set of practices that are beneficial to the environment and to grower yield/profitability. Practices range from cover crops, crop rotation, no till, reduced use of synthetic inputs, to integrated crop and livestock systems and managed grazing. It can achieve soil improvement, increase crop yields, increase biodiversity, carbon sequestration and enhance livestock grazing.

Agroforestry practices may be a component of regenerative agriculture, but it is an umbrella term that describes a broad set of practices focused on creating sustainable systems.

Agroforestry practices

Agroforestry practices, both past and present, are rooted in the **traditional ecological knowledge (TEK)** of tribes and Indigenous communities. It is the origin of modern agroforestry and has been practiced in many forms in unique ecosystems around the world for millennia. Indigenous agroforestry practices are sometimes characterized by the use of native species, integration with natural ecosystems, and historical and cultural value to tribal communities.

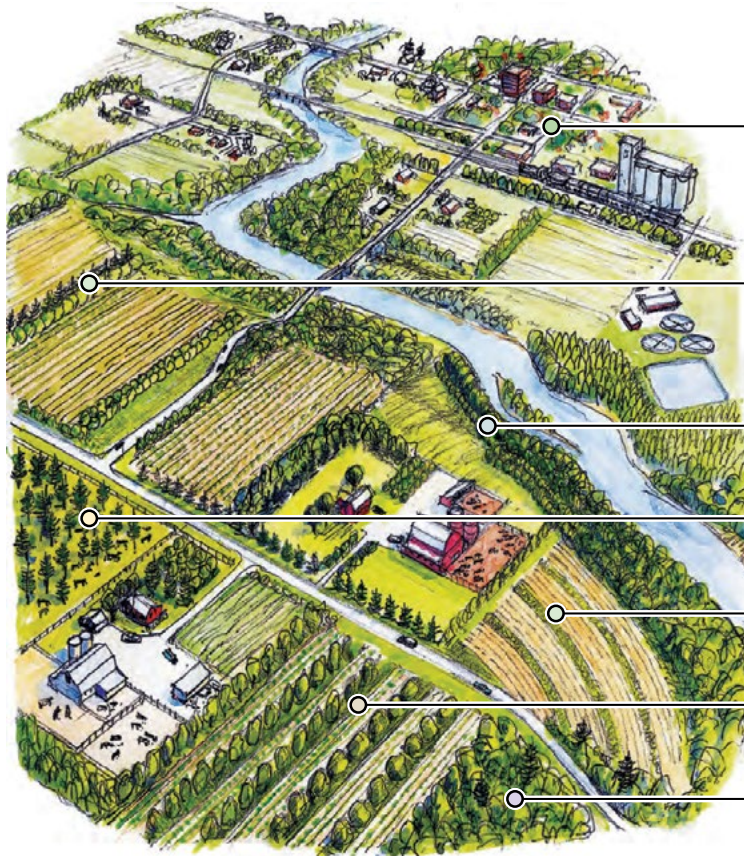
Across the US and other temperate climates, agroforestry is typically categorized into five practices: **windbreaks**, **riparian buffers**, **silvopasture**, **alley cropping** and **forest farming**.^[2] These practices are recognized and defined by the USDA via the National Agroforestry Center. The design, purpose, and management of these practices can vary significantly by region.

Two additional systems practiced relatively widely in the Northwest include **forest gardens** and **hedgerows**. Although both are considered to be important agroforestry systems, they have not yet been wholly adopted as definitions nationally. Nevertheless, because of their particular relevance and use in this region, they have been included in this handbook.

Agroforestry practices in the Pacific Northwest are implemented by diverse groups with a myriad of motivations. The unique climate and ecology of the Pacific Northwest, along with the unique challenges it faces, generates distinct adaptations of traditional agroforestry practices. Agroforestry differs regionally, and variations of these practices occur depending on economic, social, and ecological objectives.

Figure 1.1.
Agroforestry practices can be applied in myriad settings from urban homes to rural farms and forests and address a vast array of priorities ranging from income diversification to the mitigation of urban stormwater.

Adapted from Agroforestry:
Working Trees for Agriculture.
USDA National Agroforestry
Center (2012), p. 3.



<u>Practice</u>	<u>Regional priorities</u>
Forest garden	Urban biodiversity, food security
Windbreaks	Habitat, biodiversity
Riparian buffer	Forest restoration, fish habitat
Silvopasture	Habitat, biodiversity
Hedgerows	Pollinator habitat, improved forage
Alley cropping	Soil conservation, diverse yields
Forest farming	Forest resilience, income diversification



1. Alley cropping

This practice combines trees planted in single or multiple rows with agricultural or horticultural crops cultivated in wide alleys between tree rows. Alley cropping can be designed as a temporary system allowing for the production of annual crops grown in between perennial crops and/or trees until the canopy results in a decreased photosynthetically active radiation that decreases yields from annual crops. Alternatively, alley cropping can be designed to be a permanent system by incorporating low-growing perennial vegetation such as shrubs and hedgerows that complement the production of annual crops.

Alley cropping is not a common practice in the Pacific Northwest, but where these systems have been adopted landowners are commonly motivated by the opportunity to diversify, and potentially increase, income. For instance, hazelnut growers have experimented with growing agronomically viable crops between shrub rows during establishment while light availability is high. Planting trees into hayfields allows some landowners to continue to cut hay while they transition the area into silvopasture.

Expanding markets for fruit and nut producing trees that thrive in the Pacific Northwest, such as chestnuts, walnuts, and persimmon, may facilitate greater adoption of alley cropping in the region.

- Chapter 8: Alley Cropping 99
- *Alley cropping at Raising Cane Ranch*. 107



2. Forest farming

In forest farming, high-value specialty crops are cultivated under the protection of an overstory managed to produce appropriate shade conditions. This practice draws heavily from Indigenous land management and local traditional ecological knowledge. Forest farming is compatible with timber management and can include overstory trees for non-timber forest crops such as tree syrups or boughs. Forest farming can increase revenue streams or personal use crops, incentivize forest stewardship, and help sustain forests in areas with high development pressure.

In the Pacific Northwest, forest farming occurs in managed forests on private or public lands, as well as marginal woodlots on farms. Public lands and larger private ownerships are often used for low-input practices such as forest greenery and bough production or wild harvesting berries and mushrooms.

Although less common, small forests and marginal woodlots are used for more intensive practices like bigleaf maple sugaring, forest cultivated shiitake mushrooms, and cultivating high value native and non-native food and medicinal crops in the understory like Oregon grape (*Mahonia aquifolium*, *Mahonia nervosa*), tea (*Camelia sinensis*), ginseng (*Panax spp.*), and beaked hazelnut (*Corylus cornuta*).

- Chapter 9: Forest Farming 111
- *Forest farming at Neil's Bigleaf Maple Syrup* . . . 121



3. Forest gardens

Forest gardening describes a practice of creating intentional assemblages of edible and useful plants, designed to mimic the structure of a natural woodland. By mimicking the ecological niches found in a woodland, forest gardens provide both yields and enhanced ecological functions in a cultivated landscape. Forest gardens can be found nearly anywhere including farms, urban lots, schools, landscapes around commercial areas, and more.

Due to this flexibility, forest gardens are a wonderful way to bring food production closer to population centers and into food deserts, providing nutritious fresh produce and for a lower cost.

The Pacific Northwest is an ideal place to install forest gardens. Crops like berries and fruit trees grow well in our climate. Indigenous communities in the region have encouraged the growth of many species of fruiting plants and medicinal herbs to provide for their needs. Examples of these plants include salmonberry

(*Rubus spectabilis*), Pacific crabapple (*Malus fusca*), and beaked hazelnut (*Corylus cornuta*).

- Chapter 10: Forest Gardens. 125
- *Forest gardens at Sweetwater Farm*. 141



4. Riparian forest buffers

Riparian forest buffers are strips of permanent vegetation, consisting of trees, shrubs, and grasses, planted or managed between agricultural land (usually cropland or pastureland) and water bodies (rivers, streams, creeks, lakes, wetlands). Forest buffers are usually planted in three distinct zones near an agricultural stream for stabilizing streambanks, improving aquatic and terrestrial habitats, reducing runoff and non-point source pollution, and, in some cases, providing harvestable products.

Riparian buffers are frequently used in the Pacific Northwest in an effort to restore native salmon populations. Many federal, state, and local agencies provide resources to landowners interested in adopting or restoring riparian buffers on their lands. There has been growing interest and recognition of the value of “working” riparian buffers that provide opportunities for long-term harvesting of crops by integrating buffer design with other agroforestry practices.

Working buffers incentivize stewardship while allowing producers to cultivate and harvest forest crops like bigleaf maple syrup, shiitake mushrooms, and honey, while also affording for continued grazing or row cropping in the outer zones of a buffer.

- Chapter 11: Riparian Forest Buffers. 144
- *Riparian forest buffers at Nehalem River Ranch* 153



5. Silvopasture

This practice combines trees with forage and live-stock production. Silvopasture can be established by adding trees to existing pasture, or by thinning an existing forest stand and adding or improving a forage component. Trees are managed for timber or crops (e.g. fruits, nuts, boughs), and at the same time they provide shelter for livestock, reduce heat stress, and improve food and water consumption. In the winter, the protection of trees reduces cold stress therefore, animals do not lose as much energy keeping warm and are able to gain more weight.

There is growing interest in silvopasture among live-stock managers in the Pacific Northwest. It’s applied to multiple forest types and orchard settings, including grazing cattle on native understory vegetation in small, private forests and woodlands, and sheep grazing in fruit and nut orchards.

Silvopasture adoption is often motivated by the need for shade to protect livestock during the hotter summers the region is experiencing, but it may also diversify income streams with timber or tree crops. Native species are commonly used, including ponderosa pine (*Pinus ponderosa*), red alder (*Alnus rubra*), and Oregon white oak (*Quercus garryana*). Non-native species may be selected to provide additional crops, such as chestnuts (*Castanea spp.*) or fruit trees.

- Chapter 12: Silvopasture 157
- *Silvopasture at Spencer Shadow Ranch* 166



6. Windbreaks and hedgerows

It is common to see tree rows along agricultural fields. These are often left to delineate property lines or crop fields, provide wind protection, or serve as privacy screens. When managed intentionally for specific yields, these lines of vegetation take the form of windbreaks and hedgerows. These systems are planted and managed as part of a crop or livestock operation to enhance crop production, protect crops and livestock, manage snow distribution, and/or control soil erosion. Field windbreaks are used to protect a variety of wind-sensitive row crops, forage, tree, and vine crops to control soil erosion, and to provide other benefits such as improved pollination of crops and enhanced wildlife habitat. Windbreaks reduce livestock stress and mortality, improve feed and water consumption, enhance weight gain and calving, and control odor.

The Northwest saw a surge of windbreak plantings after the 1930s Dust Bowl. However, since that era, windbreaks have not been a common feature of Northwest agriculture. Hedgerows are now growing again in popularity to provide wildlife habitat on farms or as living fencing for livestock operations.

Windbreaks and hedgerows in the region are commonly a mix of native trees and shrubs, and may be designed or managed to create foraging opportunities for landowners.

- Chapter 13: Windbreaks & Hedgerows 171
- *Windbreaks & hedgerows at Heart Culture Farm* 185

Urban agroforestry

All six agroforestry practices can be applied to urban and suburban areas to address ecological and social concerns specific to those areas. Urban agroforestry can be used on urban farms, public spaces such as parks and roadsides, backyards, and more. Urban agroforestry may be designed to address a wide array of ecological issues that cities commonly face, such as air quality issues, lack of wildlife habitat, and stormwater runoff.

Urban agroforestry can also provide social benefits that improve the sustainability and resilience of communities themselves, by alleviating the urban heat island effect, providing a space for people to connect with nature, fostering connections with neighbors, promoting food security, creating privacy barriers, and educating the community about where their food comes from. Community forest gardens are one common form that urban agroforestry systems can take, and they can supply a broad array of food, social services, and ecosystem services to community members.^[3]

Agroforestry practices are fluid

These practice definitions function to facilitate understanding of agroforestry, support design and implementation, and distinguish the different benefits emphasized by individual practices. In practice, landowners and managers may elect to flex these definitions to design systems that blend those benefits in a way that best fits their objectives. Some management practices may meet the definition of agroforestry, but fall outside the definitions of the practices above, or occur in unique cultural contexts or environments.

There is inherent flexibility in how agroforestry systems are designed and implemented on the ground and this can sometimes make classification difficult. It's common for systems to link together or fit multiple practice definitions. For instance, forest farming can be practiced within riparian buffers, forest gardens may be practiced as a part of forest farming operations, and alley cropping and windbreaks both incorporate tree rows into agricultural systems, but for different purposes.

Practices can also change over time. Alley cropping systems can be transitioned to silvopasture after canopy closure, and silvopasture can be transitioned to forest farming as shade intensifies.

Regional benefits of agroforestry

Agroforestry systems are designed to fit niches within the farm to meet specific landowner objectives. They help landowners to diversify products, markets, and farm income; improve soil and water quality; and reduce erosion, non-point source pollution and damage due to flooding. The integrated practices of agroforestry enhance land and aquatic habitats for fish and wildlife and improve biodiversity while sustaining land resources for generations to come.

In a changing climate, agroforestry practices can be designed and strategically located to provide greater resiliency in agricultural landscapes so landowners can meet production objectives when faced with extreme weather (e.g., drought, floods). Tree-based practices sequester significant amounts of carbon that can help meet future potential greenhouse gas reduction goals.

Carbon sequestration

Warming temperatures and changes in rainfall will alter vegetation types across the region as climate zones move north in latitude and up in elevation. This unparalleled rate of change in habitat and species distribution will directly bear on biodiversity, ecosystem services, and cultural use of plants and animals. Agroforestry systems could contribute significantly to the region's goals to sequester carbon on working lands across the state and mitigate the effects of climate change.

Agroforestry systems incorporate perennial vegetation. This vegetation is more productive at sequestering carbon than annual vegetation as it allocates more carbon below and above ground. Deeper roots and above ground biomass occupy more dimensional space and carbon is also able to be sequestered

deeper in the soil profile. The season of sequestration is also often extended as trees continue to build up carbon for a longer growing season than most annuals and microclimates enable further productivity for ground level vegetation to put on growth.

Additionally, often the growing season of the trees and grasses are not the same, providing for a longer sequestration period. For instance, in the Pacific Northwest, cool season grasses are largely dormant in the summer while trees are photosynthesizing, while in the winter, trees are dormant while grasses are active.

Mitigating impacts of climate change

Agroforestry stands out for its capacity to fulfill mitigation needs while also being a strong tool for climate adaptation. Improvements in microclimates through wind mitigation, shade, and buffering the impacts of extreme weather events brings about multiple benefits. Shade from agroforestry practices can help limit heat stress and improve yields of crops. For example, cool season grasses produce better in the summer under partial shade, which improves their forage quality by increasing protein content.

Diversified yields from agroforestry systems reduce risk under increasingly unpredictable climate conditions. Interactions between trees and crops can also lead to new synergies. For instance, some trees, such as walnuts (*Juglans spp.*) and oaks (*Quercus spp.*), partition their roots deeper than grasses to obtain water and nutrients from separate soil horizons. In this way water competition is limited while the tree roots also catch and recirculate surplus nutrients and water from deeper soil layers back to the soil surface.

Finally, with the potential to increase both native and novel perennial tree and shrub species, agroforestry provides an opportunity to move species to more favorable conditions and conserve biodiversity through on-farm conservation as native ranges shift under climate change.



Left:
Val Kime shows how diverse native plants thrive in silvopasture at her ranch in Eugene, Oregon. Much of the oak savanna has been restored and is managed with rotational grazing.

Photo courtesy of Mitchel Davidovitz

Biodiversity

Prior to colonization, the region was composed of a human-tended mosaic of riparian forests, wetlands, hardwood dominated woodlands, ancient forests, and both wet and upland prairies. Agroforestry systems have the potential to rekindle practices and plant and animal communities associated with declining habitats, ecological functions, and cultural traditions.^[4] In doing so, agroforestry becomes a tool for the maintenance and expansion of biodiversity.

There are several ways that agroforestry systems contribute to biodiversity. First, they provide habitat for sensitive species by increasing the availability of nesting, foraging, and sheltering spaces for wildlife and integrating ecological conditions that support rare plants. An example of this would be implementing a silvopasture system in oak woodlands and savannas using prescribed grazing to maintain plant and animal diversity.

Agroforestry systems can preserve germplasm of sensitive species. Trees on farms can serve as conservation strategies for species that would otherwise only occur in rare or protected sites. This decreases the need for plants to be harvested in the wild while increasing their abundance. One example would be

incorporating the Hinds' walnut (*Juglans hindsii*) into riparian forest buffer plantings or bottomland forest silvopasture systems in Oregon. This tree is threatened with extinction in Oregon where it was harvested extensively for its wood in the homesteading era.

By modeling agricultural ecosystems more similar to natural forest, woodland, or shrub ecologies, agroforestry systems buffer the abrupt edge between natural habitats and agricultural landscapes. Typically, where plant diversity is higher, animal diversity follows.

Agroforestry can increase connectivity by creating corridors between isolated habitats. In this way agroforestry plots become stepping stones between larger core habitats. Alley crops and windbreaks integrated into grazed pastures, grass seed farms, or other large acreage can connect waterways and woodlands to allow for sheltered passage of wildlife across the fields.

Finally, agroforestry prevents habitat degradation by providing ecosystem services like erosion control, water recharge, and water quality improvements. For example, urban forest gardens can help manage stormwater in cities, helping local water recharge while providing food and aesthetic services.

Food systems

Food security promises to be a more pressing concern under climate change in the region. Forecasts demonstrate that the stresses of climate change will make annual crop production increasingly problematic and likely decrease overall productivity in the second half of this century. Agroforestry systems can serve as resilient food production systems while providing ecosystem services and mitigating and adapting to climate change. Perennials, with their deeper root systems, thicker bark, and adaptations to seasonal changes, often bring more resilience to farms than annual-only cropping systems.

Many agroforestry crops are also better suited to marginal land than annual crops. By being grown in soils and landscape contexts not typically used for annual production, crops grown in agroforestry systems can increase regional food supplies. However, simply by integrating perennials into existing agricultural systems, agroforestry has the potential to add millions of hectares to the production base of the United States without loss of protection of environmentally sensitive lands. Greater resilience to climate effects coupled with diversified local food systems brings more food security and strengthens local supply chains.

The combination of diversified food production and ecosystem services can also impart greater economic resilience. This is especially imperative in Oregon and Washington, where more than 3.5 million acres of farmland has been lost to development over the last 30 years.

Economic benefits

Farmers in the United States identify income diversification as one of the primary benefits of agroforestry systems.^[5] Income diversification occurs through the potential to integrate timber, fruit, or nuts into a grazing or annual cropping enterprise or by bringing animals and vegetables into tree crop systems.

Agroforestry also benefits farm income by enhancing ecosystem services. The microclimate effects of trees in pasture lead to temperature buffering effects which can improve crop yields, increase livestock weight gain and milk production, and extend the growing season of crops and livestock. Improvements in soil nutrient cycling, water retention, and pollination can all impart greater productivity and economic gains under agroforestry systems.

Social benefits

The ecological and economic benefits of agroforestry also lead to positive social impacts. Through their cultivation, agroforestry can become a tool for restoration of cultural foods, medicines, and craft materials as well as the practices like cultural fire that sustain them. Indeed many of the region's native plants are traditional agroforestry crops.

Agroforestry practices create diversified, perennial operations that broaden the suite of agricultural products available to local communities. Adoption of agroforestry practices on farms works in tandem with developing new markets and awareness of high-nutrition perennial products like elderberry and choke-cherry.

These practices can also create more attractive agri-tourism opportunities, which further diversify farm operations while developing stronger links between communities and local agriculture. The resulting farm resilience is critical for the mental and physical well-being of small farmers in the face of increasingly unstable climate and economic conditions.



Above: Frank Lake and his son Leland burning the understory of their tan oak and hazelnut woodland.

Photo courtesy of Frank K. Lake, PhD

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AGROFORESTRY IN THE PACIFIC NORTHWEST

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The Pacific Northwest, with its fertile soils, temperate climate, and abundant water supplies, is a highly productive agricultural region with great potential for agroforestry. But the challenge of meeting local and global food demand while accounting for the impacts of agriculture and development on species and ecosystems—all in the context of an increasingly unstable climate—weighs heavily on the region's near-term future. These issues point to a need for an ecologically oriented agriculture capable of intensified production while maintaining and restoring habitat in the region.

Agroforestry presents an opportunity to undertake a regenerative and just approach to addressing these interrelated factors. It has the capacity to increase food and other resource production on working

landscapes while reintegrating ecosystem services and habitat. It offers a way to sequester significant amounts of carbon into soils and trees through agroecological practices. And it presents an opportunity to revitalize and support indigenous agroecosystems which have used agroforestry practices for time immemorial in the region.

The Pacific Northwest has the ecological conditions, land-based knowledge, and producer interest needed to become a leading agroforestry region. Realizing that potential will require reconnecting modern agricultural systems with Indigenous stewardship traditions, regional research, technical assistance, and supportive policy.

Indigenous agroforestry

Indigenous peoples throughout the world have developed and adapted agroforestry systems to cultivate food, fiber, medicinal plants, wildlife habitat, and resilient ecosystems. In the Pacific Northwest, these systems have included burning to renew prairies and oak savannas, pruning and coppicing to encourage

useful plant growth, tending wetlands and aquatic gardens, transplanting culturally important species, and maintaining habitat features that support both target species and broader ecological health.^[1]

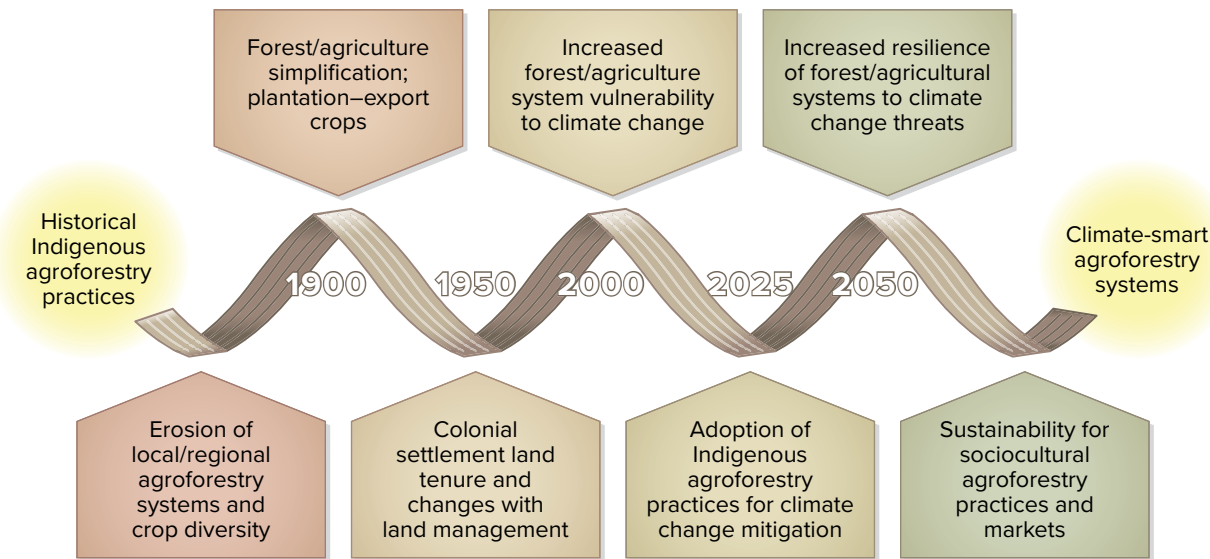
Regional examples are diverse. Aquatic polycultures have included wapato (*Sagittaria latifolia*), wokus (*Nuphar polysepala*), and hardstem bulrush (*Schoenoplectus acutus* var. *occidentalis*). Upland and savanna systems have included Oregon white oak (*Quercus garryana*), camas (*Camassia* spp.), tarweed (*Madia* spp.), and habitat for deer, elk, pollinators, birds, and other wildlife. Many plant communities now treated as wild, rare, or remnant landscapes are also living legacies of Indigenous cultivation and stewardship.

Prescribed fire was one of the central tools used by many Tribal communities in the Pacific Northwest to maintain prairie edges, oak woodlands, savannas, and other culturally important ecosystems. Fire supported

Above: Indigenous fire management in a tan oak forest promotes healthy acorns, hazel, and wild strawberry.

Photographer: Stormy Staats; courtesy of the Western Klamath Restoration Partnership

Figure 2.1. Timeline of influences on Indigenous agroforestry



Adapted from Frank K. Lake, Gen. Tech. Report WO 96, Chapter 5: Human dimensions of agroforestry systems, fig. 5.3.

vegetation renewal, improved access to foods and materials, and enhanced wildlife habitat helped sustain open conditions needed by many native plants.

These stewardship systems were carried out by skilled land managers and applied ecologists whose work was guided by cultural responsibility, governance, and intergenerational knowledge. Today, many of these practices continue through Tribal natural resource programs, cultural burning, restoration projects, first foods initiatives, native plant propagation, and community-based education. **Traditional Ecological Knowledge (TEK)** is not simply a historical source for modern agriculture; it is an ongoing body of practice connected to people, place, governance, and cultural survival.

Colonization disrupted and damaged many of these systems. Forced displacement, land seizure, warfare, boarding schools, and other acts of violence broke stewardship relationships and interrupted the transfer of knowledge across generations. The effects are still visible in the decline of native plant and animal communities, suppression of cultural fire, loss of access to

traditional foods and gathering places, and continued food insecurity in many Indigenous communities.

At the same time, Indigenous agriculture and stewardship are being revitalized across the region. Western Oregon Tribes and other Pacific Northwest Tribal communities continue to integrate Indigenous knowledge with restoration, economic development, food sovereignty, and cultural renewal. Agroforestry efforts in the region should support this resurgence by respecting Tribal leadership, protecting culturally important species, and ensuring that partnerships return benefits to Indigenous communities.

Traditional and Indigenous approaches to agriculture provide a foundation for agroforestry in the Pacific Northwest. They show that productive landscapes can be managed for people, wildlife, water, soils, foods, medicines, and materials at the same time. For contemporary agroforestry, the lesson is clear: the future of diversified working lands in this region should be rooted in respect for the stewardship systems that have long sustained them.^[1,2]

Agroforestry and modern agriculture

Outside of Indigenous land stewardship, agroforestry has played a relatively limited role in the modern era of conventional agriculture in the Pacific Northwest and across much of the United States. In national agricultural history, the large-scale planting of windbreaks in the Great Plains after the Dust Bowl is often treated as a key turning point. Those efforts demonstrated that trees could protect soils, reduce wind erosion, buffer crops and livestock, and improve the resilience of working landscapes.

Public programs such as the Civilian Conservation Corps helped plant many of these windbreaks while also supporting reforestation on public and private lands. Even where agroforestry was not the explicit goal, these projects challenged the idea that trees and agriculture belonged in separate landscapes. They also created early examples of how federal programs could support tree-based conservation on farms and ranches.

Interest in agroforestry grew slowly after those early efforts. The dominant agricultural model of the mid-twentieth century emphasized specialization, mechanization, and high-yield annual production. Diversified systems that combined trees with crops, livestock, and conservation practices often received less research attention, less technical support, and fewer clear markets.

By the late twentieth century, agroforestry began gaining renewed attention as a way to address soil health, water quality, biodiversity, climate resilience, and farm diversification. National organizations, university programs, and federal technical resources helped define agroforestry as a practical field of research and implementation. Since then, agencies, universities, conservation districts, nonprofits, and farmers have increasingly used agroforestry practices to meet both production and conservation goals.^[2]

In the Pacific Northwest, modern agroforestry adoption has followed this broader national pattern while reflecting the region's distinct landscapes. Common practices include forest farming, silvopasture, riparian forest buffers, hedgerows, windbreaks, alley cropping, and tree-based systems on small farms and peri-urban lands. These practices can be adapted to moist west-side valleys, oak savannas, inland dryland farms, forest edges, riparian corridors, and mixed crop-livestock operations.

Reported adoption in Oregon and Washington appears higher than the national average, but regional research, training, and technical assistance have not kept pace with producer interest.^[3] Many landowners are curious about agroforestry but lack locally tested models, economic examples, planting guidance, market information, and support from professionals who understand both agricultural and forestry systems. This gap is one of the central challenges for expanding agroforestry in the Northwest.^[4]

Agroforestry implementation in the Pacific Northwest has followed a similar trajectory to the rest of the country but boasts a larger number of farms practicing agroforestry compared to the national average. According to the 2022 census of agriculture, 4% and 3.25% of all farms in Oregon and Washington, respectively, reported having at least one agroforestry practice, while California and Idaho stood at 1.3% and 1.5%, respectively.^[3]

Increasing agroforestry adoption

The Pacific Northwest has strong potential for agroforestry adoption. Farmers, forest owners, Tribal governments, conservation districts, watershed councils, extension programs, and nonprofit organizations all have reasons to support tree-based systems that combine production with ecological repair. Turning that interest into widespread implementation will require coordinated work in five areas: research and demonstration, technical assistance, incentive programs, policy support, and partnerships.

Research and demonstration

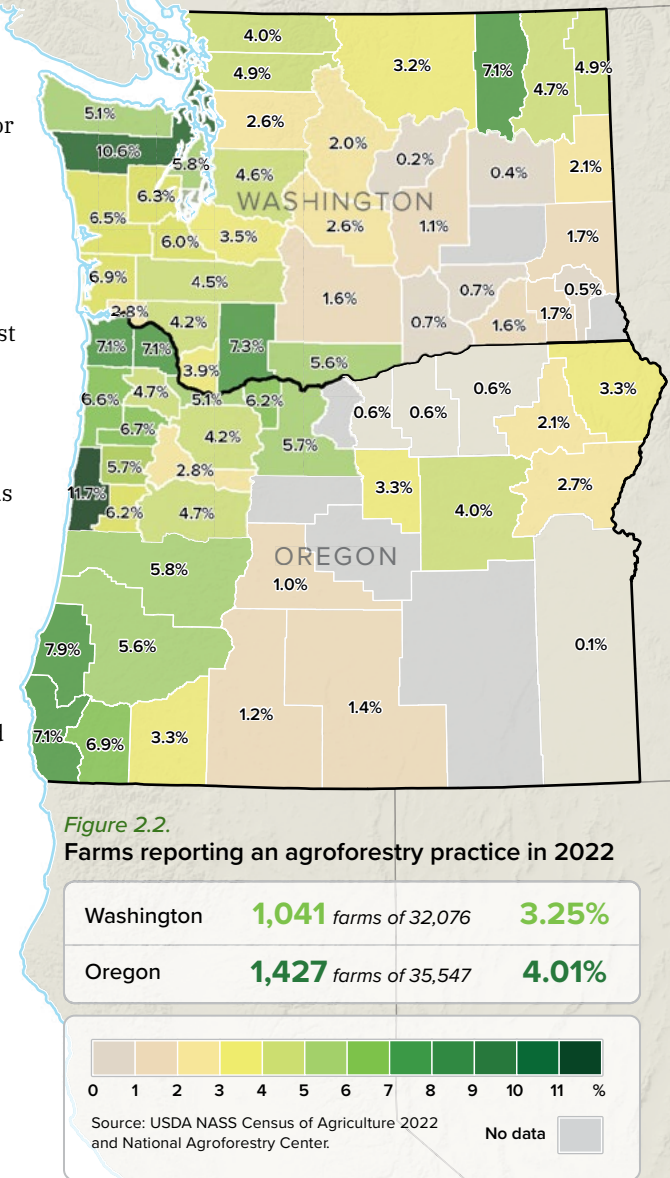
The region needs more research and demonstration sites that show how agroforestry works under Pacific Northwest conditions. Producers are more likely to adopt new practices when they can see local examples, understand establishment costs, compare management options, and evaluate realistic production outcomes. Demonstration sites also provide places for workshops, field days, peer learning, and technical training.

Research should address both ecological and economic questions. Priorities include silvopasture in western Oregon and Washington, riparian buffers in agricultural watersheds, forest farming in moist forest zones, oak savanna restoration with compatible production, hedgerows and windbreaks for pollinators and microclimate benefits, and agroforestry strategies for drier inland farms. Research funding should also support Tribal-led projects that apply Indigenous stewardship practices, cultural burning, native food systems, and culturally important plant restoration within agroforestry contexts.

Regionally adapted plant material is another important need. Agroforestry systems depend on trees, shrubs, and understory plants that can survive local soils, drought, heat, flooding, browsing pressure, and management conditions. Trials of native and noninvasive perennial crops, culturally important species, forage-compatible trees, and climate-resilient genotypes would help practitioners design systems with greater confidence.

Technical assistance

Many producers and land managers identify lack of information as a major barrier to agroforestry. Technical assistance is also limited. Conservation staff, agricultural consultants, extension educators, and agency professionals are often trained in either agriculture or forestry, but not always in the combined systems that agroforestry requires.



Expanding adoption will require professionals who can help landowners assess sites, select appropriate practices, design plantings, estimate costs, plan establishment, manage livestock interactions, protect young trees, navigate incentives, and connect products to markets. This assistance should be practical, locally specific, and accessible to producers with different farm sizes, land tenure situations, cultural priorities, and financial resources.

Useful tools could include extension publications, fact sheets, videos, webinars, podcasts, decision guides, enterprise budgets, design templates, and case studies from farms in Oregon, Washington, Idaho, northern California, and British Columbia. Training programs for technical service providers should be paired with farmer-to-farmer learning, field days, and peer networks so that knowledge moves through both professional and community channels.

This handbook is one contribution to that broader need. Its purpose is to help technical service providers, farmers, forest owners, and community partners understand how agroforestry practices can be planned, adapted, and implemented in the region's varied landscapes.

Incentive programs

State and federal incentive programs can help reduce the financial risk of establishing agroforestry systems. Many agroforestry practices have upfront costs, delayed returns, and management requirements that can discourage adoption without cost-share, grants, or other support. Incentives are especially important for practices that produce public benefits such as cleaner water, wildlife habitat, carbon storage, cultural foods, soil protection, and climate resilience.

Although few state agencies explicitly fund “agroforestry” as a stand-alone category, many already support practices that overlap with agroforestry goals. Conservation districts, watershed councils, state conservation agencies, and restoration funders can support tree planting, riparian restoration, habitat



Left:
The Center for Rural Livelihoods maintains an agroforestry research and demonstration site in Oregon.

Photo courtesy of Mitchel Davidovitz

enhancement, fencing, water systems, site preparation, invasive species control, and related practices that make agroforestry systems possible.

The Natural Resources Conservation Service (NRCS) can also support many of the practices described in this handbook through conservation planning and cost-share programs. Supporting practices such as water pipelines, cross fencing, site preparation, tree and shrub establishment, forage improvement, and riparian planting may be combined to create functional agroforestry systems. Urban forest gardens may require separate funding pathways or local programs.

Future funding could better recognize the full range of benefits agroforestry provides. Programs that support cultural foods, pollinator habitat, salmon recovery, oak savanna restoration, carbon sequestration, drought resilience, water quality, and farm viability could all help advance agroforestry when they are designed to work on active farms and forestlands.

For more details about regional incentive programs see **Chapter 16 Incentives for Agroforestry**

Policy support

Agroforestry can help meet existing public goals for climate mitigation, habitat restoration, water quality, soil health, local food production, wildfire resilience, and rural economic development. However, these goals are often addressed through separate programs, while agroforestry works across categories.

Better policy alignment would make it easier for landowners and agencies to use one integrated practice to achieve multiple benefits. Policy support could include clearer recognition of agroforestry in state conservation strategies, climate plans, working lands programs, watershed restoration priorities, and agricultural assistance programs. It could also include training for agency staff, simplified cost-share pathways, support for long-term maintenance, and metrics that value both production and ecological outcomes.

Federal agroforestry frameworks and USDA programs already provide a foundation, but regional implementation depends on state agencies, conservation districts, Tribal governments, watershed councils, extension programs, and local partners. These institutions can help translate broad policy goals into practices that fit Pacific Northwest landscapes.

Partnerships

Agroforestry sits at the intersection of agriculture, forestry, restoration, food systems, climate adaptation, and community development. Because of this, partnerships are essential. No single institution can provide all of the research, funding, training, cultural knowledge, technical assistance, and market development needed to expand agroforestry across the Northwest.

Effective partnerships could connect Tribal governments, farmers, forest owners, universities, extension services, conservation districts, watershed councils, nonprofits, state agencies, federal agencies, and buyers of agroforestry products. These partnerships can support demonstration sites, field days, technical trainings, applied research, policy development, and peer-to-peer learning networks.

Partnerships should also be designed with care. Projects involving Indigenous knowledge, culturally important species, or Tribal lands must be led by or developed in direct partnership with Tribal governments and communities. Data, benefits, recognition, and decision-making authority should be handled in ways that respect sovereignty and avoid extractive uses of knowledge.

By strengthening research, technical assistance, incentives, policy support, and partnerships, the Pacific Northwest can move agroforestry from scattered examples to a more visible and supported part of regional agriculture. The future of agroforestry in the Pacific Northwest builds on deep regional knowledge,

long-standing stewardship traditions, and growing interest among farmers, forest owners, Tribes, agencies, and communities. It will grow from renewed respect for Indigenous stewardship, practical support for farmers and forest owners, and regional collaboration that treats trees, crops, animals, water, and people as parts of the same working landscape.



Above: A forest garden at the Duma Community House in Eugene Oregon stands out as an island of green. Agroforestry can support biodiversity, stormwater mitigation, and food security in urban areas.

Photo courtesy of Mitchel Davidovitz

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II

- 3 GOAL SETTING FOR AGROFORESTRY FARMS**
- 4 SITE ASSESSMENT**

ASSESSMENT

The development of a plan for agroforestry practices is as important as the establishment of the practice itself.

The steps outlined in this handbook help identify suitable agroforestry practices, appropriate species, and profitable products. Time spent researching, preparing, and following a plan is an investment in the future success of an agroforestry system.

An agroforestry plan is based on land capability, personal and business goals, and land stewardship objectives. These goals may change as new information is gathered during planning and implementation. Understanding and working with change supports successful outcomes.

Landowners have different personal and production goals, so each agroforestry plan will vary by location and context. To accommodate these differences, this guide provides tools for making informed decisions and creating a profitable agroforestry business.

Many sources of information and advice are available to support agroforestry planning. Because agroforestry often involves fields such as forestry, agronomy, animal husbandry, horticulture, soil science, and marketing, additional knowledge may be needed. Sources listed throughout this handbook are intended to guide that process.

Chapter 3 walks through the process of defining holistic personal goals. Good goals consider economic, environmental, and community contexts. Establishing holistic goals allows a planner to chart a design path that is informed by strong intentions. It also provides a way to evaluate the success of the work after implementation, ensuring that outcomes remain aligned with the original intent. In this way, goals function both as a guide and as a monitoring tool.

Chapter 4 outlines the site assessment phase of agroforestry planning. From the history of land use to the present day soils, the conditions of the land will ultimately inform the type of agroforestry species and practices most appropriate to the site. Coupled with your personal goals, the land context understanding that arises from this assessment will set the stage for designing the specific elements of your agroforestry farm.

CHAPTER
3
**GOAL
SETTING FOR
AGROFORESTRY
FARMS**

By Jared Busan,
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Goal setting is a useful starting point for agroforestry farms. In systems where trees, crops, and sometimes livestock are integrated, complexity increases, along with the range of possible yields. Clear goals provide structure for managing that complexity over time.

This approach draws on holistic management principles, particularly the work of Allan Savory, which emphasizes defining a whole-system context that includes economic, environmental, and social outcomes. This is important in agroforestry as decisions rarely affect a single component in isolation.

Agroforestry systems develop over years or decades. Trees require time to establish, interactions between system components evolve, and early decisions influence long-term outcomes. Without clearly defined goals, it becomes difficult to balance short-term needs with long-term system development.

Whole farm planning provides a structure for this process. It connects system-level goals to the broader realities of the farm. Rather than focusing only on what the system produces, it considers how the farm functions as a whole. It shapes choices such as how to:

- earn income from underused land
- reduce costs of an existing farm or forest operation
- develop a source of long-term income
- develop a source of short-term income while awaiting long-term income from tree crops
- reduce property taxes
- protect or improve environmental conditions
- increase grazing opportunities

Connecting goals to the whole farm context helps guide agroforestry design so it meets both immediate needs and long-term objectives. Whole farm planning is built around three connected areas:

1. **Quality of life** defines how the farm is meant to support the people involved. It considers income, workload, health, roles, and long-term lifestyle.
2. **Forms of production** define what the farm must produce to support that quality of life. This includes income, but also food, ecological benefits, and social outcomes. It aligns production with available resources, labor, and markets.
3. **Future resource base** defines what must be in place over time. It considers soil, water, skills, infrastructure, finances, and community support and includes long-term planning such as succession and training.

These areas should be considered together and revisited regularly. This process should involve everyone connected to the farm including family members, business partners, and others whose work or future depends on it. Different priorities will exist. Discuss them early to build a shared direction and avoid conflict later. Set aside time to work through each area. This can be informal or structured, but should allow for open discussion. Written notes are useful.

More details about these three areas of consideration, as well as examples, are elaborated below.

Evaluating goals and decisions

These questions are not meant to be complete or answered once. Revisit them regularly as conditions change and experience builds. Whole farm planning is iterative and ongoing.

Quality of life, forms of production, and the future resource base are not fixed. Over time, goals may shift as circumstances change, including markets, policies, and personal priorities. Adjust and refine goals as needed. Goal-setting is a process, not a finished plan.

Review progress on a regular basis—monthly, seasonally, or annually—across all three areas:

- Is the farm creating the lifestyle it's meant to support?
- Are any resources degrading or becoming a challenge?
- What's getting better, and what needs more attention?
- Is community involvement where it needs to be?
- Are both personal and production goals on track?

Whole farm planning involves regularly taking stock of current conditions, available resources, and long-term direction. It should be revisited and adjusted as both farm and people managing it change over time.



Above: The long-term success of an agroforestry project rests on the establishment of clear and holistic goals.

Photo courtesy of Abel Kloster

1. Quality of life

Quality of life reflects values, priorities, and preferred ways of working and living. This includes economic security, work-life balance, health, community involvement, and the type of work undertaken. These priorities shape all other farm decisions, and should therefore inform the goals of an agroforestry system.

Key questions:

- What is the motivation for starting or changing the farm?
- Is full-time or part-time work preferred?
- What is a realistic workload?
- What does a healthy work-life balance look like?
- What defines success?
- Is the work done independently or with others?
- Which parts of the operation are preferred (production, marketing, management, etc.)?
- What does financial security look like?

Examples:

Working with family while maintaining financial independence and time for personal development

Living on a productive farm that supports both livelihood and environmental stewardship

2. Forms of production

Farms need to produce things in order to sustain the quality of life desired. This is more than just economic, this can be building social structure, creating political or policy change, producing benefits for the surrounding ecosystem.

Agroforestry may produce marketable products including food, fiber, and timber, ecological benefits like improved soil health and enhanced biodiversity, and desirable social outcomes like community connections and knowledge sharing.

Key questions:

- What resources are available to invest in this operation?
- What level of capital can be invested?
- Is the land owned or rented, and what limits or opportunities does this create?
- Is off-farm income required to make the farm operation successful in the short or long term?
- What external factors influence the farm?
- Are there existing markets for products or services?

Examples:

Enhancing local food security through market and selling at local markets

Utilizing waste outputs from one stream as an input for another stream, such as rainwater capture for irrigation or manure to fertilizer

Being part of a local farmers collaborative network sharing knowledge and best practices derived from experience

3. Future resource base

The future resource base defines what must be in place to sustain both production and quality of life over time. This includes natural, financial, and social resources. Consider soil condition, water availability, knowledge, infrastructure, and community systems.

Key questions:

- What condition should the soil and water be in?
- What skills or knowledge need to be developed?
- What role does the farm play in the community?
- What external resources are available (co-ops, extension services, etc.)?
- How might surrounding land use change?
- What long-term planning is needed (succession, land access, partnerships)?

Examples:

Eliminating or minimizing erosion from farm activities

Producing healthy foods with minimal inputs and minimal miles traveled, farm to table

Having a comfortable income for my family, working with my kids to take over the farm

Creating diverse habitat for native wildlife while maintaining a productive farm



CHAPTER 4 SITE ASSESSMENT

By Abel Kloster,
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Integrated farm design is a central goal of agroforestry planning, but it can be difficult to translate that goal into a practical sequence of decisions. Some farms begin with little existing infrastructure, while others already have roads, fences, water systems, buildings, and production areas that must be reorganized or expanded to support new agroforestry enterprises. In either case, the challenge is not simply to add trees, but to understand how each part of the farm functions within the whole.

A holistic farm plan helps organize these decisions so that major elements—such as access, water, fencing, buildings, tree crops, livestock areas, and annual or perennial cropping systems—are considered together rather than in isolation. When these elements are planned in relationship to one another, they can become mutually supportive: roads can improve access to harvest areas, water systems can serve both crops and animals, and tree plantings can be located where they enhance rather than obstruct future management.



This kind of planning is especially important in agroforestry because trees are long-term commitments. A poorly placed planting can limit future options for roads, ponds, buildings, fencing, or other infrastructure. For this reason, agroforestry design benefits from structured planning frameworks drawn from ecological design, permaculture, holistic management, keyline planning, and conservation planning.

These approaches help planners move from broad site context to specific design choices, creating farm layouts that are both ecologically grounded and practically workable.

This handbook has borrowed from a series of approaches to provide a holistic framework for planning

and design. These include Allan Savory's **Holistic Management** and its applications for developing holistic goals and objectives, and the **Keyline Scale of Permanence** for organizing the site assessment process. The Keyline Scale of Permanence originated with Australian mining geologist and rancher, P.A. Yeomans. Contemporary applications of keyline planning have also been strongly shaped by Darren Doherty and the **Regrarians Platform**, which have helped translate keyline concepts into modern whole-farm planning frameworks.

Within the Keyline Scale of Permanence, relatively fixed factors such as climate, landform, and legal constraints establish the context for subsequent design decisions. For this handbook, the scale has been expanded to include additional considerations relevant to agroforestry planning, including land use history, air quality, energy use, and aesthetics.

This expanded framework also draws from the NRCS **SWAPA-E** framework, which considers soil, water, air, plants, animals, and energy as interconnected factors in agricultural planning and management.

Together, these frameworks provide an order for observing the site before making design decisions. The sections that follow translate this framework into a practical assessment process, beginning with mapping and then moving through the major site factors that shape agroforestry planning.

Refer to David Jacke and Erick Toensmeier's goal-derived adaptation of the Keyline Scale of Permanence site analysis in **Edible Forest Gardens, Vol. 2**.

Table 4.0. Site assessment frameworks

NRCS SWAPA-E	Keyline Scale of Permanence	This Handbook
• Soil • Water • Animals • Plants • Air • Energy	• Climate • Landform • Water • Roads • Trees • Permanent buildings • Subdivision fences • Soils	• Land use history • Climate • Legal and regulatory frameworks • Landform • Soils • Water • Access systems • Vegetation • Animals • Buildings • Fencing • Energy systems • Air • Aesthetics

Mapping for site assessment and design

The first step in site assessment is to develop a base map that can guide field evaluation, planning, and design. A good base map provides a shared reference for documenting existing conditions, identifying constraints, and locating opportunities for agroforestry development. Such a map will often include:

- property boundaries
- aerial imagery
- contour lines
- waterways and water sources
- existing infrastructure, including roads, buildings, utilities, and fences

Additional map layers can be added as site information is gathered. These may include soils, slope, solar aspect, flood elevations, existing vegetation, habitat types, current land use, and future water, access, and fencing layouts.

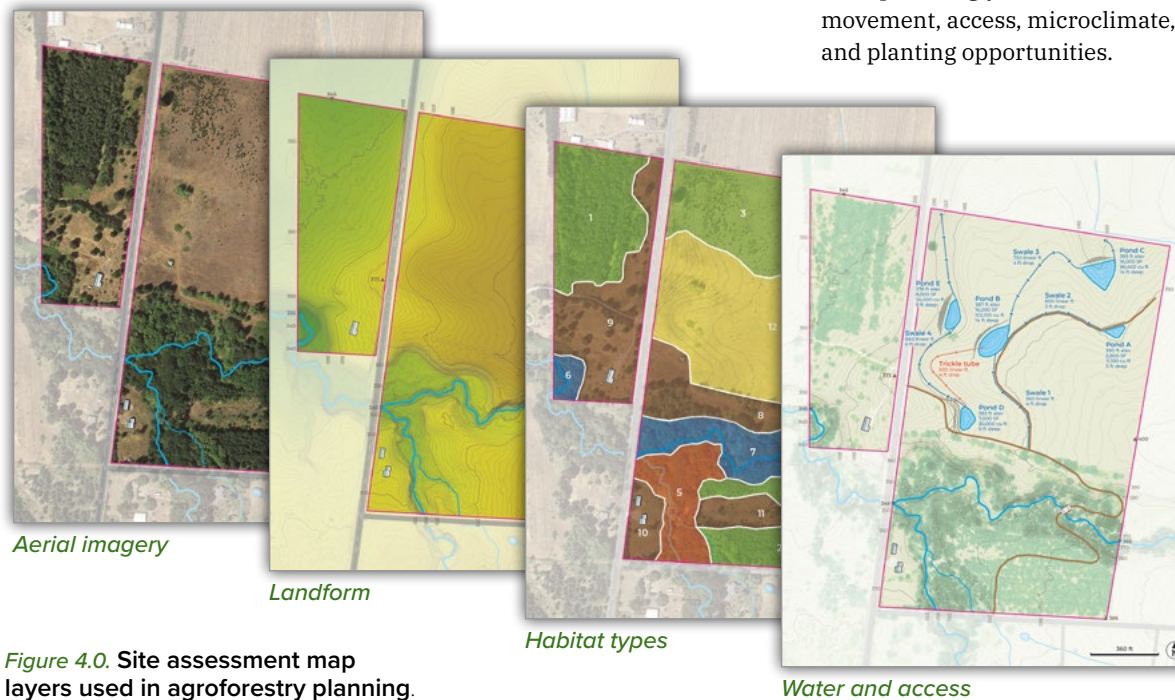


Figure 4.0. Site assessment map layers used in agroforestry planning.

As these layers are developed, they can be compared through overlay analysis to better understand relationships across the site. For example, soils, slope, hydrology, vegetation, access, and existing infrastructure can be viewed together to identify areas that may be well suited for particular agroforestry systems, species, or management strategies. This process can also reveal limitations, such as wet areas, erosion-prone slopes, poor access, regulatory constraints, or conflicts with existing land uses.

Figure 4.0 below shows how multiple map layers can be developed and compared during site assessment, moving from existing conditions toward management units and water, access, and infrastructure planning.

Cross-sectional elevation diagrams provide another useful way to interpret the landscape. These diagrams show how elevation, slope, drainage, and landform relate to one another across a site. They are especially helpful on farms with significant changes in terrain, where elevation and slope strongly influence water movement, access, microclimate, and planting opportunities.

Computer-based mapping applications:

A variety of mapping tools can be used to create base maps and planning overlays. The appropriate tool will depend on the scale of the project, the technical skills of the planner, and the level of detail required.

Google Earth is a free mapping program that can be useful for basic farm mapping and visual planning. The desktop version, Google Earth Pro, allows users to draw lines, points, and polygons to scale. These tools can be used to mark fences, water sources, roads, buildings, planting areas, and field boundaries, or to measure distances and acreage.

Geographic Information Systems (GIS) store, analyze, and display spatial data. GIS is especially useful for combining multiple layers of information, such as soils, slope, hydrology, vegetation, and infrastructure. Common GIS platforms include ArcGIS, MapInfo, and the open-source program QGIS.

Computer-aided design (CAD) software is often used for more detailed design work, including buildings, structures, irrigation layouts, and installation plans. Common programs include AutoCAD and SketchUp. While CAD uses layers, GIS is generally better suited for spatial analysis and landscape-scale planning.

State and county GIS databases are often the most accessible sources for digital map data. In Oregon and Washington, many counties provide online GIS portals with property boundaries, aerial imagery, topography, soils, waterways, zoning, floodplain information, and other useful layers. These portals can often provide much of the information needed to begin base map development.

As the planning process continues, map layers can be added to the base map or used alongside it. Many topics addressed in the remainder of this chapter can be understood as potential map layers. When viewed together, these layers help clarify where specific agroforestry practices, species, and management strategies are most appropriate, given the constraints and opportunities identified through the site assessment.

Land use history

Land use history provides important context for agroforestry planning. Every site has been shaped by long-term relationships among people, plants, animals, soils, fire, water, and climate. Understanding this history can help planners identify both constraints and opportunities, including remnant plant communities, altered drainage patterns, compacted soils, old roads, cultural resources, existing infrastructure, and management legacies that continue to influence the site.

Historical research should include both long-term Indigenous stewardship and more recent land uses associated with agriculture, forestry, grazing, settlement, and infrastructure development. Together, these histories can help explain current site conditions and guide future agroforestry design.

Indigenous stewardship and traditional land management

The Indigenous peoples of the Pacific Northwest actively managed landscapes through practices such as controlled burning, digging, coppicing, pruning, selective harvesting, seed dispersal, and propagation. These practices supported diverse plant and animal communities used for food, medicine, fiber, tools, and other materials. Prior to Euro-American settlement, Indigenous land management was extensive, with fire and other stewardship practices shaping ecosystems from valley floors to high elevation berry fields and mountain meadows.

Traditional agroforestry systems were shaped not only by direct management but also by long-term patterns of living within the landscape. Travel routes, gathering areas, refuse sites, seed dispersal, and repeated seasonal use could influence plant distribution, wildlife movement, and soil conditions over

time. These forms of passive management often reinforced more intentional practices such as burning, tending, harvesting, and propagation.

Traditional and Indigenous approaches to agroforestry remain time-tested and ecologically informed. Modern agroforestry planning can be informed by understanding the traditional horticultural practices associated with a given landscape, including their influence on species selection, planting patterns, disturbance regimes, and ecosystem management. Before consulting specific historical datasets, consider framing site-level research with questions that help clarify long-term human-ecosystem relationships:

- How important was human management in creating or maintaining a particular ecosystem condition?
- What specific stewardship practices were used, and what were their purposes?
- How often were these practices applied, and over what period of time?
- How did human management interact with climate, fire, soils, hydrology, wildlife, and other non-human factors?
- What was the historic range of variability for the ecosystem?
- Can Indigenous land practices that helped maintain ecosystem characteristics inform agroforestry practices today?

The **NRCS CEMA 222 Indigenous Stewardship Methods Evaluation** is an activity that can assist agricultural producers in gathering information about Indigenous stewardship methods suitable for the land they manage.

Historic vegetation and pre-settlement plant communities

One starting point for understanding long-term landscape conditions is to investigate vegetation communities that existed before Euro-American settlement. General Land Office surveys from the 1850s provide one useful source of information. These surveys recorded vegetation observations at quarter-section corners across much of Oregon and Washington.



Figure 4.1a. General Land Office survey.

Surveys performed in the 1850s note vegetation patterns early on in Euro-American settlement of the Northwest.

Source: Bureau of Land Management, 1855 Original Land Survey, General Land Office Records (<https://www.gloreCORDS.blm.gov>), entry for 18S 2W W.M., Lane Co., Oregon.

In Oregon, and to a lesser extent in Washington, researchers have digitized many of these original survey records and maps, making them more accessible to the public. These historic vegetation datasets can help planners understand former prairie, savanna, woodland, wetland, riparian, and forest conditions, as well as the potential influence of Indigenous stewardship on those communities.

The **Institute for Natural Resources** at Oregon State University maintains an [online catalog](#) of available historic vegetation databases for Oregon and Washington. Oregon data can also be accessed through the [Oregon Explorer](#) website.

To access the historic vegetation layer:

1. Open the layer list.
2. Select **Habitats and Vegetation**.
3. Select **Land Use and Land Cover**.
4. Select **Historic Oregon Land Cover and Land Use Level 3**.
5. Navigate to the site being assessed.

Historic vegetation data should be used as a guide rather than a fixed prescription. Current soils, hydrology, climate, land use history, invasive species, legal constraints, and management goals all influence what is possible today. However, historic vegetation can help identify appropriate reference systems, potential restoration opportunities, and species or community types that may be well adapted to the site.

Cultural resources and protected sites

Cultural resources include prehistoric and historic objects, places, structures, and landscape features. Examples may include Native American village sites, cairns, stone tools, rock images, ceramics, bottles, wagon roads, railroad grades, logging camps, mining camps, and other historic features.

Age, context, and other factors determine whether a site or object is protected as a cultural resource. On non-federal land, the cultural resource age threshold is generally 75 years. Cultural resource regulations are administered through the State Historic Preservation Office in coordination with state police, agencies, and Indigenous Tribes.

Farming, forestry, road work, excavation, pond construction, fencing, and other land management activities can reveal artifacts or cultural sites. Inadvertent discovery does not necessarily violate the law, but further disturbance may. If artifacts, burials, structures, or other cultural materials are found, work should stop in the area and the appropriate authorities should be contacted.

Cultural resource awareness is an important part of agroforestry planning because many agroforestry practices involve soil disturbance, vegetation man-

agement, earthwork, or infrastructure placement. Early identification of sensitive areas can help avoid damage, legal conflict, and disrespectful treatment of culturally significant places.

Recent land use and management history

Recent land use history can explain many of the conditions observed during site assessment. Agriculture, forestry, grazing, settlement, road construction, drainage, land clearing, and fire suppression have significantly altered many Pacific Northwest landscapes. These activities may have changed soil structure, water movement, plant communities, animal habitat, invasive species pressure, and access patterns.

A site's recent history can be pieced together through conversations with neighbors, previous landowners, local historians, agency staff, and long-term residents. Historical aerial imagery, county records, tax maps, LiDAR imagery, forest records, irrigation records, and old photographs can also provide useful information.

Useful questions include:

- Was the land grazed? If so, where were pastures, gates, water points, lanes, and fences located?
- Are there signs of compaction, erosion, overgrazing, remnant fencing, or livestock concentration areas?
- What is the agricultural history of the site?
- Was the land plowed, shaped, drained, tiled, irrigated, fertilized, sprayed, or otherwise modified?
- Did past agricultural enterprises succeed or fail, and what does that suggest about soil, water, access, markets, or climate?
- Is there residue from persistent agricultural chemicals?
- Is there an existing water supply? How reliable is it?
- Have soils been significantly altered by tillage, erosion, compaction, deposition, or amendment?
- What invasive species have been introduced or encouraged by past management?
- What is the forestry history of the site?
- Are there abandoned roads, skid trails, landings, culverts, or drainage problems related to logging or other development?

- Were forests cleared, burned, replanted, thinned, or converted to other uses?
- What plant communities appear to be remnant, recovering, planted, or highly altered?
- Has the site been affected by fire, flood, windstorms, drought, or other disturbances?
- Are there existing resources such as buildings, fences, roads, wells, ponds, irrigation systems, orchards, hedgerows, timber, or valuable planted species?
- Do neighboring properties affect the site through shade, runoff, spray drift, livestock pressure, wildlife movement, invasive species, access, or water use?

This information should be mapped where possible. Old roads, former fields, drainage features, historic structures, remnant orchards, cultural resource concerns, disturbed soils, and legacy vegetation can all influence agroforestry design. Some features may become constraints, while others may provide opportunities for access, restoration, planting, water management, habitat, or enterprise development.

Using land use history in agroforestry planning

Land use history should help explain present-day site conditions and guide future decisions. Indigenous stewardship history and historic vegetation records can provide insight into long-term ecological patterns, species relationships, and provide insight into the potential species and systems to adopt. Cultural resource review can help avoid disturbance of protected or significant places. Recent management history can reveal how farming, forestry, grazing, roads, drainage, chemicals, and infrastructure have shaped the land.

By bringing these histories together, planners can better understand why the site looks and functions as it does today. This understanding can improve species selection, planting design, restoration priorities, soil and water management, access planning, and long-term stewardship.

Climate

Climate is one of the least changeable factors shaping an agroforestry site. It determines the broad range of species that can be grown, the kinds of systems that are likely to succeed, and the management strategies needed to support plant and animal health.

A clear understanding of climate helps planners select species and varieties that are well adapted to the site, anticipate seasonal stresses, and design systems that are resilient over time.

For agroforestry planning, climate assessment should consider both regional climate patterns and fine-scale site conditions. Regional factors such as temperature, precipitation, drought, wind, and winter cold set the broad limits for production. Local conditions, including frost pockets, slope aspect, shade, heat accumulation, and wind exposure, create microclimates that may expand or limit planting options within the farm.

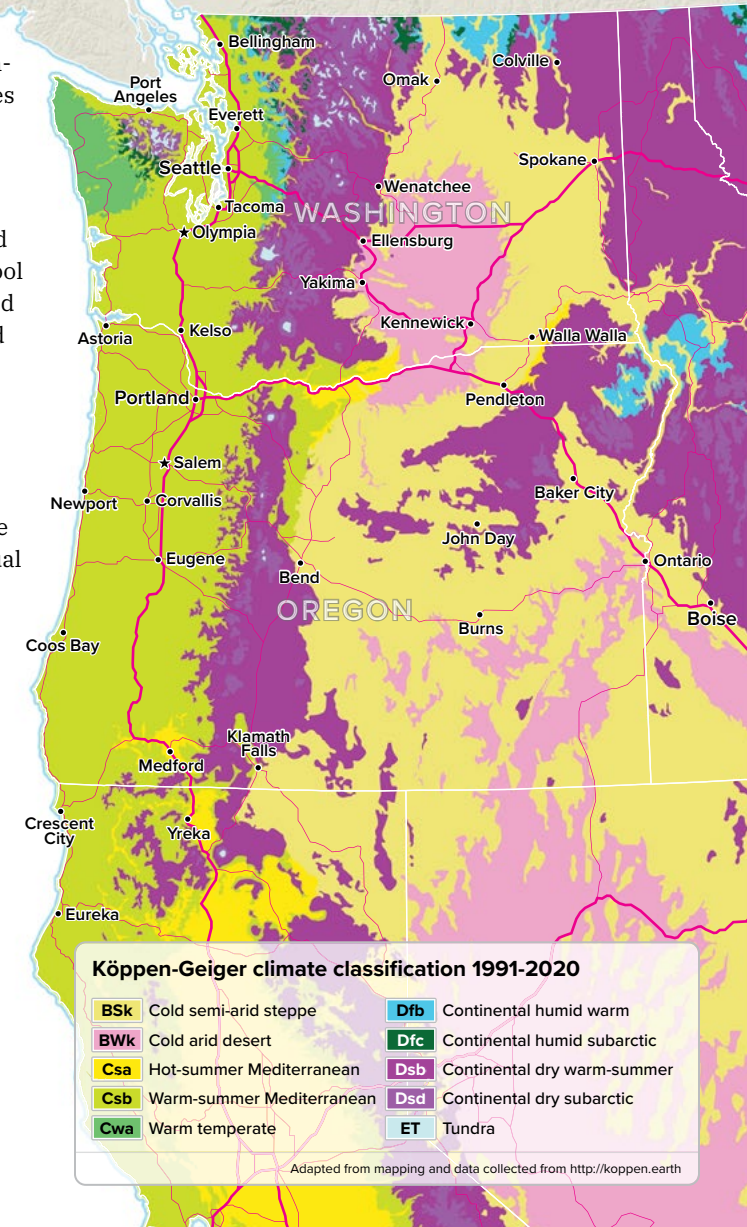
Regional climate context

The Pacific Northwest contains several major climate patterns that strongly influence agroforestry design.

The **Köppen-Geiger climate classification system** is one useful way to understand these patterns because it groups regions according to temperature and precipitation regimes. These categories provide a broad starting point for evaluating plant adaptation, water needs, livestock comfort, and climate-related risks.

West of the Cascade Mountains, much of Oregon and Washington is characterized by mild winters, wet cool seasons, and dry summers. Many areas are classified as **Warm-Summer Mediterranean**, where winter and spring rainfall support strong plant growth, while summer drought creates a pronounced dry season. Coastal regions, including parts of Washington's Olympic Peninsula and areas near the Oregon and Washington coasts, are influenced by **Warm Temperate Oceanic** conditions. These areas tend to have cooler summers, warmer winters, and smaller annual temperature swings.

Figure 4.2a. Pacific Northwest climate types



Agroforestry considerations for Northwest climates

All climates:

- Supplemental irrigation may be necessary during the growing season.
- Plant primarily frost/cold-tolerant species in all areas without significant microclimate modifications.
- Condition soil for water infiltration and retention.
- Use agroforestry systems to improve microclimates for plant and animal health during winter and summer extremes.

Warm-Summer Mediterranean and Warm Temperate:

- Wet winters and springs can lead to fungal and bacterial diseases.
- Some heat-loving species may fail to thrive or produce fruit without microclimate modifications.
- Use agroforestry systems on seasonally wet and other marginal land to expand production and minimize reliance on tillage.

Cold Semi-Arid and Cold Desert:

- Carefully select drought- and cold-tolerant species.
- Rely on water infrastructure and water retention through surface mulch, soil conditioning, and canopy cover.
- Use agroforestry systems to buffer wind and sun.

East of the Cascade Mountains, temperature and precipitation patterns are more extreme. Much of Eastern Oregon and Washington is classified as **Cold Semi-arid** or **Cold Desert** climate. These areas receive significantly less precipitation, experience larger day-to-night temperature swings, and often have colder winter temperatures. Establishing perennial crops can be more challenging in these regions, especially where irrigation is limited or exposure to wind, drought, and winter cold is high.

Future climate shifts

Agroforestry systems are long-term investments, so climate assessment should account for projected climate change. Trees, shrubs, and perennial systems planted today may remain in place for decades. Species selection, water planning, and risk management should therefore consider both current climate conditions and likely future shifts.

Climate models suggest that regional climates in the Pacific Northwest are expected to become warmer

over time, with increased summer heat and greater stress during dry periods. In some areas, current Warm-Summer Mediterranean climates may shift toward hotter summer conditions more similar to regions farther south. These changes may affect chilling hours, irrigation demand, wildfire risk, pest and disease pressure, livestock comfort, and the suitability of specific tree crops.

Interactive tools such as [Koppen.earth](#) and the [Climate Mapper](#) can help planners compare current and projected future climate conditions. These tools allow users to explore changes in temperature, precipitation, humidity, and other variables under different climate scenarios. For agroforestry planning, these projections can be used to select more resilient species, evaluate future irrigation needs, and identify management strategies that buffer heat, drought, wind, and cold.

Precipitation and seasonal drought

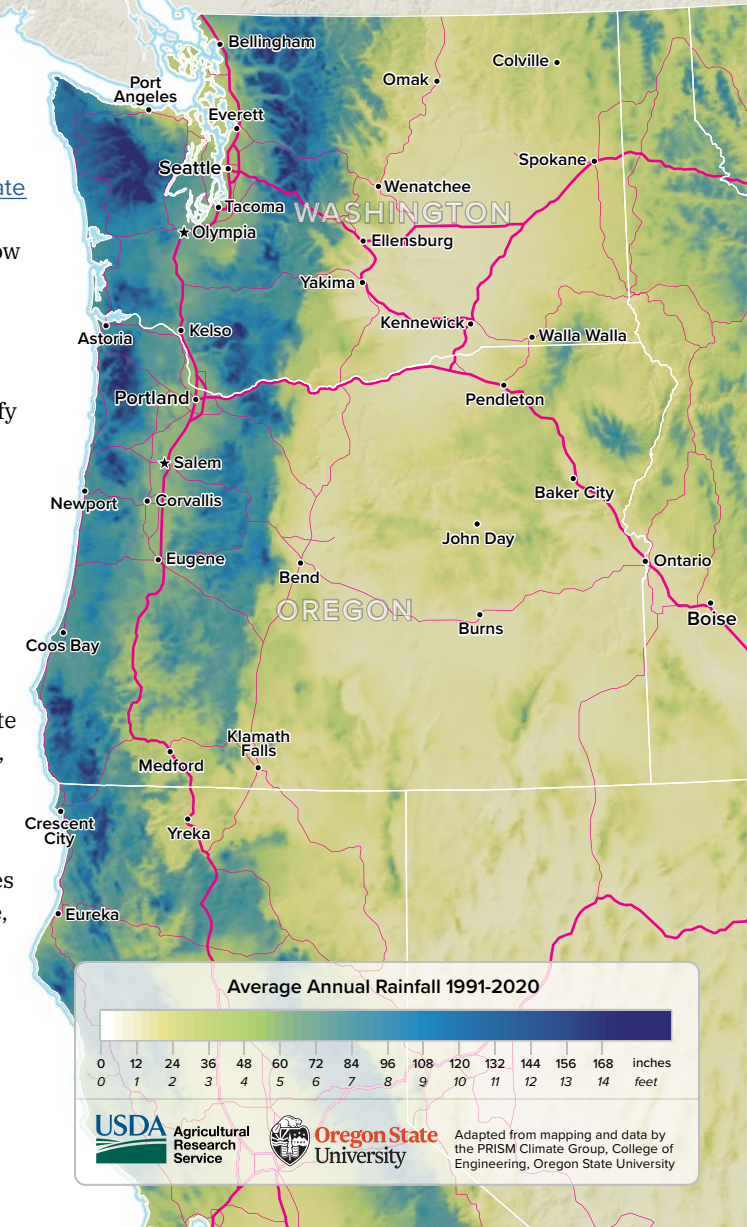
Rain and snow in the Pacific Northwest occur primarily between mid-October and mid-May. Like other Mediterranean-type climates, the region experiences a summer dry season when oceanic high-pressure systems limit incoming moisture. This seasonal drought is one of the defining factors for agroforestry planning in much of Oregon and Washington.

Precipitation varies substantially across the region. Coastal mountains and the Olympic Peninsula receive some of the highest precipitation totals, while lower-elevation interior valleys and coastal plains receive moderate rainfall. East of the Cascades, the rain shadow effect creates much drier conditions, with many areas receiving limited annual precipitation.

Site assessment should identify both the amount and timing of precipitation. Planners should evaluate whether rainfall is sufficient for crop establishment, whether supplemental irrigation will be needed, and whether soils and landform can store enough moisture to support perennial systems through the dry season. In many locations, agroforestry practices can improve drought resilience by increasing shade, reducing wind exposure, building soil organic matter, improving infiltration, and protecting the soil surface with mulch or living groundcover.

Refer to the [Climate Mapper](#) for precipitation data specific for your site.

Figure 4.2b. Average annual precipitation



Winter cold and plant hardiness

Hardiness zones are defined by average annual minimum winter temperatures and are used to select plants that are likely to survive winter in a given location. The primary factor used for determining hardiness zones is the minimum, or coldest, winter temperature, with some consideration for the number of frost-free days, summer rainfall, maximum temperatures, snow cover, and wind. Plant breeding programs have developed cultivars or varieties of

species that are adapted to different hardiness zones. To prevent costly errors, check the recommended hardiness zone for each cultivar or variety carefully. In some cases, the hardiness zone is only an approximate guide.

The [USDA Plant Hardiness Zone Map](#) covers the entire country, including Oregon and Washington.

Wind exposure and prevailing winds

Wind speed and direction are important considerations for agroforestry planning. Wind can increase evaporation, intensify wind chill, reduce pollination success, damage plants, transport dust or chemicals, and affect livestock comfort. Wind can also influence the placement and orientation of windbreaks, hedgerows, orchards, livestock areas, buildings, roads, and outdoor workspaces.

Map the prevailing wind directions for both summer and winter. In many Northwest locations, summer winds and winter storm winds come from different directions. Local landforms may also create site-specific wind patterns, such as daytime and nighttime air movement up and down valleys, winds moving

off large bodies of water, or strong winds funneled through gaps, saddles, and exposed ridgelines.

A **wind rose** is a useful tool for visualizing wind direction and frequency. The length of each spoke around the circle represents how often wind comes from that direction. Wind rose data can help determine where windbreaks, shelterbelts, livestock shelters, or drought-tolerant plantings may be most useful.

The USDA maintains wind rose records for locations in [Oregon](#) and [Washington](#). They can be used to evaluate wind direction and frequency and to determine whether wind-mitigation practices are appropriate for a given site.

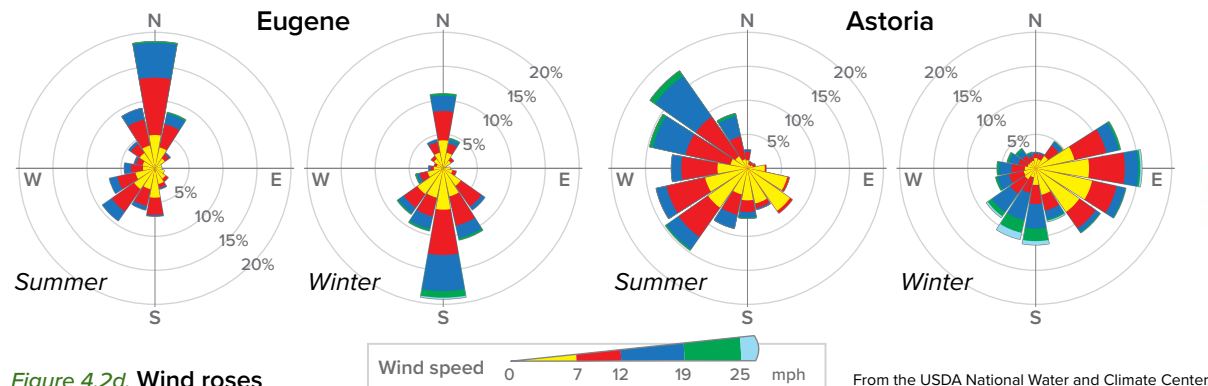
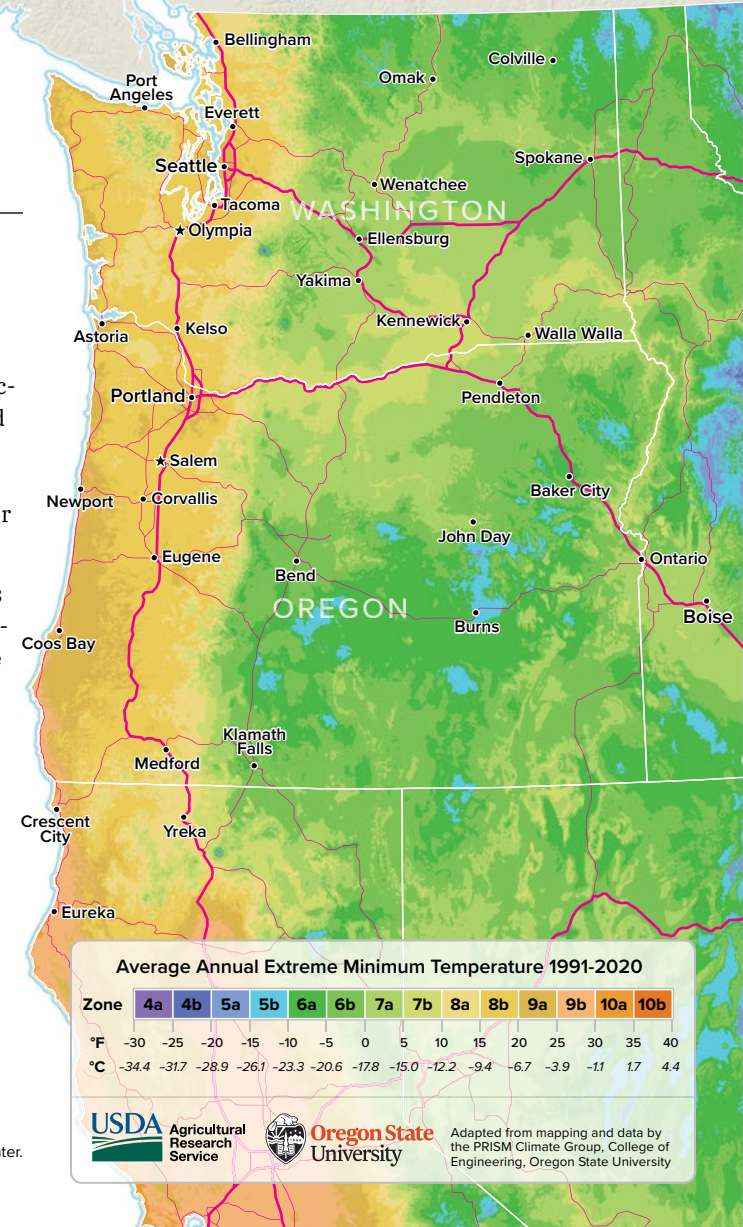


Figure 4.2d. Wind roses

Note how the prevailing summer wind direction in the valley is from the north while the winter storm winds are from the south. Coastal summer prevailing winds are off of the ocean while winter winds generally move from the land out to sea.

Figure 4.2c. USDA Plant Hardiness Zones



Chilling hours for fruit and nut crops

Deciduous trees need to spend time within a certain temperature range during dormancy before flower and leaf buds open normally in spring. Without adequate chilling hours below 45°F, many trees may flower poorly, leaf out unevenly, or fail to bear fruit reliably. As a result, some fruit trees have been bred to tolerate “low chill” conditions in warmer climates. Most temperate fruit trees require from 100 to 1,400 chilling hours to bear fruit the following season.

Temperatures in the interior valleys of Oregon and Washington and east of the Cascade Mountains are generally cold enough during a typical winter to provide sufficient chilling for many deciduous fruit crops. However, as the climate warms, some fruit and nut varieties that require high chilling hours may become less suitable for parts of the region.

Microclimates, sun, and shade

While climate describes long-term regional weather patterns, microclimates are fine-scale variations within a site. Microclimates can occur at the scale of a whole slope, a field edge, a building wall, a forest opening, or even a small depression. These local differences may affect temperature, frost risk, soil moisture, wind exposure, sun exposure, pest pressure, disease pressure, and plant performance.

Common microclimates include cold air pooling in low areas, heat collecting against south-facing slopes or walls, wind accelerating through gaps between trees or buildings, and moist conditions persisting in shaded or poorly drained areas. A year of observation is often recommended for tracking microclimates, but knowledge from farmers, neighbors, and long-term residents can also provide valuable insight.

Microclimate patterns can be mapped directly onto the base map. Planners should identify areas affected by frost pockets, strong wind, excessive heat, persistent shade, wildfire exposure, and seasonal water movement.

Wind, sun exposure, frost movement, wildfire behavior, and water flow can be understood as influences or forces moving across the landscape that affect the placement and management of agroforestry systems. Recognizing these patterns can help guide the siting of orchards, windbreaks, roads, livestock areas, buildings, ponds, and other infrastructure in ways that reduce risk and take advantage of beneficial environmental conditions.

Frost pockets and cold-air drainage

Frost pockets are especially important in perennial crop planning. Cold air flows downhill and collects in low areas or behind barriers such as buildings, dense woods, berms, or hedgerows. These localized frosts can damage flowers and new shoots, even when a crop is generally suited to the broader hardiness zone.

Assess low areas, valley bottoms, benches, and the uphill sides of dense vegetation or buildings for potential frost pockets. The absence of native berry plants or other frost-sensitive species can sometimes indicate repeated cold-air pooling. Avoid placing frost-sensitive crops in areas where cold air settles. Sloped or bench land with good air drainage is often a better choice.

Walls, buildings, and dense woods can also act as barriers to cold-air movement. When cold air flowing downhill is blocked, it may collect upslope and create a localized frost risk. For this reason, tree rows, hedgerows, buildings, or other barriers should be placed with attention to how they may affect cold-air drainage across the site.

Table 4.2a. Chilling hours for common fruit and nut trees

Crop	Common varieties	Other	Min. winter temp.	Min. frost-free period
Almond	100-500 hours		14°F (−10°C)	> 180 days
Apple	1,000-1,600 hours	400-1,800 hours	−51° to 25°F (−46° to −4°C)	< 100+ days
Blueberry	400-1,200 hours	0-200 hours	−31° to 10°F (−35° to −12°C)	< 100+ days
Cherry	900-1,200 hours	600-1,400 hours	−20 to 30°F (−29° to −1°C)	< 100+ days
Citrus	0 hours		19° to 39°F (−7° to 4°C)	> 280 days
Grape (European)	100-500 hours		−13 to 39°F (−25° to 4°C)	> 120 days
Grape (American)	400-2,000+ hours		−51° to 10°F (−46° to −12°C)	< 100+ days
Peach	400-800 hours	200-1,200 hours	−20° to 39°F (−29° to 4°C)	> 120 days
Pear	500-1,500 hours		−31° to 30°F (−35° to −1°C)	> 100 days
Pecan	600-1,400 hours		14°F (−10°C)	> 180 days
Pistachio	600-1,500 hours	400-600 hours (Asian)	14°F (−10°C)	> 180 days
Plum	800-1,200 hours	500-600 hours (Japanese)	−20° to 39°F (−29° to 4°C)	> 140 days
Raspberry	800-1,700 hours	100-1,800 hours	−51°F+ (−46°C+)	< 100+ days
Strawberry	300-400 hours		10°F (−12°C)	< 100+ days
Walnut	400-1,500 hours		−20°F (−29°C)	> 100 hours

Source: Hatfield, J., K. Boote, P. Fay, L. Hahn, C. Izaurralde, B.A. Kimball, T. Mader, J. Morgan, D. Ort, W. Polley, A. Thomson, and D. Wolfe. 2008. Agriculture. In: The effects of climate change on agriculture, land resources, water resources, and biodiversity in the United States. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Washington, DC, USA, p. 28.

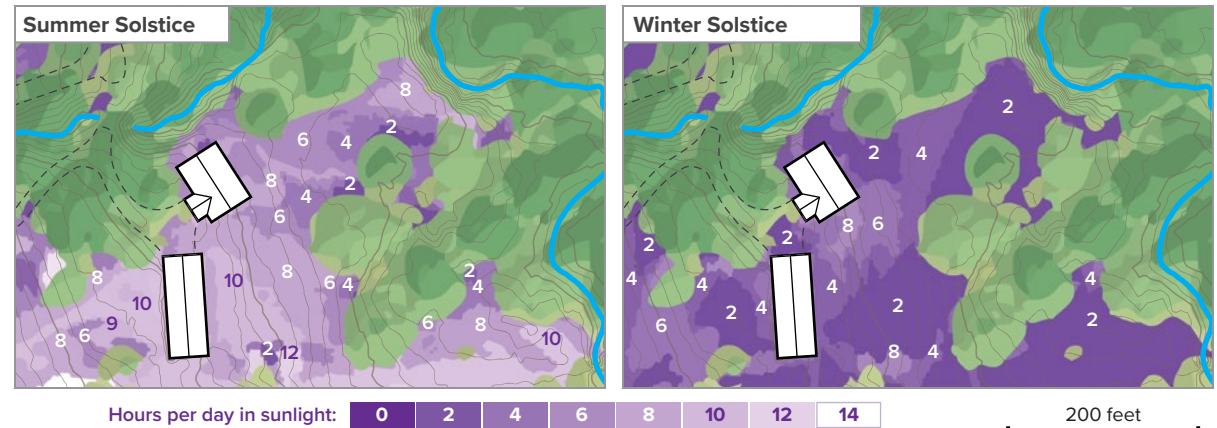
Solar exposure and seasonal shade

Evaluate sun and shade patterns carefully. Solar exposure influences soil temperature, moisture, crop productivity, disease pressure, and plant suitability. South- and west-facing slopes generally receive more solar energy and tend to be warmer and drier. North-facing slopes are often cooler, moister, and slower to warm in spring. East-facing slopes may offer morning sun with less afternoon heat stress.

Shade patterns change throughout the year as the sun angle shifts between the solstices and equinoxes. During summer solstice, the sun is higher in the sky and day length is longer, so many open areas may receive extended solar exposure. During winter solstice, the sun is lower in the sky and day length is shorter, causing trees, buildings, hillslopes, and forest edges to cast longer shadows. For areas under consideration for agroforestry, shade should be evaluated during key seasonal points, especially the winter solstice, summer solstice, and the spring and fall equinoxes.

The solar exposure maps below show how this seasonal shift can affect a site. The summer solstice map identifies areas receiving long periods of direct sun, including open fields and south- or west-facing slopes. The winter solstice map shows a much more limited distribution of solar access, with extensive shade occurring near forest edges, buildings, drainages, and lower portions of the landscape. Comparing these maps helps identify areas suited to sun-demanding crops, locations where shade-tolerant

Figure 4.2e. Solar exposure maps



Above: Summer solstice map shows hours of direct sunlight across the site. Winter solstice map shows reduced solar exposure and longer seasonal shadows.

Maps courtesy of Michael Godfrey and Resilience Permaculture Design

species may be more appropriate, and places where existing vegetation, landform, or infrastructure may limit solar access.

Solar access can also be estimated using basic sun-angle calculations. Because the sun is higher in the sky during summer and lower during winter, the same tree, building, or landform will cast very different shadow lengths throughout the year. A simple sun-angle diagram can help planners estimate how far shadows may extend from trees, forest edges, hedgerows, buildings, or other tall features. This is especially useful when siting orchards, greenhouses,

nursery areas, livestock shelters, solar infrastructure, or plantings that require reliable winter sun.

Together, solar exposure maps and sun-angle calculations provide complementary tools for assessing microclimate. Maps show the pattern of sun and shade across the whole site, while sun-angle calculations help estimate the specific shadow effects of individual trees, buildings, hedgerows, or landforms. Used together, they can guide the placement of crops, infrastructure, windbreaks, and management zones in ways that take advantage of beneficial solar exposure and avoid areas where shade may limit productivity.

Legal and regulatory frameworks

Federal, state, and local laws can shape many core decisions, including whether landowners can develop or access water, irrigate crops, build farm infrastructure, provide worker housing, process or sell farm products, and manage or reforest stands in ways that support viable agroforestry systems.

Table 4.3 outlines the primary agencies, rules, and permitting considerations that influence agroforestry planning in Oregon and Washington. Because regulations vary by location and change over time, this handbook cannot address every possible requirement. Instead, the table provides a starting point for identifying the legal and regulatory questions to investigate before any major decisions are made.

Table 4.3. Pacific Northwest regulatory agencies

Category	Oregon	Washington
Land use and zoning	- Governed by Statewide Planning Goals Exclusive Farm Use (EFU) lands allow farming and many agroforestry practices; certain processing or agritourism uses require conditional use permits. - Forestland may require specific tree-stocking rates incompatible with some agroforestry systems; however landowners may apply to develop plans for alternative forestry practices	- Governed by Growth Management Act (GMA) and county zoning codes - Agricultural lands designated for preservation; agroforestry generally compatible, but processing and agritourism often require permits. Designated Forestland Program is a tax deferral program that offers a reduced annual tax rate in exchange for a timber excise tax upon harvesting. Land must be managed for commercial timber harvest.
Water rights and use	- Managed by Oregon Water Resources Department (OWRD) - Irrigation usually requires a water right. Exempt uses include small stock watering, fire prevention, lawns, non-commercial gardens using less than 15,000 gal/day, springs, forestry, and rainwater from roofs. Limited exemptions for irrigating market crops with domestic wells. - Riparian planting and wetland alterations may require permits from the Department of State Lands (DSL). - Oregon's "limited license" rule allows temporary water use (less than 5 years) to establish a crop that then requires no further irrigation.	- Managed by Washington Department of Ecology - Nearly all withdrawals require water rights. Exempt uses include domestic and industrial uses of up to 5,000 gallons per day, irrigation of a lawn or garden a half-acre or less in size, rainwater from roofs, and stockwater. Hydraulic Project Approval (HPA) required for streamside work.
Food safety and processing	Oregon Department of Agriculture (ODA) licensing required for meat, dairy, fruit/vegetable, and other processing. Farm Direct Marketing Law exempts some small producers of direct sales of produce, honey, eggs, and limited-value-added items.	Washington State Department of Agriculture (WSDA) licensing required for most food processing. Cottage Food Law allows limited home-based food sales.
Conservation and environmental protection	Endangered Species Act (ESA) and Clean Water Act apply. Oregon Forest Practices Act sets riparian buffer requirements for forestry operations. - Riparian zones can qualify for separate tax exemptions.	Critical Areas Ordinances (CAOs) at county level restrict activities in wetlands, streams, slopes, and fish/wildlife habitat. ESA protections are particularly strong for salmon habitat. Washington Forest Practices Act regulates logging activities, incl mandatory riparian buffers, and is administered by the Washington DNR.

Landform

Identifying landforms, the surface features that make up a site's terrain, is an important early step in assessing the potential for agroforestry systems. Landforms influence the location of cropping zones, roads, fencing, buildings, and water infrastructure, so their effects should be documented early in the assessment process.

The Pacific Northwest has been shaped by active and complex geological processes, including volcanism, major offshore earthquakes, and immense Ice Age floods. While the full range of regional landforms is too broad to address in this handbook, this section focuses on common patterns most relevant to agroforestry planning.

Steep mountainous areas, including parts of the Cascades, can support agroforestry systems, but most intensively managed agroforestry projects are likely to occur in foothill and valley landscapes. These areas often contain a recognizable set of ridges, valleys, slopes, benches, floodplains, and terraces that strongly influence system selection and placement.

Topographic maps

To read landform, begin with the most detailed topographic map available. Standard U.S. Geological Survey topographic maps are useful for interpreting broad landscape patterns, but their contour lines are often spaced at 20-foot elevation intervals. While this level of detail may be appropriate for regional interpretation, it is often too coarse for planning roads, ponds, terraces, planting zones, and other site-specific features on smaller properties. More detailed elevation data may be needed to accurately evaluate landform at the farm scale.

LiDAR (Light Detection and Ranging) uses pulses of laser light, often collected from aircraft, to measure

How to understand contour lines

Contour lines are the primary lines on a topographic map. Each contour line connects points of equal elevation, much like the level edge of water in a pond or the top of a building foundation. Some contour lines are labeled with elevation, usually in feet or meters above sea level. The contour interval, shown in the map legend, is the elevation difference between two adjacent contour lines.

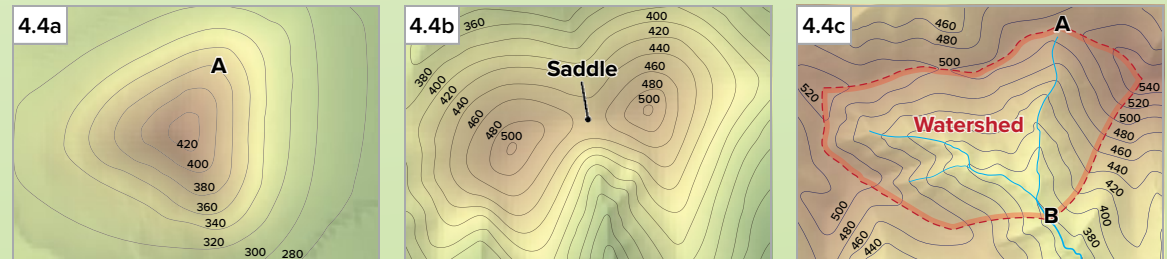
Contour spacing indicates slope. Closely spaced contour lines show steeper terrain, while widely spaced contour lines indicate gentler slopes or flatter ground. In **figure 4.4a**, the hill is shown as a series of concentric contour lines. The highest point is near the center, while each surrounding line represents a lower elevation moving outward from the hilltop.

Contour patterns also reveal landform. In **figure 4.4b**, two hills are connected by a saddle, or low point, between them. Saddles often mark transitions between drainage areas and can influence access, water movement, and potential pond locations.

Water flows downhill, generally perpendicular to contour lines. In **figure 4.4c**, the blue lines show how water collects in small drainages and moves from the upper part of the watershed toward the lower outlet. The red dashed line marks the watershed boundary, which separates the land draining toward this channel from adjacent drainage areas.

Valleys are indicated by "V" or "U" shaped contour lines that point uphill, while ridges are shown by "V" or "U" shaped contours that point downhill. This rule makes it easier to identify drainage patterns and ridgelines, even where no stream is shown on the map.

In agroforestry planning, these small drainage patterns are especially important. Minor valleys, swales, and subtle tributaries may strongly influence soil moisture, erosion, access, planting layout, pond siting, and opportunities for water-harvesting earthworks. Working with these smaller landform features is often more practical and less regulated than altering established stream channels.



Adapted from: *How to Read a Topographic Map and Delineate a Watershed*, USDA.

distances to the Earth's surface. LiDAR generates precise three-dimensional data about terrain, vegetation, and surface features. Much of Oregon and Washington has now been mapped with LiDAR, and much of this data is available through public databases.

LiDAR data can often be accessed through online GIS mapping portals, where 2-, 5-, and 10-foot contour lines may be viewed over aerial imagery. State-level datasets can also be downloaded and added to GIS programs for more detailed analysis. In Oregon and

Washington, LiDAR data are available through the [Oregon Department of Geology and Mineral Industries \(DOGAMI\)](#) and the [Washington State Department of Natural Resources](#).

Before mapping landform features, it is useful to understand how contour lines represent elevation, slope, ridges, valleys, and drainage patterns. The breakout box above provides a quick reference for reading contour maps.

Mapping the land features

Using a topographic map, aerial imagery, and field observation, begin marking the major landform features on the property. Colored pencils or separate digital map layers can be used to distinguish ridgelines, valleys, slopes, benches, saddles, floodplains, and drainage pathways. Not every property will include all of these features, and some small or flat properties may contain only subtle changes in elevation.

Main ridgelines, crests, and saddles

A **main ridgeline** divides watershed basins. It often appears on the horizon as the highest ridge from which land falls away in two or more directions. On a topographic map, the main ridgeline can be traced by following the highest connecting points between adjacent slopes and drainage basins.

If a main ridge exists on a site, it can strongly influence farm layout. Ridgelines may provide access to higher portions of the property, create distinct microclimates on either side, and serve as important locations for fire planning, water distribution, and road layout. In some cases, ridgeline roads can also function as fire breaks, especially when paired with appropriate vegetation management and hardwood agroforestry plantings.

Main ridgelines often include crests and saddles, two landform features that help define how water, wind, access, and movement patterns relate to the ridge.

Crests are convex high points along a ridge. They are the hill-shaped rises that occur along the ridgeline. On a topographic map, crests often appear where contour lines form rounded high points. Mark the top of each crest on the landform map.

Saddles are lower points between adjacent crests. They are sometimes described as passes or dips along a ridge. On a topographic map, saddles often appear where contour lines narrow between two higher areas and where slope direction changes on either side of the ridge. Mark the lowest point of each saddle on the landform map.

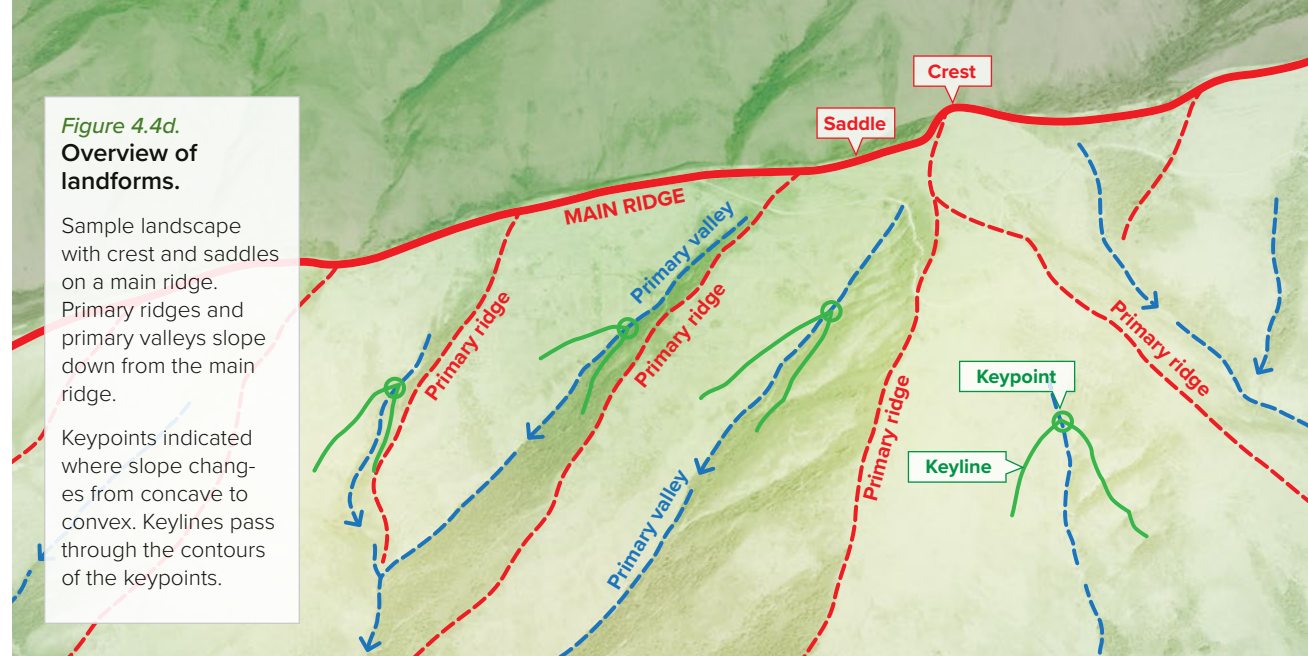


Figure 4.4d.
Overview of landforms.

Sample landscape with crest and saddles on a main ridge. Primary ridges and primary valleys slope down from the main ridge.

Keypoints indicated where slope changes from concave to convex. Keylines pass through the contours of the keypoints.

Graphic by Michael Godfrey

Crests and saddles can create important opportunities and constraints for agroforestry design. Crests may be useful for access, fire planning, wind exposure assessment, and observation points.

Saddles may concentrate subsurface or surface water movement and, under the right conditions, may offer opportunities for high-elevation water storage.

Primary ridges and valleys

Primary ridges are convex landforms that descend from a crest or main ridge toward a lower valley, stream, or floodplain. On the ground, a primary ridge functions like a spine. Water drains away from it in two directions toward adjacent valleys. On the landform map, draw a line along the center of each primary ridge from the upper crest toward the lower valley.

Primary ridges are often good locations for access routes because they are usually better drained than valleys and may have gentler, more stable grades than adjacent side slopes. They can also be useful for fire access, livestock movement, and gravity-fed water

distribution. However, ridge roads and infrastructure should still be designed to avoid erosion, excessive grading, and unnecessary exposure to wind or fire.

Primary valleys are concave landforms that collect water between primary ridges. They may contain seasonal drainages, seeps, wet soils, or concentrated surface flow during storms. On the landform map, draw a line down the center of each primary valley to show where water is likely to concentrate and move downhill.

Primary valleys often provide important clues for agroforestry planning. They may indicate areas with deeper soils, greater seasonal moisture, higher frost risk, or greater erosion potential. Depending on slope, soil, hydrology, and regulations, valleys may be appropriate for riparian buffers, silvopasture, water-harvesting earthworks, wildlife corridors, or moisture-tolerant tree and shrub plantings. In other cases, they may be poor locations for roads, buildings, or frost-sensitive crops.

Keypoints and keylines

In keyline planning, a **keypoint** is the location in a primary valley where the slope changes from a steeper upper valley to a gentler lower valley. This point often marks a transition in how water moves through the landscape. A **keyline** is a contour line that passes through the key point and can be used as a reference for planning cultivation, planting, water movement, or other landform-based design decisions.

Keypoints and keylines are most relevant on properties with clear primary valleys and enough slope to make water movement a major design consideration. They can help planners understand where water begins to slow, spread, or accumulate across the landscape. However, keyline concepts should be applied carefully and adapted to the specific soils, rainfall patterns, slope conditions, and regulatory context of the site.

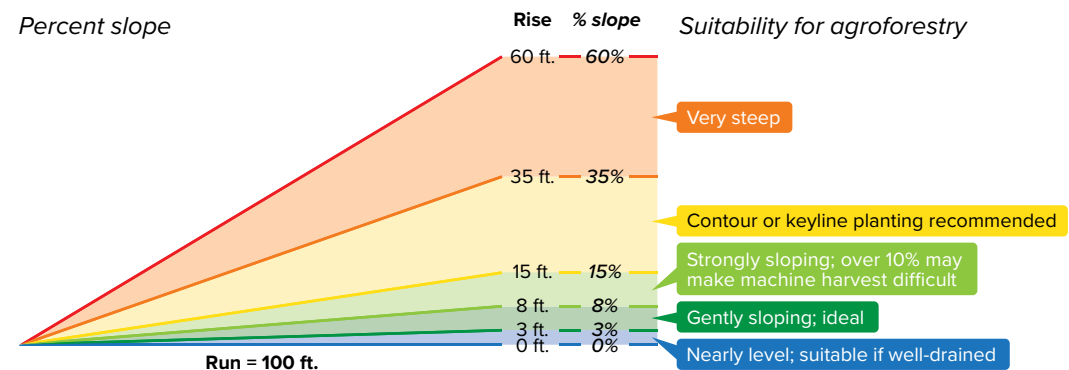
Slope and aspect

Slope and aspect are specific landform characteristics that are especially relevant to agroforestry planning.

Aspect refers to the compass direction a slope faces. It influences sunlight, temperature, soil moisture, vegetation, and plant suitability. Careful consideration of aspect can help match species and systems to the conditions they prefer.

South- and southwest-facing slopes usually receive more solar energy and tend to be warmer and drier than north-facing slopes. In hotter and drier areas of the Northwest, north- and east-facing slopes often support more forest cover, while south- and west-facing slopes may support grasslands, oak, madrone, pine, and other drought-tolerant species. West-facing slopes can be especially dry because they receive direct sun during the hottest part of the day. In some

Figure 4.4e. Slope suitability



From Ditsch, D. C., et al. *Managing steep terrain for livestock forage production*. Cooperative Extension Service, University of Kentucky, College of Agriculture, USA (2006).

areas, groundwater and soil moisture may be more persistent on north-facing slopes.

Slope gradient affects machinery access, road design, crop layout, irrigation, erosion risk, wildfire behavior, soil drainage, and air movement. Gentle slopes may be suitable for a wide range of agroforestry systems and equipment access. Moderate slopes may require careful road layout, erosion control, and planting design. Steep slopes may limit machinery use and may be better suited to tree crops, silvopasture, forest farming, conservation plantings, or low-disturbance management.

Slope can be measured in the field with a hand level or clinometer. It can also be estimated using digital elevation models, GIS software, or soil survey information. USDA Soil Survey data often provide slope ranges for soil map units, which can offer a useful starting point for understanding slope across a property. However, field observation remains important, especially on small sites where slope can vary over short distances.

Using landform assessment in agroforestry planning

Once ridges, valleys, slope, aspect, drainage patterns, and key elevation changes have been mapped, these features can be compared with soils, vegetation, access, and water resources. This combined analysis helps identify where agroforestry systems are most appropriate, where infrastructure can be placed with the least disturbance, and where landform creates opportunities or constraints for water management, livestock choice, erosion control, fire planning, or crop establishment.

Landform should not be evaluated as a static background feature. It is one of the primary organizers of farm design. Reading landform helps planners understand how water, cold air, heat, wind, fire, animals, people, and equipment move across a site. These patterns can then guide the placement of roads, ponds, fences, buildings, orchards, silvopasture systems, riparian buffers, windbreaks, and other agroforestry practices.

Soil conditions strongly influence the selection of agroforestry crops, systems, and management strategies. Soil observation and analysis are therefore critical steps in site assessment and planning. Because agroforestry systems can improve soil health and structure over time, it is also useful to establish a baseline at the beginning of a project so that changes can be monitored.

Published soil data can provide a valuable starting point, but it should not replace field observation. Soil maps, land capability ratings, and online databases can help identify likely soil types and limitations, while direct observation reveals site-specific conditions such as compaction, drainage, rooting depth, erosion, and soil structure.

Soil assessment should begin with existing soil information, then be refined through direct field observation and testing.

Gather published soil information

The [NRCS Web Soil Survey](#) provides current soil data and can generate a printable soil map for a site. [UC Davis' SoilWeb](#) is another user-friendly web-based soil mapping tool. Digitized county soil surveys are also available through the Internet Archive and can provide useful background information.

Soil survey data can be used to identify map units, parent material, soil horizons, depth to bedrock, drainage class, slope range, and land capability class. These maps can also help guide field observations by identifying which soil types and landforms should be examined directly.

Land Capability Classification

Land Capability Classification groups soils according to their ability to produce commonly cultivated crops and pasture plants without long-term deterioration. It provides a broad picture of agricultural potential by summarizing several soil characteristics into one classification system.

Capability class is the broadest category and ranges from Class 1 through Class 8. These classes apply to both irrigated and non-irrigated land and indicate increasing levels of limitation for agricultural use.

Capability subclass identifies the dominant limitation:

- **Subclass e:** erosion susceptibility or past erosion damage
- **Subclass w:** excess water, poor drainage, wetness, high water table, or overflow
- **Subclass s:** limitations within the rooting zone, such as shallow depth, stones, low moisture-holding capacity, low fertility, salinity, or sodium content.
- **Subclass c:** climate limitations, such as temperature or lack of moisture

Plan field soil observations

After reviewing published soil data, select locations for field observation and sampling. Soil survey maps can help identify broad soil types, but field observations should also be informed by landform, water movement, vegetation, current land use, and management history.

Areas under consideration for agroforestry should be evaluated in multiple locations within each major landform or soil type. As a general guideline, dig one or two soil pits per acre, and more where soils or landforms are highly variable. Dig soil pits at least 18 inches deep, or deeper where rooting depth, compaction, water table, or restrictive layers need to be evaluated.

Useful field tools include a knife, sealable sample bags, a permanent marker, a notebook, a container

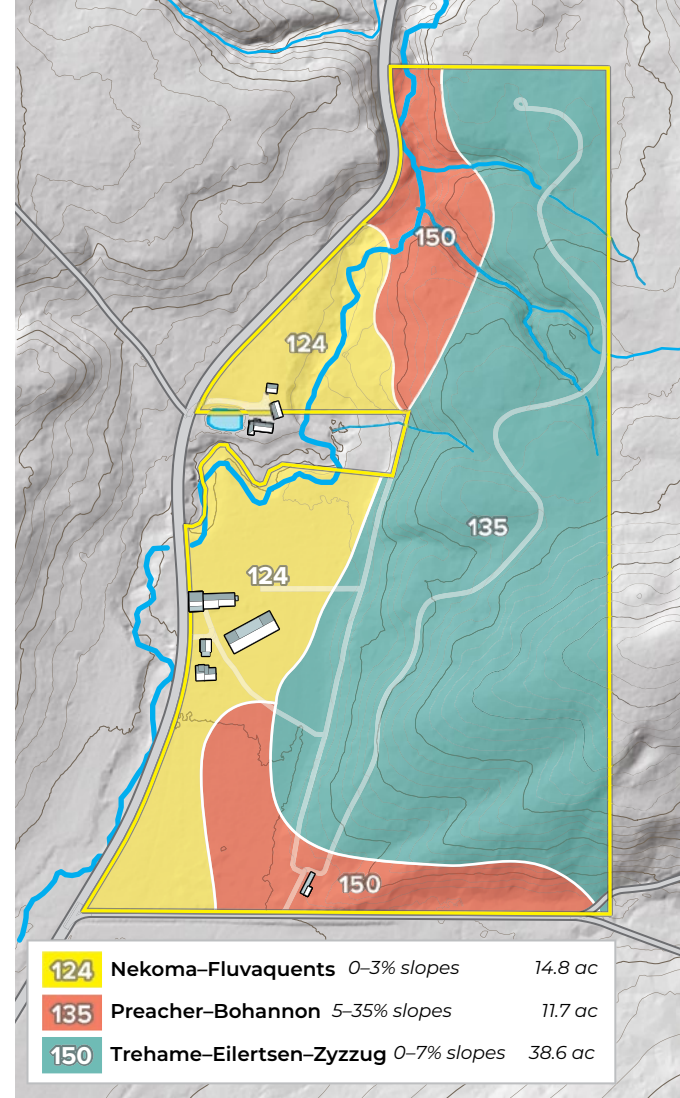


Figure 4.5a. Soil survey example

Map courtesy of Michael Godfrey and Resilience Permaculture Design

of water, and, where available, a soil penetrometer or hand lens. Record the location of each soil pit or sample on the planning map so that observations can be compared with soils, slope, vegetation, drainage, and future planting areas.

Table 4.5a. Land capability classes

	Erosion hazard	Minimum depth of water table	Flooding	Salinity (mmhs/cm)	Soil reaction (pH)	Stones or boulders only on surface	Rock outcrop	Minimum depth to bedrock	Available water capacity	Permeability	Drainage class	Land capability class definition
I	None or slight	48 in. Does not interfere with crop production.	None during growing season. Crop selection not restricted.	< 2	Favorable. Easy to modify.	< 0.1%	< 0.1%	40 in.	> 9 in.	Moderately slow to moderately rapid	Well or moderately well-drained	Soils have slight limitations that restrict their use.
II	Moderate	30 in. Delays planting or harvesting.	Rare to occasional. Slight crop damage. 0–20% yield reduction or crop selection slightly affected.	≥ 2 to ≤ 4	Favorable. Easy to modify.	≥ 0.1% to < 3%	≥ 0.1% to < 2%	20 in.	> 6 in. to ≤ 9 in.	Slow or rapid	Moderately well or somewhat poorly	Soils have moderate limitations that reduce the choice of plants or require moderate conservation practices.
III	Severe	18 in. Crop selection moderately affected.	Occasional. Moderate crop damage. 20–35% yield reduction or crop selection moderately affected.	> 4 to ≤ 8	Unfavorable. High lime to difficult to modify.	≥ 3% to < 15%	≥ 2% to < 10%	20 in.	> 3 in. to ≤ 6 in.	Very slow or very rapid	Somewhat poorly or poorly	Soils have severe limitations that reduce the choice of plants or require special conservation practices, or both.
IV	Very severe	12 in. Crop selection severely affected.	Frequent. Severe crop damage 35–50% yield reduction or crop selection severely affected.	> 8 to ≤ 16	Unfavorable. Very difficult to modify.	≥ 3% to < 15%	≥ 2% to < 10%	10 in.	≤ 3 in.		Poor	Soils have very severe limitations that restrict the choice of plants, require very careful management, or both.
V	None or slight	48 in.	Frequent. Prevents normal production of crops. If protected from flooding, • Class V equals I	< 2		≥ 15% to < 50%	< 0.1%	40 in.	> 9 in.	Moderately slow to moderately rapid		Soils have little or no hazard of erosion but have other limitations, impractical to remove, that limit their use mainly to pasture, rangeland, forest, or wildlife habitat.
VI		< 12 in. Ponding. Class II or III after drainage.	• Class VI equals II • Class VII equals III If landform is a tidal flat, then Class VIII.	> 16 to ≤ 30		≥ 15% to < 50%	≥ 10% to < 50%	20 in.	> 6 in. to ≤ 9 in.	Slow or rapid		Soils have severe limitations that make them generally unsuited to cultivation and that limit their use mainly to pasture, rangeland, forest, or wildlife habitat.
VII		< 12 in. Ponding. Class IV after drainage.		> 30 to ≤ 40		≥ 50% to < 90%	≥ 50% to < 90%	10 in.	> 3 in. to ≤ 6 in.	Very slow or very rapid		Soils have very severe limitations that make them unsuited to cultivation and that restrict their use mainly to rangeland, forest, or wildlife habitat.
VIII		< 12 in. Ponding. Cannot be drained.		> 40	Cat clays. Unfavorable. Impracticable to modify.	≥ 90%	≥ 90%	< 10 in.	≤ 3 in.			Soils and miscellaneous areas have limitations that preclude their use for commercial plant production and limit their use mainly to recreation, wildlife habitat, water supply, or aesthetic purposes.

Adapted from NRCS by Abel Kloster and Michael Godfrey of Resilience Permaculture Design

Evaluate soil horizons and physical conditions

Soil is arranged in horizons that together form the soil profile. Each horizon may differ in texture, structure, color, moisture, organic matter, compaction, and rooting conditions. These characteristics influence water movement, nutrient availability, biological activity, and the ability of tree and crop roots to grow.

Use a knife or small shovel to examine each horizon separately. Record changes in color, texture, structure, root distribution, rock fragments, moisture, and any restrictive layers such as compacted soil, hardpan, cobble, fractured rock, or bedrock.

Texture

Soil texture refers to the relative proportions of sand, silt, and clay. These particle sizes strongly influence drainage, water-holding capacity, aeration, nutrient retention, and workability.

Sandy soils tend to drain quickly and dry out easily. **Silty** soils can be fertile but may have weak structure. **Clay** soils can hold water and nutrients well, but may be dense, sticky, poorly aerated, and slow to drain. **Loam** contains a balanced mixture of sand, silt, and clay and is often favorable because it can hold moisture while still allowing drainage and root growth.

Two common field methods for estimating texture are [texture by feel analysis](#) and the [jar test](#). Texture-by-feel can be done directly in the field, while the jar test is usually done with samples collected from the site. Using both methods can help compare textures across soil horizons and landforms.

Structure and stable aggregates

Soil structure describes how soil particles are arranged and aggregated. While soil texture is difficult to change, soil structure can often be improved through management.

Granular structure is generally favorable because it allows roots, water, air, and soil organisms to move through the soil. **Blocky** structure forms smaller

angular or rounded chunks. **Platy** structure forms flat layers that can restrict water and root movement. **Massive** structure occurs when soil is cemented or compacted into large, dense masses.

Soil structure can often be evaluated with a 10X hand lens or by gently breaking apart a soil sample. A slake test can also measure the stability of soil aggregates.

Stable aggregates are a foundation of healthy soil habitat. In healthy soils, fungal hyphae, organic matter, and minerals help bind particles into stable granular aggregates. Agroforestry systems can contribute to aggregate formation through perennial roots, organic matter inputs, fungal activity, and reduced soil disturbance. Deep-rooted trees, shrubs, and perennial plants can help build soil structure over time.

Color

Soil color provides clues about organic matter, mineral composition, drainage, and seasonal water table. Dark surface soils often indicate higher organic matter. Red, yellow, or brown colors often reflect oxidized iron and well-aerated conditions. Gray, bluish,



Left: Soil pit or field soil observation showing horizons, rooting depth, color changes, and restrictive layers.

Photos courtesy of Abel Kloster

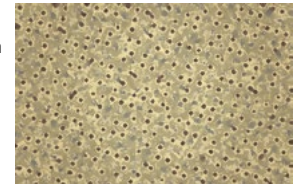
Figure 4.5b. Soil structure

Soil structure types

Granular

Crumbly soil layer most often found in surface layers with organic matter.

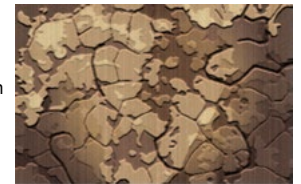
Highly permeable with the most pore space of any structure.



Blocky

Sharp- or round-edged equidimensional blocks that are usually 0.5 to 2 inches in diameter.

Blocks fit together well, but have high permeability.



Prismatic

Vertically elongated columns of soil that might be a number of inches long. Usually found in lower horizons.

Moderate permeability.



Columnar

Vertical columns of soil that have a salt "cap" at the top.

Found in arid climates where soil is effectively sealed to air and water movement.



Platy

Thin, flat pieces of soil that lie horizontally. Commonly found in compacted soil.

Platy structure has low permeability and has the least pore space.



Structureless soil types

Single grain

Highly permeable soils broken into individual particles that do not stick together. Accompanies a loose consistency, such as in sandy soils.

Massive

Low permeability soil where particles are cemented together, such as large cohesive masses of clay. Found in deep horizons and has no true structure.

or greenish colors may indicate prolonged saturation and low-oxygen conditions. Mottles, often rusty red or orange, can indicate fluctuating water tables.

With increasing depth, soil colors often become lighter, yellowier, or grayer. These color changes can help identify soil horizons and may indicate wetness, restricted drainage, or shifts in organic matter.

Depth

Soil depth determines the rooting capacity of trees, shrubs, pasture, and crops. Many upland soils in the Pacific Northwest are shallow and require careful species selection and management. Depth may be limited by bedrock, compacted layers, hardpan, cobble, clay lenses, or seasonal saturation.

In each soil pit, record the depth to any restrictive layer. Also note the amount of rock fragments in each

horizon. Shallow soils may limit rooting and water storage, but they can also support unique planting opportunities where warm microclimates, rocky outcrops, or specialized plant communities are present.

Where soils are shallow, agroforestry planning may require smaller or more drought-tolerant species, careful rootstock selection, reduced equipment traffic, soil-building practices, or pruning strategies that reduce top-heaviness in trees.

Assess compaction

Compacted soils limit root penetration, reduce infiltration and drainage, and restrict the exchange of air and gases necessary for healthy plant growth. In agroforestry systems, where trees, crops, and sometimes livestock must coexist, compaction can significantly limit establishment, productivity, and resilience.

Compaction often appears in plant performance and surface conditions. Indicators may include stunted growth, shallow roots, poor crop or pasture vigor, standing water, or persistent bare areas. Compaction is often associated with repeated traffic patterns, such as machinery lanes, livestock gateways, field entrances, and areas between crop rows.

A **soil penetrometer** measures resistance as it is pushed into the soil, helping identify both the depth and severity of compacted layers. Readings above 300 pounds per square inch are generally considered restrictive to root growth. For reliable results, take measurements in several locations when the soil is moist but not saturated.

Where a penetrometer is not available, soil pits can provide direct evidence of compaction, including plow pans, dense subsoil layers, abrupt changes in root growth, or water perched above a restrictive horizon. Bulk density testing can provide more precise laboratory analysis.

Where compaction is detected, management strategies may include reducing heavy equipment use, confining traffic to designated lanes, improving live-



Above: Assessing soil compaction with a penetrometer.

Photos courtesy of Abel Kloster

stock distribution, using deep-rooted cover crops, or applying mechanical interventions such as subsoiling under appropriate soil conditions. Over time, the diverse rooting patterns of trees, shrubs, and perennial plants can help restore and maintain soil structure.

Assess soil moisture, drainage, and hydric conditions

Soil moisture is essential for plant establishment and growth. It is strongly influenced by soil texture, structure, organic matter, groundwater levels, landform position, and impermeable layers. Coarse-textured soils often drain quickly and stay dry longer, while fine-textured soils may retain more water and remain moist for extended periods.

Drainage affects soil aeration, root development, nutrient availability, and disease risk. Poor drainage can create waterlogged conditions that reduce root growth and increase the likelihood of disease. Because drainage varies across landforms, field assessments should include uplands, slopes, benches, low areas, and locations where water concentrates.

High water table, standing water, or flooding

Wetlands, riparian zones, low areas, and soils that remain saturated for long periods require special consideration. These areas are sensitive to development and machine use, but they can also provide import-

Performing a percolation test

1. **Dig a test hole** 12 to 18 inches deep with vertical sides using a shovel or post-hole digger.
2. **Saturate the soil** by filling the hole with water and letting it drain completely. This step simulates natural conditions.
3. **Refill and measure.** Place a stick across the top of the hole for reference, refill and measure the water depth with a ruler.
4. **Time the drainage** by recording how much the water level has dropped over a 15 minute to 1 hour-long interval
5. **Calculate the rate.** Convert the drop into inches per hour to find the drainage rate.

Interpreting the results

- **Fast drainage** (more than 4 in/hr): Often sandy soil; can dry out quickly and lose nutrients.
- **Good drainage** (1–3 in/hr): Ideal for most orchards; provides the right balance of air and water for roots.
- **Slow drainage** (less than 1 in/hr): Often clay or compacted soil; may cause waterlogging, root rot, or disease.

ant wildlife habitat, water storage, riparian function, and other ecological benefits. Access may be limited during wet periods.

Mark areas with standing water, seasonal saturation, flood deposits, wetland vegetation, or a high water table. These areas may be appropriate for riparian buffers, wetland-compatible plantings, seasonal silvopasture, or moisture-tolerant species, but they may be poorly suited to roads, buildings, intensive cultivation, or species sensitive to saturated soils.

Hydric soils

Hydric soils are saturated or flooded long enough during the growing season to create anaerobic conditions and support wetland vegetation. They can be identified through a combination of surface, color, and biological clues.

Surface clues may include a strong “rotten egg” smell caused by hydrogen sulfide gas, dark mucky soil with high organic content, standing water, or soil that remains saturated well into the growing season.

Color clues may include gray, bluish, or greenish soil colors, known as gleying, which suggest prolonged saturation and reduced iron. Mottles or spots of contrasting rusty red or orange color indicate places where iron has been re-deposited as water levels fluctuate.

Biological clues may include dense mats of wetland plant roots near the soil surface and an abundance of water-loving plants such as sedges, rushes, and other wetland species.

One indicator alone may suggest saturation, but a combination of surface, color, and biological clues provides a more reliable assessment. Soil map units dominated by hydric soils may still contain small non-hydric patches at higher elevations, while non-hydric map units may include small hydric areas in depressions or low spots.

High potential crops

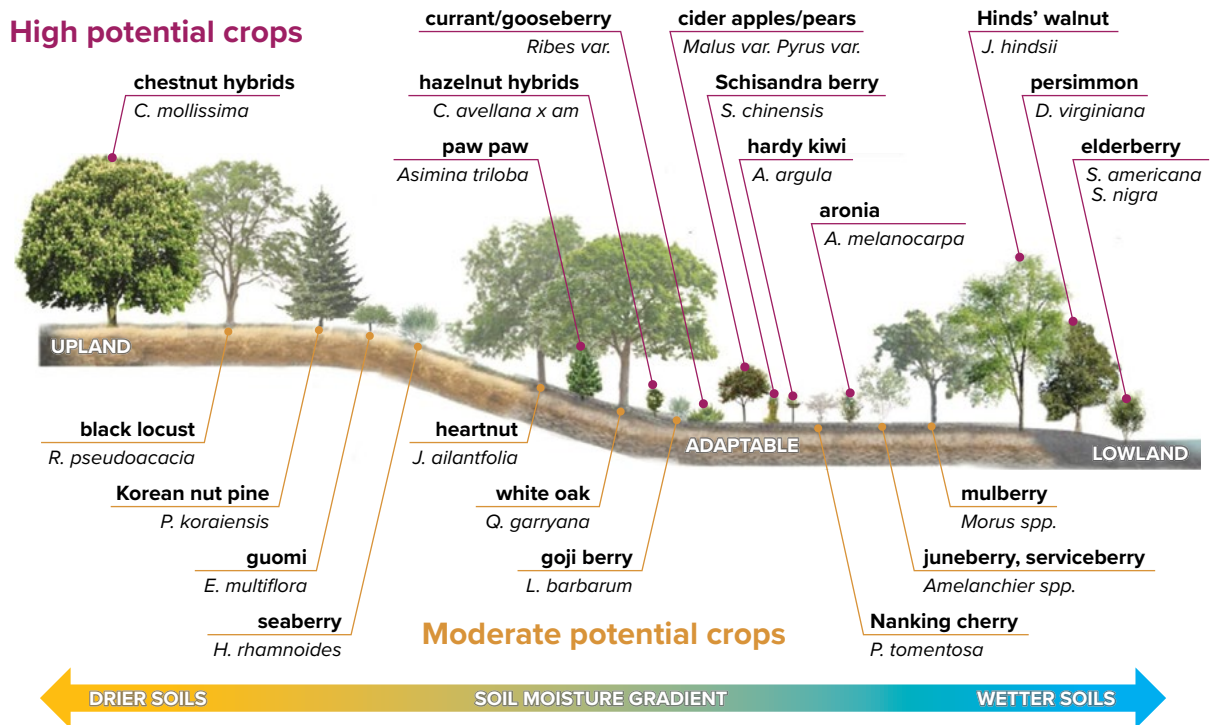


Figure 4.5c. Crop suitability along a soil moisture gradient.

Source: Regenerative Design Group

Soil drainage and agroforestry species selection

Soil drainage and moisture conditions should guide species selection, rootstock selection, planting layout, and infrastructure placement. Well-drained uplands will support different crops than seasonally wet bottoms or poorly drained clay soils. Agroforestry plans should match species to these differences rather than treating the site as uniform.

Where soils are wet, compacted, or poorly drained, management options may include improved grazing management, reduced machinery impacts, designated traffic lanes, deep-rooted perennial cover, subsoiling where appropriate, and water-tolerant rootstocks or species.

In some sites, drainage limitations may be better addressed by adapting the planting plan rather than trying to force drainage improvements.

Figure 4.5c illustrates how potential agroforestry crops can be matched to different positions along a soil moisture gradient, from drier upland soils to wetter lowland soils. This kind of gradient-based thinking can help planners identify broad planting opportunities before refining species choices through field observation, soil testing, and local experience.

Table 4.5b. Rootstocks for wet and heavy soils

Fruit/nut	Rootstock	Description
Apple	Geneva 210 (G.210)	Very tolerant of heavy/wet soils, good disease resistance
	Antonovka (seedling)	Vigorous, hardy, reliable in clay or wetter soils
Pear	OHxF 97	Strong, reliable growth on heavier/wet soils
	OHxF 87	Also a good option, but slightly less vigorous than OHxF 97
Cherry	Krymsk 6	Best option for wetter soils among cherry rootstocks
	Mazzard (seedling)	Moderate tolerance; better than Mahaleb or Gisela in heavier soils
Peach / nectarine	Krymsk 86	More tolerant of wet and clay soils than Lovell or Nemaguard
	Hansen 536 (peach-almond hybrid)	Handles heavier soils better than standard peach rootstocks
Plum	Marianna 2624	Among the best for poorly drained/heavy soils
	Marianna GF 8-1	Very tolerant of wet conditions, often used in problematic soils
	Myrobalan	Reliable choice for clay and seasonally wet soils
Walnut	Paradox hybrid (<i>J. hindsii</i> × <i>J. regia</i>)	Strong tolerance of wetter soils, widely used in orchards
	Royal hybrid (<i>J. regia</i> × <i>J. major</i>)	Better suited to heavy/wet soils than standard walnut seedlings
Chestnut	European chestnut (<i>C. sativa</i> seedlings)	More tolerant of clay and wet conditions than American types
	Dunstan chestnut (American × Chinese hybrid)	Moderately tolerant, more adaptable than pure American chestnut

For fruit and nut crops, rootstock selection can also help adapt plantings to heavier or wetter soils. **Table 4.5b** provides examples of rootstocks commonly used where drainage, clay content, or seasonal wetness may limit tree establishment.

Assess erosion

In many agricultural landscapes, soil is lost to erosion faster than it can be formed. This reduces organic matter, nutrient-holding capacity, water-holding capacity, and long-term productivity. Existing erosion should be mapped during site assessment.

Record rills, gullies, exposed subsoil, sediment deposits, bare slopes, eroding roads, unstable streambanks, and areas where runoff concentrates. These locations may require special protection through perennial cover, contour plantings, water spreading, mulch, reduced disturbance, road drainage improvements, or other erosion-control practices.

Test soil fertility and organic matter

Soil testing provides a baseline for fertility, pH, organic matter, and nutrient availability. A basic soil test usually reports pH and major nutrients such as potassium, phosphorus, calcium, and sodium. This information can help identify which crops may be naturally suited to the site and which amendments may be needed.

A soil test should include organic matter because it is a major indicator of soil productivity, water-holding capacity, nutrient retention, and biological activity. Some tree crops may also require information on minor nutrients, so sampling requests should be tailored to the species or systems being considered.

Separate samples should generally be taken for different fields, soil types, management histories, or landform positions. Samples may also be separated where slope, drainage, vegetation, or crop perfor-



Figure 4.5d. Common erosion indicators

Source: NRCS

mance varies significantly. County extension offices may provide soil testing information or discounted services, while private laboratories can provide standard soil analysis and recommendations.

Interpreting test results

When submitting samples, request nutrient recommendations for the crops or tree species being considered. If the testing lab cannot provide crop-specific

recommendations, a county extension agent, horticulture specialist, or other technical advisor may be able to help interpret the results. Nutrient management approaches vary, so it can be useful to compare recommendations before making major amendments.

Most fruit and nut trees grow well around a pH of 6.0 to 6.5, although some species tolerate more acidic or alkaline conditions. Blueberries, for example, prefer more acidic soils. Soil pH affects nutrient availability and should be considered when selecting species, rootstocks, and amendment strategies.

Nutrient availability affects plant growth, yield, product quality, and long-term system health. Soil testing can identify nutrient deficiencies or excesses, while tissue analysis can help evaluate the nutritional status of existing trees and perennial plants. Tissue analysis is often especially useful in forest soils or established perennial systems.

Organic matter influences soil structure, porosity, water infiltration, water-holding capacity, nutrient exchange, and biological activity. It also supports soil microorganisms and contributes to good tilth. Agroforestry practices can build organic matter over time through roots, leaf litter, prunings, mulch, manure, reduced disturbance, and continuous plant cover.

Using soil assessment in agroforestry planning

Soil assessment should lead directly into planning decisions. Published data, soil pits, drainage tests, compaction observations, erosion mapping, and laboratory results can be compared with landform, water, vegetation, access, and intended enterprises.

On the planning map, record soil types, sampling locations, shallow soils, compacted areas, wet or hydric soils, erosion features, drainage test results, and areas with notable fertility or pH limitations. These layers can help identify where specific agroforestry practices, species, rootstocks, infrastructure, and management strategies are most appropriate.

Table 4.5c. Qualitative soil health indicators

Indicator	Best conditions for assessing	Poor quality	Medium quality
Earthworms	Spring/fall; good soil moisture	0–1 worms in a shovelful of top foot of soil; no casts or holes	2–10 in a shovelful; few casts, holes, or worms
Organic matter color	Moist soil	Strong, reliable growth on heavier/wet soils	Surface color is closer to subsoil color
Organic matter residues	Anytime	No visible residues	Some residues
Root health	Late spring (rapid growth stage)	Few, thick roots; no subsoil penetration	Off-color (staining) inside root
Subsurface compaction	Pre-till or post-harvest; good soil moisture	Wire breaks or bends when inserting flag	Have to push hard, need fist to push flag in
Soil tilth, mellowness, and friability	Good soil moisture	Looks dead; feels like brick or concrete, cloddy	Somewhat cloddy, balls up, rough pulling seedbed
Erosion	After heavy rainfall	Large gullies over 2 inches deep joined to others; thin or no topsoil; rapid runoff; off-color soil	Few rills or gullies; gullies up to 2 inches deep; some swift runoff; colored water
Water holding capacity	After rainfall; during growing season	Plant stress two days after a good rain	Water runs out after a week or so
Drainage infiltration	After rainfall	Water lays for a long time; evaporates more than drains; always very wet ground	Water lays for a short period, eventually drains
Crop condition (how well it grows)	Growing season; good soil moisture	Problems growing throughout the season; poor growth; yellow or purple color	Fair growth; spots in field different; medium green color
pH	Annually at the same time each year	Hard to correct for desired crop	Easily correctable
Nutrient holding capacity	Over 5 years; always at the same time each year	Soil tests dropping into “low” category	Little change or slow-down trend

Source: Magdoff, Fred, and Harold Van Es. Building soils for better crops. Vol. 4. Beltsville: Sustainable Agriculture Network, 2000.

Soils should not be treated only as constraints. Many soil conditions can also suggest opportunities. Wet soils may support riparian buffers or moisture-tolerant crops. Shallow rocky areas may support drought-tolerant species or specialized habitat plantings. Deep well-drained soils may be prioritized for high-value tree crops. Compacted or degraded soils may be targeted for soil-building agroforestry practices and long-term monitoring.

Soil assessment combines published data, field observation, and laboratory testing to guide practical agroforestry decisions. By mapping soil types, drainage patterns, compaction, erosion, rooting depth, and fertility limitations, planners can better match species, rootstocks, and management strategies to the actual conditions of the site. Over time, these observations also set a baseline for tracking how agroforestry practices affect soil health, structure, and productivity.

Water

Water plays a foundational role in agroforestry design in the Pacific Northwest, where wet winters and springs are often followed by prolonged summer drought. Agroforestry systems in the region must therefore be planned around both seasonal excesses and seasonal shortages of water.

Water movement is also one of the most important influences shaping agroforestry development, affecting erosion, soil moisture, microclimates, infrastructure placement, and the long-term productivity of perennial systems.

Effective agroforestry planning requires careful evaluation of both the opportunities and limitations of available water resources on a site. Potential water sources may include rainfall harvested from roofs and runoff, seasonal waterways, ponds, wetlands, springs, and groundwater accessed through wells.

Understanding the seasonal availability, storage capacity, water quality, and legal accessibility of these resources is essential when planning irrigation systems, livestock watering infrastructure, tree establishment, and long-term farm resilience.

Water planning should also account for crop water requirements, livestock water needs, methods of delivery, infiltration capacity, and the movement of water across the landscape. In many cases, agroforestry systems themselves can improve water retention, reduce runoff, moderate drought stress, and increase infiltration through canopy cover, perennial root development, soil improvement, and water-harvesting earthworks.

Because water use in the Pacific Northwest is highly regulated, planners must also understand and comply with applicable water rights and permitting require-

ments related to wells, springs, ponds, streams, and irrigation systems.

Water assessment should begin with an inventory of existing water sources and constraints, then move toward design decisions about storage, delivery, conservation, planting layout, and long-term management.

Inventory water sources and constraints

Determining whether water is available, legally accessible, and sufficient for irrigation or livestock use is an essential early step in agroforestry planning. In many cases, this requires a preliminary hydrologic assessment and a review of issued state water rights. A permit may be required to divert surface water, install wells and pumps, store water, or put water to beneficial agricultural use.

Using a landform map, locate and assess existing water sources across the property. These may include wells, springs, roof catchment areas, seasonal drainages, perennial streams, rivers, wetlands, ponds, irrigation ditches, and areas where runoff concentrates during heavy rain. Each source should be evaluated for seasonal availability, potential yield, water quality, elevation relative to points of use, infrastructure needs, and legal limitations.

Figure 4.6a shows an example water inventory map that combines existing water sources, drainage patterns, storage locations, elevation, and water delivery infrastructure. This type of map can help planners understand where water is available, where it moves, and how it may be stored or distributed across the site.

Wells

Many rural properties rely on wells for water. Although wells are a common source of domestic and agricultural water in the region, establishing new wells can involve significant cost and uncertainty. Drilling is expensive, and a new well may not provide adequate flow, reliable recharge, or suitable water quality.

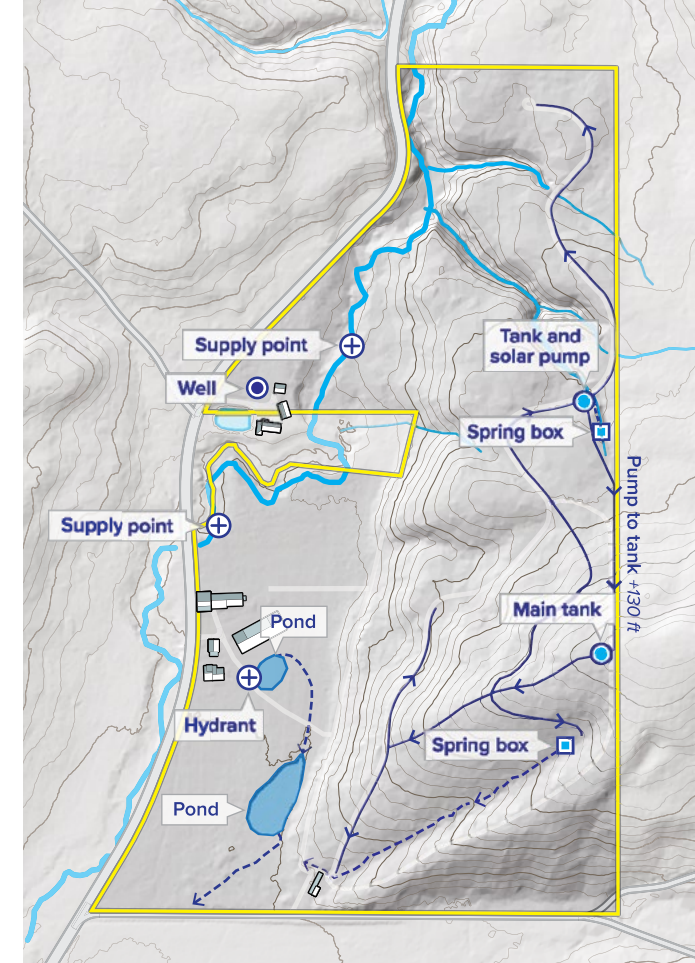


Figure 4.6a. Water source inventory and gravity-fed water supply map.

This example map locates springs, tanks, ponds, hydrants, seasonal drainages, potential off-channel water supply points, and gravity-fed water delivery routes across a site.

Map courtesy of Michael Godfrey, Resilience Permaculture

When evaluating an existing well, several characteristics should be assessed:

- **Flow rate:** the amount of water delivered, commonly measured in gallons per minute.
- **Static water level:** the resting water level in the well when it is not being pumped.
- **Drawdown rate:** how quickly the water level drops during pumping.
- **Recovery rate:** how quickly the well refills after pumping stops.
- **Water quality:** the chemical, mineral, and biological suitability of the water for its intended use.

Together, flow, drawdown, and recovery rates help determine whether a well can support household use, irrigation, livestock watering, or other farm needs.

Depending on depth, wells may access shallow groundwater or deeper aquifers. Deeper wells may provide a more reliable supply, but they can also contain problematic minerals such as salts, arsenic, or elevated hardness. Shallow wells are often more dependent on seasonal rainfall, but may still provide useful water in some settings. Well depth also affects the energy required to pump water.

If a property does not have an existing well, nearby well records can provide useful information about expected depth, yield, and water quality. The [Oregon Department of Water Resources](#) and the [Washington State Department of Ecology](#) maintain databases of well records that can be used to evaluate existing wells and assess the likely viability of new wells in the surrounding area.

Water rights and agricultural well use

Oregon and Washington distinguish between domestic wells and agricultural wells. Domestic wells are intended for household use and limited irrigation for residential use. Agricultural wells are intended for commercial agricultural production, including orchard crops and other agroforestry products.

Before relying on well water for agroforestry, planners should determine whether existing wells are permitted for domestic or agricultural use. Commercial irrigation may require an agricultural water right, metering, or other regulatory steps. In some areas, new agricultural well permits may be limited or denied due to proximity to streams, groundwater restrictions, or known aquifer depletion. For this reason, alternative water sources and water-conservation strategies should be evaluated early in the planning process.

Springs

Springs occur where groundwater emerges naturally at the surface. They have historically been valued as water sources for homesteads, livestock, and small-scale irrigation, especially where they occur uphill from points of use and can supply water by gravity.

Two broad spring types are commonly encountered:

- **Gravity springs** occur where groundwater naturally flows out at the surface, often on hillsides, cliffs, terraces, or where water encounters an impermeable layer and is forced outward.
- **Artesian springs** occur where groundwater is confined under pressure beneath an impermeable layer and is forced to the surface through a fissure or opening.

Springs may be identified by lush vegetation, saturated ground, cold water, small channels, or seepage emerging from a consistent elevation. Drainage channels can sometimes be followed uphill to locate their source.

Topographic maps may also reveal subtle channels, terraces, or slope breaks where springs are likely to emerge. If one spring is found, others may occur at similar elevations where groundwater emerges from the same bedrock layer or subsurface feature.

A useful spring generally has reliable flow, cold water, and no unpleasant odor or taste. If a spring is located, its flow can be estimated by temporarily collecting or impounding the water and measuring the discharge

over time. Water quality testing is recommended before using spring water for household, livestock, or irrigation purposes. The elevation of the spring should also be recorded, since springs located uphill from fields, tanks, or livestock areas may support gravity-fed water systems.

Flowing waterways and seasonal drainages

All waterways should be mapped across the property. This includes perennial streams, rivers, seasonal drainages, intermittent channels, and areas that carry surface flow only during heavy rain. From a planning perspective, small upstream drainages can be especially important because they influence erosion, infiltration, pond siting, road layout, and opportunities for water-harvesting earthworks.

A landform map can be used to trace the path of water across the site. Mark primary valleys, secondary drainages, seasonal channels, and year-round streams. Seasonal drainages may be shown with dashed lines, while year-round streams may be shown with solid lines. Note areas where runoff concentrates during storms, even if they do not appear as official streams.

Online datasets can help cross-reference field observations. The [US Fish and Wildlife Service](#) maintains geographic data for many wetlands and waterways, including intermittent and perennial streams. These provide a useful starting point, but field observation is still necessary because small seasonal drainages and runoff pathways may not be fully mapped.

Unless a site has recorded surface water irrigation rights, water from creeks, streams, and rivers generally cannot be diverted for crop irrigation. Surface water use should be evaluated carefully before being included in an agroforestry design.

Flood-prone areas

Flood-prone areas should be identified before locating roads, fencing, irrigation infrastructure, buildings, livestock facilities, or high-value perennial crops. The [Federal Emergency Management Agency](#) provides flood maps that can be viewed and downloaded online. These maps commonly show areas affected by 100-year and 500-year flood events.

A 100-year flood is a flood with a one percent chance of occurring in any given year. A 500-year flood has a 0.2 percent chance of occurring in any given year. These terms describe statistical probability, not a guarantee that such floods will occur only once every 100 or 500 years.

Mark the high-water extent of mapped 100-year and 500-year flood zones on the site assessment map.

Figure 4.6b provides an example of a FEMA flood map that can be used to identify mapped flood zones and flood-prone areas near a site.

Flood-prone areas may be appropriate for seasonal silvopasture, riparian buffers, floodplain restoration, or other low-impact uses. More intensive systems that depend on permanent fencing, irrigation infrastructure, roads, or high-value plantings may be less suitable in these areas.

Irrigation diversions and ditches

Existing irrigation diversion points, pumps, ditches, canals, and distribution lines should be mapped. If the property has water rights with defined points of diversion or points of use, those locations and service areas should also be marked.

Irrigation infrastructure should be evaluated for function, condition, capacity, and legal status. Older ditches or diversion systems may require maintenance, lining, repair, or redesign. They may also carry legal obligations or restrictions that should be understood before new agroforestry plantings are planned around them.

Wetlands

Wetlands should be mapped and treated as sensitive planning areas. Federal, state, and local regulations may restrict grading, filling, drainage, road construction, pond construction, or other activities that affect wetlands. Wetlands can also provide important ecological functions, including wildlife habitat, water storage, filtration, flood moderation, and groundwater recharge.

The [U.S. Fish and Wildlife Service National Wetlands Inventory](#) provides a useful starting point for identifying mapped wetlands. However, official wetland boundaries may require professional delineation, especially where development, earthwork, roads, drainage alteration, or planting changes are being considered.

Agroforestry planning should generally avoid degrading wetlands. In some cases, wetland-adjacent areas may be suitable for riparian buffers, wet meadow plantings, pollinator habitat, wildlife corridors, or other low-impact agroforestry practices.

Existing ponds

Existing ponds should be mapped and evaluated for function, condition, water source, storage capacity, and legal status. Important questions include:

- Does the pond hold water year-round or only seasonally?
- Are the banks stable, or is erosion evident?
- Are the dam, outlet, and spillway functional and safe?
- Is the pond deep enough for its intended use?
- Has sediment reduced storage capacity?
- Does the pond occur in a stream channel or off-channel location?
- Is the pond legally permitted for its current or intended use?

Many older ponds were built in lowland settings, including main channels or consistently flowing waterways. From both ecological and regulatory perspectives, in-channel ponds can create problems



Figure 4.6b. FEMA flood map showing mapped flood zones and flood-prone areas.

Flood maps can help planners identify areas where roads, fences, irrigation infrastructure, buildings, and high-value perennial crops may face increased flood risk. Image from hazards-fema.maps.arcgis.com

by impeding fish passage, blocking stream channels, altering flow, increasing water temperature, or diverting water. In many cases, new in-channel ponds are not legally permissible.

Ponds can also occur in upland settings, including saddles, ridgelines, keypoints, and upper valleys. These sites may require infrastructure to convey surplus water into storage, but their elevation may allow gravity-fed distribution to lower areas. When legally and technically feasible, elevated storage can potentially support irrigation, livestock watering, and fire preparedness without relying entirely on power-driven pumps. Older or abandoned upland ponds and earthworks may be hidden by vegetation, so these locations should be inspected during site assessment.

See **Chapter 5: Design Considerations** for a discussion of new pond layout options.

Rainwater

Rainwater collected from roofs and stored in tanks, cisterns, or reservoirs can be a practical supplemental water source. Because rainwater has not yet entered surface water or groundwater systems, it may be easier to develop than other water sources, depending on local regulations and storage design.

An inventory of roof area from existing and proposed buildings can help estimate potential catchment volume. Rainwater harvesting may be especially useful for nurseries, propagation areas, small orchards, home-scale forest gardens, livestock watering, wash stations, or irrigation during tree establishment. Storage volume, seasonal rainfall patterns, roof materials, filtration, overflow management, and delivery infrastructure should all be considered.

For a guide to estimating catchment and storage, see the [Manual for Rainwater Harvesting in Oregon](#).

Graywater

Graywater may be considered as a supplemental irrigation source around homes or other buildings, especially for trees, shrubs, and home-scale forest garden systems. Graywater is generally best suited to subsurface irrigation of non-root crops, ornamental plantings, windbreaks, or perennial woody plants.

Graywater use must be designed carefully to protect human health, soil quality, and water quality. Local codes, allowable sources, soaps and detergents, filtration, slope, setbacks, application methods, and plant suitability should all be evaluated before graywater is incorporated into an agroforestry design.

See Oregon DEQ's [Guide to Graywater Planning](#) for additional information.

Assessing water requirements

Once water sources, constraints, and legal considerations have been identified, the next step is to compare available water with the needs of proposed crops, livestock, and infrastructure. Water assessment should inform planting layout, irrigation strategy, storage needs, species selection, drought planning, livestock distribution, access routes, and conservation practices.

Assess crop water requirements

In much of the Pacific Northwest, supplemental irrigation is often necessary during the establishment phase of agroforestry systems. Irrigation demand is generally higher in dryland parts of the region, on shallow or drought-prone soils, and for crops with high water needs. Established perennial crops may also benefit from irrigation during critical growth periods to support growth, fruit development, nut fill, and product quality.

Critical growth periods are the stages when water stress can have the greatest effect on yield, quality, or long-term plant health. These periods vary by crop, but commonly include establishment, flowering, fruit set, fruit ripening, and early years of tree or shrub development.

Crop water needs should be evaluated at both short-term and seasonal scales. Daily and weekly estimates help guide irrigation scheduling and system capacity. Seasonal or annual estimates help size storage reservoirs, tanks, pumps, and distribution systems and may be needed to support water rights planning. The [USDA Irrigation Guide](#) provides technical guidance for estimating irrigation requirements, designing irrigation systems, and evaluating water management needs at the farm scale.

Several methods can be used to estimate crop water requirements. The Penman-Monteith equation is widely used for short-term irrigation scheduling because it incorporates climate variables such as temperature, humidity, wind speed, and solar radiation. The FAO publication [Crop Water Requirements](#) is a foundational reference for estimating crop evapotranspiration and irrigation demand using climate-based methods.

The Modified Blaney-Criddle method is often used for longer-term estimates in moderate climates and relies primarily on temperature data. Because methods vary in complexity and data requirements, planners should use locally appropriate irrigation tools, extension guidance, NRCS resources, or professional irrigation support when sizing systems or estimating seasonal demand.

Align water supply with crop water needs

After estimating water supply and crop water needs, planners can evaluate how much land can realistically be planted with the currently available water.

This comparison can also identify whether additional storage, improved delivery systems, water conservation, or alternative crop choices are needed before expanding agroforestry production.

Strategies for reducing the gap between water demand and available supply may include:

- selecting efficient irrigation equipment
- dry farming where conditions are suitable
- using drought-tolerant or native species
- increasing infiltration through water-harvesting earthworks
- storing more water in soil through mulch, organic matter, and perennial cover
- using graywater where appropriate and legally allowed
- sizing new plantings to match available water rather than overextending supply

Water supply should be treated as both a design constraint and a design opportunity. Matching crop choice, planting density, establishment timing, and irrigation infrastructure to available water can improve resilience and reduce long-term management risk.

Assess livestock water requirements

Planners should evaluate livestock water needs wherever silvopasture, managed grazing, or livestock integration is part of the agroforestry plan. A common planning estimate for livestock water needs is one gallon of water per 100 pounds of body weight per day, but actual intake varies with animal type, body size, health, growth stage, lactation, forage moisture, and air temperature.

Water demand increases during hot weather, and this need may be compounded when forage becomes drier. Livestock watering systems should therefore be sized for peak seasonal demand, not just average conditions. Location is also important. Water points influence grazing patterns, livestock movement, soil compaction, and the distribution of manure and nutrients.

Table 4.6a summarizes estimated daily water intake for common livestock classes at moderate and hot temperatures. These values can be used as a starting point for estimating livestock water demand, but final system sizing should account for herd size, climate, forage conditions, delivery distance, storage volume, and backup water access.

Integrating water assessments into the agroforestry plan

Water assessment should be integrated with land-form, soils, vegetation, access, infrastructure, and legal constraints. On the planning map, record water sources, seasonal drainages, flood-prone areas, wetlands, ponds, irrigation infrastructure, roof catchment areas, points of diversion, points of use, and areas where runoff, erosion, or drought stress are likely.

These mapped patterns can help determine where agroforestry practices are most appropriate. Drier uplands may call for drought-tolerant species, wider spacing, mulch, or dry farming strategies. Wetter lowlands may be better suited to riparian buffers, wet meadow plantings, seasonal silvopasture, or species adapted to periodic saturation. Areas with reliable water access may support higher-value or higher-water-demand tree crops, while areas with limited supply may require more conservative planting plans.

Water planning should connect irrigation, storage, infiltration, and delivery into a coordinated farm system. When water supply, legal access, crop demand, livestock needs, storage capacity, and distribution infrastructure are planned together, agroforestry systems are better able to handle both winter wetness and summer drought.

Table 4.6a. Livestock water intake

Livestock	Daily water intake (gallons per head)	
	50°F	90°F
Beef animals		
400 lb. calf	4	10
800 lb. feeder	7	15
1000 lb. feeder	8	17
Cows and bulls	8	20
Dairy animals		
Cows	15	30
Calves	2	12
Replacement heifers	6	15
Bulls	8	20
Horses and mules	8	12
Sheep or goats	1.5	3.5

Source: D.M. Ball, C.S. Hoveland, and G.D. Lacefield. 2000. Southern Forages and the Foundation for Agronomic Research. Norcross, Georgia.

Access systems and management zones

Access systems form the foundation of circulation and management across the farm. Roads, trails, crossings, turnarounds, landings, gates, and work areas shape the movement of people, livestock, water, equipment, and harvested products. These features influence labor efficiency, management timing, erosion risk, infrastructure costs, and the long-term organization of agroforestry systems.

Access patterns are closely tied to management intensity. Areas that require frequent observation, irrigation, harvesting, livestock movement, or processing generally benefit from easier access and closer proximity to central infrastructure. Lower-intensity systems, such as timber production, extensive silvopasture, habitat plantings, or conservation areas, may be located farther from primary activity centers.

This relationship between access and management intensity can be evaluated through zone analysis, a planning approach commonly used in Permaculture design. **Zone analysis** organizes landscapes according to the frequency and intensity of human use. Systems requiring the most frequent attention are placed nearest to homes, shops, processing areas, barns, or other centers of activity, while lower-intensity systems are located farther away.

Table 4.7a summarizes how agroforestry elements may correspond to different management zones and expected frequency of access. These zones should not be applied rigidly. Instead, they provide a practical way to compare access needs, labor requirements, and the most appropriate locations for different agroforestry practices.

An access inventory should then be added as a layer on the working base map. This inventory helps

identify which roads, trails, crossings, and work areas can be retained, improved, relocated, or abandoned as the agroforestry plan develops. Access mapping should include four-season vehicle roads, dry-season vehicle roads, vehicle turnarounds and landings, stream crossings, headlands for tractor turnaround, foot trails, small-vehicle trails, livestock lanes, gates, harvest routes, staging areas, and processing areas.

Each type of access can be shown with a different color, line style, or map symbol. Where access networks are extensive, a mapping application can be used to track roads and trails in the field. These routes can then be uploaded into a GIS map or transferred onto a working base map.

Existing access should be evaluated according to the type and volume of traffic it receives, the season when it is used, and its effect on soils, water movement, vegetation, and farm operations. Heavy equipment routes, livestock lanes, and harvest roads often require different surfaces, grades, widths, and drainage features than footpaths or light-vehicle trails.

Access routes should also be compared with landform, soils, water, and vegetation maps. Roads or trails located on steep slopes, wet soils, unstable streambanks, or erosion-prone areas may create long-term maintenance problems. In contrast, routes located on stable ridges, benches, or well-drained ground may provide more durable access with fewer impacts.

Hillshade and slope imagery derived from bare-earth LiDAR can be especially useful where old roads, skid trails, terraces, or other earthworks are hidden by vegetation. These features can be sketched onto the base map and then checked through field observation. Where historic roads or trails are uncertain, a narrow exploratory path may be cleared first before committing to a permanent road alignment. This approach reduces unnecessary disturbance and allows planners to confirm whether a route is useful, stable, and compatible with the larger agroforestry design.

Table 4.7a. Management zones

Zone	Access frequency	Agroforestry elements
Zone 1	Multiple visits per day	Kitchen gardens, small livestock, culinary herbs
Zone 2	Daily or frequent access	Nurseries, forest gardens, orchards, intensive forest farming
Zone 3	Regular seasonal access	Silvopasture, alley cropping, coppice systems, aquaculture
Zone 4	Occasional or low-frequency access	Timber systems, savanna grazing, habitat hedgerows
Zone 5	Minimal access	Intact habitat, wetlands, sacred or culturally significant areas

An access inventory can reveal opportunities beyond basic circulation. Existing forest roads, skid trails, culverts, drainage ditches, water supply lines, tanks, ponds, and fire-water supply points can be mapped together to identify where access routes already support, or could be improved to support, water management, fire preparedness, harvest logistics, and long-term agroforestry operations.

Access planning should look for opportunities to reuse stable existing roads, landings, and skid trails; reduce unnecessary road length; improve drainage along roads and trails; avoid wetlands, steep slopes, unstable soils, and riparian areas; and provide turnarounds, staging areas, and equipment access before trees or perennial systems are established. Access routes can also be coordinated with water tanks, hydrants, ponds, irrigation lines, livestock lanes, gates, and emergency response routes.

A well-planned access system organizes work, reduces wasted movement, protects sensitive areas, and supports the practical management of agroforestry systems over time.

Vegetation

The next step in site assessment is to inventory and evaluate the plants growing on the property. This means adding a vegetation layer to the planning map and assessing both vegetation communities and individual plant species across the landscape. Vegetation provides important clues about soil moisture, drainage, disturbance history, microclimate, habitat value, and the agroforestry systems most likely to fit the site.



Above: Vegetation provides important insights into the type of agroforestry systems and species most likely to fit the site.

Photos courtesy of Patrick Shults

Assess vegetation communities

Vegetation communities may include oak woodlands, savannas, conifer forests, riparian forests, wetlands, pastures, cropland, old orchards, residential areas, and other heavy-use zones. Mapping these areas helps identify where agroforestry systems may be most compatible with existing site conditions.

Prior to colonization, the Pacific Northwest was a human-tended mosaic of wet and upland prairies, oak woodlands and savannas, streamside forests, wetlands, and mixed conifer woodlands. The loss of Indigenous stewardship, outlawing of cultural fire, and conversion of land to modern agriculture and forestry have led to extensive habitat loss and fragmentation.

Today, many remaining habitats face additional pressure from population growth, development, agricultural expansion, invasive species, altered fire regimes, and climate change. At the same time, farms, forests, and ranches can play an important role in restoring habitat function and ecosystem services through well-planned agroforestry.

Agroforestry can increase production while maintaining or restoring habitat values associated with meadows, forests, rivers, wetlands, and woodland edges. To do this effectively, planners must consider both the present vegetation and the historical ecological context of the land.

A vegetation community inventory can help:

- identify existing species and plant communities that can be maintained or enhanced for habitat and production;
- identify native or site-adapted plants that may suggest compatible market crops;
- detect threatened, sensitive, or endangered species that should be protected or enhanced;
- connect agroforestry system design to existing habitat types and plant associations;
- identify management practices, such as grazing, fire, coppice, restoration forestry, or forest farming, that may restore or maintain important vegetation communities.

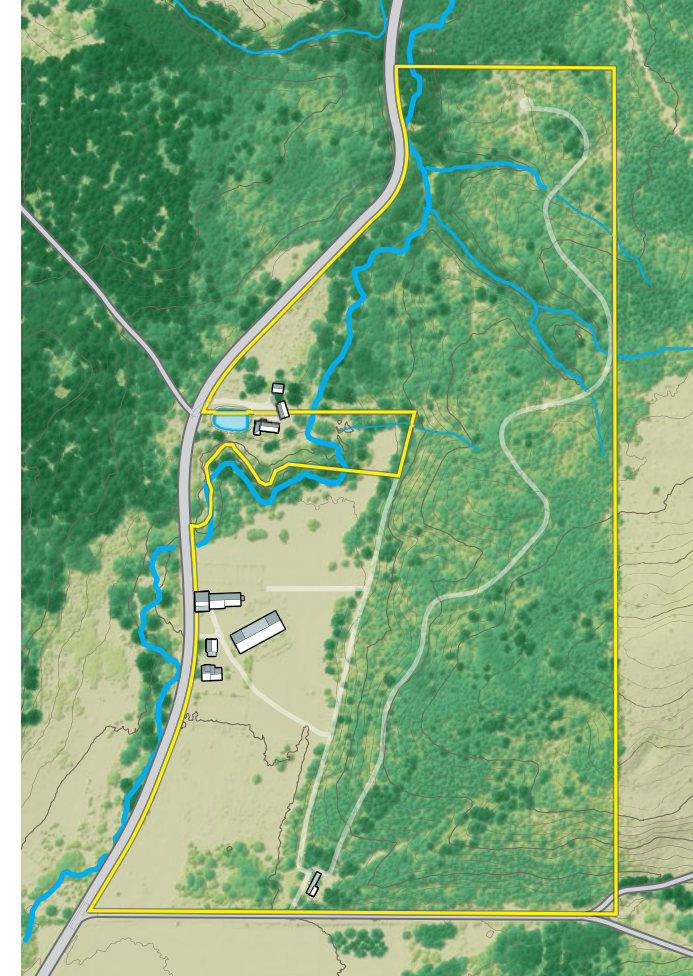


Figure 4.8a. Canopy height and vegetation map.

Map courtesy of Michael Godfrey and Resilience Permaculture

Vegetation communities can be mapped by drawing boundaries around each major type on the base map. These boundaries do not need to be exact at first. They can be refined through field observation, aerial imagery, canopy height data, soils, landform, and water mapping.

Figure 4.8a shows an example of a canopy height and vegetation structure map. Maps like this can help identify forested areas, open fields, riparian corridors, scattered trees, canopy gaps, and areas where vegetation structure changes across the site.

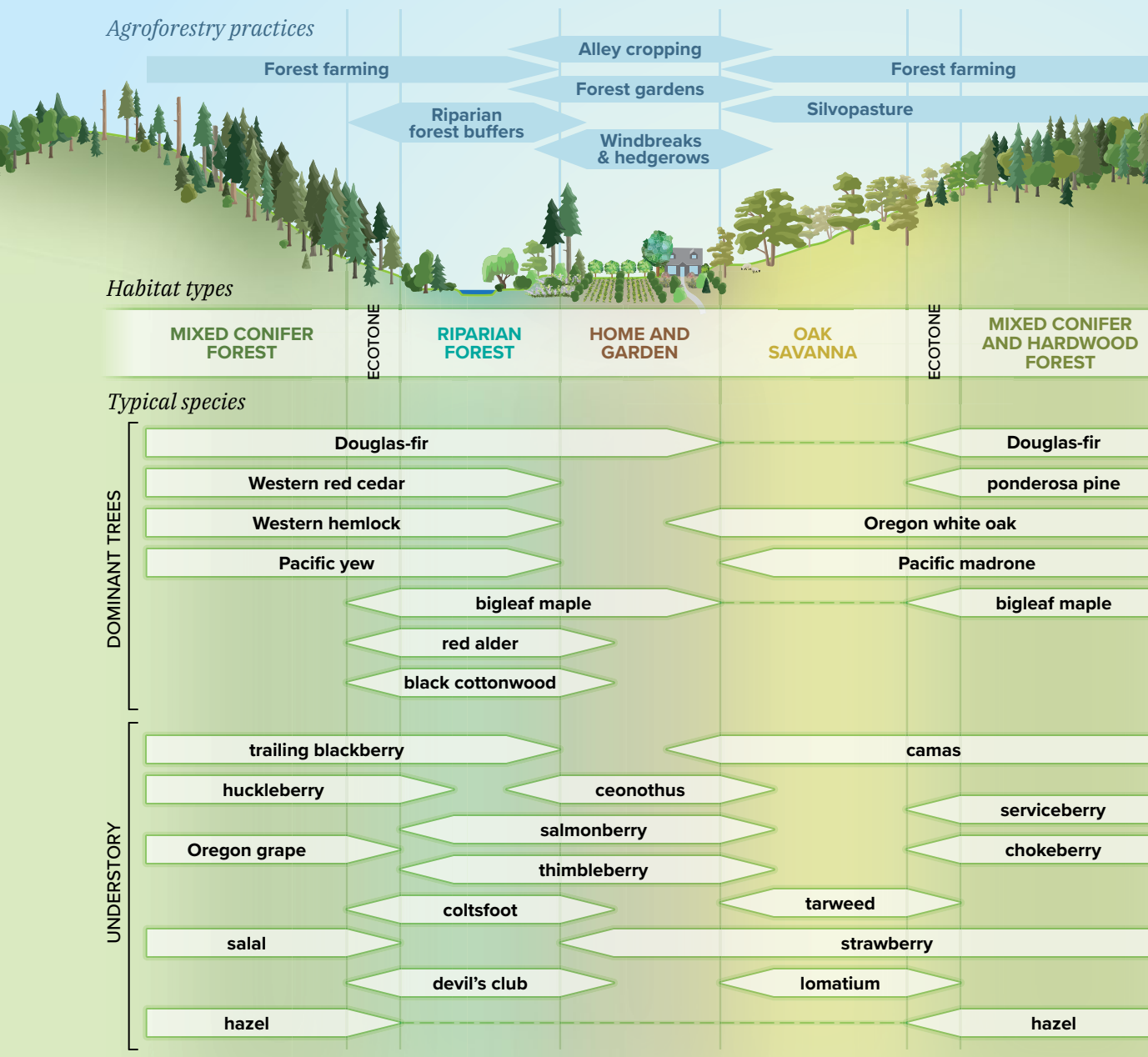


Figure 4.8b. Vegetation profile across landscape positions. Example vegetation profile showing how dominant trees and understory vegetation can shift across riverine, plain, upland, ecotone, and highland positions.

Adapted from Holmgren, D. (1994). *Trees on the treeless plains: Revegetation manual for the volcanic landscapes of central Victoria*. Holmgren Design Services.

Figure 4.8b provides an example of how vegetation can be understood along a landscape gradient. Although actual plant communities will vary by region and site, this type of profile shows how landform position, moisture, and ecotones can influence dominant trees, associated species, and understory vegetation.

The following descriptions summarize several major vegetation types found in the Pacific Northwest. This is not an exhaustive list. For a more detailed reference on regional vegetation types, see [Natural Vegetation of Oregon and Washington](#) by Franklin and Dyrness.

Native vegetation communities

Oak woodlands

West of the Cascades, oak woodlands are found at lower elevations, on dry sites, and in areas historically shaped by frequent, low-intensity fire. They may occur in a mosaic with prairies, oak savannas, chaparral, dry conifer woodlands, and riparian habitats. Oaks are common on valley floors and low-elevation slopes, often between grassland or savanna and conifer forest.

East of the Cascades, oak woodlands occur near transitions between ponderosa pine or mixed conifer forests on slopes and foothills and the shrublands or grasslands farther east. These oak habitats differ in structure and composition from those west of the Cascades, but they also support important wildlife and rare plant communities.

Many oak woodlands are now affected by conifer encroachment, dense regeneration, and long periods without fire or active tending. In some places, formerly open oak systems are now encountered as crowded stands with multiple generations of seedlings and competing trees.

Agroforestry can help maintain or restore the open stand conditions preferred by oaks.

Silvopasture presents an opportunity to maintain the open stand condition preferred by oaks as animals prevent the rampant growth of new trees and shrubs. Grazing can be paired with fire to maintain open stand conditions and prevent larval predation on acorns and hazelnuts. **Forest farming** of wild and cultivated mushrooms, nuts and berries, and craft materials is also a common agroforestry use for oak woodlands.

Savanna

Oak woodlands often grade into oak savannas. Oak savannas are characterized by upland prairie with widely spaced Oregon white oaks (*Quercus garryana*) and, in some cases, scattered conifers. Oak trees in savannas are often large, open-grown trees with broad limbs and well-developed canopies. Other savanna types in the region may include open glades of pine or larch.

Less than 2 percent of the original savannas of the Pacific Northwest remain. Like oak woodlands, savannas are threatened by conifer encroachment, land conversion, and lack of active management. Many surviving examples occur as remnants along edges between dense woodland and open fields.

Savannas are often found at the edge between dense woodlands to open, treeless fields. In these spaces, **silvopasture** is a typical choice.

Savannas can also be maintained more intensively as **forest gardens**, mixing native species with cultivated perennials. **Forest farming** mushrooms and other woodland edge species like wild strawberry, hazelnut, and elderberry are also compatible.

Hardwood glades

Some forested areas include hardwood-dominated stands of aspen (*Populus tremuloides*), red alder (*Alnus rubra*), bigleaf maple (*Acer macrophyllum*), or other deciduous trees. These areas may occur in moist draws, disturbed sites, riparian edges, or openings within conifer forests.

Hardwood glades can provide useful habitat diversity, pollinator resources, leaf litter, wildlife forage, and microclimate variation. Depending on soils, slope, access, and understory conditions, they may be suitable for **silvopasture**, **forest farming**, mushroom production, maple syrup production, basketry materials, or other understory crops.

Conifer forests

Conifer forests occur across much of the Pacific Northwest and vary widely by elevation, rainfall, temperature, soils, and disturbance history. Four broad types are common:

- **Coast Range forests**, often dominated by Douglas-fir (*Pseudotsuga menziesii*), Western hemlock (*Tsuga heterophylla*), Sitka spruce (*Picea sitchensis*), and Western red cedar (*Thuja plicata*).
- **Inland conifer forests** west of the Cascades, often dominated by Douglas-fir with Western hemlock, Western red cedar, incense cedar (*Calocedrus decurrens*), Pacific yew (*Taxus brevifolia*), grand fir (*Abies grandis*), and bigleaf maple.
- **Mixed conifer and hardwood forests** of southwest Oregon, which may include Douglas-fir, incense cedar, ponderosa pine (*Pinus ponderosa*), white oak, madrone (*Arbutus menziesii*), chinkapin, and bigleaf maple.
- **Dry conifer forests** east of the Cascades and in interior regions, commonly including ponderosa pine, Douglas-fir, grand fir, lodgepole pine (*Pinus contorta*), and Western larch (*Larix occidentalis*).

Many conifer forests have been simplified by plantation-based management, fire exclusion, or repeated harvesting. Dense, even-aged stands may have limited understory diversity, high competition for water, and reduced resilience. With appropriate management, some stands can be thinned or diversified to support multiple canopy layers, understory crops, wildlife habitat, and reduced fire risk.

Silvopasture and **forest farming** may be compatible within conifer forests. Possible products include bigleaf maple syrup, hazel stems for basketry, medicinal plants, truffles, log-grown mushrooms, berries, and other shade-tolerant crops. Suitability depends on canopy density, soil moisture, access, slope, livestock compatibility, and long-term forest objectives.

Grasslands

Native grasslands generally occur on dry slopes, plateaus, valley bottoms, and other well-drained sites with sandy or loamy soils. Dominant species vary across the region, but many native grasslands are characterized by perennial bunchgrasses and diverse forbs.

In some areas, grasslands share structural similarities with wet prairies and wet meadows and may support prairie-associated plants and animals. Intact native grasslands are among the rarest habitat types in the region and should be carefully evaluated before tree planting, tillage, or other major changes are proposed. Where native plant communities are still present, management should prioritize maintaining or improving their ecological condition.

Management-intensive rotational grazing and prescribed fire may be compatible where they support native species, reduce encroachment, and maintain open structure. In some settings, **silvopasture** focused on expanding oak or conifer savanna may complement grassland conservation goals.

Riparian forests

Riparian habitats occur next to rivers, streams, springs, seeps, terraces, and many low-elevation floodplains. Throughout much of the region, riparian vegetation includes deciduous trees and shrubs such as bigleaf maple, alder, aspen, cottonwood, red twig dogwood (*Cornus sericea*), willow (*Salix spp.*), and Oregon ash (*Fraxinus latifolia*).

Conifers and oaks may also occur in riparian zones depending on elevation, latitude, flooding frequency, and surrounding forest type. Riparian shrublands may include willow, red twig dogwood, western birch (*Betula occidentalis*), hawthorn (*Crataegus spp.*), alder, and chokecherry (*Prunus virginiana*).

Streamside edges often have fertile soils, shallow groundwater, and important wildlife habitat. **Riparian buffers** can diversify farm yields while protecting water quality, reducing erosion, increasing shade, and improving habitat connectivity. Agroforestry products may include elderberry, maple syrup, nuts, timber, basketry materials, pollinator plants, and other species adapted to moist edge conditions.

Wetlands

Wetland habitats are highly diverse. Two common types in the Northwest include:

- **Seasonal ponds and vernal pools** hold water during winter and spring and typically dry during summer, often occurring as networks of shallow depressions filled by rainwater. They support specialized plant and animal species, including important native invertebrates.
- **Wet prairies** generally occur in lowlands and floodplains, while **wet meadows** often occur in depressions surrounded by forest or in areas with snowmelt. They are commonly dominated by grasses, sedges, rushes, and wildflowers.

Important Indigenous food and material wetland plants include camas (*Camassia quamash*), giant bulrush (*Schoenoplectus californicus*), cattail (*Typha latifolia*), willow, yellow pond lily (*Nuphar lutea*), and wapato (*Sagittaria latifolia*).

Cultivation, drainage, grading, and heavy disturbance are generally not compatible with wetlands. However, carefully managed grazing in **silvopasture** systems, prescribed fire, and **riparian buffers** may help maintain some wetland-associated plant communities where such practices are legally and ecologically appropriate. Agroforestry may support wetland restoration, and in some cases, new wetlands or wetland-adjacent plantings may be created as part of broader water, habitat, and agroforestry planning.

Converted/impacted vegetation communities

Pasture

Many native grasslands and prairies have been converted to pasture through generations of seeding, grazing, cultivation, and non-native grass introduction. These landscapes may still support valuable forage production and can often be adapted to agroforestry.

Pastures may be candidates for many types of agroforestry enterprises including **silvopasture**, as well as tree intercropping systems like **alley cropping**, **windbreaks**, and **hedgerows**. Around homes, some pasture areas may also be converted to **forest gardens**, nurseries, orchards, or other management-intensive systems.

Cropland

Cropland is often a priority area for agroforestry because it already has access, open growing space, and a history of agricultural management. Appropriate agroforestry additions depend on the current crop, equipment needs, irrigation, soils, drainage, market goals, and field layout.

All agroforestry systems, including **alley cropping**, **windbreaks**, **hedgerows**, **riparian buffers**, **forest gardens**, **silvopasture** systems, can be established on cropland. System choice should be guided by the site assessment as a whole, including soils, water, access, legal constraints, and vegetation goals.

Old orchards

Many farms contain established orchards in various states of maintenance. These sites may already have suitable soils, slope, access, and microclimate for tree crops. Reclaiming an old orchard can provide an opportunity to revive existing production, preserve heritage varieties, or integrate new crops.

Old orchard sites can also present challenges. Pest and pathogen buildup may contribute to replant disease, especially when new trees are closely related to the previous crop. Soil nematodes, disease history, drainage, compaction, and declining tree health should be evaluated before investing in new tree plantings.

Where spacing allows, old orchards may support **alley cropping** with berries, vegetables, herbs, or other crops. **Silvopasture** can sometimes reduce grass competition, cycle nutrients, and help manage insects. **Forest farming** or **forest gardening** may be appropriate where partial shade, tree spacing, and access allow.

Residential areas and heavy-use zones

Map residential areas, farmyards, barns, driveways, processing areas, and other heavy-use zones. These areas often have frequent access, existing water and power, protection from wildlife, and proximity to labor and tools.

Agroforestry systems near homes and farm centers may include **forest gardens**, **hedgerows**, **windbreaks**, culinary herbs, nurseries, small livestock areas, specialty crops, and demonstration plantings.

Conduct a plant inventory

After mapping general vegetation communities, planners can add detail through a plant inventory. A plant inventory identifies individual species, plant populations, and useful associations within each mapped vegetation type. It can help develop a list of “best bet” plants that are already adapted to the site or closely related to species growing successfully nearby.

A plant inventory can:

- identify existing species with agroforestry potential
- document the health, abundance, and location of useful plants already growing on site
- suggest compatible crop relatives, such as black elderberry where blue elderberry is thriving, or cultivated currants and gooseberries where native *Ribes* species are present
- suggest compatible agroforestry systems, such as forest farming where medicinal understory plants are present, or silvopasture where oak-associated plants occur
- document habitat plants for wildlife, pollinators, and beneficial insects
- help evaluate soil stability, water infiltration, shade patterns, and nutrient cycling
- support yield estimates for wood, fruits, nuts, stems, or other products
- identify site-adapted seed sources or plants that could be propagated for expansion

Inventory methods

A simple plant inventory can be conducted by walking the property and recording observed species. On larger sites, or where more reliable estimates are needed, a plot-based approach may be more useful.

Inventory plots are defined sample areas where species, abundance, size, condition, and other features are recorded. Data from these plots can then be used to estimate what occurs across a larger area.

Plot-based methods are especially useful in forests, shrublands, pastures, and large agroforestry development areas.

A basic plot cruise involves counting and classifying plant species within a series of circular sample plots. Circular plots are often 1/10 acre in size, with a radius of 37.2 feet. Plots should be distributed across vegetation types, slope positions, and other site conditions. As a general guideline, each major vegetation type should include at least four plots. Random or systematic plot placement helps reduce bias.

For each plot, record species, number of individuals, approximate size, health, regeneration, evidence of browsing or disease, and any other features relevant to agroforestry planning.

Establish random or systematic plots

Digital mapping tools can be used to place plot points before fieldwork. Points can be selected on an aerial image using tools such as Google MyMaps, Google Earth, OnX, or Avenza. These points can then be exported to a phone app or GPS device, or recorded as latitude and longitude coordinates for field navigation.

An analog approach is to establish an approximate grid. Planners can choose a spacing interval, use a compass to follow a predetermined direction, and pace a consistent distance between plots. This approach creates a systematic sample across the site.

Species of concern

Any threatened, endangered, sensitive, or culturally significant plant species should be recorded. The location, population size, health, and surrounding vegetation should be noted. Agroforestry plans should protect these species and, where appropriate, identify management practices that maintain or increase their populations.

Weed identification

Weed identification should be approached as both a management task and an ecological assessment. Plants that spread aggressively often indicate underlying site conditions, such as disturbance, exposed soil, increased light, altered hydrology, compaction, nutrient imbalance, or repeated livestock pressure. During agroforestry establishment, activities such as clearing, irrigation, soil amendment, grazing, and increased access can create conditions where opportunistic plants expand quickly.

Common species of concern in the region include:

- **Canada thistle** (*Cirsium arvense*)
- **Japanese knotweed** (*Reynoutria japonica*)
- **Himalayan blackberry** (*Rubus armeniacus*)
- **field bindweed** (*Convolvulus arvensis*)
- **Scotch broom** (*Cytisus scoparius*)

These plants may require active management, especially in riparian areas, pastures, and forest edges. However, management should begin by asking what conditions are allowing them to thrive and what functions they may be performing, such as covering bare soil, accumulating biomass, stabilizing banks, creating shade, or occupying disturbed ground.

Effective weed management should therefore combine direct control with changes to the site conditions that favor the unwanted species. Strategies may include reducing disturbance, improving ground cover, adjusting grazing timing and intensity, planting competitive desired species, restoring shade or hydrology where appropriate, and using cut material or biomass in ways that support soil-building without spreading the plant. The goal is not only to suppress problem species, but to guide the plant community toward a more stable, diverse, and useful agroforestry system.

Completing the plant inventory

All inventoried areas should be marked on the planning map. Then compile raw plot data into a format that helps guide design decisions. Plot data can be used to estimate plant abundance, existing yields, propagation potential, habitat value, and management priorities across each mapped vegetation type.

Look for opportunities to:

- retain and manage useful plants already growing onsite
- propagate well-adapted plants from existing seed or cuttings
- protect sensitive or culturally significant species
- connect plant communities to compatible agroforestry systems
- identify native analogs for potential market crops
- reduce weed pressure before planting new crops
- use existing vegetation as nurse plants, wind protection, shade, or habitat
- design plantings that build from healthy plant communities already present

Estimating plants per acre from inventory plots

The number of plants recorded in each sample plot can be converted into an estimated number of plants per acre.

If three 1/10-acre plots contain 8, 12, and 4 blue elderberry shrubs, the average number of shrubs per plot is calculated as follows:

$$(8 + 12 + 4 \text{ plants}) \div 3 \text{ plots} = 8 \text{ plants per plot}$$

Since each plot is 1/10 acre, the expansion factor is 10:

$$8 \text{ plants per plot} \times 10 = 80 \text{ plants per acre}$$

This estimate can then be multiplied by the total acreage of the mapped vegetation type to estimate the approximate plant resource across the area.

Additional vegetation surveys and tools

Timber stand inventory

Forested sites may require a timber stand inventory in addition to a general plant inventory. A stand inventory provides information about tree species, diameter, density, trees per acre, canopy structure, regeneration, and timber volume. This information can help determine whether a stand is ready for agroforestry or whether thinning, restoration forestry, understory development, or other preparation is needed.

For example, a silvopasture system may require thinning to allow enough light for preferred forage species. A forest farming system may require evaluation of shade levels, canopy composition, slope, access, and understory conditions.

Many landowners work with a forester to complete a stand inventory. For those conducting their own assessment, [Basic Forest Inventory Techniques for Family Forest Owners](#) provides an overview of timber stand inventory methods for Northwest contexts.

Pasture assessment

Pasture Condition Scoring (PCS) is a method for evaluating pasture health and management conditions. A high score indicates strong plant growth, good ground cover, and conditions that support livestock health. A low score may indicate weed pressure, poor forage vigor, bare ground, soil loss, compaction, drainage problems, or other management concerns.

Pasture conditions should be scored as a baseline and then re-scored over time, especially before grazing, during periods of high or low forage growth, during stressful weather, or after new management practices. Repeated scoring helps determine whether pasture conditions are improving or declining.

PCS does not replace forage measurement, but it provides a way to assess pasture health and identify management actions that may support silvopasture planning. See the [National Pasture Condition Scoring Guide and Score Sheet](#) for additional guidance.

Plant databases

Plant databases can help identify species, understand plant distributions, and compare site observations with regional plant records.

The [Washington Native Plant Society](#) provides an online resource for exploring the plants of Washington, including a searchable [native plant database](#) and downloadable plant lists by county.

[OregonFlora](#) also provides a plant database and mapping tools for Oregon. It can be used to identify species, explore plant distributions, and review geo-located plant inventory records that help describe local plant communities.

These tools can support field identification, species selection, restoration planning, and the development of agroforestry plant lists suited to the site.

Integrating the vegetation assessment into an agroforestry plan

Vegetation assessment helps connect agroforestry planning to the living patterns already present on the site. By mapping vegetation communities, identifying useful and sensitive species, evaluating weeds as indicators of site conditions, and documenting existing plant resources, planners can choose systems that build from the strengths of the landscape.

These observations can guide species selection, restoration priorities, management strategies, and long-term monitoring as agroforestry systems become established.

Animals

Animal assessment includes evaluating the needs, impacts, and opportunities associated with both livestock and wildlife. Agroforestry systems can provide forage, shelter, shade, habitat, pest management, nutrient cycling, and movement corridors, but they can also create conflicts if animal needs are not considered early in the planning process.

Livestock and wildlife should be assessed together because they often use the same resources: water, shade, forage, cover, corridors, edges, and seasonal habitat. Early assessment can help identify where domestic animals can contribute to vegetation management, fertility, pest reduction, and production, while also protecting wildlife habitat, sensitive species, and ecological functions.

Livestock

Livestock already present on the farm, or planned for future integration, should be evaluated in relation to the resources they need and the functions they may provide within agroforestry systems. Different animals vary widely in feeding behavior, containment needs, tolerance to slope and climate, compatibility with trees and crops, and potential effects on soil, vegetation, and wildlife.

Livestock needs and impacts

Livestock assessment should consider:

- forage requirements, including quantity, quality, and seasonal availability
- tolerance to heat, cold, wet conditions, and other climate factors
- water requirements/access to reliable watering points
- susceptibility to predation
- feeding behavior, including grazing, browsing, scratching, rooting, or foraging

- potential impacts on trees and crops, incl. browsing, rubbing, rooting, trampling, and fruit or nut consumption
- crop protection needs, including tree guards, fencing, timing, and exclusion areas
- infrastructure needs, including fencing, shelter, lanes, gates, handling areas, and water systems
- suitability for site conditions, including slope, soils, vegetation type, and access
- compatibility with planned agroforestry crops and management goals
- level of containment required

Livestock can also provide important functions in agroforestry systems. Grazing animals may help manage pasture growth, cycle nutrients, reduce fuel loads, or maintain open stand conditions. Poultry may help reduce some insect pests, clean up fallen fruit, and add fertility. Pigs may help with site preparation or fruit and nut cleanup in some settings. These functions depend on careful timing, stocking rate, containment, and protection of trees, soils, and sensitive habitat.

Site resources for livestock

The farm environment should also be evaluated for the resources it can provide to livestock. These may include existing forage, shade, shelter, water, mast crops, tree fodder, and seasonal access.

Site assessment should consider:

- availability of existing forage, including quantity, quality, and seasonal distribution
- presence of mast crops such as acorns, chestnuts, walnuts, honey locust pods, or fallen apples
- availability of tree fodder species such as mulberry, willow, poplar, black locust, and ash
- need for pest management, nutrient cycling, or vegetation control

Left: Drew Thomas tending sheep in the silvopasture at the Center for Rural Livelihoods campus.

Photo courtesy of Mitchel Davidovitz



- need for fuel load reduction or brush management
- resilience of existing vegetation to browsing, grazing, scratching, or rooting
- sensitivity of soils to compaction or erosion under livestock use
- availability of local livestock genetics, nearby markets, processors, and support services

Livestock should be matched to the landscape rather than added as a generic management tool. Cattle, sheep, goats, pigs, poultry, and other animals each interact with vegetation, soil, water, and infrastructure in different ways. The right fit depends on both the animal and the site.

Wildlife

Wildlife assessment focuses on the habitat features, movement patterns, food sources, water sources, and sensitive species present on the site. Oregon and Washington support many animal species of conservation concern, including species associated with grasslands, oak woodlands, riparian zones, wetlands, and conifer forests. Habitat loss, fragmentation, altered fire regimes, invasive species, and incompatible land uses have reduced the quality and extent of many of these habitats.

Agroforestry can help protect and enhance wildlife habitat when it is planned with existing vegetation, water, landform, and habitat structure in mind. Wildlife considerations during later management may include wildlife-friendly fencing, timing work to avoid nesting or breeding seasons, retaining snags and downed wood, maintaining forest structure during thinning, protecting water sources, and adding features such as nest boxes or pollinator habitat. During site assessment, the main task is to identify existing habitat features, barriers, corridors, and opportunities for improvement.

Terrestrial wildlife habitat

Permanent vegetation and water sources strongly influence terrestrial wildlife movement and habitat use. Large patches of vegetation near water can support

Table 4.9a. Livestock considerations for agroforestry

Livestock	Applications	Site considerations
Cattle	• pasture conditioning and fertility • preference for grasses can promote forbs and shrubs	• good to have permanent perimeter fencing • less steep land preference • abundant grass forage necessary
Sheep	• pasture conditioning and fertility • intermediate grazing preference provides control of herbaceous invasive vegetation • some smaller breeds applicable to silvopasture with shrubs and vines • fuels reduction	• good to have permanent perimeter fencing • moderately steep land possible • abundant grass forage preferred • can reduce forb abundance and degrade food sources for pollinators if not managed
Goats	• brush control and thicket opening • browsing preference provides control of woody brush • fuels reduction	• necessary to have permanent perimeter fencing • steep land possible • requires tree protection • can reduce forb abundance and degrade food sources for pollinators if not managed
Pigs	• rooting preference provides control of invasive perennials • fruit and nut cleanup promotes pest reductions • land clearing and conversion for new plantings	• requires electric fencing • destructive to natural habitat and wildlife nectar and food sources if unmanaged
Chickens	• scratching helps with weed management around perennials • fertility management • fruit and leaf litter cleanup • insect and snail control	• protect from predators • destructive to natural habitat and wildlife nectar and food sources • destructive to natural habitat and wildlife nectar and food sources if unmanaged
Ducks	• fertility • slug and snail patrol	• protect from predators • prefer bathing water source
Geese	• fertility • weed management around perennials • insect, snail, and slug patrol	• protect from predators • prefer water source
Rabbits	• fertility	• protect from predators • prevent from burrowing

many species and may serve as sources for recolonizing smaller habitat patches.

Agroforestry plantings can help connect isolated patches of forest, shrubland, riparian vegetation, prairie, or hedgerows, providing shelter, food, and movement corridors.

Small, isolated fragments may lack the food, water, cover, or breeding habitat needed to sustain wildlife populations. Wide breaks in vegetation, such as tilled fields, mowed areas, roads, or heavily used farmyards, can create barriers or hazards. Corridors and stepping-stone plantings can help wildlife move between habitat patches and access missing resources. However,

er, habitat design should be matched to target species. Grassland species and pollinators, for example, may need open habitat and may not benefit from dense tree corridors in all situations.

To assess terrestrial habitat, look for opportunities to:

- locate agroforestry practices near streams, ponds, wetlands, and other water sources;
- expand existing forest patches, field borders, hedgerows, and riparian buffers;
- connect isolated habitat patches with corridors or stepping-stone plantings where appropriate;
- shape plantings to support target wildlife, such as deep, blocky patches for interior forest species, elongated edges for edge species, or corridors for movement;
- select agroforestry systems and species that create desired habitat structure, including canopy layers, shrub cover, flowering plants, seed sources, and nesting sites;
- retain or protect existing habitat features such as snags, large downed wood, rocky outcrops, brush piles, shrub thickets, and native grassland patches;
- locate high-disturbance activities, machinery routes, and intensive livestock use away from sensitive habitat areas, especially ground-nesting bird habitat and rare grassland remnants.



Above: Coastal giant salamanders (*Dicamptodon tenebrosus*) are important indicators of water quality and forest health.

Photo courtesy of Abel Kloster

Aquatic wildlife habitat

The condition of stream channels and surrounding land cover directly affects aquatic life. Straightened or simplified channels through agricultural land often indicate past modification, reduced floodplain connection, low woody debris, and limited habitat complexity. Agricultural and urban runoff can increase storm flows, erode banks, scour channels, and carry sediment or nutrients into waterways.

Without riparian forest, streams receive more direct sunlight, which can raise summer water temperatures. Dams, culverts, and drop structures may also block fish movement to otherwise suitable habitat.

In contrast, watersheds with permanent vegetation, connected floodplains, riparian forests, and stable channels are better able to support aquatic wildlife. Riparian forests provide shade, stabilize banks, contribute leaf litter and woody debris, filter runoff, and help maintain cooler water temperatures. Meandering streams with connected floodplains provide more diverse pools, riffles, gravel bars, and seasonal habitat.

To assess aquatic habitat, look for opportunities to:

- establish or widen agroforestry practices along streams, ponds, wetlands, shorelines, and riparian zones;
- increase summer shade over streams and shallow water bodies;
- ensure riparian corridors are wide enough to provide shade, bank stability, leaf litter, and woody debris over time;
- connect new plantings to existing riparian forests or wetland vegetation;
- use fast-growing, site-appropriate tree and shrub species for quick shade or bank stabilization;
- retain large wood, complex channel features, and floodplain vegetation where they are present;
- use flood-tolerant trees and shrubs where frequent flooding occurs;
- time management activities to avoid sensitive periods for aquatic species and to reduce sediment movement into streams.

Integrating animal findings into the agroforestry plan

Animal assessment should be integrated with vegetation, water, soils, access, fencing, and infrastructure planning. On the site map, record existing livestock areas, water points, shade, shelters, gates, lanes, fences, wildlife corridors, nesting or breeding habitat, riparian areas, wetlands, snags, downed wood, and sensitive habitat patches.

These mapped features can help determine where livestock can contribute to agroforestry management and where protection or exclusion may be needed. Some areas may be well suited to silvopasture, orchard grazing, poultry integration, or targeted browsing. Other areas may be better managed primarily for habitat, riparian protection, pollinator resources, or wildlife movement.

The goal is not simply to add animals to the system, but to understand how domestic and wild animals already interact with the landscape. When livestock needs, wildlife habitat, fencing, water, access, and vegetation are planned together, agroforestry systems can support production while also improving habitat function and ecological resilience.

Buildings and farm infrastructure

Buildings and farm infrastructure should be evaluated as part of the whole agroforestry site plan. Permanent structures, portable structures, storage areas, processing spaces, livestock facilities, utilities, and work yards all influence how people, animals, equipment, crops, and materials move across the farm.

Record the location, function, condition, and seasonal use of existing structures on the planning map. Note whether each structure is permanent, movable, in active use, underused, or in need of repair. Building placement should be compared with access routes, utilities, water systems, fields, orchards, livestock areas, forest edges, and future agroforestry plantings.

Well-sited buildings can improve workflow, reduce travel time, support harvest handling, provide shade or shelter, take advantage of windbreaks, and reduce energy use. Poorly placed buildings may create inefficient movement patterns, increase infrastructure costs, limit planting options, or create conflicts with livestock, equipment, drainage, or future expansion.

Inventory existing buildings and structures

The building inventory should include homes, barns, sheds, greenhouses, livestock shelters, storage areas, processing spaces, equipment yards, cold storage, root cellars, lumber storage, beekeeping infrastructure, and portable structures.

For each structure, record:

- location and footprint;
- current use and potential future use;
- condition and repair needs;
- access by foot, vehicle, tractor, or livestock;
- availability of water, power, drainage, and waste-handling infrastructure;
- relationship to fields, orchards, pastures, forests, roads, and work areas;
- exposure to sun, shade, wind, flooding, fire risk, or seasonal wetness;
- opportunities for reuse, expansion, relocation, or removal.

Evaluate building placement and function

Homes and farm centers should be evaluated in relation to daily activity patterns, energy use, shade, wind protection, access, and proximity to key operations. Buildings near the center of daily activity may

be appropriate for tools, nurseries, small livestock, propagation, washing, packing, or high-value crops that require frequent attention.

Assess sheds and outbuildings for storage, equipment access, maintenance needs, and proximity to fields or orchards. A well-placed shed can reduce wasted travel time and make routine management easier.

Livestock facilities, including barns, shelters, loafing sheds, and handling areas, should be sited where they have good drainage, ventilation, access to water, and practical connections to forage areas or silvopasture rotations. They should also be evaluated for manure management, predator protection, animal movement, and winter use.

Root cellars and cold storage areas should be located where harvested products can be moved efficiently from field, orchard, or forest to storage. These facil-



Right:
Buildings and farm infrastructure
should be evaluated for their
opportunities and constraints.

Photo courtesy of Mitchel Davidovitz

ities should be evaluated for temperature stability, humidity, access, ventilation, and energy needs.

Lumber storage and other agroforestry product storage should keep materials dry, organized, and accessible. Storage areas for poles, firewood, sawlogs, mushrooms, nursery stock, nuts, fruit, medicinal herbs, or other products should be planned around product quality, access, airflow, and protection from weather or pests.

Processing spaces for fruit, vegetables, nuts, herbs, meat, dairy, mushrooms, or value-added products should be evaluated for access to utilities, sanitation, drainage, waste handling, biosecurity, and proximity to production or distribution points. Where regulated processing is involved, facility planning should account for applicable food safety, zoning, and permitting requirements.

Portable and seasonal structures

Portable structures can add flexibility to agroforestry systems. Chicken tractors, mobile coops, rabbit hutches, portable milking parlors, shade structures, temporary fencing, bee equipment, and mobile shelters can support rotational grazing, nutrient distribution, pest management, pollination, and seasonal use of different areas.

Portable structures should be evaluated for ease of movement, access to water, predator protection, animal comfort, slope, soil moisture, and compatibility with crops or young trees. Their use should be coordinated with grazing plans, orchard management, pasture recovery, and soil protection.

Examples include:

- chicken tractors for rotational poultry grazing and nutrient cycling;
- mobile coops for orchard cleanup, insect management, and manure distribution;
- rabbit hutches that can move to fresh ground for forage access;
- portable milking parlors for flexible livestock management;
- temporary shelters for shade, lambing, kidding, calving, or seasonal pasture use;
- beekeeping infrastructure placed near forage, water, access, and wind protection.

Integrating buildings and infrastructure into the agroforestry plan

Building assessment should be integrated with access, water, soils, landform, vegetation, energy, and enterprise planning. On the site map, record existing structures, portable infrastructure, utilities, storage areas, processing spaces, animal facilities, work yards, access routes, drainage concerns, and areas suitable for future development.

These findings can help determine where high-use agroforestry elements should be located, where storage or processing capacity is needed, and where buildings may support or constrain future plantings. In some cases, existing structures can be adapted to new agroforestry enterprises. In others, inefficient or poorly placed infrastructure may need to be relocated, repaired, or phased out.

Buildings and infrastructure should support the daily work of the farm while protecting long-term flexibility. When structures are planned together with access,

water, energy, livestock movement, and crop handling, they can strengthen the practical function of the whole agroforestry system.

Evaluate the location of both permanent and portable structures, their condition, and how their placement integrates with fields, trees, and infrastructure. Well-sited buildings can take advantage of tree shade or windbreaks, reduce energy use, and improve workflow, while poorly placed facilities may create inefficiencies or limit flexibility.

Homes

- Placement for shade or wind protection; energy efficiency and proximity to key farm operations.

Sheds and outbuildings

- Livestock facilities (barns, shelters, loafing sheds) sited for drainage, ventilation, and proximity to forage or silvopasture
- Root cellars and cold storage located near harvest areas for easy access and preservation of produce
- Lumber storage designed to keep agroforestry products dry and accessible
- Meat processing facilities sited for biosecurity, waste management, and access to utilities
- Fruit and vegetable processing spaces for value-added products, ideally near production or distribution points

Portable structures

- Chicken tractors for rotational poultry grazing, placed to cycle nutrients evenly
- Rabbit hutches that can be moved to fresh ground for forage access
- Portable milking parlors
- Beekeeping infrastructure

Fencing

Fencing influences livestock management, crop protection, wildlife movement, access, and the protection of sensitive areas. In agroforestry systems, fences often need to serve more than one purpose: containing animals, excluding animals, protecting young trees, guiding rotation, separating incompatible uses, and allowing safe movement through the farm.

Add the existing fence layout as a layer on the planning map. Understanding the location, type, condition, and function of existing fences helps determine whether small modifications will be sufficient or whether larger changes are needed before livestock, tree crops, or conservation plantings are added.

Inventory existing fencing

Inventory all existing fencing, gates, lanes, crossings, and barriers. Record the type of fence, its condition, and whether it is functional for its current or intended use. Fence types may include woven wire, barbed wire, high-tensile electric, temporary electric netting, wood rail, wildlife fencing, orchard fencing, deer exclusion fencing, or other materials.

For each fence line, note:

- fence type and approximate height
- condition of posts, wire, braces, gates, and energizers
- whether the fence is permanent, temporary, portable, or abandoned
- whether perimeter fencing is complete and functional
- whether internal fencing creates useful paddocks or management areas
- gate locations, gate widths, and ease of equipment or livestock movement
- existing livestock lanes, alleyways, and handling areas
- where fence crosses streams, ditches, or steep slopes
- areas where fences are difficult to maintain because of vegetation, flooding, erosion, or terrain

Evaluate fencing for livestock and crops

Existing fences may support rotational grazing, continuous grazing, exclusion areas, orchard protection, or temporary browsing control, but they may also limit flexibility if they do not match landform, water access, shade, or planned paddock layout.

Assessment questions include:

- Does the existing fencing support rotational grazing, or is it primarily set up for continuous use?
- Are paddocks sized and located in ways that match forage availability, water access, shade, slope, and livestock movement?
- Are there young trees, hedgerows, riparian buffers, wetlands, or sensitive plantings that need protection?
- Are crops already protected, or will new guards, cages, exclusion fences, or temporary fencing be needed?
- Does the fence layout efficiently move livestock between forage, water, shelter, and handling facilities?
- Are there places where fencing causes congestion, compaction, erosion, or repeated animal pressure?

Different livestock require different containment strategies. Goats, pigs, poultry, cattle, sheep, and horses each place different demands on fences and gates. Crop protection also varies by animal pressure. Deer, elk, rabbits, livestock, poultry, and rodents may all require different forms of protection depending on crop type and stage of establishment.

Consider wildlife movement and sensitive areas

Some fences create barriers, entanglement hazards, or movement restrictions for wildlife. Others may protect riparian areas, wetlands, restoration plantings, or young trees from browsing and trampling.

During the inventory, note places where wildlife clearly pass through, under, or over fences. Also record areas where animals appear to become trapped, funneled into roads or hazards, or blocked from water, cover, or movement corridors. Fencing near streams, wetlands, grasslands, forest edges, and known wildlife routes should be evaluated carefully.

Assessment questions include:

- Are there visible wildlife trails, crossings, tracks, scat, or browse lines near fence lines?
- Might fences entangle deer, elk, birds, or other wildlife?
- Are there places where wildlife can move freely?
- Are there areas where wildlife exclusion is needed to protect crops, young trees, or restoration plantings?
- Do fences protect streams, wetlands, rare plant communities, or sensitive soils from livestock pressure?
- Do fences create barriers between habitat patches, water sources, or seasonal movement routes?

Where wildlife movement is important, fence design may need to allow safe passage for desired species while still containing livestock or protecting crops. Where sensitive areas need protection, fencing may be used to guide livestock away from streambanks, wetlands, restoration areas, steep slopes, or fragile soils.

Integrating fencing into the agroforestry plan

Plan fencing alongside access, water, livestock, wildlife, vegetation, buildings, and future agroforestry plantings. On the site map, record existing fence lines, proposed fence changes, gates, lanes, protected areas, paddocks, wildlife crossings, livestock water access, and areas where temporary fencing may be useful.

A well-planned fencing system can reduce labor, protect crops, improve livestock rotation, support wildlife movement, and prevent damage to sensitive areas. In many cases, existing fencing can be repaired, modified, or supplemented with temporary fencing rather than fully replaced. In other cases, poorly located fences may need to be removed or redesigned so that the overall farm layout works more effectively.

The goal of fencing assessment is not only to determine what barriers exist, but to understand how fences shape movement, protection, and management across the whole agroforestry system.

Energy systems

Energy assessment examines where energy comes from, how it is used, and how farm systems can reduce demand or develop renewable sources. On agroforestry farms, energy use is closely tied to buildings, irrigation, processing, storage, access, livestock systems, and crop handling. Energy systems should therefore be assessed as part of the whole site plan rather than as a separate utility concern.

Many farms rely on fossil fuels for machinery, irrigation, heating, cooling, refrigeration, drying, and transportation. Agroforestry can reduce some of these energy demands by providing shade, wind protection, improved soil moisture, fuelwood, coppice wood, biomass, and more efficient placement of farm infrastructure. In some cases, agroforestry systems may also support renewable energy production or provide on-farm energy resources.

Inventory energy sources and infrastructure

Begin by identifying the primary energy sources. These may include electricity from the grid, gasoline, diesel, propane, natural gas, firewood, solar power, wind power, batteries, generators, or biomass.

Record the location of major energy infrastructure on the planning map, including utility lines, meters, transformers, fuel tanks, generators, battery systems, solar arrays, pumps, heating systems, refrigeration units, greenhouses, workshops, and processing areas.

Right: Energy use should be assessed to reduce demand, improve system efficiency, and produce renewable energy or on-farm fuel resources.

Photo courtesy of Center for Rural Livelihoods

The inventory should identify which systems use the most energy and which enterprises depend on reliable power or fuel. Irrigation pumps, greenhouse heating, walk-in coolers, freezers, dryers, ventilation fans, maple syrup evaporators, wash-pack areas, and value-added processing spaces may all be important energy users. Planners should also note whether these systems support existing or planned agroforestry enterprises.

Evaluate energy use and efficiency

After energy infrastructure has been mapped, evaluate the condition and efficiency of major equipment and systems. Older pumps, heaters, coolers, fans, lighting, wiring, insulation, or motors may increase operating costs and reduce resilience. Poorly located buildings, unshaded storage areas, exposed livestock

facilities, or inefficient irrigation systems can also increase energy demand.

Assessment should consider:

- which systems use the most electricity or fuel
- whether pumps, motors, heaters, coolers, dryers, fans, and lighting are efficient and properly sized
- whether buildings are insulated, shaded, ventilated, and protected from wind
- whether irrigation systems are efficient and matched to crop needs
- whether fuel storage, wiring, transformers, and electrical systems are safe and functional
- whether energy demand changes seasonally during irrigation, harvest, processing, heating, or cooling periods
- whether current energy systems can support planned agroforestry enterprises



Assess renewable and agroforestry-based energy options

Agroforestry systems can support energy planning in several ways. Windbreaks can reduce wind exposure around homes, barns, greenhouses, and livestock shelters. Shade trees can reduce summer cooling demand and improve livestock comfort. Mulch, perennial cover, and improved infiltration can reduce irrigation demand by helping soils store more water. Coppice woodlots, hedgerows, orchard prunings, forest thinnings, and other woody biomass may provide fuelwood, mulch, biochar feedstock, or other on-farm energy resources.

Renewable energy systems should also be evaluated where appropriate. Solar panels, wind turbines, battery systems, and backup generators may support pumps, buildings, processing areas, refrigeration, electric fencing, water systems, or remote infrastructure. These systems should be assessed in relation to sun exposure, wind exposure, access, maintenance needs, fire risk, theft risk, grid connection, and proximity to the loads they serve.

Agroforestry and renewable energy planning should be coordinated carefully. Trees and shrubs can improve microclimate and reduce energy demand, but they can also shade solar arrays, interfere with utility lines, or restrict equipment access if poorly placed. Energy infrastructure should therefore be mapped alongside future tree growth, windbreak placement, building sites, and access routes.

Plan for storage, backup power, and resilience

Energy assessment should also consider storage, redundancy, and exposure to hazards. Farms may need backup power for wells, livestock water, refrigeration, freezers, greenhouse systems, electric fencing, communications, or processing equipment. Batteries, generators, gravity-fed water systems, stored fuel, stored biomass, and thermal mass can all contribute to resilience when grid power or fuel access is disrupted.

Energy infrastructure should be evaluated for exposure to storms, flooding, wildfire, falling limbs, heat, rodents, and access limitations. Where appropriate, agroforestry practices such as windbreaks, shade plantings, defensible space, erosion control, and improved drainage can help protect infrastructure and reduce energy demand during extreme weather.

Energy assessment resources

The NRCS Conservation Evaluation and Monitoring Activity 228, Agricultural Energy Assessment, can support a comprehensive review of on-farm energy use and opportunities for efficiency improvements or renewable energy integration. This assessment is often used as a prerequisite for NRCS cost-share assistance for eligible energy-saving practices.

Examples of systems that may be eligible for energy efficiency evaluation or improvement include:

- lighting
- ventilation and fans
- irrigation pumps
- greenhouse systems
- maple syrup evaporators
- dryers and refrigeration units
- insulation

Integrating energy assessment into the agroforestry plan

The energy assessment should be integrated with buildings, water, access, livestock, processing, storage, and future agroforestry plantings. On the site map, record energy sources, major energy loads, utility infrastructure, renewable energy systems, fuel storage, backup systems, and areas where shade, wind protection, biomass production, or improved water efficiency could reduce energy demand.

Energy planning should support the practical work of the farm while reducing vulnerability to rising costs, outages, and climate-related stress. When energy demand, infrastructure location, renewable supply, and agroforestry design are considered together, the farm can become more efficient, resilient, and adaptable over time.

Air should be included in site assessment as both a condition of the farm environment and a pathway for smoke, dust, chemical drift, odors, noise, and other pollutants. These factors can affect human health, livestock comfort, crop quality, worker safety, and the overall farm experience. Like water, wind, sun, access, and landform, air-related patterns can shape where agroforestry plantings, buildings, roads, livestock areas, and outdoor workspaces are best located. An assessment of air can also account for greenhouse gas emissions and carbon sequestration, providing a baseline for understanding the climate impacts and mitigation potential of different farm practices.

Air movement can carry beneficial influences, such as cooling breezes and ventilation, as well as potential hazards, including wildfire smoke, road dust, pesticide drift, livestock odors, exhaust, and noise from roads, railways, industry, or neighboring land uses. As discussed earlier in this chapter, these influences can be understood through **sector analysis**: the mapping of external energies or forces that enter the site from particular directions.

As part of the mapping process described earlier in this chapter, wind, smoke, dust, noise, spray drift, odor, and wildfire exposure should be mapped alongside sun, water, access, and landform patterns so that agroforestry plantings and infrastructure can be located to buffer negative impacts and take advantage of beneficial airflow.

During site assessment, identify nearby sources of air pollution or disturbance, including highways, gravel roads, confined animal areas, industrial facilities, burn piles, pesticide-intensive fields, rail lines, airports, and high-traffic work areas. Also note seasonal patterns. Summer winds may carry dust, smoke, or spray drift from one direction, while winter storm

winds may affect the site from another. Topography, existing vegetation, buildings, and other physical features can influence how air, smoke, odors, or pollutants move through or settle on a site.

Agroforestry practices can help improve air-related conditions. Windbreaks, shelterbelts, hedgerows, riparian buffers, and multi-layered tree and shrub plantings can reduce wind speed, intercept dust, absorb some pollutants, buffer noise, screen odors, and improve comfort around homes, livestock areas, roads, and workspaces. Plantings can also separate sensitive areas, such as homes, outdoor classrooms, farm stands, nurseries, livestock shelters, and high-value crops, from pollution or disturbance sources.

Air assessment should also consider greenhouse gas emissions and opportunities for climate mitigation. Tools such as [COMET-Farm](#) can help estimate

farm-level greenhouse gas emissions and carbon sequestration associated with cropping systems, livestock, soils, energy use, and conservation practices. While COMET-Farm does not replace a full site assessment, it can provide a useful baseline for comparing management options and identifying practices that may reduce emissions or increase carbon storage over time.

On the planning map, record prevailing seasonal winds, smoke pathways, dust sources, pesticide drift concerns, odor sources, noise corridors, wildfire exposure, ventilation patterns, and areas where buffers or shelterbelts may be needed. When air quality, noise, pollution, and greenhouse gas emissions are assessed together, planners can locate plantings and infrastructure in ways that buffer unwanted impacts, improve comfort, and support healthier conditions for people, plants, and animals.



Above: Windbreaks in Walla Walla, Washington reduce wind and increase irrigation efficiency. This windbreak also produces black locust and walnut timber.

Photo courtesy of Abel Kloster

Aesthetics

Aesthetic assessment considers how agroforestry systems will shape the visual and sensory character of the farm. The appearance, sound, smell, movement, and overall feeling of a place influence how people experience and care for the landscape. Agroforestry plantings can strengthen this experience by adding shade, seasonal color, texture, structure, wildlife activity, and visual diversity, while also screening undesirable views, buffering noise, and softening the edges of buildings, roads, and production areas.

The visual character of a landscape is shaped by form, line, color, shape, texture, depth, and space. Existing field patterns, forest edges, hedgerows, water features, buildings, roads, and topography all contribute to the identity of a place. Uniform land cover may feel monotonous, while well-placed tree and shrub plantings can create a more varied and appealing mosaic within cultivated landscapes.

Aesthetic assessment should also consider non-visual qualities. Road noise, railway noise, livestock odor, waste handling, dust, smoke, and snow drift can affect comfort, safety, and enjoyment. Other qualities, such as quiet, fragrance, seasonal change, cultural memory, spiritual meaning, and sense of place, may be just as important as visual appearance.

Evaluate landscape experience

Observe the farm from roads, homes, work areas, fields, trails, neighboring properties, and public view-points. Note which views are desirable and should remain open, and which views may benefit from screening or softening. Also record sensory concerns such as noise, odor, dust, wind exposure, snow accumulation, glare, or visual clutter.



Above: Aesthetic assessment considers how agroforestry will shape the visual and sensory character of the farm.

Photo courtesy of Mitchel Davidovitz

On the planning map, identify:

- desirable views, scenic corridors, and focal points;
- undesirable views, industrial, road, or utility corridors;
- areas affected by noise, odor, dust, smoke, glare, or snow drift;
- visually important entrances, roadsides, field edges, and building areas;
- culturally meaningful, spiritual, historic, or emotionally significant places;
- existing vegetation that contributes to the character of the farm;
- opportunities where agroforestry plantings could improve the look and feel of the site.

Identify views, buffers, and screening needs

Agroforestry plantings can be used to frame views, screen undesirable sights, reduce noise, filter dust, provide shade, and soften transitions between land uses. Windbreaks, hedgerows, riparian buffers, forest gardens, and scattered shade trees can all contribute to the visual and sensory quality of the farm.

Plantings should follow the natural lines, shapes, and patterns of the landscape where possible. Rows, clumps, corridors, and edges often feel more integrated when they respond to landform, water flow, field shape, access routes, and existing vegetation.

Plantings that extend or strengthen existing vegetation patches may appear more natural and can also improve habitat connectivity.

Buffers and screens should be placed carefully. They can reduce views of roads, buildings, industrial areas, parking areas, or waste facilities, but they should not block desirable views, important sightlines, or necessary supervision of farm activities. Plantings near roads and intersections should be set back far enough to avoid blind spots and safety hazards.

Integrating aesthetic considerations into the agroforestry plan

Aesthetic planning should support both beauty and function. Species selection can include plants with seasonal flowers, colorful foliage, fruit, bark texture, evergreen structure, fragrance, or wildlife value. Clumps of visually distinctive species can be placed

near entrances, field edges, building areas, or planting transitions to add interest and diversity. At the same time, aesthetic choices should be coordinated with production, maintenance, access, safety, and ecological goals. Plantings used for screening may also provide wind protection, pollinator habitat, fruit, nuts, biomass, or wildlife corridors. Trees planted for shade may also reduce building cooling needs or improve livestock comfort. Hedgerows that improve visual quality may also reduce dust, intercept spray drift, and create habitat.

On the final site plan, record areas where plantings should preserve views, frame views, screen undesirable features, reduce noise or dust, improve entrances, buffer roads, protect privacy, or strengthen the character of the farm. Aesthetic assessment helps ensure that agroforestry systems are not only productive and ecological, but also inviting, meaningful, and well integrated into the landscape.



Left:
A beautiful roadside landscape in Eugene, Oregon provides privacy to the home and a bounty for passersby.

Photo courtesy of Mitchel Davidovitz

Conclusion

A thorough site assessment provides the basis for successful agroforestry planning. Climate, landform, soils, water, vegetation, infrastructure, land use history, and management goals all interact to shape the opportunities and constraints of a landscape. Understanding these relationships allows agroforestry systems to be placed where they are most likely to succeed while reducing avoidable management challenges and ecological risks.

The assessment process is not simply an inventory of site features. It is a way of understanding how water, energy, organisms, and human activity move across the landscape over time. Mapping and evaluating these patterns can reveal opportunities for water harvesting, soil improvement, biodiversity enhancement, livestock integration, microclimate modification, and resilient perennial production.

Site assessment also supports future design decisions related to roads, water infrastructure, fencing, buildings, tree placement, and enterprise selection. By carefully observing and documenting the ecological and operational realities of a site before development begins, planners can design agroforestry systems that improve productivity, reduce unnecessary inputs, and support the health and resilience of the farm and surrounding ecosystem.

III

CHAPTERS

- 5 DESIGN CONSIDERATIONS
FOR ALL AGROFORESTRY
FARMS**
- 6 SYSTEM SELECTION**
- 7 SPECIES SELECTION**

PROJECT PLANNING

Part III builds on the site assessment process by moving from observation and analysis to practical design decisions. It considers how the farm's main structural systems are arranged, which agroforestry practices are best suited to the site, and which trees and shrubs are most likely to thrive and provide the desired benefits. These decisions are closely connected: infrastructure and land-use patterns influence which systems are feasible, while site conditions, management capacity, and project goals shape both practice and species selection.

The following chapters present a sequence for developing the plan, beginning with the farm's overall physical organization, then narrowing to the selection of appropriate agroforestry practices and species.

Chapter 5 introduces design considerations that apply across agroforestry systems, including water, access, fencing, infrastructure, livestock movement, and tree layout, with particular attention to Pacific Northwest conditions where dry-season water planning is often central to farm design.

Chapter 6 provides a framework for selecting agroforestry practices by translating site conditions, farm goals, ecological function, management capacity, and market opportunities into realistic system options.

Chapter 7 focuses on species selection, outlining criteria for matching trees and shrubs to site conditions, production goals, ecological functions, management needs, and long-term resilience.

Together, these chapters help turn assessment findings into an integrated agroforestry plan that is practical, site-specific, and adaptable over time.

CHAPTER

5

DESIGN CONSIDERATIONS FOR ALL AGROFORESTRY FARMS

By Abel Kloster,
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Successful agroforestry design begins with the thoughtful arrangement of the farm’s “mainframe” systems: **water, access, fencing, trees, and infrastructure**. These foundational elements establish the long-term pattern of movement, production, and ecological function across the landscape, shaping nearly every future decision on the farm. When carefully planned from the outset, they simplify the placement of fields, buildings, irrigation systems, livestock infrastructure, and perennial plantings while improving operational efficiency, resilience, and adaptability over time.

In the Pacific Northwest, where the primary growing season coincides with the dry season, water often becomes the central organizing factor in farm design. For this reason, much of this chapter focuses on

strategies for capturing, storing, distributing, and efficiently using water through soils, ponds, irrigation systems, and water-harvesting earthworks.

The following sections explore these interconnected systems in greater detail, including water infrastructure, access design, fencing, livestock watering systems, and tree layout strategies. Together, they provide a practical framework for designing integrated agroforestry systems that balance agricultural productivity, ecological function, and long-term resilience within Pacific Northwest conditions.

Above: The garden of Jude Hobbs, permaculture designer and educator in Cottage Grove, Oregon.

Photo courtesy of Mitchel Davidovitz.

Water systems

In the Pacific Northwest, crop water demand and seasonal water scarcity often peak at the same time, making thoughtful water planning essential to farm and agroforestry design. Declining average rainfall in some areas, more intense storms, recurring drought, and limited access to new agricultural water rights increase the importance of using water efficiently and storing it wherever practical.

Some farms have ample and readily accessible water, but many do not. Even farms with established water rights may experience reduced supply because of drought, increased demand, infrastructure limitations, or declining groundwater and surface-water availability.

Planning a new farm or agroforestry project therefore requires a careful assessment of whether sufficient water is available for crop establishment and long-term production. This assessment should consider rainfall, soil-water storage, crop demand, existing water sources, opportunities for water harvesting, and the capacity to store water for the dry season.

Assessing effective rainfall and water demand

Not all rainfall contributes to soil moisture or plant growth. Some water is lost through runoff, evaporation, or deep percolation beyond the active root zone. Understanding how much rainfall is retained and available to crops is a critical first step in designing a resilient farm water system.



Effective rainfall and crop water needs

Effective rainfall is the portion of total rainfall that remains available to meet crop needs. The amount of effective rainfall depends on factors such as:

- the timing, intensity, and duration of rainfall
- soil texture, structure, and water-holding capacity
- slope and runoff potential
- vegetation cover and surface residues
- rooting depth
- evaporation and transpiration rates
- crop growth stage and seasonal water requirements

In agroforestry systems, estimating effective rainfall helps determine whether irrigation is needed and, if so, how much supplemental water must be supplied. Rainfall received during the wet season may recharge soil moisture and groundwater, but it may not meet crop demand during the region's characteristically dry summers.

Reducing irrigation demand

Before investing in additional water infrastructure, maximize the landscape's ability to capture, retain, and efficiently use available rainfall. This establishes the foundation for determining how much additional water the farm requires.

Above: In the Pacific Northwest, where the primary growing season coincides with the dry season, water often becomes the central organizing factor in farm design.

Photo courtesy of Abel Kloster

Strategies for reducing crop water demand and improving the use of available moisture include:

- emphasize dry-farm strategies whenever possible
- favor deep-rooted perennial crops that can access moisture from a larger volume of soil
- select drought-tolerant species and crops with lower water requirements during periods of peak demand
- use trees and shrubs to improve farm microclimates by reducing wind, providing partial shade for cool-season crops, and moderating temperatures through evapotranspiration
- retain crop residues and apply mulch to reduce soil-surface evaporation
- minimize tillage and unnecessary soil disturbance
- improve soil infiltration and water-holding capacity
- slow and retaining water in swales, ponds, infiltration basins, and other water-harvesting earthworks
- collect runoff from roofs, roads, and hillslopes for dry-season use
- evaluate and, where appropriate, develop existing water sources such as seasonal or year-round springs

Strategies for using irrigation water efficiently include:

- apply deficit or partial-season irrigation where crops and production goals allow
- irrigate before critical crop growth periods to reduce moisture stress
- schedule irrigation using local climate data, on-site rainfall measurements, crop growth stages, and field-level soil-moisture monitoring
- select efficient irrigation methods suited to the crop, soil, and site
- inspect and maintaining pumps, pipes, valves, filters, and emitters to prevent water loss
- limit irrigated acreage to the area that can be adequately served by the available water supply

Storing water in the soil

The soil is the farm's primary and most important water-storage system. Soil stores water in the pore spaces between mineral particles and organic matter. A soil's capacity to retain plant-available water depends largely on its texture, structure, organic-matter content, and rooting depth.

Clay and loam soils generally hold more water than sandy or rocky soils, although not all stored water is equally available to plants. Through effective management, farmers can improve soil structure and increase both infiltration and available water capacity.

Biological processes play an important role in forming and maintaining soil structure. Roots and earthworms create stable channels that improve infiltration, drainage, aeration, and root penetration. Root exudates, fungal hyphae, and bacteria produce compounds that help bind soil particles into aggregates.

Well-aggregated soil contains a mixture of pore sizes. Larger pores allow rainfall and irrigation water to infiltrate, drain, and carry air to roots and soil organisms. Smaller pores retain water through capillary action and gradually supply it to plants during dry periods. Organic matter further improves this sponge-like function by increasing aggregation and the soil's overall water-holding capacity.

Table 5.1a.

Organic matter increases water-holding capacity

Percent organic matter	Typical inches of water per foot of soil		
	Sand	Silt loam	Silty clay loam
1%	1.0 in.	1.9 in.	1.4 in.
2%	1.4 in.	2.4 in.	1.8 in.
3%	1.7 in.	2.9 in.	2.2 in.
4%	2.1 in.	3.5 in.	2.6 in.
5%	2.5 in.	4.0 in.	3.0 in.

Adapted from the publication *Water Management: The Irrigator's Pocket Guide*. National Center for Appropriate Technology. 2023

With deeply rooted perennials, it is possible to rely on available soil water as the sole source of water supply. Dry farming produces crops without summer irrigation by relying on moisture stored in the soil during the rainy season. [Oregon State University's Farming Collaborative](#) is an important resource for farmers seeking dry farm advice in the Northwest.

Many practices that improve soil health also improve infiltration and water-holding capacity. Agroforestry systems can support these outcomes by maintaining perennial roots, increasing plant diversity, protecting the soil surface, and adding organic residues.

Reduce soil disturbance

Practices that reduce soil disturbance include:

- increase the proportion of long-lived perennial crops
- use deeply rooted crops, such as daikon radish and turnip, as biological tillage to fracture compacted soil
- interseed compatible orchards, vineyards, and other perennial systems with low-growing living mulches
- disturb only the crop row through strip tillage or zone tillage
- use no-till drills or planters where site conditions allow
- terminate high-residue cover crops as surface mulch to suppress weeds and protect soil structure

Retain and cycle plant residues

Practices that retain and cycle organic material within the field include:

- integrate livestock in ways that stimulate soil biological activity without causing excessive compaction
- maintain adequate post-grazing stubble heights
- grow diverse cover crops and returning their residues to the soil;
- add appropriate organic materials such as compost, manure, mulch, and biochar
- leave tall crop stubble after harvest
- coppice or pollard suitable perennial trees and shrubs so that cut biomass can be used as mulch while a portion of the corresponding root system decomposes in the soil

Reduce compaction

Practices that help reduce soil compaction include:

- minimize wheel and hoof traffic on wet soils
- use permanent traffic lanes where practical
- grow deeply rooted cover crops such as oats, cereal rye, and forage radish
- favor perennial crops and long-lived root systems
- maintain winter leaf litter, cover crops, or other protective soil cover

Increase infiltration and slow runoff

Practices that increase infiltration and reduce the speed of surface runoff include:

- shape soil surface to slow, spread, and infiltrate water
- use contour cultivation and terraces where appropriate
- construct swales, infiltration basins, rain gardens, and similar earthworks
- maintain vegetation or residue cover on exposed soil
- install beaver dam analogs or similar low-tech process-based restoration structures along suitable small or seasonal waterways

Water-management earthworks should be designed carefully. Poorly placed or undersized structures can concentrate runoff, cause erosion, saturate unstable soils, or damage downstream areas.

Water sources and storage

Irrigation water may come from streams, springs, ponds, wells, stored runoff, or a combination of sources. Water may be delivered by gravity or pumped to fields and storage facilities.

Wells and surface-water diversions are among the most common agricultural sources in the region. However, declining groundwater levels, variable streamflow, drought, and limited access to agricultural water rights may require farmers to diversify their supplies and make better use of water already available on the farm.

Strategies for supplementing water supplies include:

- evaluate and develop springs
- collect roof runoff and storing it in tanks
- install earthworks that slow, spread, infiltrate, or convey runoff
- collect runoff from roads and other suitable surfaces
- enlarge or improve existing ponds
- construct new ponds or reservoirs where site conditions allow
- site agroforestry crops in locations where it is possible to dry farm

Any proposed water source should be evaluated for seasonal yield, water quality, elevation, energy requirements, storage needs, ecological effects, and legal availability.

Springs

Springs can provide water for livestock, irrigation, domestic uses, or storage where groundwater naturally emerges at the soil surface. Because spring flow can vary greatly by season, a spring should be observed or measured throughout the year, especially near the end of the dry season. A spring that flows strongly during winter may produce little or no water when summer irrigation demand is highest.

A spring's usefulness depends not only on its total yield but also on its elevation and rate of flow. A low but continuous flow may be valuable when it can be collected gradually in a tank or pond and stored for periods of peak demand. Springs above fields or livestock watering points may also provide gravity-fed distribution, reducing pumping and energy costs.

Spring development should protect the source from sediment, livestock access, surface contamination, and unnecessary disturbance. Depending on the site, water may be collected in a protected spring box, infiltration gallery, or other structure and conveyed to storage or a point of use.

Before developing a spring, evaluate:

- year-round and dry-season flow
- water quality and intended use
- elevation and opportunities for gravity delivery
- storage requirements
- potential effects on wetlands, streams, habitat, and downstream water users
- access for inspection and maintenance
- applicable water rights, permits, and construction requirements

Rainwater harvesting

Stored roof or surface runoff can supplement wells, springs, and surface-water supplies when flows decline, infrastructure fails, or water-use restrictions take effect. Rainwater harvesting can also slow runoff and reduce soil erosion and nutrient loss.

Although the Pacific Northwest generally receives abundant winter rainfall, much of the growing season receives little or no precipitation. Water intended for summer irrigation must therefore be stored for weeks or months. The volume required can be substantial, particularly for field-scale irrigation.

Before installing a rainwater-harvesting system, estimate:

- the catchment area
- average and drought-year rainfall
- likely collection efficiency
- seasonal crop demand
- storage capacity
- overflow routes
- water-quality requirements
- pumping or gravity-distribution needs

One inch of rain falling on one square foot of catchment produces approximately 0.62 gallons of water before losses. Actual collection will be lower because of initial wetting, evaporation, leakage, overflow, and diversion of the first runoff from dirty surfaces.

Strategies to maximize harvested rainwater include:

- collect runoff from suitable impermeable surfaces wherever practical
- direct clean roof runoff to tanks, ponds, or lined reservoirs
- use adequately sized gutters, downspouts, filters, and overflow structures
- keep runoff from contaminated surfaces separate from cleaner supplies
- use lined reservoirs for high-volume, non-potable storage where they are more economical than tanks
- reserve enclosed tanks for potable or higher-quality uses that require smaller volumes
- protect stored water from sediment, algae, debris, animals, and mosquitoes
- use winter and early-spring rainfall to support nursery crops and hoop-house seedlings before field transplanting

Rainwater systems should include a safe overflow route. Overflow should be directed to stable, vegetated areas, infiltration basins, swales, ponds, or other locations where it will not damage buildings, roads, slopes, or neighboring properties.

Water-harvesting earthworks and conveyance

Rainwater harvesting in the Pacific Northwest often depends on maximizing the contributing catchment area and conveying runoff to locations where it can be infiltrated or stored. Strategically designed channels, swales, roads, and other earthworks can intercept water moving across the landscape and convey it toward fields, ponds, or infiltration areas.

The design of any conveyance system should account for catchment size, expected peak flow, slope, soil type, erosion potential, overflow location, and any downstream effects. All earthworks should be designed to remain stable during large storms, not only during average rainfall events.

Water-conservation channels

Water-conservation channels are graded ditches designed to collect and move runoff. They typically include a V-shaped or flat-bottomed channel and a compacted bank on the downhill side. The channel is placed on a gradual slope so that water moves toward a pond, reservoir, or other stable outlet without causing erosion.

Tree or shrub belts are often planted downslope of the channel to use water that infiltrates into the surrounding soil. Vegetation can also help stabilize soil, filter sediment, and capture nutrients.

The appropriate gradient should be determined through site-specific design rather than applied as a universal standard. A channel that is too flat may accumulate sediment or overflow unpredictably, while one that is too steep may erode.

Roads

A properly designed road can serve as both an access route and a water-harvesting surface. Road runoff can be directed through rolling dips, broad-based drains, culverts, or stabilized channels to ponds, infiltration areas, or vegetated fields.



Above: A swale installed uphill of a pear and currant forest garden guild at Center for Rural Livelihoods in Oregon.

Photo courtesy of Abel Kloster

Because roads can generate large volumes of concentrated runoff, drainage structures must be placed frequently enough to prevent erosion. Runoff should not be discharged onto unstable slopes, bare soil, streambanks, or neighboring land.

Swales

Swales are shallow channels with uncompacted berms on their downhill sides. They are commonly installed on or near contour to slow runoff, spread it across the landscape, and encourage infiltration.

Swales may be designed to:

- infiltrate rainfall where it falls
- distribute water from a tank or pond
- receive runoff from roads, roofs, or adjacent slopes
- overflow safely into another swale or infiltration area
- move surplus water slowly across the landscape on a slight grade

In wet-winter, dry-summer climates, graded swales may be preferable as fully level structures would remain saturated for long periods or intercept more water than the soil can safely absorb.

Plant selection should reflect moisture conditions within and around the swale. Trees are often planted on or below the berm, where roots can access infiltrated moisture without obstructing the channel. Moisture-tolerant shrubs may be placed along the inner slope or in other areas where temporary saturation is expected.

Swales should not be installed automatically on every site. They may be inappropriate on unstable slopes, shallow soils, areas with landslide risk, poorly drained clay soils, or locations where intercepted water could threaten buildings, roads, septic systems, or neighboring properties.

Ponds and reservoirs

Ponds and reservoirs can store runoff, spring flow, pumped groundwater, or diverted surface water for later use. They can also support aquaculture, wildlife habitat, fire protection, frost protection, and other farm functions. Pond siting should consider:

- the size and reliability of the contributing catchment
- soil permeability and the potential need for a liner
- slope stability and geotechnical conditions
- dam size and construction requirements
- sediment movement
- ecological and downstream effects
- access for construction and maintenance
- pumping and gravity-distribution opportunities
- water quality and intended use
- evaporation and seepage losses
- emergency overflow routes
- applicable permits and water rights

There are five general landscape positions in which ponds may be located.

Crest or turkey's-nest ponds

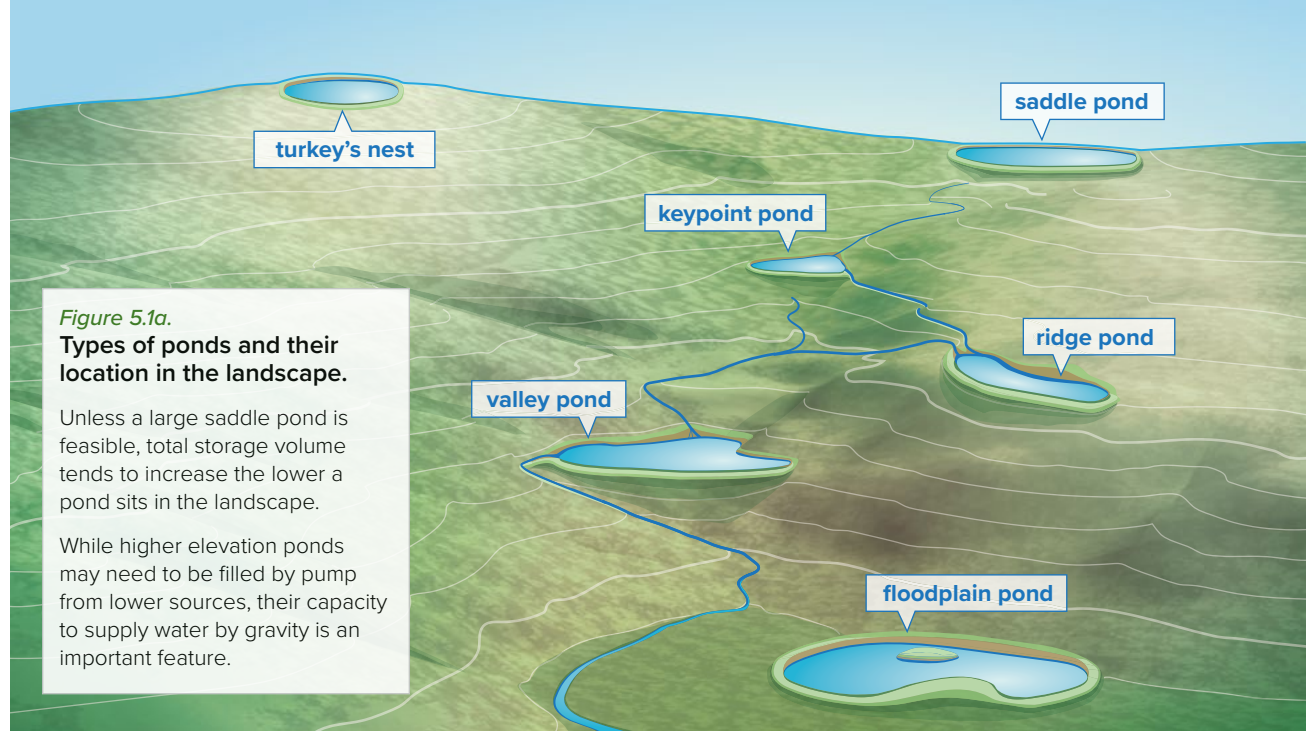
Crest ponds are located near the top of a ridge or other high point. They are generally surrounded by an earthen embankment and are usually filled by pumping or by conveying water from another catchment.

Their high position can provide gravity-fed distribution to fields below. Where pumping is practical and water is intended for non-potable use, a lined crest pond may provide lower storage costs per gallon than an enclosed tank.

Because crest ponds are elevated and impounded by constructed embankments, careful engineering, overflow design, and regular inspection are essential.

Saddle ponds

Saddle ponds are located in a low point between two adjacent ridges or crests. They are usually positioned to one side of the ridgeline and may receive runoff conveyed from slopes on either side.



Graphic by Michael Godfrey

Saddle ponds may require lining and may also be filled by pumping from a lower-elevation source. Their location can provide gravity pressure for downslope irrigation and helicopter dipping potential during fires, but the stability of surrounding slopes and embankments must be carefully evaluated.

Valley and keypoint ponds

Valley ponds are located in drainage valleys and receive water from natural runoff, or conveyance channels from adjoining slopes.

Pond placement should balance two objectives:

1. capture sufficient runoff from the upstream watershed
2. retain enough elevation to distribute water by gravity to land below

In keyline terminology, a keypoint pond is located near the highest practical position in a primary valley where the landform changes from steeper upper slopes to gentler lower slopes. A keypoint pond is the highest sensible valley pond that can be constructed



Above: Valley ponds naturally capture water from seasonal flow and can also be filled via water harvesting channels from adjoining ridges.

Photo courtesy of Abel Kloster

before the landform gets too steep and the upper catchment area grows smaller.

Hillside or ridge ponds

Ridge ponds are constructed on sloping land outside the primary valley. They may be placed along broad ridges, benches, or suitable side slopes and are often supplied by water conveyed from an adjacent valley or pumped from a lower source.

Ridge ponds can provide useful elevation for gravity irrigation and are often the largest pond that can be built at higher elevations, given the shape of the landform.

Floodplain ponds

Floodplain ponds are located on relatively level river floodplains or older floodplain terraces. Flat terrain may allow large storage volumes with comparatively less excavation or embankment construction.

These ponds may be used for irrigation storage, aquaculture, wildlife habitat, or pumping to higher-elevation reservoirs. However, floodplain ponds can interact with groundwater, wetlands, streams, and flood flows. Their development may be subject to more substantial local regulations.

Right:
Ridge ponds
can provide
ample room for
storage at higher
elevations.

Photo courtesy
of Abel Kloster



Integrating agroforestry with ponds

Ponds can support agroforestry production when deliberately designed. Vegetation can provide food, biomass, habitat, shade, erosion control, and improved water quality. Planting should not interfere with dam integrity, spillways, or other important access points. Large woody plants are generally inappropriate on pond dams as they can cause the structure to leak.

Shade and evaporation reduction

Trees and shrubs can provide wind protection and partial shade and therefore reduce evaporation. It is generally good to have at least some sections of a pond covered by shade over the course of a day.

Food and specialty crops

Moist pond margins and adjacent soils may support crops adapted to periodic saturation or acidic conditions. Depending on the site, these may include:

- **blueberry** (*Vaccinium corymbosum*)
- **huckleberry** (*Vaccinium ovatum* or *V. parvifolium*)
- **highbush cranberry** (*Viburnum opulus*)
- **wapato** (*Sagittaria latifolia*)
- **wokas** (*Nuphar polysepala*)
- **fuki** (*Petastites japonicus*)
- **wild rice** (*Zizania palustris*)

Microclimates provided through the temperature buffering effects of water can also make ponds ideal sites for cold sensitive species.

Raised growing beds separated by water channels may resemble chinampa systems with dry farmed agroforestry species growing on islands within the pond itself. Biomass and habitat plants

Emergent and shoreline vegetation can stabilize soil, filter runoff, provide habitat, and produce useful biomass. Appropriate species may include:

- **cattail** (*Typha latifolia*)
- **water plantain** (*Alisma plantago-aquatica*)
- **native sedges** (*Carex* spp.)
- **rushes** (*Juncus* spp.)

Native or adapted noninvasive species should be favored. Some aquatic plants can spread rapidly or obstruct water access and should be managed carefully.

Livestock and wildlife integration

Livestock access should be controlled to prevent bank erosion, nutrient loading, damage to liners, and contamination of stored water. Fenced access points, hardened crossings, or off-pond watering systems are generally preferable to unrestricted entry.

Ponds may also include habitat features such as vegetated shelves, shallow-water areas, logs, or islands for waterfowl. Wildlife features should be designed so that they do not compromise water quality, irrigation equipment, spillways, or dam safety.

Other farm uses

Additional uses may include:

- dipping or soaking areas for mushroom logs
- propagation of aquatic or moisture-loving plants
- irrigation-water storage
- aquaculture
- emergency water for fire suppression
- educational or demonstration areas
- fishing and swimming

Keyline design for agroforestry

Keyline design is a farm planning system developed by the late Australian mining geologist and rancher, P.A. Yeomans. Keyline organizes cultivation, access, and planting around keypoints and keylines to slow, spread, and sink water across the landscape.

The **keypoint** is a term for the location in a primary valley that marks a significant change in the slope and water dynamics. The keypoint is the **highest strategic point to do the most work** with water downhill and it marks the point where water naturally begins to slow down before entering flatter ground, making it ideal for influencing water distribution.

From the keypoint, draw a contour line—called the **keyline**—which becomes the main “guideline”. The orientation of all other contour-parallel work is derived from this line. Parallel lines running downhill and up from this guideline set the keyline pattern. Unlike laying out tree rows and other systems on contour, this line maintains a consistent spacing between intervals. This pattern can be followed for water distribution, cultivation, access, fencing, and tree and crop layout.

The keypoint is relevant to agroforestry because:

1. Sets a pattern for tree layout

In agroforestry, the keyline is used to align tree belts, shelterbelts, alleys, and silvopasture strips along or slightly off contour so that tree roots, litter, and deep infiltration work together to rehydrate soils, reduce erosion, and create more productive, resilient planting zones. The even row spacing of keyline design is amenable to alley cropped agroforestry and other types of systems that require even tree distribution, but want to achieve the benefits of contour management.

2. Sets a pattern for cultivation

Keyline cultivation is designed to distribute runoff water away from the center of the valley, reducing the concentration of flow in these erosion-prone areas. A keyline plow is commonly used to fracture compacted subsoil layers, improving infiltration and creating space for deeper root development. Seeders, compost tea applicators, fertilizer injectors, and other cultivation implements may also be used in conjunction with keyline ripping.

By cultivating parallel to identified keylines, the resulting pattern encourages runoff to spread more evenly across the landscape rather than concentrating in valley bottoms along its natural drainage path. This improves water distribution, enhances valley stability, and increases resistance to erosion and washouts. Compared to strict contour cultivation, keyline cultivation can also reduce the risk of machinery rollover when operating on side slopes.

3. Informs the location of farm infrastructure.

Roads, trails, fences, and watering pipelines may all follow the pattern determined by keyline layout. Roads can run above and below paddocks subdivided by tree rows on the keyline. These roads may channel water to reservoirs as they run on a sloped gradient toward the ridge. Fences can also be integrated with access routes and water distribution systems aligned along the keyline pattern.

4. Informs pond placement.

The keypoint is often where you would site your highest elevation pond—a high, efficient storage location that can gravity-feed water to ponds located on the ridge or lower in the valley.

Identifying the keypoint

Every primary valley has a keypoint. It is often identifiable by the appearance of a noticeable channel or the presence of lush grass growth, deeper soil, or more organic matter compared to the surrounding area.

When walking up the floor of a primary valley, the slope will often begin gradually before abruptly becoming steeper; this transition point may indicate the keypoint of the valley.

On a topographic map, contour lines typically appear farther apart at the keypoint. This is the location in a valley where the slope transitions from steeper above to gentler below, or where the landform shifts from a convex shape, which sheds water, to a concave shape, where water naturally accumulates.

The keypoint marks the beginning of the water retention zone, where the movement of water slows and transitions from primarily erosive force to one of deposition and infiltration.

Sometimes, valleys begin to widen (in addition to becoming less steep) around the location of a keypoint. These factors set the stage for the highest viable location for a larger pond in primary valleys.

Because major ridge systems gradually decline in elevation as they extend away from the headwaters, keypoints likewise tend to descend in elevation from one valley to the next moving away from the ridge peak. As a result, the keypoint in an adjacent valley will typically be located at a different elevation (often lower, though occasionally higher depending on local topography) than the previous keypoint.

Zones of water

Keyline designers have outlined four numbered zones of water in a landscape.

Water Catchment Zone

This is the area above all water stored in ponds and infiltration earthworks. This area is suited to non-irrigated agroforestry and other land uses. It can be left as managed or non-managed forest or devoted to silvopasture or forest farming. Unless water is supplied from ponds located above the keypoint pond or through pumped irrigation, the area above the keypoint will generally fall into this category. In terms of land use, it is well-suited for forestry use or low-intensity silvopasture and/or forest farming.

Water Retention Zone

This portion of the landscape where water is stored and distributed passively through ponds, infiltration earthworks, soils, and vegetation. It lies within the

broader “lens” of retained water created by higher-elevation storage features, but outside the area that can be directly irrigated. Positioned between the catchment zone and the irrigation zone, this area benefits from increased soil moisture and subsurface water movement without relying on active irrigation systems.

This zone is particularly well suited to deeply rooted perennial crops and tree-based systems that can tolerate dry summer conditions while still benefiting from the enhanced water availability created by upslope water storage. Agroforestry systems designed around keyline and contour cultivation patterns are especially appropriate in this landscape position.

Irrigation Zone

This is the portion of the landscape that can be actively supplied with water through irrigation systems. Located downslope from the Water Retention Zone, it

includes areas that are capable of being irrigated by gravity-fed flood channels, sprinklers, drip systems, or other managed delivery methods.

Because this zone is often situated on gentler and more workable terrain, it is generally suitable for a wide range of agroforestry systems, depending on soil conditions, climate, and overall site design. The reliable availability of supplemental water also allows for the cultivation of crops with higher water demands or lower drought tolerance.

Water Reconstitution Zone

This area lies below the Irrigation Zone and includes the valley drainage and riparian areas. Where site conditions permit, this zone is often well suited to permanent forest cover, with riparian forest buffers being an especially appropriate choice in many landscapes.

For more information on keyline design, see:

- [Regrarian's Platform](#)
- [Regrarian's eHandbook](#)
- [Geoffrey Booth's Keyline Video Archive](#)
- [Allen Yeomans Keyline Systems Explained](#)



Left A keyline plow prepares to simultaneously subsoil and seed a keyline on a ranch in California.



Right: Keyline plow furrows after treatment show the minimal surface disturbance after the subsoiling. Note stakes marking the keyline and setting a pattern for parallel cultivation along the slope.

Photos courtesy of Abel Kloster

Irrigation systems

Irrigation layout should be planned alongside tree rows, access routes, fencing, and water storage. In agroforestry systems, irrigation infrastructure must often serve long, linear plantings, irregular tree arrangements, alleys used by equipment, and multiple crop layers with different water needs.

A good layout reduces pressure losses, simplifies maintenance, protects pipes and emitters from livestock or equipment damage, and allows different parts of the system to be watered according to soil type, slope, crop age, and seasonal demand.

Irrigation layout and zoning

Most irrigation systems are organized around a hierarchy of mainlines, sub-mains, and laterals. Mainlines move water from the source, pump, or storage pond to the general irrigation area. Submains divide the system into manageable zones, while laterals deliver water directly to crops through drip tubing, emitters, micro-sprayers, bubblers, or sprinklers. In alley cropping and linear tree systems, laterals commonly follow tree rows or alley edges. In more irregular plantings, laterals may need to be looped, branched, or grouped into zones based on plant clusters and pressure requirements.

Irrigation zones should be designed around water demand, crop type, soil texture, slope, and system pressure. Young trees, vegetable alleys, nursery areas, windbreaks, and mature perennial plantings may all require different watering schedules. Separating these areas into independent zones allows managers to irrigate young or shallow-rooted plants more frequently without overwatering established trees or drought-tolerant species. Zoning also allows portions of the farm to be shut off as plantings mature and become less dependent on supplemental water.

On sloping ground, irrigation layout must account for pressure changes caused by elevation. Lines running downhill gain pressure, while lines running uphill lose pressure. Long laterals, steep slopes, and uneven terrain can produce uneven water distribution unless the system is divided into shorter zones, pressure-regulated emitters are used, or valves are placed to balance flow. Where possible, mainlines can follow access routes or ridges, while laterals should extend across or slightly off contour to serve similarly aligned tree rows and alleys.

Irrigation infrastructure should be placed where it can be inspected, repaired, and winterized without interfering with field operations. Place valves, filters, pressure regulators, flush points, and hose connections near roads, headlands, or other accessible points. In systems with mowing, grazing, cultivation,

Table 5.1b. Irrigation layout considerations by agroforestry system

Agroforestry system	Irrigation layout considerations
Alley cropping	- Run laterals along tree rows and provide separate irrigation for annual crop alleys. - Keep valves, risers, and flush points accessible from roads or headlands.
Silvopasture	- Protect pipes, valves, risers, and emitters from livestock. - Bury lines where possible, reinforced risers, and water distribution systems that coordinate with trough placement and paddock layout.
Riparian forest buffers	- Irrigation may be temporary and used primarily for establishment. - Keep permanent infrastructure outside of the flood zone. - Avoid layouts that disturb sensitive banks, concentrate runoff toward waterways, or interfere with riparian restoration goals.
Forest gardens / multilayer plantings	- Use flexible zones that can serve mixed species with different water needs. - Bubblers, micro-sprayers, or short drip loops may work better than long, uniform runs.
Windbreaks and hedgerows	- Drip or micro-spray laterals can follow the planting line. - Design for long, narrow zones and maintain pressure consistency across the row. - Irrigation may be temporary and used primarily for establishment.

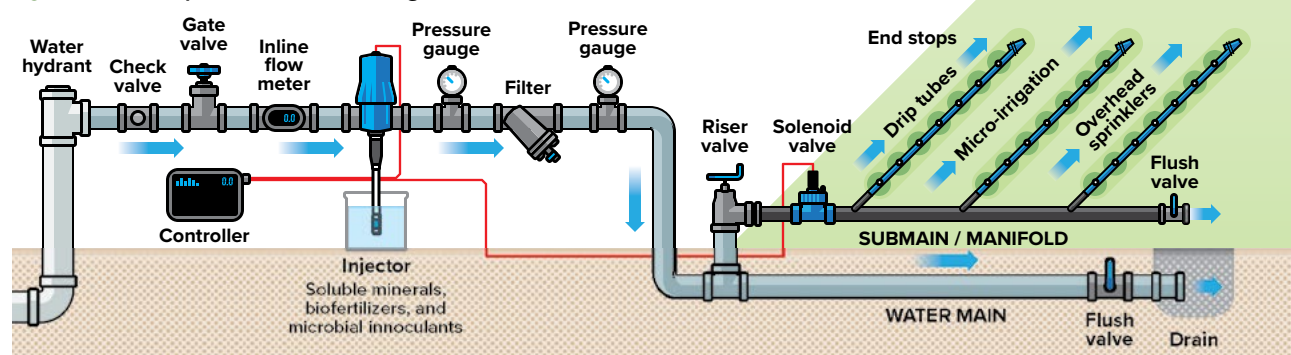
or harvest equipment, aboveground components should be protected or placed outside travel lanes. Buried mainlines and sub-mains reduce damage risk, while aboveground laterals may be useful where systems are temporary or need seasonal adjustment.

Irrigation needs often change as agroforestry plantings mature. Newly planted trees and shrubs usually require consistent moisture during establishment, especially through the first several dry seasons. As roots deepen and canopy structure develops, some species may require less supplemental irrigation or only

need water during severe drought or critical growth periods. Layouts should therefore be designed with flexibility, allowing sections to be expanded, reduced, converted, or shut off over time.

Irrigation layouts should include flush valves, drain points, accessible filters, and isolation valves so the system can be cleaned, repaired, and winterized. Low points in buried systems may need drains to prevent freeze damage, while high points may require air-release valves. Filters should be easy to access and sized for the water source, especially when drawing

Figure 5.1b. Components for field irrigation.



Graphic by Michael Godfrey

from ponds, surface water, or stored rainwater where sediment and biological material may clog emitters.

Irrigation layout should also be adapted to the specific agroforestry system being established. **Table 5.1b** summarize common layout considerations for different agroforestry applications.

Once the overall layout, zones, and access points have been established, growers can select the irrigation method, or combination of methods, best suited to each planting area.

Irrigation methods

The four basic irrigation methods include:

- **Surface**—Water is applied by gravity across the soil surface by flooding or in small channels. Examples include paddies, irrigated furrows, and flood irrigation from contour ditches. Although surface irrigation is not a common approach for tree crops, one option is to fill contour swales where plantings are located either above, below, or on the downhill side of the swale. Water can then infiltrate into the root zone. In the Northwest, these swales will likely need to be filled by an abundant water source during the dry season.
- **Sprinkler**—Water is sprayed from impact or gear-driven heads, with water delivered by surface or buried pipelines, or both. Sprinkler irrigation systems include solid set, hand-move laterals, side-roll laterals, center pivot, linear move, and stationary or traveling gun systems. The most common and relevant sprinkler types for agroforestry systems are solid set and hand-move lateral systems, as they can be designed into linear plantings or woven through nonlinear arrangements.
- **Microirrigation**—Water is applied through low-pressure, low-volume discharge from drip tubing, drip emitters, micro-sprayers, or bubblers supplied by surface or buried pipelines. Drip lines, micro-sprayers, and bubblers are often used for the perennial components of agroforestry systems, while drip tubing may also be used for vegetables or other annual crops integrated into alleys.
- **Subirrigation**—Water is made available to the crop root system by upward capillary flow through the soil profile from a controlled water table.

Table 5.1c. Advantages and disadvantages of irrigation types

Irrigation type	Advantages	Disadvantages
Drip irrigation	• low pumping costs • large water savings in young plants due to accurate and even water placement • no wetting of fruit or foliage, reducing fungal disease pressure • potentially the most water-efficient piped system • allows access to orchard or crop areas at all times • highly suited to precise irrigation scheduling and fertigation • allows high mowing or scything without risk to the system	• requires a high degree of filtration • requires frequent monitoring and a reliable water supply • cover crop establishment may depend on rainfall or a secondary irrigation system • little margin for error, as plants may stress quickly if the system fails or watering is delayed • not suited to frost or heat control.
Micro-sprayers	• minimal wetting of fruit and foliage, reducing fungal disease pressure • wind effects can be minimal when emitters are set low to the ground • suited to most soils • lower pumping costs than overhead sprinkler • some frost control and canopy cooling may be possible • well suited to fertigation; adaptable to a wide range of crop types	• maintenance and inspection can be labor-intensive • canopy management and weed control necessary to prevent vegetation from blocking spray patterns • more susceptible to physical damage from pickers, livestock, and machinery than sprinklers or drip systems.
Sprinklers	• low labor and maintenance requirements • functioning and nonfunctioning sprinklers are easily seen • can be used for frost control and canopy cooling • useful for establishing and maintaining fine-seeded crops such as clover and mustards	• Relatively high water use • more prone to poor distribution uniformity • poor distribution effects are amplified when using fertigation • wind reduces efficiency and distribution • high evaporation losses on hot, windy days • can create conditions conducive to disease • may damage susceptible crops close to harvest • wetting foliage can lead to salt uptake in leaves when water contains salts • high sprinkler output and slow soil infiltration may lead to runoff • not well-suited to heavy clay soils due to surface sealing • droplet impact on bare soil can form a dense surface layer and reduce infiltration.

In agroforestry systems, irrigation design is most effective when it is integrated with the larger farm layout rather than treated as a separate utility. By coordinating irrigation with tree rows, access routes, fencing, slopes, crop water needs, and long-term system maturity, growers can reduce water waste, protect infrastructure, and maintain flexibility as plantings develop over time.

Livestock water

Livestock watering systems are an important part of agroforestry layout because they influence animal movement, grazing distribution, soil impact, and the protection of trees and sensitive areas. Water points should be planned together with paddock design, fencing, access routes, shade, and irrigation infrastructure so that animals can reach water easily without concentrating pressure in vulnerable parts of the farm. Well-placed and well-protected watering systems improve livestock health, reduce erosion and compaction, and support more even use of pasture and silvopasture areas.

Trough placement and location

Trough placement should balance grazing distribution, livestock health, ease of maintenance, and protection of soils and infrastructure. Ideally, livestock should not travel more than 800 feet to water, as greater distances can lead to uneven grazing, erosion, compaction, and reduced animal performance. Centrally located troughs encourage more even grazing distribution, though placement near fences or access roads may improve maintenance access and reduce interference with machinery. When troughs are located near fences, they should be offset or protected with reinforced barriers to prevent fence damage.

Troughs should be positioned away from gateways, livestock camping areas, steep or erosion-prone ground, and depressions where mud and manure can accumulate. Placement near tracks or roads improves monitoring and maintenance access. Locating troughs on the leeward side of vegetation or shel-

terbelts can reduce wind exposure, dust, and debris while improving livestock comfort. Some shade can help reduce algae growth, evaporation, and water temperature, though excessive shade may encourage livestock congregation and soil degradation.

Where practical, a single trough positioned beneath or across a fence line can serve two paddocks simultaneously, reducing installation and maintenance costs by sharing valves, fittings, and infrastructure between paddocks. Photovoltaic (PV) systems are increasingly used to power livestock and irrigation pumps, particularly in remote locations. Because peak water demand for irrigation and livestock generally coincides with the season of greatest solar availability, solar-powered pumping systems can provide reliable operation with lower long-term costs and a reduced environmental footprint compared to conventional energy systems. In the Northwest, use of surface water sources for livestock watering may require a domestic livestock watering permit through the [Oregon Department of Water Resources](#) or [Washington Department of Ecology](#).

Water quality

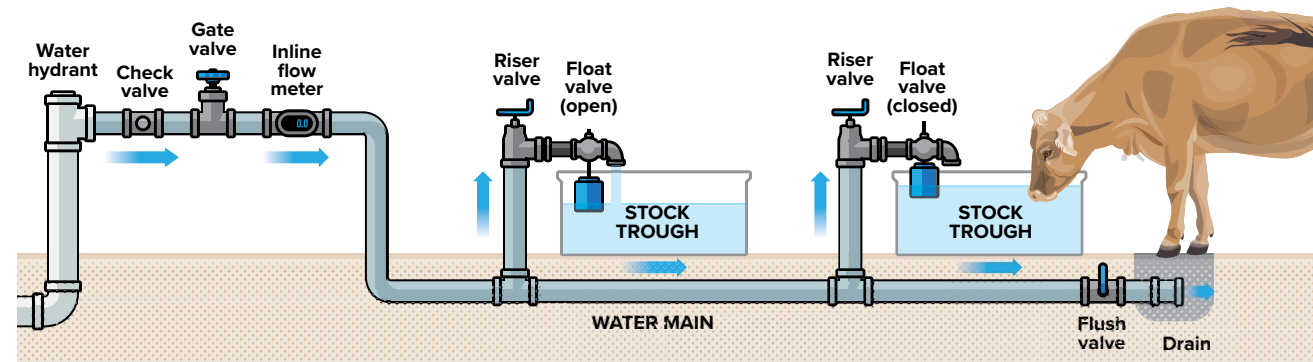
Patterns of land use strongly affect water quality. Disturbed areas such as cultivated fields, livestock confinements, and urban developments tend to generate higher pollutant loads, particularly on steep

slopes and flood-prone landscapes. Runoff from these areas moves downslope into natural waterways, while constructed drainage features—including ditches, terraces, drainage tiles, and culverts—can concentrate and redirect water flow across the landscape. Infiltration may also transport soluble nutrients, sediments, and pesticides into soils and shallow aquifers.

Agroforestry practices can play an important role in slowing runoff, improving infiltration, filtering pollutants, stabilizing soils, and protecting riparian systems. The following guidelines outline ways agroforestry can be strategically applied to improve water quality and reduce nonpoint source pollution across the farm landscape:

- Place agroforestry practices, such as buffers, swales, hedgerows, or livestock exclusion fencing, in disturbed areas that generate high pollutant loads, including tilled fields or livestock areas on slopes and floodplains.
- Install these practices immediately downhill from major pollutant sources and in areas where runoff concentrates before entering channels or drains.
- Align row or strip plantings along topographic contours.
- Establish riparian buffers and floodplain plantings in floodplains and riparian zones to filter shallow groundwater and intercept overland flow.
- Adjust the size and width of plantings, buffers, and earthworks to match the volume of runoff intercepted.

Figure 5.1c. Components for livestock watering facilities.



Graphic by Michael Godfrey

Access systems

Roads and access systems are among the most permanent and influential features established on a farm. Their placement affects water movement, erosion risk, fire management, livestock distribution, machinery access, and the long-term efficiency of farm operations.

When thoughtfully integrated into the natural land-form, access systems can serve multiple functions beyond transportation, including water harvesting, drainage management, and the definition of management zones across the landscape.

- Consider siting a main access system along the keyline to create natural firebreaks and define zones of use.
- Locate roads along main and primary ridges when the vertical grade of the slope is less than 16%. This location minimizes the need for excavation, has an excellent line of sight in both directions, allows for livestock fencing along watershed boundaries, maintains fire breaks along ridges, and provides natural drainage with little runoff.
- When running roads through valleys, locate them along wide valley floors above and outside of the maximum flood line. Be sure that roads located in valleys will not be prone to flooding by future efforts to reconnect floodplain habitats through beaver dam analogs and other channel restoration efforts.
- Position roads on south- and west-facing aspects to encourage faster drying in the spring and after rains.
- Plan roads across less-sloped sections where the least amount of excavation and grading is necessary.
- Site roads along contours when traversing a slope. This maximizes safe vehicle travel, minimizes erosion, allows for water harvesting, simplifies drainage management, and establishes fire breaks on slope.
- Run roads across pond dams, natural benches, bluffs, and saddles (if adequately dry) can be the best locations for staging areas, turnarounds, buildings, water tanks, and ponds.

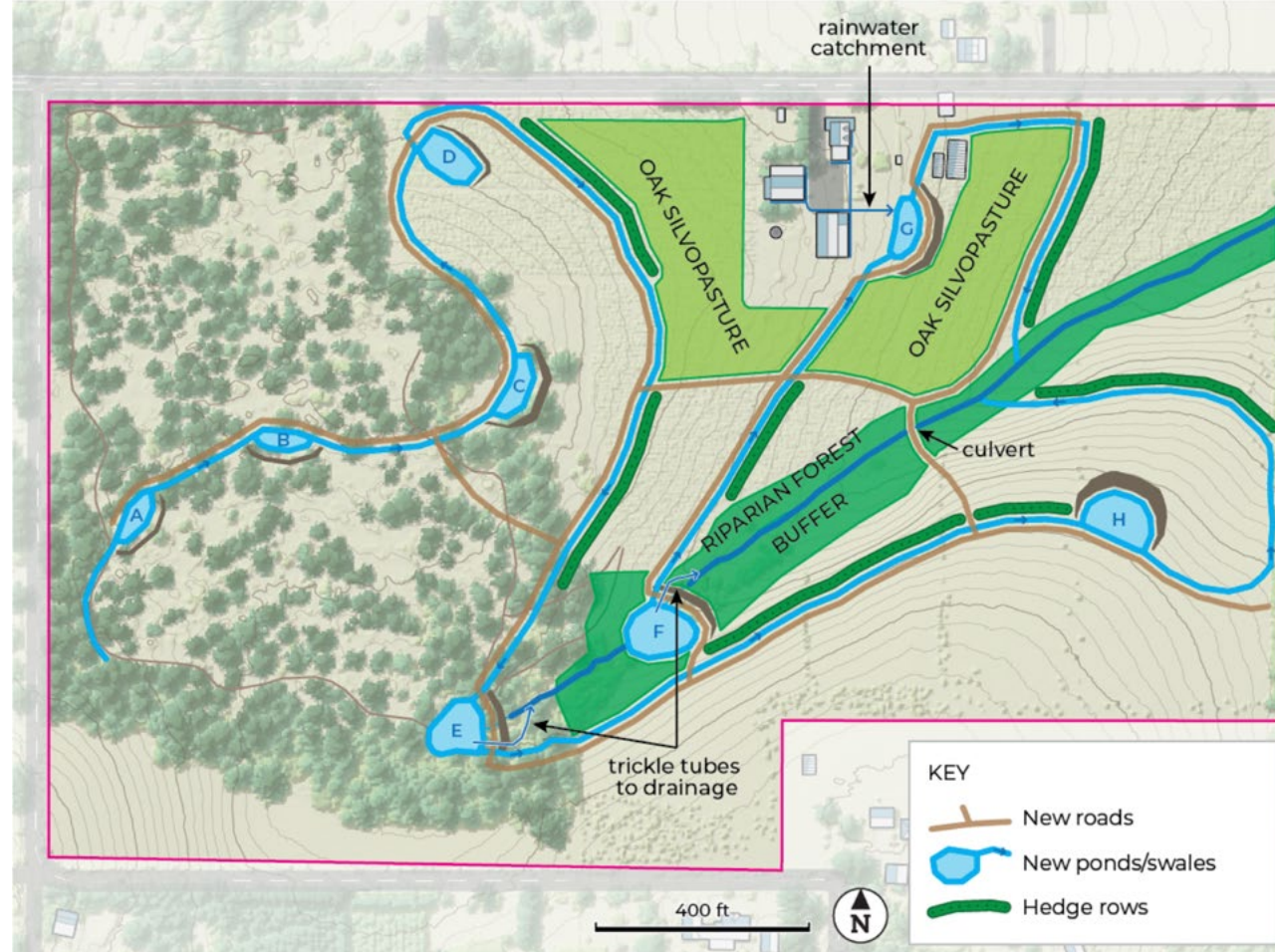


Figure 5.2a. Access plan.

On this agroforestry farm in the Cascade Foothills, the access roads, drainage, windbreaks, and hedgerows were designed in tandem.

Plan courtesy of Michael Godfrey and Resilience Permaculture Design

Areas to avoid for road development:

- historic sites and areas of cultural significance
- through sensitive, threatened, or endangered plant and animal populations
- highly erosive soils and over shallow bedrock.
- poorly drained soils that become saturated and mucky in the winter.
- below the highest flood level of streams, or high water line of ponds and wetlands
- on exposed bedrock or along cliffs and rock outcrops
- through narrow valley floors

Fencing systems

Fencing is a critical component of agroforestry design, shaping livestock movement, protecting perennial plantings, and defining management zones across the farm.

Well-designed fencing systems can support rotational grazing, improve pasture utilization, protect sensitive ecological areas, and allow trees and shrubs to establish when integrated with animals. Because agroforestry systems change over time as vegetation matures and management goals evolve, fencing should be planned with durability, flexibility, wildlife movement, and long-term maintenance in mind.

Design and layout

Fencing should be planned to assist with rotational grazing. Create paddocks that allow livestock to move regularly while preventing overuse of any one area. Layouts must also protect young trees and shrubs from browsing or rubbing, which can quickly damage or kill plantings. In silvopasture, interior fencing often serves both to guide animal movement and to safeguard the establishment of perennial vegetation.

Consider laying out fencing following the edges of different vegetation types as well as pastures of varying productivity in order to assist with the unique management needs of different zones. Fences can follow patterns of layout similar to roads and water pipelines in order to simplify maintenance and delineate zones of use. Fencing should also be used to exclude livestock from riparian zones, steep slopes, wet areas, or freshly planted tree stands.

Durability

Materials should be matched to livestock type, stocking density, and intended lifespan. High-tensile wire and electric fencing are common choices, providing

strength and longevity when properly maintained. Stronger fencing may be necessary for larger or more persistent animals, while lighter systems may suffice for smaller stock. Woven wire fencing is a reliable option for most animals.

Flexibility

Because agroforestry systems evolve as vegetation grows, fencing systems should allow for adaptation. Portable or temporary electric fencing is particularly useful for adjusting paddock size, protecting new plantings, or testing different grazing patterns. This flexibility reduces long-term risk and makes it easier to refine management over time.

Cost and maintenance

Effective fencing requires balancing upfront installation costs with the labor and time needed for repairs. Higher-quality materials may reduce long-term expenses, but maintenance is unavoidable. Regular inspection and prompt repair of damage will extend fence life and protect both livestock and plantings.

Wildlife considerations

In addition to livestock management, fencing design should account for wildlife. Avoiding unnecessary barriers, using smooth wire on top and bottom strands, or leaving passage points can minimize hazards while still keeping livestock contained.

Where wildlife corridors are a priority, fencing can be aligned and constructed to support their movement. Water troughs can also be outfitted with escape ramps. If sensitive butterfly species are known to exist on site, avoid grazing specific plants when butterfly larva or adults are active.

For more information on fencing design, see:

→ [Paddock Design, Fencing and Water Systems for Controlled Grazing](#) (Morrow, 2009)

Maintaining native cover and wildflower species

Carefully timed rotational grazing can be used as a tool to protect and enhance desired plant populations. Strategies include:

- **Prevent animals from over-grazing spring ephemerals** by limiting utilization of woodlands during the heaviest wildflower flushes;
- **Allow wildflowers to set seed before being trampled or consumed** by minimizing dense and intensive grazing during the flowering period. Grazing sections of the property every other year during the flowering period could help guarantee new seed introductions over time;
- **Target specific areas by mob grazing in the fall** while spreading native seed to increase native wildflower seed banks;
- **Rest sections with good native diversity for a season** to allow for native seed bank establishment;
- **Limit herd impacts on saturated soils** during the wet season;
- **Keep grazing periods short** to allow for adequate plant recovery;
- **Focus on spring grazing in grass-dominated pastures** so as not to impact wildflower seed set;
- **Graze woodland pastures later in the summer** when grasses are still green in the understory but the wildflowers and herbaceous native plants have gone to seed;
- **Use a deferred rest/rotation system** that leaves a portion of the pasture per year ungrazed; and,
- **Graze or mow grass and other herbaceous vegetation in the late fall** after nesting season and seed set to prevent the re-establishment of brambles and woody plants.

Tree protection in grazing systems

Although tree tubes are commonly used for protection, they can be pushed over by animals. Wire cages are more effective, but more costly. Tree tubes in conjunction with single strand electric fencing provides extra protection for the trees. Electric fencing requires maintenance of weeds and grasses to ensure that it is working, and extra weed management is required as animals will not be foraging pasture species near the trees. Postponing livestock integration until trees have had a chance to sufficiently establish above browsing height may be necessary in certain contexts.

Tips for protecting trees:

- **Tree tubes are not sufficient.**
- **Electric fencing is good tree protection** if the fence is effective; however, weed management is difficult because animals cannot browse close to the tree.
- **Tree tubes plus a single-strand electric fence** may provide the best weed control and tree protection at reasonable cost
- **Postponing livestock may be necessary for large plantings.**
- **Conifers are less susceptible than hardwoods to browsing.**
- **Remove livestock before forage is grazed down more than 90%** so that they do not turn to less palatable but available forages
- **Two-step grazing:** 1) turn animals out to a treed pasture in the spring when the rapidly growing grasses will be favored over rapidly growing trees and then 2) summer graze when trees have stopped their growth but shrubs and grasses can still be browsed. This strategy works well for conifers because their growth tips are no longer growing in the summer.

Once young trees are adequately protected from livestock and competing vegetation, the broader arrangement of tree rows, clusters, and spacing becomes the next major design consideration.



Above: Tree protection and livestock exclusion is necessary to protect young trees.

Photo courtesy of Mitchel Davidovitz

Tree layout systems

The layout and spacing of trees are among the most important design decisions in agroforestry systems, influencing water movement, solar access, machinery efficiency, forage production, wildlife habitat, and long-term tree development.

Tree arrangement should respond to the natural landform, climate, soils, and management goals of the site while balancing the needs of both woody and understory crops. Different planting geometries—including linear, contour, Keyline, and savanna layouts—offer distinct advantages depending on slope, water dynamics, and the intended relationship between trees, crops, and livestock.

Equally important is the spacing between trees and rows, which affects crown development, timber quality, light penetration, root competition, understory productivity, and ease of management. Thoughtful spacing and layout can improve the productivity and resilience of the entire agroforestry system while allowing efficient integration of irrigation, access, grazing, and harvesting operations.

Tree layout

Tree spacing and layout should respond to slope, soil fertility, moisture availability, solar exposure, and the intended balance between tree, crop, and forage production within the system. The four primary layout patterns commonly used in agroforestry design include linear, contour, Keyline, and savanna arrangements.

Linear plantings are often oriented toward the sun in an alley cropping format for even distribution of light to the tree and understory component. Linear plantings can form grids of parallel or offset trees. Linear plantings enable even access for machinery and other management requirements.

Plantings can be oriented to provide frost drainage (as is often the case in vineyards or sensitive species like tea camellia, kiwis, or olives). Linear plantings can also be considered “lanes.” These types of arrangements can be found where trees are planted along a road or trail or where hedgerows subdivide a field.

Systems laid out on **contour** will often be found on steep slopes to maximize water and nutrient catchment in tree rows or in situations where trees want to follow a natural drainage line to maximize water infiltration. Upland and riparian buffer systems are

often assembled in contour layouts with rows oriented along waterways and designed to capture water movement as it moves across the slope.

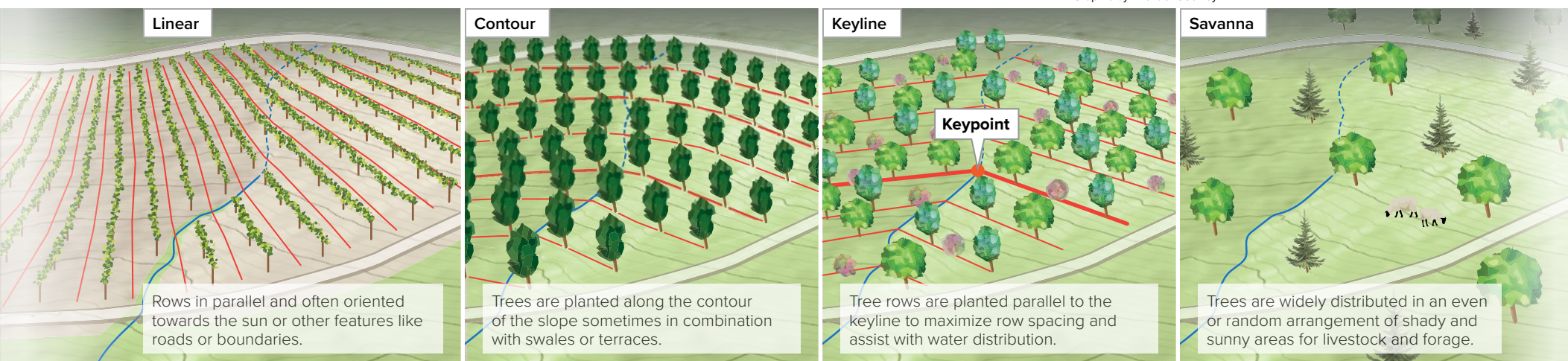
Keyline layouts occupy a middle ground between strict contour plantings and conventional linear rows. Like linear systems, tree rows remain parallel and evenly spaced, making them well suited to machinery access and organized farm operations. However, instead of following straight compass-oriented lines, Keyline rows are aligned parallel to a contour line established at the keypoint of a valley.

As these parallel lines extend across the landscape, they gradually drift off contour, running slightly downhill from the valley toward the ridge. This subtle pattern helps distribute water more evenly across the slope rather than allowing it to concentrate in valley bottoms.

Keyline layouts are often paired with subsoil ripping to further encourage water movement from valleys toward ridges, increasing infiltration and spreading moisture more evenly across the landscape. At the same time, the consistent row spacing improves ma-

Figure 5.4a. Tree layout patterns.

Graphic by Michael Godfrey



chinery movement and provides safer sidehill travel compared to strict contour layouts.

Savanna plantings are commonly used in tree intercropping and silvopasture systems where greater emphasis is placed on understory forage, crops, or livestock production, or where the goal is to emulate the open structure of natural savannas. Unlike dense forest-style plantings, savanna systems maintain wider spacing between trees, allowing more sunlight to reach the understory and supporting productive pasture or crop growth beneath the canopy.

Tree distribution within savanna systems may be irregular, mimicking the natural pattern of scattered individual trees and clustered groves found in native savanna woodlands, or arranged more systematically along contour or keyline patterns to improve water distribution, access, and management efficiency.

Other layout patterns include multistrata plantings and lanes. **Multistrata** plantings are often found in forest farming, riparian buffers, and forest garden layouts that include species arranged into multiple overlapping layers. **Lanes** follow existing landscape features such as streams, pathways, property boundaries, and access routes. They commonly take the form of hedgerows, treed avenues, contour strip plantings, and streamside forest buffers.

Tree spacing

Tree spacing strongly influences tree growth, crop and forage productivity, light availability, and long-term system function. Research in Oregon silvopasture systems has shown that excessive tree density is often the primary factor limiting tree growth, while spacing in oak systems also affects crown development, acorn production, and stand longevity.^[2,3] In agroforestry systems, spacing should account for solar access, shading, root interactions, machinery movement, crop timing, establishment costs, and management goals.^[4]

Tree density also shapes understory productivity. In general, approximately 40–60% light infiltration



Above: Apple trees arranged in alleys with spacing to allow for baling hay at Raising Cane Ranch.

Photo courtesy of Mitchel Davidovitz

is generally needed to maintain productive forage growth and healthy understory plant communities. Spacing further influences tree form, including crown size, trunk development, and rooting spread. While denser plantings can improve bole form on poor or windy sites, wider spacing combined with pruning can still produce high-quality timber while allowing room for silvopasture or intercropping systems beneath the canopy.

Orchard spacing depends on rootstock vigor, mature tree size, slope, and management system. In Pacific Northwest orchards, rows are ideally oriented north-south to maximize sunlight interception, with row spacing generally approximating mature tree height. Machinery access, turnaround space, irrigation infrastructure, and harvest efficiency must also be considered. As planting density increases, however, systems eventually encounter diminishing returns, where the cost of additional trees outweighs gains in productivity.

Tree distribution

The distribution of trees strongly influences the character and productivity of the understory. Widely spaced trees arranged in linear rows are commonly

used in alley cropping systems where sufficient sunlight is maintained for crops grown between tree rows. In silvopasture systems, trees may be distributed more openly as individual specimens or grouped in clusters to balance shade, forage production, and livestock shelter.

Evenly spaced trees maximize the distribution of light, root space, and forage production across the site, while clustered or row-based plantings concentrate shade and root influence in specific areas while leaving larger open pasture spaces between them. Clumped tree arrangements can also provide important shelter for livestock from wind, heat, and winter weather, functioning as “living barns” within the pasture.

Grouped tree patterns increase structural diversity within the landscape, creating a wider range of habitats for wildlife and opportunities for layered woody crop systems. These arrangements can support integrated canopy and understory plantings suited to forest gardens, riparian buffers, forest farming systems, and other multifunctional agroforestry designs.

Conclusion

Agroforestry design depends on the careful integration of long-lasting farm systems that shape how water, people, livestock, equipment, and vegetation move across the landscape. In the Pacific Northwest, where dry summers and increasingly variable water supplies make water a central design constraint, resilient farms must be planned to capture, store, distribute, and use water as efficiently as possible. Soil health, ponds, rainwater harvesting, irrigation systems, Keyline design, and water-conscious access routes all contribute to a farm's ability to remain productive through seasonal drought and changing climate conditions.

These mainframe systems are most effective when designed together rather than in isolation. Roads can function as access routes, firebreaks, and water-harvesting surfaces. Fences can support rotational grazing while protecting young trees and sensitive ecological areas. Tree layouts can improve water infiltration, create shade and shelter, support wildlife, and maintain productive understory crops or forage. Livestock watering systems, irrigation infrastructure, and tree protection strategies must likewise be coordinated with long-term management goals.

Ultimately, successful agroforestry design is not only about placing trees on a farm, but about arranging the whole farm so that each element supports the others. By responding to landform, water movement, soil conditions, farm operations, and ecological function, growers can create agroforestry systems that are productive, adaptable, and resilient over time. Thoughtful design at the outset reduces future conflicts, improves management efficiency, and lays the foundation for farms that can support both agricultural livelihoods and healthy landscapes.

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SYSTEM
SELECTION

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Photos courtesy of Mitchel Davidovitz

Once site conditions, farm goals, and mainframe systems have been identified, the next step is determining which agroforestry systems, species, and enterprises are best suited to the landscape. This process involves more than matching plants to climate and soils; it also requires consideration of ecological function, infrastructure, labor capacity, market opportunities, management intensity, and long-term farm objectives.

Agroforestry systems are rarely selected all at once or developed from a single objective. Rather, they emerge through a gradual process of observation, experimentation, organization, and evaluation. Multiple systems may ultimately be integrated across different ecological settings and management areas of the farm, each responding to distinct ecological conditions and production goals.

The following sections outline a process for identifying, organizing, evaluating, and refining potential agroforestry systems into a coherent and realistic farm plan. Considerations include ecological compatibility, management requirements, economic viability, long-term system development, and comparative evaluation tools that support informed decision-making. Together, these approaches help guide the selection of agroforestry systems that are both ecologically functional and operationally resilient within the broader context of the farm.

From site assessment to system selection

The site assessment process helps reveal the ecological opportunities, constraints, and management realities that shape agroforestry development on the farm. Climate, soils, hydrology, landform, vegetation, infrastructure, and farm goals all influence which agroforestry systems are likely to function successfully on a given site.

The next step is to translate this information into a practical framework for identifying and refining potential agroforestry enterprises. The assessment considerations outlined in **table 6.1** on the next page can help narrow potential opportunities by relating site conditions, management goals, and operational capacity to different agroforestry practices.

Agroforestry practices should also be evaluated for the unique benefits they provide to the farm ecosystem. On the following page, **table 6.2** can be used to evaluate how specific needs and constraints identified during the assessment process can be addressed by a given system.

These considerations provide a starting point for developing and evaluating systems that are ecologically appropriate, operationally realistic, and aligned with the long-term vision of the farm.

Table 6.1. Assessment considerations for system selection

	Alley cropping	Forest farming	Forest gardens	Riparian buffers	Silvopasture	Windbreaks/hedgerows
Climate	• Winter and/or summer microclimates	• Riparian climate favors cool/moist understory • Permanent forest cover is preferred for climate mitigation	• Urban heat island cooling	• Habitat and shade along waterways	• Shade for livestock and forest health • Winter shelter	• Winter and/or summer wind mitigation • Snow drifts • Odor mitigation
Regulations		• Land use requires permanent forest		• Riparian setbacks for forestry and agriculture	• Land use requires forest or agricultural income	
Landform	• 0-15% slope for machine operation • Installed tree rows on terraces up to 50% slopes	• Solar aspects promote specific crop microclimates	• Intensive plantings best maintained on relatively flat ground	• Floodplains	• All terrains, esp. where steep uplands prevent intensive cropping	• May be placed on sites prone to valley winds
Water	• Irrigation compatible when adding to an existing crop (i.e. not pivot)	• Irrigation supply for water-dependent crops • Lack of water lends itself to native forest species	• Graywater and/or rainwater	• Ample ground water reserves for established plantings	• Available water supply for establishing new trees on pasture • Established woodland requires little water besides for livestock	• Irrigation compatible when adding to an existing crop (i.e. not pivot) • Available water supply for establishing new trees/shrubs
Access	• Amenable to existing machinery widths and turnarounds	• Layout allows for management and water reticulation		• Machinery for adjacent crop is not impacted by use of area	• Layout allows for rotational grazing and water reticulation • Slope allows use of ATV to manage livestock	• Amenable to existing machinery widths and turnarounds
Vegetation	• Amenable to existing crops	• Expansion of existing vegetation • Suitable canopy openings		• Lack of streamside warrants forest new plantings	• Aquatic habitats	• Soil conservation
Animals	• Wildlife corridors	• Forest wildlife conservation priorities	• Urban biodiversity	• Aquatic habitats	• Domestic livestock welfare	• Pollinator/beneficial insect habitat • Wildlife corridors
Soils	• Soil conservation	• Compatibility of forest soils with desired crop • Soil condition limits annual cropping	• Soil condition limits annual cropping	• Soil conservation	• Soil supports rangeland but poor for agriculture	• Soil conservation
Infrastructure	• Existing infrastructure compatible or complementary to the future management system					

Brainstorming potential agroforestry systems

Once site conditions, farm goals, and mainframe systems have been assessed, the next step is to identify agroforestry systems, enterprises, and species that are well suited to the landscape.

This process should begin with a broad, exploratory approach, drawing from site observations, existing regional models, market opportunities, management goals, and species already adapted to the ecological conditions of the farm. In many cases, multiple systems may ultimately be integrated across different landforms and management areas on the farm.

At this stage, it is helpful to compile a broad list of potential practices, species, and enterprises without immediately narrowing or eliminating options.

Input from neighboring producers, technical service providers, researchers, consultants, family members, and other land managers may help reveal opportunities that would otherwise be overlooked.

This preliminary list serves as a starting point for identifying potential “best bets” for the site based on ecological suitability, management goals, production interests, and market opportunities.

Organizing and prioritizing opportunities

After generating a preliminary list of potential agroforestry “best bets,” it can be helpful to organize systems into broader categories that clarify relationships across the landscape, reveal patterns and priorities, and simplify the process of refining a final agroforestry plan. Grouping systems according to ecological conditions, management requirements, or long-term development patterns can help reveal compatible enterprises, identify infrastructure needs, and support phased implementation strategies.

Table 6.2. Categories of agroforestry practices in the United States

Practice	Primary benefits and uses
Alley cropping Trees or shrubs are planted in sets of single or multiple rows with agronomic crops, horticultural crops, or forages produced in the alleys between the trees that can also produce additional products.	• Produce annual and higher value but longer term crops. • Enhance microclimate conditions to improve crop or forage quality and quantity. • Reduce surface water runoff and erosion. • Improve soil quality by increasing utilization and cycling of nutrients. • Enhance habitat for wildlife and beneficial insects. • Decrease offsite movement of nutrients or chemicals.
Forest farming Existing or planted stands of trees or shrubs that are managed as an overstory with an understory of plants that are grown for a variety of products.	• Control wind erosion. • Protect wind-sensitive crops. • Enhance crop yields. • Reduce animal stress and mortality. • Serve as a barrier to dust, odor, and pesticide drift. • Conserve energy. • Manage snow dispersal to keep roads open or to harvest moisture.
Riparian forest buffers An area of trees, shrubs, and herbaceous vegetation established and managed adjacent to streams, lakes, ponds, and wetlands.	• Reduce nonpoint source pollution from adjacent land uses. • Stabilize streambanks. • Enhance aquatic and terrestrial habitats. • Increase carbon storage in plant biomass and soils. • Diversify income either through added plant production or recreational fees.
Silvopasture Trees combined with pasture and livestock production.	• Produce diversification of livestock and plant products in time and space. • Produce annual and higher value but longer term products. • Reduce nutrient loss.
Windbreaks and hedgerows Single or multiple rows of trees or shrubs that are established for environmental purposes; depending on the primary use, may be referred to as crop or field windbreak, livestock windbreak, living snow fence, farmstead windbreak, or hedgerow.	• Improve crop diversity by growing mixed but compatible crops having different heights in the same area. • Improve soil quality by increasing utilization and cycling of nutrients. • Increase carbon storage in plant biomass and soil.
Special applications Use of agroforestry technologies to help solve special concerns, such as disposal of animal wastes or filtering irrigation tailwater, while producing a short- or long-rotation woody crop.	• Treat municipal and agricultural wastes. • Manage stormwater. • Produce biofeedstock.

Source: Schoeneberger, M. M., & Bentrup, G. (2017). Agroforestry: enhancing resiliency in US agricultural landscapes under changing conditions. Gen. Tech. Report WO-96. Washington, DC: US Department of Agriculture, Forest Service, 96.

One useful approach is to organize systems according to **land units** or **landforms** across the property. Different parts of the landscape naturally lend themselves to different agroforestry practices based on slope, soils, moisture availability, solar exposure, and access. Riparian areas may be best suited to stream-side forest buffers and seasonal grazing systems, while deep alluvial soils may favor orchards or alley cropping. Rocky uplands, dry south-facing slopes, or shallow soils may be more appropriate for savanna systems, silvopasture, or drought-tolerant tree crops. Organizing systems according to the land unit reinforces the principle of placing the right system in the right place.

Systems can also be grouped according to **management intensity**. Some enterprises require frequent monitoring, irrigation, pruning, harvesting, or livestock movement, while others function with relatively low annual inputs once established. High-intensity systems such as orchards, nurseries, or market-oriented alley cropping may benefit from close proximity to roads, irrigation infrastructure, and central work areas. Lower-intensity systems such as timber plantings, riparian buffers, or extensive silvopasture may be better suited to more remote areas of the property. Organizing systems in this way can help align labor demands, infrastructure development, and long-term management capacity.

Agroforestry systems may also be grouped according to **succession stage** or **long-term development** over time. Many systems evolve substantially as trees mature and site conditions change. Early phases may emphasize annual crops, pasture establishment, or cover cropping between young trees.

Intermediate stages may support silvopasture, berry production, or mixed perennial systems, while mature systems may transition toward forest farming, timber production, or closed-canopy woodland conditions. Considering how systems develop over time helps create more adaptive and resilient farm plans while allowing for phased implementation and evolving management goals.

Ecological fit and system function

After organizing potential systems, the next step is evaluating whether they are ecologically compatible with the long-term conditions of the site. Even economically promising enterprises may fail if species are poorly matched to climate, soils, hydrology, disturbance regimes, or patterns of ecological succession. Careful consideration of ecological fit helps reduce long-term inputs, improve resilience, and support the development of stable and productive agroecosystems.

Key considerations include drought and shade tolerance, rooting depth, nutrient and water requirements, and the ability of species to tolerate seasonal flooding, poor drainage, heat, wind exposure, or fire risk. Functional characteristics may also influence system design. Nitrogen-fixing trees and shrubs can improve soil fertility, flowering species may support pollinators and beneficial insects, and diverse woody plantings can provide habitat, shelter, and movement corridors for wildlife. In integrated crop and livestock systems, compatibility with grazing behavior, browsing pressure, and animal health should also be assessed.

Ecological compatibility should be evaluated not only under current conditions but also in relation to how species interactions will change as the system matures. Increasing shade, expanding root systems, and greater competition for water and nutrients may alter which crops, forages, or understory species can persist. Anticipating canopy closure, root competition, and other long-term interactions helps ensure that the system remains functional and productive throughout its development.

Together, these considerations help determine whether a proposed agroforestry system can function ecologically on the site over the long term while supporting the broader goals of productivity, resilience, and ecosystem health.

Economic and management considerations

Even ecologically well-suited agroforestry systems may fail if they exceed the labor, infrastructure, or financial capacity of the farm. For this reason, potential systems should be evaluated according to how realistically they can be established, managed, harvested, processed, and marketed over time. A successful agroforestry enterprise must fit not only the ecology of the site, but also the operational realities of the farm.

Labor requirements and seasonal timing are particularly important considerations. Different enterprises demand varying levels of pruning, irrigation, harvesting, livestock movement, monitoring, and maintenance throughout the year. Some systems may create seasonal bottlenecks where multiple enterprises compete for labor during critical planting or harvest periods. Others may complement existing operations by distributing labor more evenly across the season. Management intensity should also be evaluated in relation to available labor, equipment, skill level, and long-term management goals.

Infrastructure requirements can significantly influence the feasibility and cost of an agroforestry system. Irrigation systems, fencing, livestock watering infrastructure, processing facilities, storage areas, roads, and equipment access may all be necessary for successful operation. In some cases, the cost of developing or maintaining infrastructure may outweigh the potential productivity of a proposed enterprise. Systems that align with existing infrastructure or can be developed incrementally may provide lower-risk pathways for implementation.

Market considerations are equally important when evaluating agroforestry opportunities. Local demand, product perishability, processing requirements, transportation costs, scalability, and opportunities for value-added production should all be considered before committing to a system. Diversified enterprises that combine multiple products or market streams

may improve economic resilience, particularly where climatic variability or market fluctuations create uncertainty.

Together, these considerations help determine whether a proposed agroforestry system can be realistically managed, supported, and sustained within the long-term ecological and economic context of the farm.

Evaluating and comparing agroforestry options

After ecological suitability, management requirements, infrastructure needs, and market considerations have been assessed, the remaining agroforestry options can be compared more directly. At this stage, the goal is no longer simply to generate possibilities, but to refine and prioritize systems according to their overall strengths, limitations, risks, and long-term viability within the broader context of the farm. Structured evaluation tools can help clarify tradeoffs between enterprises and support more informed decision-making.

SWOT analysis

One useful framework is the **SWOT analysis**, which evaluates the **Strengths, Weaknesses, Opportunities**, and **Threats** associated with a particular agroforestry system or enterprise. Strengths and weaknesses generally refer to internal characteristics of the system, such as existing infrastructure, labor capacity, ecological suitability, or management experience. Opportunities and threats typically relate to external factors including market trends, climatic risks, competition, regulatory constraints, or emerging consumer demand.

SWOT analysis can help identify systems that align well with both the resources of the farm and broader economic or environmental conditions. SWOT analysis can also help evaluate each agroforestry species or system option. For example, a tree species might have strengths such as fast growth or high quality timber, but weaknesses like high water needs.

A SWOT analysis can be carried out in seven steps:

- 1. Identify candidate species**
List the trees, shrubs, or understory crops you are considering for your agroforestry system.
- 2. Assess strengths**
Ask: What advantages does this plant bring?
- 3. Assess weaknesses**
Ask: What limitations might it have?
- 4. Evaluate opportunities**
Ask: What external conditions favor this plant?
- 5. Evaluate threats**
Ask: What external risks could limit success?
- 6. Compare across species**
Lay out SWOT summaries side by side. Look for plants whose strengths/opportunities align with your goals while keeping weaknesses and threats manageable.
- 7. Decide and prioritize**
Choose species that are most resilient and beneficial for your site. You may also combine species with complementary strengths to balance risks.

See **table 6.3** on the following page for an example of SWOT analysis applied to consideration of a silvopasture system.

Porter's Five Forces

Porter's Five Forces framework provides another method for evaluating the economic environment surrounding a potential enterprise. This approach considers factors such as market competition, buyer power, supplier dependence, barriers to market entry, and the availability of substitute products. While originally developed for business analysis, it can help agroforestry practitioners better understand the economic resilience and competitive pressures associated with different products or production systems.

Applied to **choosing plants for agroforestry**, this model helps evaluate whether a crop or tree species has a favorable market environment. For instance:

- A nut crop might face **low rivalry** (few producers) but **high buyer power** if only a few large distributors dominate the market.

- A medicinal plant could have strong **opportunities** if demand is rising and substitutes are limited.
- A timber species may face **high rivalry** and a **threat of substitutes** (other woods or composites), making it less attractive.

By analyzing plants through Porter's Five Forces, land managers can prioritize species that not only grow well on their land but also offer stronger and more resilient market positions. The following questions can be asked in analyzing the five forces:

- 1. Competitive rivalry**
 - How much competition exists in the market for a given product?
 - How many other producers are growing this plant locally or regionally?
 - Is the market crowded, or does it have room for new entrants?
- 2. Barriers to entering the market**
 - How easy is it for others to start producing and selling the same product?
 - Are there barriers (special knowledge, long time to maturity, certifications) that limit new competition?
- 3. Threat of substitutes**
 - Are there alternative crops or products consumers could buy instead?
 - Is this plant unique, or can buyers easily switch to another product?
- 4. Bargaining power of buyers**
 - How much influence do customers have over price and demand?
 - Do a few buyers (wholesalers, processors) control the market, or are there many customers?
 - Can buyers easily push down prices?
- 5. Bargaining power of suppliers**
 - How much control do suppliers (e.g., for seeds, equipment, processing) have over costs and availability?
 - Are seeds, seedlings, or inputs readily available and affordable?
 - Do suppliers have control over costs or access?

After filling out the list for each plant, compare the results. Plants with low competition, few substitutes, strong demand, and low supplier/buyer dominance usually offer the best long-term opportunity.

Additional comparative tools may also assist in narrowing and prioritizing options. Simple ranking systems, enterprise budgets, weighted scoring matrices,

Table 6.3. Sample SWOT Analysis

Practice: Silvopasture integrating fruit and nut trees with managed livestock grazing on pasture	
<i>Helpful</i>	<i>Harmful</i>
Strengths	Weaknesses
• Diversifies farm income through fruit production, livestock grazing, and potential value-added products • Produces multiple outputs from the same acreage, increasing land productivity • Provides shade and shelter to improve livestock welfare, reduce heat stress • Improves soil health through increased organic matter, deeper rooting systems, and enhanced nutrient cycling • Increases biodiversity; provides habitat for pollinators and beneficial insects • Reduces erosion and improves water infiltration and watershed function • Sequesters CO₂ and improves climate resilience • Creates opportunities for agritourism, educational programming, and direct-to-consumer marketing • Can increase long-term property value through establishment of permanent perennial crops • Enhances resilience by reducing dependence on a single enterprise	• Requires significant upfront investment in trees, fencing, irrigation, and tree protection • Fruit trees may take several years before generating meaningful income • Management is more complex than conventional pasture or orchard systems • Young trees are vulnerable to livestock damage and require protection • Harvesting and maintenance activities must be coordinated with grazing operations • Requires knowledge of both orchard management and livestock production • Irrigation is often necessary during establishment and dry summer periods • Disease and pest management can be more complicated in diversified systems • Tree maintenance, pruning, and harvest increase labor requirements • Cash flow may be limited during the establishment phase
Opportunities	Threats
• Growing consumer demand for locally produced fruit and regenerative agricultural products • Eligibility for conservation and agroforestry funding • Opportunities to market products under regenerative, climate-smart, or agroforestry branding • Potential for value-added enterprises such as cider, dried fruit, preserves, vinegar, and specialty products • Integration with sheep, poultry, or cattle can improve pasture utilization and reduce mowing costs • Permanent tree crops can provide long-term family and farm legacy benefits • Educational workshops, demonstration sites, and farm tours can generate additional revenue • Agroforestry systems may qualify for ecosystem service, carbon, or conservation incentive programs • Diversification improves farm profitability and resilience to market fluctuations • Expanding interest in local food systems creates new marketing opportunities	• Increasing summer drought and water limitations associated with climate change • Extreme weather events including heat waves, late frosts, windstorms, wildfire smoke, and ice events • Losses due to frost, disease, pests, or poor pollination • Fluctuating fruit markets and competition from larger commercial orchards • Wildlife damage from deer, elk, birds, rodents, and other animals • Diseases common in western Oregon, including fire blight, apple scab, cankers, and fungal pathogens • Labor shortages during critical pruning and harvest periods • Tree mortality during establishment due to drought, poor site selection, or grazing damage • Rising costs for labor, irrigation infrastructure, and agricultural inputs • Regulatory changes or market disruptions that affect fruit or livestock enterprises

or side-by-side comparisons of labor requirements, establishment costs, infrastructure needs, and ecological benefits can help reveal which systems best align with the long-term goals of the farm. In many cases, no single enterprise will excel in every category, and tradeoffs between profitability, resilience, ecological function, and management complexity will need to be balanced.

Ultimately, the purpose of these evaluation tools is not to identify a single “perfect” system, but to support thoughtful decision-making and help refine a diverse set of agroforestry opportunities into a cohesive, manageable, and resilient farm plan.

Revise and refine “Best Bets”

After evaluating potential systems through ecological assessment, management considerations, and comparative tools such as SWOT analysis or Porter’s Five Forces, the initial list of agroforestry “best bets” can be refined into a smaller group of enterprises with the strongest overall potential for the farm. This process involves balancing ecological suitability, labor capacity, infrastructure requirements, production goals, economic viability, and long-term management considerations in order to identify systems that are both practical and resilient.

At this stage, it is helpful to compare how well different systems align with the broader conditions and goals of the farm. Some enterprises may perform well ecologically but require infrastructure, labor, or technical expertise beyond the capacity of the operation. Others may fit naturally within existing management systems, complement current enterprises, or provide

multiple ecological and productive benefits simultaneously.

Considerations such as drought resilience, compatibility with livestock, establishment costs, access requirements, seasonal labor demands, and long-term maintenance needs should all be weighed together rather than evaluated independently.

Timing and system interactions are also important considerations during this stage. Harvest periods, livestock movement, irrigation demands, and maintenance requirements should be evaluated in relation to other farm activities to avoid creating unnecessary bottlenecks or management conflicts. Likewise, systems should be considered in terms of how they may evolve through time as trees mature, canopy conditions change, and management priorities shift. In many cases, phased implementation or small pilot projects can help reduce risk while allowing practical experience to guide future expansion.

Where existing vegetation or established plantings are present, inventory information can help estimate current and future production potential. For newly proposed systems, projected yields, infrastructure needs, and anticipated management demands can assist in determining appropriate planting scales and implementation strategies.

Ultimately, refining “best bets” is a process of narrowing a broad range of possibilities into a focused and integrated agroforestry plan that aligns with the ecological conditions, operational realities, and long-term vision of the farm.

Conclusion

Selecting appropriate agroforestry systems is an iterative process that balances ecological conditions, management capacity, infrastructure, economics, and long-term farm goals. Rather than identifying a single ideal system, the process involves narrowing a broad range of possibilities into a set of complementary enterprises that function together across the landscape and through time.

The evaluation and refinement process described in this chapter is intended to support thoughtful and adaptive decision-making. Agroforestry systems often evolve as site conditions, markets, management experience, and personal objectives change. Beginning with well-considered systems that align with the ecological realities and operational capacity of the farm can help create productive, resilient, and multifunctional landscapes capable of adapting over the long term.

SPECIES SELECTION

By Kidane Giday, PhD

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The trees and shrubs within agroforestry systems serve as the foundation for the enterprise. Different trees provide different products and benefits: some can be grown for timber, others for fruits, nuts, or even bioenergy. Trees also vary in their ability to capture carbon, support biodiversity and protect soils.

The right choice of species can lead to increased productivity, improved soil health, and ecological benefits. Additionally, because each tree species has specific requirements for soil type, rainfall and temperature, it is essential to match the right tree with the right environment/ecology, to achieve the intended benefit.

Selecting appropriate tree species for a farm can be a complex decision. Establishing trees is also expensive and time-consuming, and they occupy land for many years and take longer to produce marketable crops than other agricultural crops. However, the right species choice upfront will lead to greater ecological and economic benefits in the long run. The selection

of tree species is therefore a pivotal step in designing sustainable and effective agroforestry systems.

The following pages provide additional information on tree/shrub species selection for agroforestry practices, including the steps, criteria, considerations across practices, and a species selection evaluation matrix across production objectives. These resources are not exhaustive, but rather a starting point.

The species listed for a region may not be suited to all sites, and species not generally recommended for a given region may have appropriate applications on individual sites. Therefore, verification at each stage of the species selection process is recommended.

Plant growth and fruit yield depend on microclimatic factors such as number of chill hours and growing degree days, so it is important to match species with the microclimatic features of a site.

For known cultivars and varieties, suppliers often provide information on length of growing season, including chill hours and growing degree days required for successful production. However, these details are often not known for plants from unknown sources. When moving native plants or plants of unknown seed source across the landscape, such as from one woodland to another, two other factors come into play: latitude and altitude.



Photos courtesy of Tao Orion (left) and Mitchel Davidovitz (right)

While many non-native tree crops are now commonplace and appropriate for production in the Pacific Northwest, such as apples, pears, cherries, citrus, plums, figs, strawberries and grapes, there are risks to planting unfamiliar plants that have not been introduced before.

Predicting the future is always difficult, especially when it comes to living systems, but if a non-native plant has a risk of becoming invasive and presenting a future management problem, cultivation is discouraged. When deciding whether to plant native plants or introduced plants, both ecological and economic factors must be weighed. While native species are prioritized for ecological compatibility, adapted exotics can provide economic value.

So, what makes a tree appropriate for an agroforestry system? The answer is not always the same for any given situation, and will likely vary according to each landowner's specific interests and goals. That said, plant species and corresponding site layout, including configuration and density, can be designed to meet several objectives and hence species selection to fit such requirements is a very critical step.

Selecting trees and shrubs for your site

Depending on the practice selected, species selection considerations often include:

- Landowner goals
- Economic costs and benefits, including the marketability of various products derived from the species selected.
- Economic value and rate of growth (i.e. fast growing with low value?, slow growing with high value?)
- Species suitability to the site and environmental conditions, including soil, topography, water availability, and hardiness zone.
- Plant interactions and compatibility with other trees/shrubs/crops in the system (i.e. competition for moisture or nutrients through root interactions, or shade characteristics throughout different growth cycles and time periods.)
- Management implications (timing of labor and harvest cycles, equipment available, etc.), planting configurations and companion crops consideration. Always consider the products you wish to produce, any conservation or wildlife benefits desired and on-farm equipment you might use.

Usually agroforestry species selection criteria fall into five main categories: goals and desired products of landowners, site and environmental conditions, plant species characteristics, plant interactions and management in the system, and stock availability.

A successful selection process results in a resilient system that can provide multiple benefits over the long term. The following species selection criteria are among the common basic steps one has to go through with regard to agroforestry species evaluation for an intended objective and site.

Desired characteristics of species for different agroforestry practices and landowner objectives

Agroforestry systems combine trees, shrubs, crops, and/or livestock to fulfill landowner goals. Across these systems specific species are weighted in terms

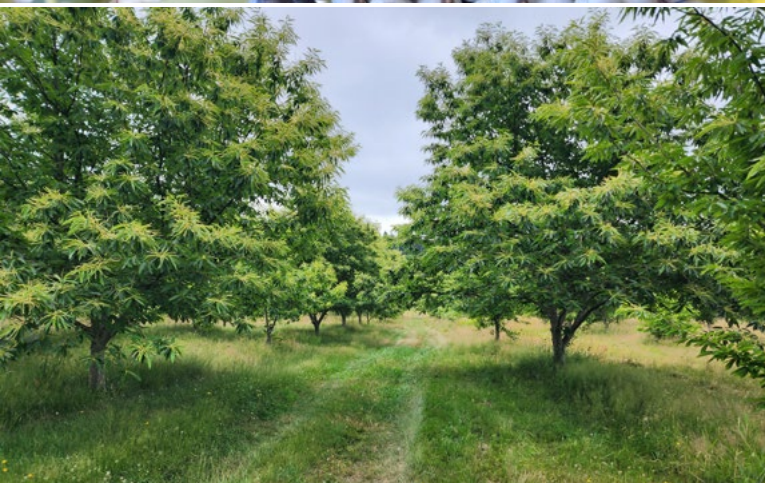
Table 7.1. Considerations for species selection across sustainability dimensions

Agroforestry practice	Ecological	Economic	Social
Alley cropping Trees or shrubs are planted in rows with crops cultivated in the alleys between them. Pair trees e.g., black walnut, hazelnut, red alder with crops like berries or vegetables	Fast-growing, nitrogen-fixing trees; shade-tolerant crops	High-value timber or fruit trees, can diversify income; align market access and growth rates	Species with cultural significance or multipurpose uses (e.g., fodder, fuel wood)
Forest farming Shade-tolerant crops or non-timber products (e.g. mushrooms, ginseng) under canopy (e.g. bigleaf maple [<i>Acer macrophyllum</i>], black walnut [<i>Juglans nigra</i>], or red alder [<i>Alnus rubra</i>] with mushrooms), evergreen huckleberry (<i>Vaccinium ovatum</i>)	Tree species balancing shade provision with light availability, and preferred understory crops	High value products, consider access to niche markets, Nuts/ veneer, berries; florals	Traditional knowledge of forest products, less labor-intensive harvesting
Riparian buffers Trees and shrubs planted along waterways to reduce erosion and filter runoff in combination, e.g. willow (<i>Salix nigra</i>), elderberry (<i>Sambucus canadensis</i>), Pacific crabapple (<i>Malus fusca</i>), switchgrass (<i>Panicum virgatum</i>), Oregon grape (<i>Mahonia aquifolium</i>)	Species tolerate wet soils, fast rooting, and stabilize banks	Non-timber products, crafts/ florals; coppice, fruit for cider/wildlife, berries/medicinals	Native or culturally significant species
Silvopasture Trees are integrated with pasture for livestock grazing (e.g. Douglas-fir, bigleaf maple) with pasture for livestock and shade.	Trees that are palatable, nutritious, provide shade, and resistant to grazing	Timber or fruit trees	Fodder-producing trees support landowners
Windbreaks and hedgerows Rows of trees or shrubs protect crops, livestock, or soil from wind erosion using fast-growing trees (e.g. hybrid poplar), hazelnut (<i>Corylus spp.</i>) or shrubs (e.g., serviceberry).	Tall, dense, drought-tolerant species are critical in dry regions	Reduce wind speed, desiccation, coppices; thrives in clay-rich and acidic soils	Incorporating multipurpose species to maximize returns

of their ability to provide the desired products and services and also to fit into the resource base and requirements of the production site.

Table 7.1 above summarizes key species, their characteristics, and their alignment with agroforestry practices and landowner goals, providing a framework for designing sustainable and productive systems. Based on these criteria, species can easily be selected that are fit to the site conditions/regions, fulfilling the ecological, economic, and social benefits desired by the landowner.

Table 7.2 is a comprehensive agroforestry species selection matrix. It highlights all important species selection criteria, from setting landowner objective to assessing the site, system type, all the benefits expected of a species in choice across evaluation matrix, some example species and resources/tools to consult.



1. Goals and desired products

The process of selecting the right trees and shrubs for an agroforestry system begins with the producer's goals. The selected species should be capable of providing the products and services desired by the landowner. Is the focus on production, an ecosystem service such as improving water quality, conserving habitat, or modifying wind speeds, or a combination of several goals? What species and varieties can meet those goals? "I want to grow chestnuts or elderberries because I think there is a good market for them," is just the beginning.

- **Production and profitability:** When generating income from trees, it is important to identify the products to be marketed, such as timber, nuts, fruits, or fodder. Selecting species that yield multiple products can increase income diversification and provide greater flexibility. Priority should be given to high-value tree species with established markets, emerging markets with strong growth potential, or newer markets that may offer profitable opportunities.
- **Ecosystem services:** If improving the environment or providing ecosystem services is a goal, consider prioritizing species that can provide ecological functions like attracting pollinators and beneficial insects, enhancing soil fertility through nitrogen-fixation, preventing erosion, or improving soil structure with varying root depths.
- **Conservation:** To promote conservation, focus on species that preserve native genetics, provide food and habitat for wildlife, and build genetic resilience to climate change.

2. Site and environmental conditions

Getting to know your site and selecting the trees that prefer those conditions is critical to the success of your efforts. Trees planted in their preferred environment are more resilient, longer lived, and faster growing.

- **Climate:** Evaluate both cold and heat hardiness as described below:
 - **USDA Hardiness Zones** divide the country into 11 zones based on the average minimum winter temperature. Zone 1 is the coldest and zone 11 is the hottest. The average minimum temperature varies about 10°F between zones. State-specific maps are also available at USDA's [Plant Hardiness Zone Map](#).
 - **Tolerance to site extremes:** Become familiar with potential extreme conditions on your site. Many regions experience regular drought or are prone to periodic flooding. Some sites are exposed to heavy winds and winter ice storms. Select trees that can withstand these conditions if they are a threat in your area. Consider how climate variability, such as extreme heat, drought, or late frosts, could impact species performance over its lifetime. Refer to the [American Horticultural Society Heat Zone Map](#).
- **Aspect, slope, and drainage:** These factors influence sun exposure, soil temperature, and water retention. Consider the placement of species within the landscape to protect them from environmental stressors. For instance, in south and west aspects where it is hotter and drier with high sun exposure, sun loving and drought tolerant species would be best suited; while for steep slopes, deeply rooted species would be beneficial for stability and erosion control.
- **Soil:** Choose plants adapted to soils' type, texture, and pH. Consider available nutrients and soil compaction.
- **Existing vegetation:** Assess what species already exist on the site. Choosing native plants can reduce input needs and improve adaptation. Also, observe weedy pioneer species for clues about site conditions.

Refer to **Chapter 4: Site Assessment** to provide a detailed account on climate, hardiness zones, chilling hours and other site conditions that should be taken into account in on site-species matching.

Photos courtesy of Abel Kloster (top), Mitchel Davidovitz (middle), and Tao Orion (bottom)

3. Plant species characteristics

- **Growth habit and tolerance:** Consider canopy density, light requirements, growth rate, and size.
- **Management:** Select species that respond well to regular management, such as pruning, and can be managed with existing or accessible equipment.
- **Resilience:** Choose species that are resistant to common local pests and diseases. For long-term viability, select species that are adaptable and resilient to future climate shifts.
- **Genetic diversity:** Planting different varieties or using seeds from different sources (seed lots) can increase genetic diversity and make the system more resilient to pests, diseases, and extreme weather.

Species selection: Provenance

Provenance refers to the geographic origin or source location where a plant or its seeds were collected or grown. It indicates the specific environmental conditions—such as climate, soil type, altitude, and rainfall—that shaped the plant's genetic traits.

Provenance matters because it affects a plant's adaptability, growth, and suitability for a specific site or ecosystem. Factors include:

- **Adaptability to local conditions:** Plants from a specific provenance are genetically tuned to thrive in similar climates and soils.
- **Ecological compatibility:** Native plants from local provenances support local ecosystems better, providing appropriate food and habitat for pollinators, birds, and other wildlife.
- **Resilience to stress:** Plants adapted to local conditions are more resistant to drought, pests, and diseases common to that area.
- **Climate change considerations:** Provenance selection can anticipate shifting climates. Some experts suggest sourcing plants from slightly warmer or drier provenances to prepare for future conditions, though this must be balanced with maintaining genetic diversity.
- **Avoiding invasiveness:** Non-local provenances can become invasive or hybridize with local populations, altering ecosystems, caution is necessary.

4. Plant interactions and management

Managing species interactions involves optimizing the relationships between trees, crops, livestock, and other organisms to enhance productivity, biodiversity, and sustainability. There are key strategies and considerations to be taken to balance competition, facilitation, and synergy.

Species selection and compatibility

- **Complementary traits:** Choose species with complementary growth habits, resource needs, and life cycles. For example, pair deep-rooted trees (e.g., walnut) with shallow-rooted crops (e.g., annual crops) to minimize competition for water and nutrients.
- **Functional diversity:** Incorporate species diversifying functionality, like nitrogen-fixing trees e.g., red alder (*Alnus rubra*) to enhance soil fertility for crops.

Species selection considerations

Select deeply rooted trees with open or prunable canopies. Pair with shallow-rooted, shade-tolerant understory crops (e.g. huckleberry [*Vaccinium membranaceum*], Oregon grape). Start with sun-loving crops, later shift to shade-tolerant ones as canopy closes. Use vertical layers: tall trees (e.g., bigleaf maple) over mid-layer shrubs (e.g., hazelnut) and low shade plants.

- **Livestock considerations:** Choose trees that are tolerant of livestock impacts and are not poisonous. Consider fencing to protect young trees.

Design and management considerations

Use alley cropping, wide rows, and planned spacing to reduce shading. Design clear vertical strata from the start. Prune trees regularly for light. In dry areas, add root barriers or trench to limit root spread. Adjust crops as shade increases to maintain productivity with minimal competition.

Practical tips

- Check [seed zone maps](#) or consult local nurseries for provenance data.
- Source locally when possible; prioritize plants within a 100- to 200-mile radius, depending on species. Rule of thumb: “don’t move a plant more than 75 to 100 miles north or south” and “don’t move it more than 1,000 feet in elevation.
- For climate resilience, consider “assisted migration” cautiously, using plants from slightly different but compatible provenances.

5. Species selection based on availability

Ensure planting material (seeds, seedlings, and cuttings) is accessible and of good quality. Source seedlings from reputable nurseries to ensure healthy, disease-free stock, those with ease of propagating, availability of improved cultivars, and dependable supply chains.

USDA Seedlot Selection Tool

The [Seedlot Selection Tool](#) helps foresters, landowners, and land managers to consider climate change when planning reforestation and afforestation projects. This online tool maps climate variables that are important to tree growth, reproduction, and survival.

Forest landowners and natural resource managers can use this tool to explore options for responding to climate change by determining where seeds or seedlings can be sourced so that they are suited to current and future climates.

The Seedlot Selection Tool matches seedlots (seedlings from a known area) and planting sites by mapping climate variables such as temperature and precipitation within a range that is suitable to the tree. The tool has an automatic option to choose climate variables important to tree growth and survival. It also allows users to choose climate variables based on current or future climate change scenarios.

They can then apply constraints based on their local knowledge of the site, plant material, management goals, climate change assumptions, and risk tolerance in order to select species that fit those criteria.

The tool provides both basic and silviculturists' guides making every step well described and ease of use. The basic guide provides information about the features, functionality, and internal calculations of the tool while the Silviculturists' Guide demonstrates how to use the tool for silviculturists working in the Pacific Northwest.

Table 7.2. Agroforestry species selection matrix with some examples and resources

Criteria	Evaluation metrics	Example species	Resources/tools
Goals and objectives	Determine primary purpose (e.g. income, restoration, food, and feed)		Landowner needs and circumstances
Site condition To match species to local climate, soil, and topography	- Climate: temperature range, frost risk, drainage, fertility - Topography: slope, aspect, elevation	Douglas-fir (<i>Pseudotsuga menziesii</i>) acidic well-drained soils, shade, windbreak Red alder (<i>Alnus rubra</i>) fixes nitrogen, thrives in nutrient-poor, wet soils Bigleaf maple (<i>Acer macrophyllum</i>): moist, fertile soils for forest farming Huckleberry (<i>Vaccinium membranaceum</i>): shaded, acidic, well-drained soils	- UC Davis SoilWeb for soils - PRISM Climate Data for Pacific Northwest weather - Local extension services.
Agroforestry system type Align species with the intended system (e.g., silvopasture, alley cropping, etc)	- Compatibility with system goals (e.g., timber, fodder, shade, crops) - Canopy/root structure for layering or livestock integration	- Silvopasture: white oak (<i>Quercus garryana</i>) for shade, forage grasses; red alder (<i>Alnus rubra</i>) combined with pastures to fix nitrogen in rotational grazing - Alley cropping: hazelnut and native wildflower seed. Enhances soil health, attracts beneficial insects, and provides a diverse income stream - Forest farming: Western red cedar (<i>Thuja plicata</i>) with shade-tolerant herbs (e.g., nettles); shiitake mushrooms cultivated under hardwoods like alder or maple	- USDA Plants Database - Agroforestry Species Switchboard - Indigenous knowledge resources
Ecological benefits Enhance biodiversity, soil health, and ecosystem services	- Nitrogen fixation, soil stabilization, carbon sequestration - Pollinator support, wildlife habitat - Water retention, erosion control	Red alder fixes nitrogen and improves soil fertility Salal (<i>Gaultheria shallon</i>): understory shrub, supports pollinators Willow (<i>Salix spp.</i>): riparian buffers, erosion control Elderberry (<i>Sambucus nigra/canadensis</i>): stabilizing banks, aides salmon habitats Hazelnut flowers support pollinators; shiitake enhances forest fungal networks	
Economic viability Ensure market demand and profitability for products	- Marketable products (timber, fruit, non-timber forest products [NTFPs]) - Growth rate and yield potential - Cost of establishment/maintenance	Hazelnut (<i>Corylus avellana</i>) is a high-demand crop suitable for alley cropping Truffle-inoculated trees (e.g., Douglas-fir): high-value NTFP Black walnut (<i>Juglans nigra</i>): timber and nuts Shiitake mushrooms generate income from forest farming Elderberry berries for jams and medicine in emerging markets	- Local market reports (e.g., Oregon Hazelnut Board) - NRCS cost-share programs - Economic analysis tools (e.g. Farm Service Agency)
Social/cultural value Incorporate community needs, Indigenous knowledge, and cultural preferences	- Alignment with local traditions and Indigenous knowledge - Community acceptance, food/ medicinal uses - Aesthetic or recreational value	Camas (<i>Camassia quamash</i>): Indigenous food, supports cultural restoration Huckleberry (<i>Vaccinium spp.</i>): food source, cultural significance Western yew (<i>Taxus brevifolia</i>): medicinal (taxol), cultural uses Elderberry holds medicinal value in local and Indigenous cultures Black walnut features in artisan crafts and woodworking heritage	
Management compatibility Species resilience to pruning, grazing, or other management practices	- Ability to withstand lopping, coppicing, or grazing - Growth rate post-management - Low competition with crops/ livestock	Black locust (<i>Robinia pseudoacacia</i>) coppices well and fixes nitrogen. Roemer's fescue (<i>Festuca roemer</i>) is a grazing-tolerant, perennial bunch grass. Serviceberry (<i>Amelanchier alnifolia</i>) is tolerant of pruning and fruit is edible. Black walnuts (<i>Juglans nigra</i>), suited in deep fertile soil with ample moisture and protection from frost. Needs immune companions to avoid its allelopathic nature	
Climate resilience Adaptability to changing climate (e.g., drought, temperature swings)	- Tolerance to extreme weather - Projected range shifts under climate models - Genetic diversity	Oregon white oak: drought-tolerant, suited to warmer Pacific Northwest climates Elderberry (<i>Sambucus spp.</i>): resilient to variable conditions, edible Red alder tolerate flooding and wetter winters Hazelnut windbreaks protect against summer wind	
Biodiversity contribution Promote diverse species interactions and ecosystem resilience	- Support for pollinators, birds, or beneficial insects - Functional group diversity (e.g., canopy, understory, groundcover). - Native species preference	Snowberry (<i>Symphoricarpos albus</i>): wildlife habitat, native forage Indian plum (<i>Oemleria cerasiformis</i>): early season nectar source Western hemlock (<i>Tsuga heterophylla</i>): shade tolerant, canopy structure Red alder increases soil microbes and insect diversity Bigleaf maple supports cavity dwelling wildlife and pollinators	

Agroforestry species selection process matrix

The previous page contains a comprehensive agroforestry species selection matrix with species selection criteria, evaluation matrix, and some example species for each group.

This matrix to assist in filtering species based on site conditions, system type, and desired outcomes. Species evaluation will vary based on landowner's objectives and specifics they want to achieve.

Grasses and herbaceous plants in agroforestry

Grasses and herbaceous plants play a vital role in agroforestry systems, contributing to soil health, biodiversity, erosion control, and livestock support while complementing trees and shrubs. Their provenance—geographic origin—remains critical for ensuring adaptability and effectiveness.

Contributions of grasses and herbaceous plants in agroforestry system include:

- **Soil health:** Nitrogen-fixing legumes (e.g., clover, alfalfa) enrich soils, benefiting crops and trees. Deep-rooted grasses like switchgrass improve soil structure.
- **Erosion control:** Grasses like tall fescue or perennial ryegrass stabilize slopes, critical in Oregon's hilly and riparian areas.
- **Fodder production:** Grasses (e.g., orchardgrass) and legumes (e.g., white clover) support livestock in silvopastoral systems.
- **Biodiversity and pollinators:** Native wildflowers and grasses attract pollinators, enhancing fruit and nut tree yields (e.g., hazelnuts, a key Oregon crop).
- **Weed suppression:** Cover crops like crimson clover suppress weeds, reducing herbicide use in alley cropping.

Table 7.3. Grasses and herbaceous species for agroforestry practices and traits

Species	Forage quality	Shade tolerance	Native or introduced	Ease of establishment	Best use in agroforestry
Red clover <i>Trifolium pratense</i>	high	moderate	native / introduced	easy	silvopasture, alley cropping (hazelnut alleys)
Orchardgrass <i>Dactylis glomerata</i>	excellent	high	introduced	moderate	silvopasture (ideal under walnut)
Tall fescue <i>Festuca arundinacea</i>	good	moderate	introduced	easy	riparian buffers, silvopasture
Yarrow <i>Achillea millefolium</i>	moderate	moderate	native	easy	alley cropping, windbreaks, pollinator support
Camas <i>Camassia quamash</i>	low	moderate	native	moderate	riparian buffers
Bluebunch wheatgrass <i>Pseudoroegneria spicata</i>	moderate	low	native	moderate	silvopasture, windbreaks
Alfalfa <i>Medicago sativa</i>	excellent	low	introduced	easy	alley cropping, silvopasture
Idaho fescue <i>Festuca idahoensis</i>	moderate	low to moderate	native	moderate	windbreaks, silvopasture
Sulfur-flower buckwheat <i>Eriogonum umbellatum</i>	low	low	native	easy	alley cropping, windbreaks, pollinator support
Showy milkweed <i>Asclepias speciosa</i>	low	low	native	moderate	windbreaks, pollinator support

What makes a forage appropriate?

The answer will likely vary according to each landowner's specific interest and goals. That said, many trees and shrubs can be planted in configurations or densities that will also enhance the production of select forages and/or grasses. In fact, the Center for Agroforestry has researched and identified many cool season grasses and legumes that produce better or the same under 50% shade as compared to full sun.

When you decide on the appropriate forage for your agroforestry practice, you should then seek out specific information on how to manage or establish that specific forage species. Some considerations that will have a significant influence on the success of the forage/grass of choice include: soil pH, time of seeding, use of companion or nurse crops, use of herbicides

to control undesirable or competing species, seeding method (broadcast vs. drilling), seeding rates, need for inoculation, seed bed preparation, and soil fertility.

When selecting a forage species, consider compatibility with the site. The selected species should be capable of providing the products and services desired by the landowner. Depending on the agroforestry practice selected, other forage/grass considerations may include: level of shade tolerance, season of production, i.e. warm vs. cool season, productivity capacity for the site, i.e. drought-tolerance vs. capability to grow on a wet site, compatibility with end use, i.e. is the forage for livestock or is the grass intended for erosion control?, and existing vegetation, i.e. can a natural forage/grass stand be enhanced?

Selecting animals for agroforestry

Selecting animals for agroforestry involves choosing species that complement the integration of grasses, herbaceous plants, and trees while aligning with the system's goals. Animals in agroforestry must be suited to the local environment, compatible with selected plants, and manageable within the diverse climates.

Below are key considerations to selecting animals for agroforestry, considering their compatibility with forage, shade tolerance, native/introduced plants, and ease of establishment.

- **Compatibility with forage:** Animals must thrive on available plants and tolerate their nutritional profiles.
- **Shade tolerance:** Animals must adapt to partial shade, esp. in silvopasture systems with dense tree cover.
- **Impact on plants and soil:** Select animals that minimize damage to native and introduced plants and contribute to soil health (e.g., via manure or light grazing).
- **Ease of management:** Choose species/breeds suited to your climate, terrain, and farm resources, with low maintenance needs and resilience to local conditions.
- **Ecological/economic goals:** Animals should support biodiversity, pest control, or product diversity (e.g., meat, milk, wool) while aligning with market demands
- **Management practices:**
 - **Rotational grazing:** Prevents overgrazing of native plants (e.g., camas, Idaho fescue) and maintains pasture health.
 - **Fencing:** Essential for goats and sheep to protect trees and sensitive areas.
 - **Shelter:** Provide shade structures or use trees for poultry and small ruminants.
- **Monitoring:** Regularly assess plant health and animal impact on native vs. introduced species to ensure balance.

Summary

Species selection in agroforestry should be guided by landowner goals, environmental conditions, plant characteristics, management considerations, and stock availability.

Important factors include the intended products or ecosystem services, site suitability, compatibility with crops or livestock, resilience to pests and climate stress, and the availability of quality planting material. Ecological considerations including biodiversity, soil improvement, and avoiding invasive species should also inform selection decisions.

The species selection matrices and evaluation tables can be used to compare species traits, ecological functions, management requirements, climate adaptability, and economic opportunities across different agroforestry practices. Local expertise and regional resources can help verify that selected species are appropriate for specific site conditions and management objectives.

Careful species selection ultimately supports the development of productive, resilient, and sustainable agroforestry systems over the long term.

Additional resources

- USDA NRCS Plant Database: <http://www.plants.usda.gov/>
- Plant Resource Guide: Materials and Management, Center for Agroforestry, University of Missouri. (free download at www.centerforagroforestry.org)
- Agroforestry: 5 practices for adding trees to your farm or ranch in Oregon, OSU Extension Service. <https://extension.oregonstate.edu/catalog/em-8988-agroforestry-5-practices-adding-trees-your-farm-or-ranch-oregon>
- Silvopasture: An Agroforestry Practice, OSU Extension Service. <https://extension.oregonstate.edu/catalog/em-8989-silvopasture-agroforestry-practice>
- Agroforestry: A Land Use Integration System, OSU Extension Service. <https://extension.oregonstate.edu/sites/extd8/files/documents/em8988.pdf>
- Design and application of silvopasture in Washington state. https://www.researchgate.net/publication/373978846_Design_and_application_of_silvopasture_in_washington_state
- Grow Native: <http://www.grownative.org/>
- Native Plant Information: <https://grownative.org/native-plant-database/>
- Forage Production Under Agroforestry Systems, College of Agricultural Sciences, Oregon State University. <https://smallfarms.oregonstate.edu/smallfarms/forage-production-under-agroforestry-systems>
- Silvics of North American Trees: Silvics Manual Volume 1-Conifers and Volume 2-Hardwoods, US Forest Service. https://www.srs.fs.usda.gov/pubs/misc/ag_654/table_of_contents.htm

PART

IV

CHAPTERS

- 8 ALLEY CROPPING
- 9 FOREST FARMING
- 10 FOREST GARDENS
- 11 RIPARIAN FOREST BUFFERS
- 12 SILVOPASTURE
- 13 WINDBREAKS & HEDGEROWS

AGROFORESTRY PRACTICES



Part IV of this handbook provides design guidance for each of the six major agroforestry practices. After completing the personal and land assessment (Part II) and settling on the appropriate system and species given your context (Part III), you are ready to plan the details of your agroforestry system!

Navigate this section according to the type of practice or practices appropriate to your site. Or read the whole chapter to get inspiration for the wide potential of agroforestry in the region. Each chapter is followed by a case study. Each case study highlights a farm and is intended to ground the reader in a real-world example of the practices described throughout this chapter.

ALLEY CROPPING

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Definition

Alley cropping is an agroforestry practice in which rows of trees or shrubs are planted at wide spacings, creating alleys between them where additional agricultural, horticultural, or forage crops are grown.

Author Note: This chapter is based in part on original narrative developed by Dusty Walter, Shibu Jose, and Diomy Zamora for the University of Missouri and used with permission. The chapter has been revised, expanded, and updated by Carrie Brausieck and Jared Busen for this publication.

Alley cropping systems offer a unique opportunity to grow wood, nuts, or fruit while simultaneously generating an annual income from companion crops. This method of intercropping trees not only provides diverse products but also significantly enhances natural resource conservation on the farm.

Alley cropping systems often use valuable hardwood species, nut trees, and fruit trees, as well as shrubs that produce berries or materials for cuttings. While these are common choices, many other tree, shrub, and crop combinations exist.

Although alley cropping may lead to a slight decrease in the yield of individual crops or trees compared to a monoculture, the combined value of all products is typically greater. This concept is measured by the **Land Equivalent Ratio (LER)**, which shows how much more efficient this mixed-use system is. Ultimately, alley cropping boosts land-use efficiency and offers significant environmental benefits.

By combining short-term cash flow from annual crops with medium- to long-term products from woody components, alley cropping diversifies a farm's enterprises. In addition to potential yields of nuts, berries, and fruits, well-managed timber can also serve as a valuable long-term investment.

Above: Raising Cane Ranch in Snohomish, Washington, where hay is grown in between rows of cider apple trees in an alley cropping system.

Photo courtesy of Mitchel Davidovitz

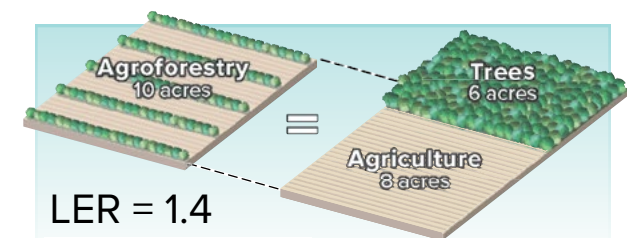


Figure 8.1. Land Equivalent Ratio

Alley cropping functions

Alley cropping impacts landscapes through numerous mechanisms including water management, nutrient cycling, soil quality, microclimate modification and pest management.

Alley cropping impacts **water management** by altering the hydrologic cycle, improving water management. The tree and crop alleys limit surface runoff and increase water infiltration into the soil. More complex and extensive root systems allow water to be filtered and used more thoroughly throughout the system.

These systems also have a significant impact on **nutrient cycling** and **soil quality** by allowing deeply rooted trees to access nutrients from lower soil layers and return them to the surface through leaf litter. The use of nitrogen-fixing plants further enriches the soil by adding valuable nitrogen. Beyond nutrient benefits, the extensive and complex root systems of trees and shrubs enhance soil biology by increasing macro and microorganisms. This, combined with a reduction in soil erosion from both wind and water, collectively helps to maintain and improve overall soil health.

Alley cropping also **modifies the microclimate** on the farm. The trees reduce wind velocity and provide shade, which in turn lowers air temperatures and decreases the rate of evapotranspiration from the crops and soil. The added protection from trees allows for the cultivation of more sensitive crops that might not otherwise thrive. Additionally, the tree canopy intercepts rainfall and can capture moisture from fog, adding extra water to the site.

Pest management can be strengthened through the structural diversity in the landscape developed by the intentional association of trees and crops. Alley cropping creates habitat to build up biodiversity and associated populations of natural enemies of pest insects, diseases, or weed pests and can interrupt pest cycles.

Benefits and challenges

Benefits

Well designed and managed alley cropping systems may offer numerous benefits for farms and ecosystems. As an integrated farming system both productivity and ecological resilience benefits can be achieved.

Such benefits include:

- diversified farm income/enterprise by layering in additional crops
- reduced soil erosion from wind and water with large tree and shrub root systems
- improved soil health metrics through increased organic matter input
- improved water quality
- microclimate protection from trees—reduced evapotranspiration, protection from wind
- enhanced wildlife and pollinators through more diverse plant communities
- improved aesthetics
- increased carbon sequestration through trees
- increased water use efficiency and drought tolerance

Similar to riparian forest buffers and windbreaks, alley cropping offers multiple environmental benefits. These systems can intercept and filter sediments, nutrients, and other pollutants, much like buffers along a stream. The practice also enhances wildlife habitat, providing a reliable source of food, cover, nesting sites, and safe travel lanes for a variety of species.

Not all of these functions may exist with each application of alley cropping. The function is dependent upon the way the plant components are integrated in the design process. Additional research is required to understand how different combinations of trees/shrubs/herbaceous plants interact with each other.

Challenges

Alley cropping systems present several challenges that can make them more complex to manage than traditional farming systems. The design of an alley cropping system should be carefully planned to address challenges to include:

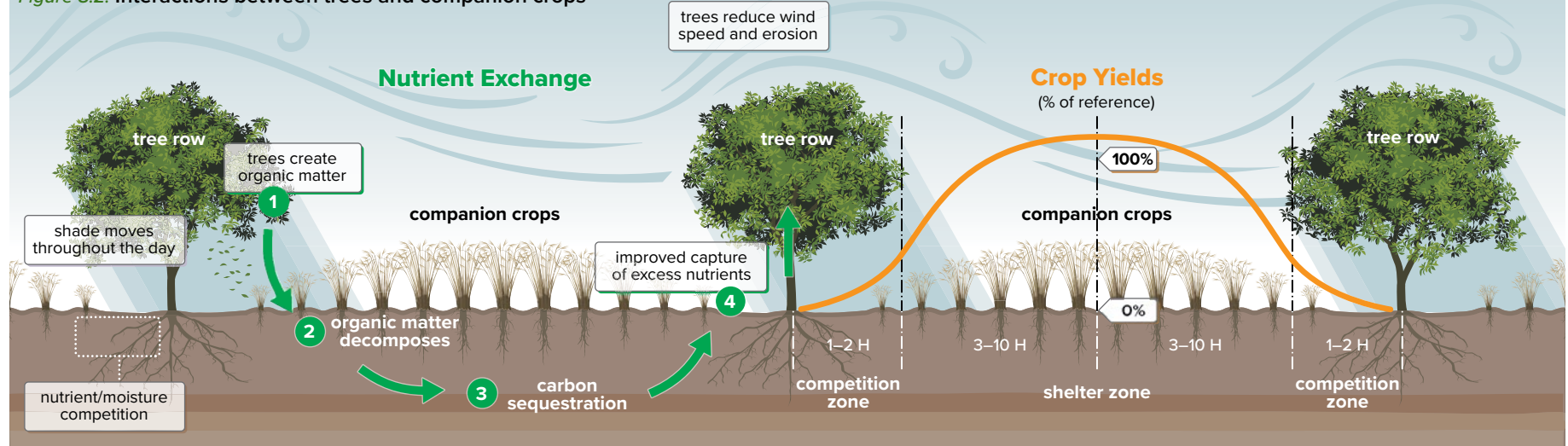
- more intensive management required
- land removed from annual crop production and trees may not provide a financial return for several years
- marketing infrastructure required for forest products that may not be presently established
- trees may be an obstacle to crop cultivation if not carefully planned and managed
- trees may compete with crops for light, moisture and nutrients
- companion crops may compete with trees for moisture and nutrients
- herbicide drift from crops may damage trees

Special assessment considerations

In an alley cropping system, tree and/or shrub rows are placed at intervals across the crop field, either on contour or perhaps perpendicular to prevailing winds. Several factors are used to determine the interval between rows of trees or shrubs including slope length, field width, crop light requirements and equipment width.

Each alley cropping practice can be uniquely designed to reflect landowner needs and site potential. The objectives of the land manager will determine the products to be harvested from the alley cropping practice. These objectives also determine arrangement of trees/ shrubs and crops and the management practices needed to obtain those products.

Figure 8.2. Interactions between trees and companion crops



Adapted from MacFarland, Kate (2017) *Alley Cropping: An Agroforestry Practice* (Agroforestry Notes). Lincoln, Neb.: National Agroforestry Center.

Alley cropping practices are highly diverse and range from simple to complex. Plantings can consist of a single tree species or a number of species. Similarly, single tree rows or multiple rows may be used. There are several key factors to consider when planning and establishing the practice on a given site: single or mixed species, number of tree rows (singular vs. multiple), alley width, and within row spacing.

Factors to consider when deciding how many rows to establish and the arrangement within the rows may be based on a number of potential benefits including:

- annual crop being produced and area removed from production by tree/shrub rows
- desired trees/shrubs and management needed to enhance production (such as weed control and pruning)
- erosion concerns that multiple rows and combinations of trees/shrubs/grasses can better address
- equipment width and how equipment moves through and around rows
- wildlife habitat created through multiple rows of combined trees/shrubs/grasses

The physical interactions between the rows of woody species and the companion crop should also be un-

derstood and reflected in plans for the alley cropping practice design. Physical growth traits of individual trees and how these influence the adjacent crop(s) are based on three factors: **light competition**, **root competition for water and nutrients**, and **allelopathy**.

Light competition (above ground)

Select tree species based on how they complement the sunlight requirements of a specific crop that is chosen to be planted in the alleys. Several tree species have foliage that casts light, dappled shade that makes them well-suited to alley cropping systems. Depending on the alley crop, tree species with lighter shade patterns may be preferable to heavy shade species. When considering trees for alley cropping, light shade is generally preferable to heavy shade.

In addition to choosing species that shade less, light competition can be reduced in the following ways:

- **Spacing:** When the distance between rows of trees or shrubs is increased, the years an alleyway may be cropped with minimal competition may also increase.
- **Row orientation.** An east-west tree row orientation maximizes sunlight received by an alley crop,

however trees may be planted on the contour if erosion is a consideration. Trees may be planted in other orientations if prevailing winds have a negative influence on crop yields.

- **Maximize available light:** Trees with small fine leaves will allow more light through the canopy.
- **Determine tree phenology:** Trees that leaf-out late in spring and/or drop leaves early in fall extend the season of light available to crops beneath their canopies. If the alley crop matures in early spring, such as winter wheat (*Triticum aestivum* L.), a tree that breaks dormancy late is ideal; alternatively, a crop harvested in late fall pairs well with a tree that drops its leaves early. Black walnut (*Juglans nigra*) is a good example of a tree that satisfies both scenarios.
- **Timely thinning and pruning:** Properly thinning trees within rows can maintain semi-open crown conditions. With regular thinning, these openings can promote the vigorous growth of shade intolerant companion crops. Proper pruning of basal branches before they reach one inch in diameter improves future wood quality and thins the depth of the canopy permitting more sunlight to reach companion crops. Pruning can increase berry/fruit/nut production while maintaining live crown ratio and minimizing branch encroachment over the companion crop and interference with farm equipment.

Root competition (below ground)

Competition for water and nutrients between the tree and the intercropped species can also occur below ground between the roots of the intercropped species. Root competition not only affects the yields of the companion crop, but also the growth of the trees.

Similar to understanding the structure of crown and leaf density, knowing the pattern and size of a species' root systems is important to be able to minimize and manage root competition. Vertical distribution of root systems varies among species. Deeply rooted species have a reduced volume of roots near the surface, good for minimizing competition with adjacent crops.

Tree species have different site requirements. For instance, wetland species tend to be shallow rooted, while others send roots deep underground to search for the water table. It is always useful to consult your local agroforester or forester for assistance in determining species suitable to your planting site.

As the trees grow, roots can also be cut underground using a ripper, coulter, or chisel plow in order to encourage roots to grow deeper, rather than laterally into the alleys where other crops are growing.

Allelopathy (chemical interactions)

The term **allelopathy** denotes the negative biochemical influence exerted by one plant on the growth of nearby plants. For example, pine needles produce acids that inhibit plant growth on the forest floor, while black walnut tree roots produce a compound called juglone, which also inhibits the growth of other plants.

Chemical interactions can be controlled by choosing plant combinations that work together. Juglone, for instance, does not affect all plants. Conversely, nitrogen-fixing plants are only useful to neighboring plants that require extra nitrogen. Understanding the root biochemistry of the desired alley cropping species' roots will ensure that potential negative interactions are mitigated.

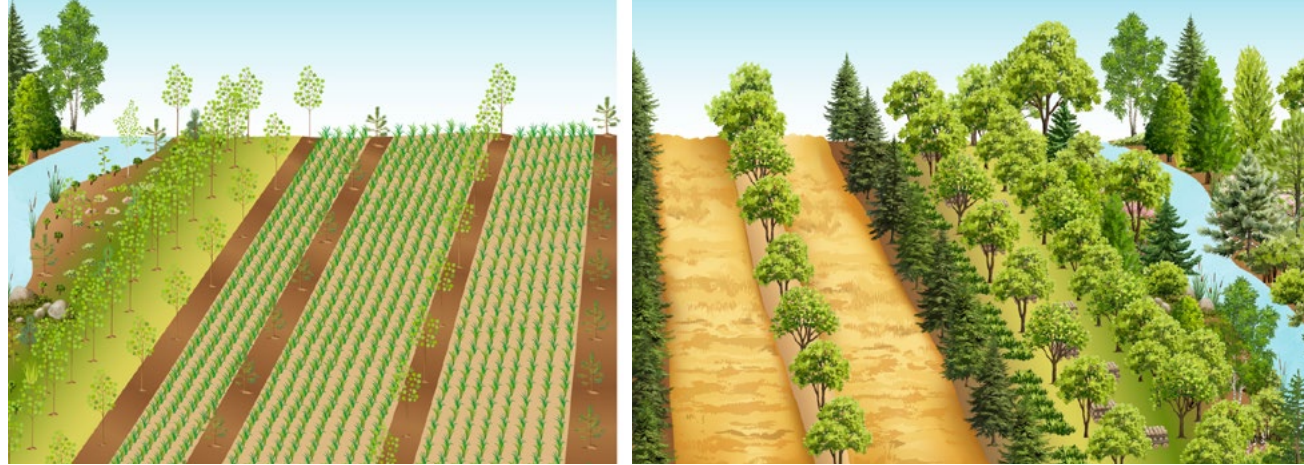


Figure 8.3. Left: Recently established alley cropping system. Right: Mature alley cropping system.

Illustrations courtesy of WSU Extension

Design

Tree and shrub selection

There are many desirable characteristics for trees or shrubs grown in alley cropping systems. Some ideal species characteristics are listed below. Note that no one species will exhibit all of these characteristics. Use them as starting points for selecting ideal plants to include in an alley cropping system.

- produces a commercially valuable product or multiple products (i.e., timber, nuts, fruit) that has a local market.
- is relatively fast growing (medium growth rate on high value trees is acceptable) or highly valued for production or conservation benefits
- produces appropriate shade for the companion crop
- adapted to a variety of sites and soils
- is deeply rooted with minimal roots at the soil surface to minimize competition with crops in the alleyway
- produces leaf litter that decomposes quickly so as not to cover the crop, e.g., ash leaves decompose in a few months while beech leaves can take up to 7 years.
- has foliage with minimal acid-generating potential if companion crops prefer a pH neutral soil. Conifers acidify soil so combine well with acid loving crops, such as alfalfa or blueberries.
- does not produce growth inhibitory chemicals (allelochemicals) that would prevent some crops from growing near them (e.g., black walnut)

- has a growing season that complements the crop
- produces wildlife benefits
- produces additional forage for livestock

If growing annual or biennial row crops (small fruits, grains, legumes, vegetables) as companion plantings between tree rows, plan for timing of tree maturity, as many row crops are shade intolerant. Root encroachment from faster growing trees like poplar can interfere with the root zones of row crops within 3-4 years.

Slower growing trees may take up to a decade to interfere with crop growth. However, some crops have been shown to benefit directly from tree intercropping—yields from sweet corn planted in close proximity to rows of nitrogen-fixing red alders increased significantly, especially double rows of red alder.^[1]

Tree crop spacing also plays an integral role on row crop growth, with wider spacing allowing for more light for a longer time period before significant yield declines are observed. As the trees grow, the amount of space for row crops continues to decrease. In this way, planning on row crops for the first several years after planting tree crops, then transitioning to other more shade-adapted species that will provide yields in the more mature phase of tree growth, represents a time-based adaptive alley cropping strategy.

Single vs. mixed species

Tree rows can have either a single species or mixed species. A single species is the easiest to plant and manage, but mixed species plantings with similar growth rates and site requirements may provide greater economic and environmental diversity. Mixed species can diversify income by combining fast growing (pulp, biomass, fodder) and slow growing trees (lumber or veneer).

Mixed species systems increase the spatial and temporal diversity of root systems, improving nutrient cycling and increasing water and fertilizer usage efficiency. Species need to have matched growth rates so one does not outcompete the other and become dominant, reducing or eliminating overall benefits.

Selecting companion crops

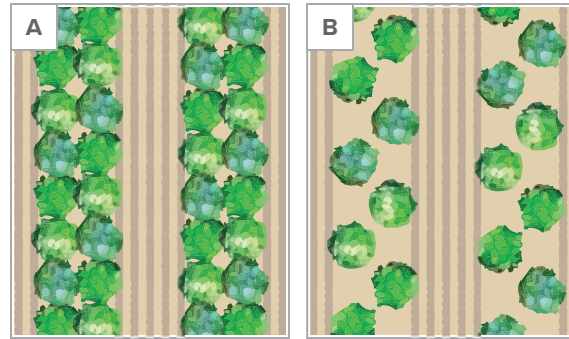
Landowner goals, site characteristics, available markets, tree selection and tree morphology are some of the many factors when determining crops. Three major groups of crops can be grown in an alley cropping practice:

1. row/cereal and forage crops
2. fruit, vegetables, native seed production, and other specialty crops
3. biomass-producing crops

Initially, the growing environment in the alley will be favorable to row crops requiring full sun such as corn, soybeans, wheat, and flowers. As trees grow taller and develop larger crowns, they exert greater influence on the alley with more shade, water and nutrient competition and humidity levels, along with decreased temperatures and decreased wind movement.

While availability of sunlight is a key factor that determines how well crops perform in the alley, water and nutrient competition is even more significant. The tree canopy density is partially determined by spacing within a row and the width between rows. This spacing will also influence below-ground competition.

Figure 8.4. Offsetting crowns.



Crown competition between adjacent trees (A) as compared to the increased growing space available to individual trees when planting in an offset configuration (B). Double or triple rows of alder, maple, cherry or birch can be grown either as (A) or (B) configuration.

Selection of forage crops

In an alley cropping practice, forage crops such as fescue, orchard grass, or alfalfa, are grown for hay production between rows of planted trees, but are not grazed. This distinguishes the alley cropping practice from a silvopasture practice.

Many of the forage grasses that perform well in the Pacific Northwest tolerate considerable shade. Tall fescue and orchard grass tolerate considerable shade and are very productive cool-season grasses. Other native grasses such as blue wild rye (*Elymus glaucus*) and Sitka brome (*Bromus sitchensis*) can also be used as forage crops and show good shade tolerance.

Other forage crops such as alfalfa have less shade tolerance, so tree spacing in alley cropping systems including alfalfa should be carefully planned to ensure yields are maintained.

Biomass crops

Both woody and herbaceous plants for biomass production are also potentially suitable as alley cropping selections. Fast growing woods such as alder, cotton-

wood, hybrid poplars, and willow can be grown as the companion crop, or as the main tree crop in alley cropping systems.

Trees that respond to coppicing/pollarding can also be grown as the main tree crop or companion crop. Live stakes for afforestation and restoration have an established market in the Pacific Northwest, and willows for basketry and other crafts are a growing market in the region. Markets for soft hardwood species are growing for pulp, paper, wood pellets, and even biomass energy, making these species potentially attractive for diversifying farm income streams. Herbaceous biomass crops (e.g. switchgrass) are another option for biomass companion crops.

Integrating specialty crops into an alley cropping practice

Specialty crops, including fruits, medicinal herbs, and craft materials also have potential for integration into alley cropping practices. Full sun species can be planted as companion crops and those requiring shade can be planted directly below the trees, and expanded into the alley as the trees mature.

- **Christmas trees** can be grown as the companion crop in diversified tree rows depending upon spacing.
- **Currants, berries, and elderberries** can also be grown in diversified rows or as crops within the alleys.
- Many high value crops such as **ginseng, goldenseal** or **mushrooms** can be grown directly under the trees once enough shade is established.
- **Oregon grape** (*Mahonia* spp.) and **tea** (*Camellia sinensis*) are high value crops currently being studied in the Pacific Northwest understory.

Many species grown as specialty crops in the Pacific Northwest are particularly well-adapted to partial shade environments, and can be grown successfully in alleys as trees mature and more shade is cast.

See **Chapter 10: Forest Farming** and **Chapter 11: Forest Gardens** for more information.

Establishment and management considerations

Single vs. multiple row sets of trees

Single rows

Advantages to single rows:

- less tree-to-tree competition
- reduced competition between tree and crop
- wildlife habitat enhanced
- plant-insect relationships increased
- economics improved through diverse yields

For timber production, single rows of trees take up the least space, but they require pruning to produce high-quality wood. In contrast, multiple rows allow interior trees to self-prune. For example, to grow timber from red alder or bigleaf maple, it is possible to use conifers such as Douglas-fir as “trainer” trees in the outer rows. This will encourage the hardwoods to grow a straighter trunk. Nitrogen-fixing “nurse” trees may be interplanted as well to enrich the soil.

Single rows create an ideal environment for nut trees to develop full crowns. Trees in single rows that are spaced further apart develop wider, more branched crowns. In single rows, trees are open on at least two sides, and therefore have less competition between trees within each row, when compared to multiple row configurations.

Double rows

Advantages to double rows:

- reduced competition between tree and crop
- wildlife habitat enhanced
- improved economics from diverse yields
- plant-insect relationships increase
- mutualism or cooperation between trees
- increased trees per acre without additional loss of light transmission to the crop

Double rows can be planted next to each other or offset. When offset, double rows maintain similar advantages to single row plantings while improving potential environmental benefits, such as soil and water protection. Compared to rectangular grid patterns of tree planting, double rows allow the maximum space for companion crops.

Offset row configurations can reduce light competition. However, deciduous hardwood trees tend to have a strong phototropic response, tending to grow towards light. If there is more light to one side of a tree's crown, most hardwood species will grow towards sunlight, and away from competition. This can cause devaluing of the tree for wood products due to sweep (stem curvature).

Triple+ rows

Advantages to triple+ rows:

- benefit from competition between tree rows (conifers competing for light will grow straight and fast reaching for available light)
- wildlife habitat enhanced
- plant-insect relationships increased
- improved economics through diversified yields
- mutualism or cooperation between trees
- increased trees per acre without loss of light transmission to the companion crop

Multiple rows of trees planted in offset configurations maintain exposure of a majority of each tree's crown/canopy to sunlight. Double rows provide the same benefits as a single row alley crop setting, but allow greater structure (vertical and horizontal vegetative layering and density components) and diversity (variety of species planted). This environment allows tree rows to be used by more wildlife. Finally, products coming from the farm are further diversified.

Certain trees benefit from some light competition. High-value wood is often grown in a single, straight stem which can be achieved by planting ‘trainer’ trees on either side, encouraging natural pruning and straight stem growth. Ultimately, this starts the

Figure 8.5. Tree row configurations



Above. Single, double, and multiple row configurations for alley cropping at the Horticulture and Agroforestry Research Farm in New Franklin, Missouri. The illustration below shows a triple row of trees using conifers to train high-value hardwoods.

Single rows



Double rows



Triple+ rows



Graphic by Michael Godfrey

process (may also require pruning) of producing a straight, clear (small or no knots) log of higher quality than might be grown in an open setting.

Trees with a strong phototropic response may not be suitable for double or multi-rows. If the tree tops grow towards the higher light availability and over the companion crop, it both devalues the wood and shades the companion crop. Pruning can prevent or minimize this, but the labor is increased.

Wildlife habitat increases greatly within wider rows. More animals use this space for travel and it creates protective cover for birds and small mammals.

Plant-insect benefits are the same for single and double row configurations, though some advantages may be gained by diversifying the species planted. Economic benefits are similar to double row configurations. As with double rows, additional trees per acre may also qualify for cost-share assistance and create opportunities for medium-term tree crops (e.g., trees grown for landscaping).

Within row spacing

The primary objective for the trees and the cost of the planting stock will help determine row spacing. To control erosion, closer spacing gives better results. If the tree stock is of unknown origin and quality, a closer spacing would also be desirable to give more opportunities to select the best quality trees during succeeding thinnings. Closer spacing may also be required if minimum numbers of trees per acre are required to meet government cost share requirements. However, if expensive grafted tree stock is used for nut production, a wider spacing may reduce cost.

Tightly spaced trees tend to grow up towards the light. This is highly desirable when growing trees for quality wood production. Additionally, as these tightly spaced trees begin to shade one another, shaded branches will begin to die and eventually fall off. This is called **self-pruning**, and is again desirable when trying to grow high quality wood in timber production.

Alley width

If wood, fruit, or berry production is the priority, closer row spacing is desirable. Wider row spacing is preferred when nut production is desired.

Spacing should also be adjusted based on multiples of the widest farm equipment to be used in the alley way. Accommodating equipment is particularly important in nut production when early crown development is desirable. For example, in **figure 8.6**, a 60-foot alley allows for 4 passes of a 13-foot wide disk (52 feet) and a 4-foot buffer (to ensure damage is not done to the base of the tree) adjacent to each tree row.

The number of years that light-demanding crops are to be grown in the alleyways is another consideration:

- 60-foot spacing will generally allow crop production (e.g. corn, soybeans, cereals, etc.) for 5 to 10 years
- 80- to 120-foot spacing will allow production for up to 20 years or more
- As shade increases over the life of the trees, the alley crop may need to change to a shade-tolerant crop such as greens, herbs, or tea

Headlands

It may be necessary to plan headlands into field borders to make turns. These zones are opportunities for perennial grasslands and can be pollinator and bird habitat and overwintering sites for invertebrates. Headlands reduce erosion and are vegetated based on desired species of pollinating insects and birds. Habitat may increase the conservation value of the farm and entitle the operation for conservation subsidies. Leave headland space equal to 1 to 4 times the width of the largest machinery, including implements.

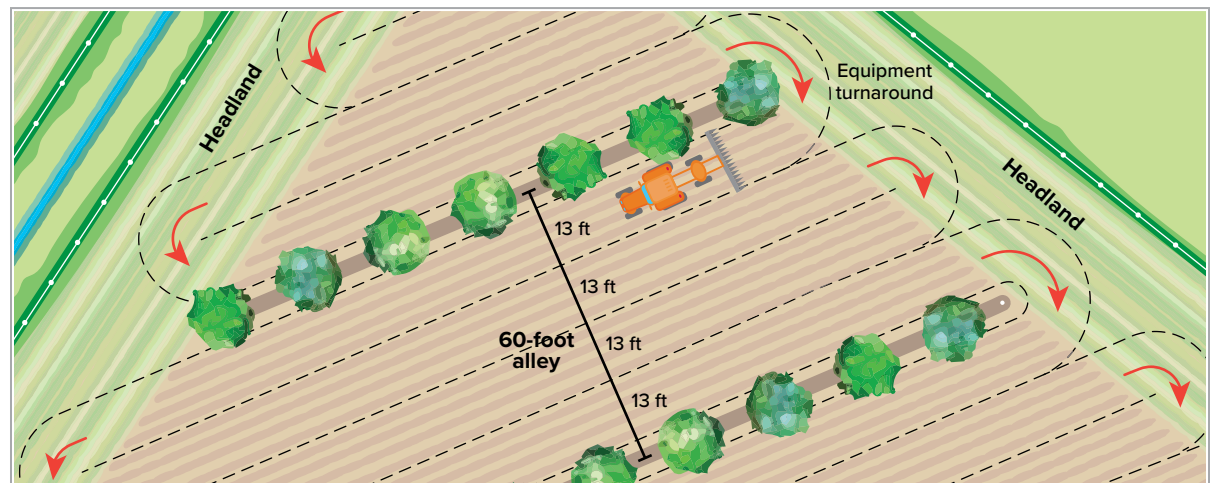
Operation and maintenance

Pest management

Periodic inspection of crops and trees is recommended to detect and identify possible pests. Insects and diseases can be significant factors in reducing the health and vigor of both the tree crop and the intercrop. Corrective actions taken should minimize the impacts on beneficial insects. Consult with a local forester to help diagnose any trees causing concern.

Figure 8.6. Alley widths and headlands.

The planning of spacing between tree rows should accommodate the width farm equipment for one or more passes of the alley cropping. Headlands allow for the equipment turn radius at each end of the alley.



Graphic by Michael Godfrey

Fertilization and nutrient management

A normal fertility program should be applied for the intercrop in the alleyway. Competition for nutrients can be minimized by root pruning or by adding more nutrients. Nutrients can be added in the form of chemical fertilizer, animal manure or a wide range of other materials such as living mulches or green manures. Only apply nutrients per a soil test to avoid overapplication, leaching, and excess nutrient runoff.

Canopy management (pruning)

If there is too much shade under an existing stand of trees, prune the canopy to allow more light to reach the understory. Clear-stem pruning may be a way of improving timber production. This involves removing branches low on the tree in order to raise the height where the canopy begins. This allows more light into the understory from side angles while also creating adequate space for operating equipment. However, removing more than 40% of the tree's foliage significantly reduces tree growth, so it is best to always have at least 40-50% of a tree's height in crown or foliage.

Root training

Periodic root "training" will improve crop yields. Based on research into tree and crop interactions it has been shown that even during the early years of tree development, competition for water and/or nutrients is the major reason for reduced crop yields. By early (beginning with young trees) and repeated (annual, biennial) deep ripping of lateral roots, the number of tree roots can be significantly decreased in the plow zone. Row crops will continue to produce commercial yields even as shade levels increase.

Weed control

Weeds need to be minimized in the tree row(s) for the first three to five years in a band about three feet on either side. Weed removal can be done in a number of ways, from herbicides and cutting, to cultivation and mulching. Also consider fabric barriers or living mulches to control competing grasses.

Maintenance tasks specific to trees

- **Replanting:** Replace all trees or shrubs that have failed for the first 3 years.
- **Branch pruning:** Pruning may improve wood quality, companion crop microenvironment, equipment access, or correct storm damage. Proper pruning techniques, such as clean cuts close to the branch collar, can improve the lumber's value. While poor techniques such as leaving branch stubs to become loose knots or knotholes can devalue the wood product.
- **Root pruning:** Deep ripping of tree roots (up to 2 feet deep) projecting into the alley reduces competition. Do not rip both sides of the trees in the same year and wait two years before ripping the other side. Repeat deep ripping on an annual or biennial interval.
- **Thinning:** In timber systems, rows normally need to be thinned to increase light in the alleys and speed production. To achieve maximum tree growth rates, growers must periodically thin trees. Failure to do so adversely impacts growth rates and rotation length. Pre-commercial thinning can also be an income source.

Summary

Alley cropping provides a practical way to combine tree and crop production on the same land. When carefully designed, it can diversify farm products and income while improving the soil and water, moderat-

ing microclimates, and providing wildlife habitat. The combined production of trees and companion crops may also make more efficient use of the land than either component grown alone.

Successful alley cropping systems depend on matching tree and crop species to site conditions, management goals, available markets, and farm equipment. Row configuration, alley width, within-row spacing, and row orientation should be planned to limit competition for light, water, and nutrients while allowing room for equipment and ongoing maintenance.

Management needs will change as the trees mature. Crops that perform well early on may need to be replaced with more shade-tolerant forages or specialty crops as canopy cover and root competition increase. Weed control, pruning, thinning, pest monitoring, and nutrient and root management may also be needed to maintain tree quality and crop production. Alley cropping requires more planning and management than many conventional cropping systems, but it can provide a productive and adaptable approach to integrating woody plants into working farms.

Additional resources

- Non-Timber Forest Product Resources—Extension Agroforestry Notes from USDA National Agroforestry Center. <https://www.fs.usda.gov/nac/resources/publications/index.php#agroforestry-notes>

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ALLEY CROPPING at Raising Cane Ranch

Snohomish, Washington

Above: Nick Pate of Raising Cane Ranch in Snohomish, Washington, where hay is grown in between rows of cider apple trees in an alley cropping system.

Photo courtesy of Mitchel Davidovitz

By Katherine Favor, *National Agroforestry Center*

Nick Pate is the owner and operator of Raising Cane Ranch, a 38-acre organic farm and ranch in Snohomish, Washington. Much of the land is open pasture, including hay fields that are grazed by Highland cattle, which Nick raises and sells for beef. In 2010, Nick converted 3 acres of these hay fields into an alley cropping system by planting rows of cider apple trees into the hay fields in intercropped rows.

Alley cropping is defined by the NRCS as the practice of growing trees or shrubs in rows with other crops produced in the alleys between them.^[1] Adding cider apple trees has helped Nick diversify his income and increase the overall productivity of his farm. Continuing to cultivate hay in between tree rows through the practice of alley cropping has allowed him to generate revenue from the land while the young apple trees are still maturing. Over time, the alley cropping system at Raising Cane Ranch has also provided other benefits to the surrounding Snohomish River Watershed ecosystem.

How it started

Nick purchased Raising Cane Ranch in 2006. At the time, it was a struggling hay and beef cattle operation. “When we first bought the farm, it was all hay fields. There were only maybe a dozen trees on the whole 38-acre site,” says Nick. “But financially speaking, that model didn’t make sense. We needed a second source of income.”

Initially, Nick explored berry production, but the area’s high rainfall creates significant fungal pressure, making berries a difficult crop to manage. Instead, he began researching more resilient fruit crops for the area and eventually landed on cider apples—a crop that often retains market value in Washington even with blemishes from pests and diseases.

Rather than establishing a traditional orchard, Nick chose to integrate cider apples with his existing hay production by designing an alley cropping system. In 2010, he planted cider apple trees in rows across a 3-acre parcel, with hay grown in the alleys between

the rows. The apple trees are a mix of over a dozen varieties of sweet, bittersweet, sharp, and bitter-sharp apples so that Nick can make custom cider blends.

The hay is harvested, baled, and fed to his herd of Highland cattle, which he markets directly to consumers. Nick eventually plans on transitioning out of hay and cattle production entirely, but alley cropping allows him to maintain cash flow in the meantime. “Because it can take 5 to 10 years before cider apples generate a profit, it’s important to diversify in that initial period, so that income can be generated through other means,” he explains.

Nick’s decision to plant trees wasn’t only financially motivated; he also was interested in their ecological benefits. Raising Cane Ranch borders a riparian area that drains into the Snohomish River Watershed—the second largest watershed in the Puget Sound region. This watershed supplies clean drinking water to surrounding communities and also provides critical habitat to numerous plants and animals, including salmon—a keystone species in the region.^[2]

Before Nick bought the land, the farm experienced some erosion and leaching of agrochemicals during seasons of heavy rainfall. By incorporating trees into the landscape both through his alley cropping system and an adjacent riparian forest buffer, Nick aimed to stabilize the soil, reduce erosion, and minimize nutrient and chemical runoff, helping protect the health of the watershed downstream.

Design

The design of Nick’s alley cropping system was centered around the goal of streamlining farm management for greater efficiency. Apple trees were planted in straight lines across Nick’s existing hay fields to facilitate operations. “Straight lines, whether we like them or not, are very effective for mowing and maintaining and getting equipment in here,” Nick explains.

Spacing was also a key consideration in the design process. Nick spaced the tree rows at 20 feet apart



Above: Planting trees in an alley cropping system alongside this riparian waterway has helped reduce the amount of sediment runoff and agricultural nutrient load that ends up in the river.

Photo courtesy of Mitchel Davidovitz

—just wider than the width of the tractor and mower that he had already invested in to cultivate his hay. Within each tree row, apple trees were spaced 15 feet apart to maximize productivity while also minimizing competition between trees.

Planting density for cider apple orchards in Washington varies widely. Traditional low-density orchards may have around 300 trees per acre, while high-density systems can exceed 1,300 trees per acre.^[3]

Nick opted for a very low planting density of just around 145 trees per acre. This spacing reduces competition between the apples and hay, but it also significantly lowers per acre apple yield. Likewise, Nick’s hay yield within the alley cropping system is also lower—just half of what an adjacent field yielded that was planted only to hay.^[4] “It isn’t ideal for hay



Above: Nick spaced apple trees at 20 feet between rows and 15 feet within rows, to accommodate his existing hay production equipment.

Photo courtesy of Mitchel Davidovitz

production, and it isn't ideal for apple production either, but for our system, it makes sense," Nick notes.

This aligns with research indicating that while individual crop yields tend to decrease in alley cropping systems, the overall system productivity—or combined yield of both crops—is often higher.^[5] For Nick, this tradeoff is worthwhile. The system allows him to produce more combined yield overall, and to continue producing hay for cattle feed and generating income during the early, low-yield years of the orchard's establishment, when he would have otherwise generated very little income.

Alley cropping systems are dynamic and they evolve as the trees mature. As trees grow, they increasingly impact the understory crops by casting more shade and competing more for below-ground resources like water and nutrients. Because of this, the design and management of understory crops also often require modification. Nick is anticipating this shift. "In five years, I'd like to transition out of producing cattle and hay anyway, and that'll be about the same time that these trees are producing a lot of fruit," he says.

When the apple trees are more productive and cast more shade, he plans to replace the hay with a more shade-tolerant crop, adapting the system as its conditions and productivity evolve. Some options for future understory crops Nick has considered include cut flowers or lavender. Alternatively, he might continue producing fodder for his cattle, but instead of growing hay, he might switch to a more shade-tolerant species, like cool-season grasses or legumes.

Establishment

Planting trees involves a high upfront cost, and it can take years for trees to produce a harvestable crop and a return on investment. Harvesting hay during the trees' initial growth period has helped Nick alleviate some of this cost.

He also sought support from government programs and organizations, which made the transition to alley cropping far more feasible.

"A lot of my costs were the initial investment—those plants, the hours, the compost," says Nick. "To make that initial investment, with all the variables—it's expensive and it's risky."

To help with these costs, Nick received technical and financial assistance from several sources, including the NRCS's Environmental Quality Incentives Program, Western SARE's Farmer and Rancher grant, the Snohomish Conservation District, the Washington Department of Ecology, NOAA, and the USDA Farm Service Agency's Conservation Reserve Program. "Getting help with the initial funding is a huge help for these pilot projects," he says.

Management

Managing the hay component of the system is relatively straightforward. Nick harvests the hay three times a year—once in the spring and twice in the summer—by cutting it to a height of six inches using a 60-inch deck mower. After cutting, the hay is baled and stored for use as livestock feed in the winter.

As much as possible, Nick aims to reduce reliance on external inputs by creating synergies between different parts of the farm. For instance, he feeds his cattle rotten apples and leftover pressings from cider production rather than throwing them away. In turn, he uses cattle manure to fertilize the apple trees.

"There is a bit of a full circle thing going on here, with livestock being a big, integral part of that," says Nick.



Above: Hay grown in alleys provides an income while the apple trees are maturing.

Photo courtesy of Mitchel Davidovitz

Climate risks and adaptation strategies

Hot and dry summers

Hot and dry summers are becoming increasingly common across Washington.^[6] Extended periods without precipitation can place stress on the hay at Raising Cane Ranch, which is unirrigated. However, alley cropping systems can alter the microclimate surrounding understory crops and reduce evapotranspiration. Nick has observed that the hay in his alley cropping system remains greener for longer during the summer compared to his other fields.

The partial shade provided by the apple trees helps retain soil moisture and protect the hay from the full intensity of the summer heat.

High winter rainfall

Snohomish, Washington receives an average of 11.25 inches of precipitation during the winter months,^[7] with some years bringing even more rainfall. Nick's land is flat and sits just 10 feet above sea level, so in the winter pooling and ponding are common. To deal with this issue, Nick chose native crabapple rootstock to graft his apples onto, as crabapple rootstock is well-adapted to seasonal periodic flooding and saturated soils.

Extreme weather

Periods of extreme rainfall are common in Washington, and this trend is expected to intensify in the coming years.^[8] Extreme rainfall can occasionally cause hay to rot before it can be harvested. However,

because Nick is already generating income from the apples in his alley cropping system, the hay produced there serves more as a safety net than a primary crop. "This is sort of like my savings in the bank," he explains. "Most of my other hay fields give me what I need through the winter for my livestock, but in some years, production is low, or sometimes the hay gets rained on and damaged."

Having an extra field of hay in his alley cropping system provides Nick with supplemental hay during these difficult years. "If the other hay fields aren't sufficient for whatever reason, the hay in this alley cropping section at least give me a little bit of a bump."

Conclusion

Nick Pate's alley cropping system at Raising Cane Ranch is an example of how diversification can create resilient farming systems that are better-equipped to withstand the ups and downs of markets and the climate. By integrating cider apples with hay production, Nick has built a transitional system that supports his livestock and finances while his orchard matures. At the same time, integrating trees is helping to improve the long-term health of the surrounding watershed ecosystem. Although alley cropping requires tradeoffs, like lower individual crop yields and higher upfront costs, it can offer increased overall productivity, climate resilience, and many ecological benefits.

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FOREST FARMING

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Definition

Forest farming is the intentional and sustainable cultivation of non-timber forest products in managed woodlands.

Author Note: This chapter is based in part on original narrative developed by John Munsell, Jeanine Davis, and Jim Chamberlain for the University of Missouri and used with permission. The chapter has been revised, expanded, and updated by Patrick Shults for this publication.



Forest farming can range from tending wild plants to intensive horticultural practices. It diversifies forest management and enhances associated income opportunities. It also improves forest composition, structure, and long-term health, ensuring they continue to provide ecosystem services like wildlife habitat, carbon sequestration, and water quality enhancement.

Forest farmers actively monitor and manage interactions between trees and understory crops with long-term forest health and productivity in mind. Both timber and non-timber crops can be managed on the same forested land, or non-timber crops can be grown in forests where timber harvesting is not suitable, such as in riparian buffers.

What are non-timber forest products (NTFPs)?

Forest farming is defined as the intentional and intensive management of forests to produce site-appropriate **non-timber forest products (NTFPs)**. Forest farmers may intentionally manage shade levels in a forest and among understory plants to favor cultivation or enhanced growth and yield of NTFPs with viable markets. NTFPs include a broad range of goods harvested from woodlands.

Herbal plants such as Oregon grape (*Mahonia nervosa*, *Mahonia aquifolium*) and Western trillium (*Trillium ovatum*), specialty mushrooms like shiitake (*Lentinula edodes*) and oyster (*Pleurotus spp.*), floral greenery like salal (*Gaultheria shallon*) and beargrass (*Xerophyllum tenax*), and wild foods such as nettle (*Urtica dioica*) and huckleberries (*Vaccinium spp.*) that grow in Pacific Northwest forests are termed NTFPs. Canopy trees can also be managed for products, such as bigleaf maple (*Acer macrophyllum*) syrup, cascara (*Frangula purshiana*), or decorative cedar (*Thuja plicata*) boughs. Non-native, non-invasive forest crops, such as ramps (*Allium tricoccum*) and wasabi (*Eutrema japonicum*), can also be forest-farmed where suitable site conditions are available.

Above left: Collecting sap from maple trees to produce syrup, known as “sugaring”, is a common form of forest farming in the eastern US and growingly popular in the Northwest using bigleaf maple (*Acer macrophyllum*).

Above right: Oregon grape (*Mahonia aquifolium*) is a common understory species in the Northwest. It is highly shade tolerant and has diverse uses, including medicine (roots, stems), food (berries), plant stock, and decoration.

Photos courtesy of Patrick Shults, WSU Extension

Unlike other agroforestry practices such as alley cropping or windbreaks, where trees are introduced into an agricultural system, forest farming intentionally integrates agricultural techniques into existing or newly established forests to farm NTFPs.

Many forest farmers cultivate and harvest with revenue in mind, but this practice is also used by tribes and other forest managers to provide food, fiber, and medicine for personal or community use.

The total value of the NTFP industry is challenging to estimate due to lack of data, and the fact that many economic activities associated with NTFPs are considered part of the informal economy, and are rarely reported. In the Pacific Northwest, NTFPs contributions to the forest product market are estimated to be in the hundreds of millions of dollars.^[1] For instance, wild harvested mushrooms were estimated at \$41 million in the early 1990s across Washington, Oregon, Idaho, and British Columbia, which would be closer to \$100 million today.^[2] Floral greens are likely the largest NTFP market in the region, and was estimated at \$235 million in 2002 in Washington alone.^[3] Other significant NTFP markets include huckleberry, cascara, Oregon grape, and specialty wood products.

Many other crops with informal and/or immature markets could be further developed as income opportunities, including forest cultivated nursery stock, essential oils, other medicinal or edible species. However, producing NTFPs for personal use is often sufficient motivation for forest owners to consider adopting forest farming practices.

There are several types of forest-farmed NTFPs, but they can generally be broken down into the following categories:

- **Medicinal**
- **Edible**
- **Decorative and specialty wood**
- **Plant stock**



Above: Forest farming trials established by WSU Extension and Agroforestry Northwest to examine multiple high-value, shade tolerant crops.

Photos courtesy of Patrick Shults, WSU Extension

Examples of forest farming products with markets (Not all of these crops are suitable for the Pacific Northwest)

Medicinal

- Pacific yew
- stinging nettle
- blue elderberry
- chokecherry
- ginseng
- goldenseal
- black cohosh
- bloodroot
- mayapple
- Solomon's seal
- wild ginger
- Oregon grape
- false unicorn (fairywand)
- ginkgo
- skullcap
- slippery elm
- wild yam
- Culver's root (black root)
- blue cohosh
- boneset
- lady's slipper

- passionflower
- partridge berry
- hawthorne
- pink root
- spikenard
- stargrass (devil's bit)
- stoneroot
- Virginia snakeroot
- yellow indigo
- yellow root

Edible

mushrooms

- shiitake
- oyster
- chanterelles,
- morels
- maitake
- native truffles
- lion's mane

nuts

- hazelnuts
- pine nuts

fruits and berries

- gooseberries,
- currants
- blackberries
- crab apples,
- elderberries
- huckleberries

vegetables

- fiddleheads
- wild onion (ramps)
- wasabi
- tea plant
- beargrass
- miner's lettuce
- bigleaf maple flowers
- dandelion
- nettles
- watercress

syrups

- bigleaf maple
- birch

honey

Decorative

- bark, pine needles, wood splints, various stems, and bark for baskets
- pine cones, fall colored leaves, and moss for decorations
- boughs from conifers for wreaths, roping, and garlands
- salal, pussywillows, ferns, and beargrass for floral greens
- pine straw for landscaping mulch
- spring ephemerals sold as potted plants incl. columbine, foxglove, lupine, and trillium

Specialty wood

- fine woods for musical instruments and decorative bowls and plates, including:
 - figured maple
 - burls
 - live-edge wood

Biomass plants

- willow and poplar grown as short rotation crops
- waste products incl. sawdust, wood chips, bark, stumps, and branches
- high quality sawlogs
- low quality trees, firewood, and woody residues for energy production

Medicinal NTFPs have been collected by Indigenous peoples since time immemorial. Much of the present-day understanding of the medicinal qualities of plants is rooted in **Traditional Ecological Knowledge (TEK)**. Medicinal substances derived from forest products are used in nutraceutical, herbal health, cosmetic, and other products.

Knowledge about medicinal NTFPs is often informal, but formal information regarding cultivation is increasing. Commonly harvested medicinal species in the Pacific Northwest include cascara, Oregon grape, devil's club (*Oplopanax horridus*) and stinging nettle. The part of the plant (bark, leaves, flowers, etc.) that provides medicinal benefits varies by species. These can be harvested and sold as raw material but are often developed into tinctures, teas, essential oils, or other value-added products for sale.

Edible NTFPs have similarly been cultivated and harvested in Pacific Northwest forests for millennia. There are a wide variety of edible products in forests, including mushrooms, tree syrups, berries, leaves, and flowers. Demand for these products is consistent and in some cases increasing.

Forest-farmed food crops are often prized for their flavor and culinary applications. For example, forest



Above: Forest cultivated shiitake is a common forest farming crop using small-diameter logs as substrate.

Photos courtesy of Patrick Shults, WSU Extension

cultivated shiitake mushrooms, which are grown on logs, are considered by some to have better flavor than sawdust-grown (also called “bag grown”) mushrooms and may sell at a higher price point. Similarly, bigleaf maple syrup is prized for its unique flavor profile and is used in cooking, baking, and cocktails.^[4,5] Like medicinal products, edible NTFPs can be sold as raw materials but are also processed into value-added products like jams, jellies, and liqueurs.

Decorative and specialty wood NTFPs are forest species harvested for their aesthetic value and used in bouquets, wreaths, woodcraft, and art products. There are well-established markets in the Pacific Northwest for decorative greenery. Common species include:

- **salal** (*Gaultheria shallon*)
- **noble fir** (*Abies procera*) boughs
- **Western red cedar** (*Thuja plicata*) boughs
- **beargrass** (*Xerophyllum tenax*)
- **Oregon grape** (*Mahonia aquifolium*)
- **sword fern** (*Polystichum munitum*)

Much of the current market is supplied by harvest on public lands, but small forest owners with sufficient populations can contract harvesters to collect on their land or harvest themselves and sell directly to wholesale markets. Wholesale prices for boughs and greenery are generally low, but most of the species harvested require minimal management to tend existing populations. As a result, forest decoratives can provide valuable supplemental income to forest owners with minimal input. Greenery can also be developed into value-added products like bouquets and holiday wreaths and sold directly to consumers.

Specialty woods, such as figured maple or burls, are prized by woodworkers for use in furniture, flooring, and musical instruments. Managing forests for specialty wood products like figured maple is not well understood, but can produce materials of high value.

Plant stock and seed NTFPs involve cultivating native and non-native plants as container or bare-root plant stock or seed collection under a forest canopy. Selling plant or seed material often supplements existing

forest farming operations. For instance, many forest farmers that grow crops like ginseng or wasabi also sell “plant starts” or seed. However, there is significant opportunity to grow a wide array of plants for stock and seed that benefit from being grown beneath a forest canopy.

Traditional Ecological Knowledge

Of all agroforestry practices, forest farming has the deepest roots in the Traditional Ecological Knowledge created by Indigenous peoples. Although there are fewer examples of forest farming in the Pacific Northwest today, historically, tribes and Indigenous communities managed woodlands to produce food, fiber, and medicine for millennia. This includes plant propagation and breeding, intentional use of fire, managing forest density, and other practices to sustainably produce non-timber forest products.

Forest gardens consisting of trees, shrubs, and other plants that produced culturally important crops were cultivated near settlements in forest canopy gaps where greater sunlight was available.^[6] Oak (*Quercus spp.*) woodlands in the Pacific Northwest were historically managed by Indigenous people for a variety of foods, including acorns, camas (*Camassia spp.*), and wild game. Cultural burning, or the intentional use of fire to manage land, was used to clear the understory of these forests, stimulate forage for wild ungulates, maintain camas beds, and reduce weevil populations that damage acorns.^[7] High elevation forests were critical for huckleberry production, and were also maintained with fire to create open conditions that improve berry yields.^[8]

Although the management was vastly different from how most forests are managed today, Indigenous peoples left a significant footprint on the landscape, and much of that management could be considered forest farming or other forms of agroforestry. Although some of that knowledge has been lost, many tribes and Indigenous communities with access to land continue to implement these practices and pass them down to younger generations.

Special assessment considerations

Most forest farming crops require specific growing conditions, so the site assessment and selection process takes on greater importance. Proper site selection will reduce incidence of disease while improving crop vigor and yields.^[9] Landowners with greater forested acreage will have more flexibility in site selection than a landowner who is limited to marginal woodlots or riparian buffers, which is often the case for agricultural producers interested in forest farming. While some forest farming crops, like forest cultivated shiitake, simply require sufficient shade, others require specific soil, topographic, and light conditions. Understanding the site conditions available will help determine which crops are most appropriate for the space.

Topography

Elevation, slope, and aspect can have significant influence on the natural vegetation in forests and thus will determine what forest farming crops can be cultivated there. Higher elevations experience colder temperatures and increased snowfall, while lower elevations typically have milder temperatures.

Slope greatly impacts soil hydrology and operations. Steeper slopes tend to be better drained, but can also be difficult to work on.

Aspect is particularly important for forest farming. North- and east-facing slopes tend to be cooler and have higher soil moisture throughout the year, which is ideal for species that are sensitive to drought and heat (e.g. ginseng, ramps, shiitake). South- and west-facing slopes may be limited to species that can handle higher temperatures and lower soil moisture (e.g. Oregon grape).

Soils

For tree or understory crops that will be cultivated directly in the ground, soil characteristics take on significant importance. A given species habitat will include preferred soil drainage, organic matter levels,

Benefits and challenges

A well-managed forest can offer diverse financial opportunities. Managing the understory for NTFPs in addition to other activities such as timber harvesting and habitat improvement can increase revenue and benefit forest health and plant conservation. Success depends on realistic objectives in accordance with time, labor, and site conditions and amendments. Managing site-appropriate species with growth and value potential will help maximize revenue opportunities. While timber harvests are common sources of revenue for woodland owners, it is often several years between harvests. Forest farming of marketable NTFPs can provide owners with intermediate income opportunities while timber and other salable products mature, or in place of timber harvest where it is restricted or not desirable.

Advantages

- Enhance forest health
- Improve forest composition
- Diversify income opportunities
- Profit from the rising popularity of forest-farmed products
- Range of operation sizes possible
- Use marginal lands for production
- Income opportunities in areas restricted from timber harvest
- Produce NTFPs for personal use

Challenges

- Informal or immature markets
- Variable yield
- Limited information available on how to produce crops
- Volatile markets for some products
- Some crops attractive to poachers
- Crop options limited by shade tolerance



Left: Many forest farming practices, including log-grown shiitake, can be practiced within forested riparian buffers.



Right: Skunk cabbage is a reliable indicator of wetland soils. These soils will be saturated most or all of the year and limit what crops can be cultivated there.

Photos courtesy of Patrick Shults, WSU Extension

macro and micronutrient concentrations, and acidity. For instance, ginseng (*Panax ginseng*) requires soils high in calcium. Without it, plants are subject to poor growth and disease.

While some characteristics, such as soil texture and acidity, can be determined with simple tools and methods, organic matter and nutrient concentrations must be determined through laboratory tests. These traits can be highly variable in forest soils, so it is better to sufficiently test a small area than do fewer tests over a broad area. Narrow down the area of interest through other site assessment methods first, then consider soil tests. Contact the local extension office or conservation district to inquire about soil testing.

Indicator species

Existing vegetation can provide valuable information about site conditions. A plant that requires specific site conditions to establish and grow can be considered an indicator species. The presence of these species indicates that certain conditions are present, often related to soil moisture and texture, soil nutrients, light availability, or some combination thereof.

Devil's club is a good example of an indicator species because it exclusively grows in wetland sites with poor drainage where soils are saturated for much

of the year. It grows near skunk cabbage (*Lysichiton americanus*), Western red cedar, and lady fern (*Athyrium filix-femina*), creating a wetland plant community. Similarly, wild lily of the valley (*Maianthemum dilatatum*) requires moist, well-drained loamy soils high in organic matter and is often found growing alongside sword fern, red elderberry (*Sambucus racemosa*), and red huckleberry (*Vaccinium parvifolium*) in the understory and an overstory with a significant hardwood component, such as bigleaf maple.

There is often overlap between plant communities and habitats, especially in transition areas, but identifying and inventorying the relative abundance of species growing and researching the growing conditions they prefer will help determine the site's characteristics. Keep in mind that noxious weeds like Himalayan blackberry (*Rubus armeniacus*), Scotch broom (*Cytisus scoparius*), or English ivy (*Hedera helix*) are competitive across a wide range of sites and do not reliably indicate site conditions.

Shade

Assessing shade in a forest is critical for cultivating understory crops, which often have specific light requirements. For example, ginseng and ramps both grow best in 70-80% shade. Shade levels are influ-

enced by both the structure and composition of the overstory. Dense forest canopies prevent light from reaching the forest floor, while low-density forests will have greater light availability. Conifers provide shade year-round, while deciduous (i.e. hardwood) trees only provide shade from April to October.

The intensity, type, and timing of shade significantly influence what can be grown there. For instance, spring ephemerals, such as ramps or nettle, grow best in deciduous forests because they complete most of their growth during early spring before canopy trees leaf out and light availability is high.

Foresters assess shade with a **densiometer**, a tool which quantifies shade as a percentage. An alternative approach is the **Paper Plate Method**.^[10]

Shade levels determine whether a site requires overstory manipulation through thinning and/or pruning to achieve ideal growing conditions.

Below left. The paper plate method is a quick and easy way to assess shade using household materials.

Below right. However, a densiometer is a more accurate tool that foresters use and is relatively inexpensive.

Photos courtesy of Patrick Shults, WSU Extension

Paper Plate Method

1. Place 10 or more white paper plates at even distances on the ground at approx. noon on a sunny summer day.
2. Count the number of plates that are at least half shaded.
3. Next, divide the number of shaded plates by the total number of plates placed on the ground.
4. Multiply this number by 100 to get percent shade.



Accessibility

Choosing a site that is accessible for you and your equipment is essential to establishing and maintaining a forest farm. Ideal sites will be close to your residence and a limited distance from roads, pathways, or other access points. It can also be beneficial to be within an operational distance of water and electricity, especially true for forest cultivated mushroom systems (i.e. shiitake) or any crops requiring irrigation.

Conversely, readily accessible sites may be susceptible to theft, i.e. poaching. Forest farming requires significant inputs and produces high-value crops with limited land. Finding a balance between easy access and protecting your investment from poaching is important. To protect crops, ensure they are not easily visible from roads and other heavily trafficked areas, mark boundaries with no trespassing signs, and consider installing wildlife cameras.

Design

Management requirements differ based on the crops being forest-farmed. For example, medicinal herb production often involves cultivating the forest floor and possible canopy management to create appropriate growing conditions. For instance, small diameter hardwoods removed for timber stand improvement may be used as logs for mushroom production. Forest farming methods range from minimal to intensive and vary depending on what is being produced but often relate to tradeoffs between time and money.

Existing site characteristics will also have significant impacts on inputs, whether one is starting with no forest and will be planting one or manipulating an existing forest to match desired conditions. Proper site selection can minimize short- and long-term inputs.

There are three recognized methods of forest farming:

- **managed wild populations or “wild stewarding”**
- **wild-simulated**
- **woods cultivated**

Managed wild population

Work with plants or fungus that already exist. Modify the forest canopy to favor desirable NTFP growth. Remove some understory plants competing with desired species. Annual harvests might not be possible. Very low inputs and yields vary depending on species and how often it is harvested.



Wild-simulated

Cultivate NTFPs in natural growing environments that can deliver products similar in appearance and quality to wild-grown. Use minimally invasive techniques to expose the soil and plant seeds or starts. Fertilizer and pesticide use is rare. Despite potential decrease in yield, market prices are often higher than those more intensely cultivated.



Woods cultivated

Most intensive forest farming. In addition to thinning the overstory, it often involves clearing undesirable understory vegetation and other practices more closely related to agronomy (i.e. tillage, fertilization, weeding, and control of disease, insects, and wildlife). Higher inputs can be costly and time-consuming but render larger NTFP yields.



Illustrations courtesy of WSU Extension

Woods cultivated is the most intensive and involves comprehensive site preparation and follow-up management. Start-up costs often are high, but the inputs can significantly increase yield. **Wild simulated** is less intensive in terms of site preparation and may involve some canopy management and clearing of the forest floor, but once the plants or seeds are planted, little else is done management wise.

Compared to woods cultivated, **wild simulated** typically renders less volume, but because the inputs are less, the risks are reduced and the returns may be similar. For some species (e.g. ginseng), the slower growth and more wild appearance of the roots often command price premiums, resulting in higher returns.

Managing wild populations (known as “wild stewarding”) involves tending an existing population of a plant or fungi. It may involve canopy management, removal of competing understory plants, and thinning of plants to provide for better growing conditions. This method requires the least inputs, comes with less risk, and usually does not provide high returns, but may be very desirable for products that have unpredictable markets or low-value products used as sources of passive income (e.g. salal, cedar boughs).

Wild stewarded systems often include a variety of species, while wild simulated and woods cultivated systems tend to incorporate fewer or even just a single species to maximize yields. Lastly, although not a

farming method, a landowner might choose to simply wild-harvest (or forage) marketable NTFPs from their forest. When harvested sustainably, these plants and fungi should be available for harvest in future years.

Establishment and management considerations

It is recommended to start small when establishing a forest farming operation. It often takes multiple years to master NTFP cultivation. The first few years are typically filled with a mix of successes and failures in terms of growing and marketing. The next few years are a time to leverage lessons learned to refine production, increase efficiency, and build on developed markets. Starting small allows a forest farmer to gain experience and suffer some setbacks without losing large amounts of money. Small areas can be used to test different crops, sites and management practices. Initial operations usually focus on two or three crops, but can include more if markets and labor are not a limiting factor.

Forest farming depends in large part on site conditions that are present and those required by the desired NTFPs. It is necessary to match and maintain appropriate sites to particular NTFPs. Over time, changes occur in a mature or a developing forest that may necessitate tree removal, planting of additional trees, or providing artificial shade to maintain ideal site conditions. Every forest farming operation should contribute to overall forest health and productivity.

Thinning is an important tool in forest management and forest farming. Thinning is a form of **timber stand improvement (TSI)** and typically treated as an intermediary treatment between forest establishment and timber harvest. In forestry, the goal of thinning is to remove trees to improve species composition, stand structure, wildlife value, regeneration, and forest health. In forest farming, thinning is used to manipulate light conditions on the forest floor and create or maintain a desired level of shade.



Above: Alley cropping with fast-growing trees can be a quick way to establish the required shade conditions for forest farming. In this photo from southwest Oregon, black and blue cohosh are cultivated between rows of hybrid poplar.

Photos courtesy of Eric Burkhardt, Penn State

Pruning can also be used to manipulate shade, but to a lesser degree. Comparing the shade level measured in the site assessment with the light needs of the selected crops and project size will help determine the intensity and scale of thinning or pruning required.

Some landowners may find themselves in the position of planting a new forest with the goal of eventually forest farming there. Riparian buffer plantings and other afforestation projects can easily be designed to include forest farming practices in the future.

When starting by planting a forest, it is important to plan long-term and incorporate structural and composition changes over time. Selecting overstory species that can add value to a system will maximize

potential outputs. For example, planting bigleaf maple, red alder (*Alnus rubra*), and Western red cedar will facilitate maple syrup, substrate for forest cultivated shiitake, and decorative bough production, respectively. Mid-story species like elderberry, serviceberry (*Amelanchier alnifolia*), or cascara can be planted during establishment or underplanted as the forest develops.

Another method is to purposely leave small canopy gaps during planting and filling these areas with productive mid and understory perennials to develop food forests. Otherwise, understory perennials and ground flora are generally not established until the canopy closes and provides sufficient shade. Using

alley cropping design concepts, a landowner can establish trees while temporarily developing or continuing cultivation of agricultural crops between rows, then transition towards shade tolerant forest farming crops when the canopy closes.

What makes a good forest farming crop?

The ideal understory forest farming crops are ones that not only survive but thrive in full shade.^[9] Forest medicinals like American ginseng and goldenseal (*Hydrastis canadensis*) are some of the most popular forest farming crops grown in the US because they perform better in shade than in full sun. In fact, many medicinal products improve in quality and value by being grown in shade and “wild” conditions.

Similarly, shade can positively affect the flavor and nutrition of some food crops. For instance, shade can reduce polyphenols and increase umami flavor in tea leaves (*Camellia sinensis*), while reducing heat stress on the plant.^[11] Other species may not be improved by shade, but are able to perform similarly in shade as in full sun, such as stinging nettle, while others require shade to be able to grow and yield, like wasabi and forest cultivated shiitake. So, when selecting crops for a forest farming operation, it is important to not only ask whether the crop *can* be grown in shade, but whether it *should* be grown in shade.

In the Pacific Northwest, forests naturally have abundant understories with a diversity of species that are able to establish, grow, and regenerate beneath a closed forest canopy. However, many species that can grow in these conditions will not produce commercially viable yields without greater light availability. For example, most berry-producing shrubs (serviceberry, huckleberry, etc.) are able to survive in moderate to dense shade, but yields will be low in these conditions and the berries tend to be smaller and more tart. Although there can be markets for “wild” berries with these traits, the commercial opportunity will be limited by low production, especially on smaller acreages.



Above: Depending on the crop, fencing may be needed in woods cultivated and wild simulated systems. “Floating block” fencing is an inexpensive approach where deer fence is hung from high tensile wire using trees as posts.

Photos courtesy of Patrick Shults, WSU Extension

Similarly, nut-producing species like hazelnut (*Corylus cornuta*) grow in the understory of forests, but don’t yield well in these conditions. Fruit and nut production can be increased by cultivating these species along forest edges and in canopy gaps, or by reducing stand density to increase light availability. Managing stands for lower density is particularly suitable to dry forest types such as ponderosa pine (*Pinus ponderosa*) stands and oak woodlands. However, even with this management, they are unlikely to provide the same yield and quality as when grown in open spaces, but reduced yields may not be an issue for those focused on growing NTFPs for personal consumption.

Indigenous communities in the Pacific Northwest know this well, and for centuries have followed natural disturbances like wildfire or intentionally used fire to create and manage large openings in forests where they can cultivate berry crops in full sun.

Forest health and stewardship

Woodland owners typically have a diverse set of other objectives for their forestland, including conservation, wildlife habitat, recreation, timber, and more.^[12] Managing a forest for one or more of these requires planning, monitoring, and sweat equity. The combined effort towards these various goals is often referred to as **forest stewardship**. Forest farming creates additional complexity for forest planning and management.

The foundation for all forest stewardship activities is actively monitoring and managing forest health. Forest health refers to the ability of a forest to sustain biophysical processes and conditions that result in key social, environmental, and cultural benefits. Forest resilience describes the ability of a forest to respond to disturbances like insects, diseases, or abiotic

factors (e.g. drought, wildfire) to maintain health and function.

Enhancing resilience is a preventative strategy, while forest health management typically relies on diagnosis and treatment. Forest farmers rely on a healthy tree canopy to produce crops, and thus should become familiar with forest health and resilience concepts, as well as local pests and diseases of concern.

Another important factor all woodland owners must factor into their management is climate change. Warming temperatures, changes in precipitation, and increased extreme weather events can have significant impacts on forests and require careful planning and preparation. Long-term impacts could include geographic shifts in species habitat, meaning some species may no longer grow on sites where they used to. Adapting to new conditions may require additional inputs like irrigation, thinning to reduce competition,

using improved plant stock or seed, or shifting to different species compositions (including NTFPs).

Wildfire is a naturally occurring disturbance regime and an important factor to consider when managing forests in the Pacific Northwest. In most parts of the region, warming temperatures and longer stretches without precipitation related to climate change are expected to increase the frequency and severity of wildfire.^[13]

Fires of any severity level can have significant impacts on forest farming operations. Strategies like fuels reduction and shaded fuel breaks can enhance wildfire resilience. In some ecosystems, prescribed fire can be used to reduce fuels and wildfire risk, while providing co-benefits to forest farming.

Indigenous communities in the Pacific Northwest routinely used cultural burning practices to maintain oak woodlands for acorn and camas production in

the understory.^[7] This mitigated the build up of fuels and also left the area open to support wild ungulate habitat and hunting opportunities.

Appropriate management for wildfire can be specific to individual forest types and other site conditions, so woodland owners should seek out resources or advice from professionals on how to incorporate it into their forest farming planning.

Learning more about how to recognize and manage forests before and after disturbances will help woodland owners ensure that forest conditions remain suitable for forest farming. Management of the forest overstory trees will impact forest farming possibilities regardless of the NTFP crop.

Forest stewardship planning is an effective tool tying multiple objectives into a cohesive strategy, including forest farming. For more information on forest stewardship planning, contact the local extension or conservation district office.

Summary

Unlike practices that incorporate trees into agricultural systems (e.g., alley cropping and silvopasture), forest farming integrates cropping systems into existing or newly established forests. Benefits include providing intermediate and periodic income from crops while timber matures or where timber harvesting is not possible or desirable.

Forest farming practices help diversify forest management and provide important and useful products, while supporting forest ecosystem services (carbon sequestration, wildlife habitat, etc.). This makes forest farming highly compatible with meeting conservation-based objectives in the Pacific Northwest, including preserving and creating habitat for threatened and endangered species (e.g. salmon). Management should focus on site conditions and tradeoffs between time and money in terms of method intensity. It also may be necessary to manage shade levels by thinning, pruning, and/ or adding trees.



Above: Root diseases are common in Pacific Northwest forests and can cause mortality in overstory trees, which impacts shade management for forest farming. Use gaps created by root disease for species with higher light requirements.

Photos courtesy of Patrick Shults, WSU Extension

Before beginning an enterprise, forest farmers should:

- Identify and investigate existing or developing NTFP markets.
- Select NTFPs of interest from the list of those with viable markets.
- Obtain site requirements, production, and processing information for selected NTFPs.
- Decide on a production method and operational investments.
- Thoroughly investigate technical resources and engage technical experts.

Markets for forest-farmed products vary, but often are direct-to-consumer and via local stores, cooperatives, or farmers markets. However, in some cases, larger-scale markets are available. For example, shiitake, maitake, morel, and chanterelle mushrooms, as well as truffles, may be sold in small volumes at farmers markets or to gourmet restaurants, or in larger volumes to distributors for resale in regional markets.

The floral market for decorative products like salal and bear grass or cedar boughs can also support

wholesale production, but typically require large amounts to be profitable. These can be sold through cooperatives or to local buyers. Non-local buyers may be reached through the internet. However, by marketing directly to consumers, a grower is more likely to retain a greater share of profits than when a middleman is involved.

A market analysis and business plan can help a beginning forest farmer chart out required inputs and is an essential starting point. This training manual offers a thorough framework for analyzing specialty crop markets and planning successful farming enterprises. Carrying out comprehensive and careful planning during and after startup will help minimize problems and increase chances for long-term forest farming success.

Sources of expertise on growing and producing NTFPs can be obtained online from county extension offices, state land grant universities, the NRCS, the USDA Forest Service, state forestry and conservation agencies, and internet sources.

Additional resources

- National Agroforestry Center—Forest Farming (<https://www.fs.usda.gov/nac/practices/forest-farming.php>)
 - Non-Timber Forest Product Calculator (<https://www.fs.usda.gov/nac/resources/tools/ntfp.shtml>)
- Non-Timber Forest Product Resources—Extension Literature. (<https://www.ntfpinfo.net/lit>)
- OSU Extension: Non-Timber Forest Products. (<https://extension.oregonstate.edu/forests/non-timber-products>)
- WSU Extension Working Riparian Lands Toolkit. (<https://extension.wsu.edu/wrlp>)
- Forest Stewardship and Health Resources
 - WSU Extension Forestry Program. (<https://forestry.wsu.edu/>)
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FOREST FARMING at Neil's Bigleaf Maple Syrup

Acme, Washington

Above: Neil McLeod's 200-acre diversified bigleaf maple forest in Acme, Washington, where he harvests maple syrup from trees.

Photo courtesy of Mitchel Davidovitz

By Katherine Favor, National Agroforestry Center

Neil McLeod is the owner and operator of Neil's Bigleaf Maple Syrup, a 200-acre forest that produces maple syrup in Acme, Washington. Tapping bigleaf maple trees (*Acer macrophyllum*) for sap in the context of a multi-species, diversified forest is one form of forest farming. The NRCS defines forest farming as growing or managing stands of trees or shrubs in coordination with understory plants or nontimber forest products.^[1]

The "overstory" and "understory" layers in forest farming systems are not always distinct. In the case of Neil's operation, he manages bigleaf maple trees, which make up one layer of vegetation, while other native trees form additional layers. Species like Western red cedar (*Thuja plicata*), grand fir (*Abies grandis*), paper birch (*Betula papyrifera*), and Pacific madrone (*Arbutus menziesii*) are encouraged to grow alongside the bigleaf maple. When managed together intentionally, this diverse mix of species forms a multi-layered cropping system that produces a harvestable product while also protecting the forest ecosystem.

Bigleaf maple is considered a commercial hardwood tree species, but it often has higher felling, yarding, and milling costs than other trees in Washington State.^[2] It also often yields a lower price compared to other tree species in Washington.^[3] Additionally, timber operations have long harvest intervals—decades can pass between harvests. Because of this, it can be difficult for forest landowners to generate a steady income from selling timber alone in bigleaf maple-dominated forests.

Bigleaf maple forest ecosystems also support many types of flora and fauna, including woodpeckers, bald eagles, elk, black-tailed deer, rough skinned newt, tailed frog, western red-backed salamander, and a diverse array of fungi, mosses, and lichen.^[2] By engaging in forest farming and harvesting nontimber forest products like maple syrup, Neil is able to generate a reliable income while also supporting an ecosystem that is vital for many forms of plants and animals.

How it started

Tapping maple trees is common in the East and Midwest, but historically has not been common in the Pacific Northwest because the West Coast's unpredictable freeze/thaw cycles lead to inconsistent sap production. Twelve years ago, Neil started experimenting anyway. Before that, he had been a beekeeper for years until his hives unexpectedly died.

Needing a sweetener for his coffee in the morning and without the ability to produce his own honey, Neil decided to try tapping a bigleaf maple on his land, just to see what would happen. He had low expectations at first. "Everyone told me 'It can't be done on the West Coast' and that it wasn't worth the effort," says Neil. Still, he kept experimenting. After several failed trials, he finally figured out the right tapping technique. "I got really good at it," Neil says. "I could pick out the trees to go after, I hit the runs just right, and before long, we were making a lot of syrup."

Design and management

Neil cares deeply about protecting wildlife, so maintaining a diverse forest ecosystem is one of his top priorities. He manages his land so that roughly 80% of the trees are bigleaf maple, while the remaining 20% are other native trees like western red cedar and grand fir. By stewarding a mix of species, Neil is creating a more ecologically complex system than if he managed for only one species.

To keep his forest healthy, Neil removes diseased, dying, and dead trees every few years. This helps prevent the spread of disease and gives the remaining trees more space and sunlight to grow. With less competition, these trees become more resistant to potential pest outbreaks.^[4] Climate change models project that pest issues may worsen in the coming years,^[5] so having resilient, healthy trees is especially important for promoting resilient future forests.

Removing weak trees also reduces crowding, which allows Neil's bigleaf maple trees to produce higher



Above: Neil McLeod stewards multiple tree species in an integrated forest farming system, including bigleaf maple, cedar, and other Washington natives.

Photo courtesy of Mitchel Davidovitz

yields of sap.^[6] However, Neil does not thin healthy trees. "My philosophy is largely to leave the forest alone as much as possible," Neil explains. When Neil removes weak or dead trees, he always follows that task by planting new trees in their place. In addition to maples, he plants a mix of native trees, to ensure that the forest remains diverse.

Sap harvest and processing are the most labor-intensive parts of Neil's operation. The sap harvest season lasts from late December to early February, when nights are still cold, but the days are getting warmer.

To collect sap, Neil developed an elaborate harvest system throughout the forest consisting of spiles (small metal taps) inserted into trees to draw out the sap. The spiles are connected to a hanging network of one-inch polyethylene tubes. These tubes suspend from trees horizontally and are connected in a complex network throughout the forest that lead to a vacuum pump. The vacuum gently pulls the sap out

of the trees, through the tubing, and into a collection tank, increasing the speed of harvest.

Neil finds this vacuum-based harvest system to be much more efficient than the common gravity-fed system, where sap is gravity-fed into tanks in different parts of the forest and transported to the main processing center by truck. Thanks to his vacuum harvester, Neil has significantly reduced his labor and gas costs while maintaining a consistent flow.

Once the sap is collected, Neil refines it into syrup. First, he runs the sap through a reverse osmosis filter, which removes some of the water and increases the sugar content to 10 percent. Next, he boils the sap in a machine called an "evaporator" at 219.7°F, until



enough water evaporates and the remaining liquid reaches a desired consistency.

“When it gets to the temperature I want, the machine automatically opens a valve and pours off the syrup,” explains Neil. He stops the process once the syrup reaches a sugar content of around 68%, resulting in a thick and sweet final product.

Cleaning the network of taps and harvest pipes several times a year is another important management task. Neil used to clean them with bleach, but he stopped because he did not want the bleach residue to contaminate his product or the ecosystem. Today, Neil opts for a more natural cleaning solution by collecting excess sap and fermenting it into a low-acidity vinegar. In his experience, this vinegar cleans the pipes without leaving behind contaminants. Because Neil produces vinegar as a cleaning solution from his own sap, he also spends less money on external inputs.

Today, Neil’s property has around 600 taps, producing between 20,000 and 40,000 gallons of sap most years. After boiling, this results in roughly 200 to 400 gallons of syrup. He sells his syrup both online and to restaurants, and he notes that there is always more demand than supply.



Top: Harvest is facilitated by a network of spiles and polyethylene tubes that run through the forest and connect to a vacuum pump.

Middle: Neil uses a vacuum pump to pull sap out of trees, which reduces labor costs.

Bottom: By filtering and processing with specialized equipment, Neil is able to produce viscous, sweet syrup that maintains its quality despite Washington’s winter temperature fluctuations.

Photos courtesy of Mitchel Davidovitz

Climate risks and adaptation strategies

Higher winter temperatures

Maple syrup production is sensitive to weather fluctuations. “Weather is always a challenge—our winters are completely different from the East Coast’s winters,” explains Neil. In many regions that produce maple syrup, nighttime temperatures stay below freezing during the spring, while daytime temperatures often rise above freezing. This creates a steady freeze-thaw cycle, leading to consistent production of high-quality, clear sap with a higher sugar content. In Washington, however, nighttime winter temperatures regularly fluctuate above and below freezing.^[7] This can cause pressure changes inside the tree that form air bubbles in sap. The result is that some weeks, Neil’s land yields high-quality, clear sap, while some weeks it yields low-quality, foamy sap.

This trend is expected to continue, as climate models project that Washington’s winters will get warmer in the future.^[8] To deal with this, Neil developed a specialized filtration system that separates foam from the sap. This equipment helps Neil quickly and efficiently manage the unpredictable sap quality caused by Washington’s oscillating winter temperatures.

Increased risk of flooding

Neil’s land has a high water table and the creek that runs through his property often rises during the winter, causing seasonal flooding. Because the ground stays wet for much of the year, logging in these areas is difficult, and building houses or traditional farming is not an option. “It’s kind of considered useless land,” says Neil. “It’s hard to log it, you can’t build houses on it, you can’t farm it. But it does produce an awful lot of sap.”

Flooding in Washington State is expected to become more frequent and severe in the coming years due to climate change.^[5] Instead of fighting these conditions, Neil decided to work with them. Since bigleaf maple naturally thrives in wet environments, he found a

way to turn a challenge into an opportunity. “Some of the best runs I’ve ever seen are after major flooding,” says Neil. Choosing to lean into these challenges, Neil planted even more bigleaf maple saplings on some other flood-prone areas of his land. He looks forward to continued production despite what many would consider unfavorable climatic challenges.

Conclusion

Neil’s Bigleaf Maple Syrup is an example of what alternative forest management can look like in some areas of the Pacific Northwest. Neil’s forest farming approach demonstrates that tapping bigleaf maple trees can provide a sustainable annual income stream while maintaining the integrity of the forest. This method allows the land to stay productive while supporting an ecosystem that supports diverse plant, animal, and fungal life.

Neil hopes that his model can serve as an inspiration for other land stewards who work with bigleaf maple forests. As he puts it, “Over the next 100 years you’d be making money off those trees without destruction of this great habitat.” Neil’s work exemplifies how harvesting maple syrup through the practice of forest farming can be both an economically and ecologically viable solution for land stewards looking to balance profit with conservation.

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CHAPTER

10

FOREST GARDENS

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Definition

Forest gardening is the practice of creating and cultivating plant communities that mimic the physical structure of a native forest while also providing ecological functions and yields.

Forest gardens are intentionally designed ecosystems that produce a wide diversity of yields for both people and the broader community of life. As interest in regenerative land use grows, this practice has gained momentum as a response to deforestation, declining ecological function, and increasing food insecurity by integrating the principles of afforestation with resilient food production.

By mimicking the structure and relationships found in natural forests, forest gardening restores ecological processes while generating meaningful human benefit. Importantly, these systems are highly adaptable, with applications ranging from small urban spaces to large-scale rural landscapes.

Forest gardens are multi-tiered agroforestry systems. Trees are featured as the tallest layer in the system. Below the overstory, there may be understory tree species, shrub species, herbaceous species, groundcovers, vining plants, mushrooms, and bulbs or tubers below the ground.

In a forest garden, plants are carefully selected to meet the specific needs of the place and community, including food, medicine, habitat, soil health, and climate resilience, while enhancing ecological functions and services.

The needs of each species are considered both in the layout and in the selection of companion plants to help enhance the resilience of the forest garden area. For example, understory species may be grown to enhance the populations of predator arthropods to assist in preventing a pest or disease outbreak. Flowering plants may be grown to attract beneficial insects and pollinators during the bloom period of the primary crop. Groundcovers can be used to prevent erosion, minimize evaporation, or discourage weeds.

Above:

The Duma Community Forest Garden in Eugene, Oregon.

Photo courtesy of Mitchel Davidovitz



Each plant in a forest garden may provide multiple benefits to the system. Depending on the designer and the scale of the planting, species selection for a forest garden can be simple or complex.

While the term “forest garden” is relatively new, the practice itself reflects long-standing land stewardship traditions of Indigenous peoples around the world. In the Pacific Northwest, for example, managed camas prairies illustrate a sophisticated cultivation pattern in which oaks, camas, and a diversity of edible and useful plants were intentionally maintained as a productive polyculture.

Stewardship practices like selective harvesting, tending, and encouraging berry-producing shrubs along travel routes and near villages shaped these landscapes to increase both abundance and accessibility. A wide array of native species can be thoughtfully integrated into contemporary forest garden systems in the Pacific Northwest drawn from this legacy.

Modern diets in the Pacific Northwest and many other regions rely heavily on plants that are not native to the region, and forest gardening offers a way to localize food production across backyards, neighborhoods, urban spaces, schools, and farms.

By drawing on the ecological functions and relationships found in native forests, we can design novel plant communities that mimic these systems—substituting species that meet human needs into similar ecological niches. In this way, familiar cultivated crops such as apples, pears, plums, and berries can be integrated into resilient, multi-layered plantings that function like natural ecosystems. This approach not only supports productive and diverse landscapes, but also brings food closer to where people live, reducing transportation distances, hidden environmental costs, and overall vulnerability in the food system.

Native plants play an important role in forest gardens. The design of forest gardens does not advocate for reducing their use; rather, it encourages their thoughtful integration alongside cultivated species.

Forest gardening recognizes that by producing food and other resources within managed systems, we can reduce pressure on wild ecosystems while still supporting biodiversity, habitat, and ecological function. In this way, forest gardens serve both human needs and the health of the broader landscape.

To be successful, a forest garden needs to consider the unique qualities of the space where the garden will be planted as well as the needs of the people who will be tending to the garden. A thoughtful site analysis helps to create an achievable design that can be implemented in the desired time frame.

Disclaimer: This guide is intended as a primer and is not site-specific nor comprehensive. Refer to the resources listed at the end of this chapter for extended information on forest garden planning, design, and management.

Benefits and challenges

Forest gardens offer a wonderful way to enhance local production of materials that humans need while also cultivating plants with ecological functions in both urban and rural environments. Like a tree, the benefits of this system are exponential.

Forest gardens enhance habitat for birds and other wildlife who visit the planting and provide pest control while eating any surplus fruit, turning it into a rich fertilizer to help perpetuate the system. Plants like parsnips or comfrey grow deep roots in the soil to help enhance soil tilth and receptivity to water and airflow. Plants like these can also be used as “chop-and-drop,” generating mulch for the system to help cover the ground to prevent erosion, evaporation, and crusting.

Forest gardening can be practiced in urban environments, bringing food production into population centers, while also reducing the impact of the urban heat island effect. Urban forest gardens provide healthy habitat for wildlife, including food for birds as they migrate through the area.

Forest gardens can be installed on the municipal level to create localized recreational, community, stewardship, play, and gardening opportunities. Spaces like these also offer an opportunity to integrate stormwater runoff close to where it falls as a resource for watering the plantings while assisting with groundwater recharge—an increasingly important need in many areas where water is seasonally scarce.

Forest gardens are naturally attractive to wildlife. As birds visit these forest gardens, they will find food to eat and rest in the branches. Naturally, they will contribute some feces that will help to fertilize the planting. Both the feces from birds and leaf drop and small branches will contribute to carbon storage in the soil. Increasingly, there have been reports of epidemics in bird populations that spread easily between bird feeders and concrete where feces accumulate. In contrast, food gardens provide a place where birds can find fresh feed throughout the year in the form of berries, seeds, leaves, and fruit. When they poop below the plants, the manure becomes a positive asset to helping the garden thrive while mitigating disease.

The shade created by trees in a forest garden offers a welcoming space for community gathering and connection. These spaces can be managed in many ways—supported by grants or neighborhood associations, stewarded collectively by local residents, integrated into school grounds, or maintained by a single household. Regardless of scale, having a dedicated steward or advocate helps ensure continuity of care and a clear vision for the site over time.

Management is typically most intensive during the first three to five years, as the system becomes established. After this period, the focus shifts toward ongoing maintenance, seasonal management, and harvest. Since the management of forest gardens is quite different from row crop agriculture, it can be challenging for people to learn how to manage such a diverse range of species. In general, plan to start small and build on successes.

Special assessment considerations

Urban vs rural

Urban forest gardens address two interconnected challenges: the loss of ecosystem services and limited access to fresh, healthy food. In many cities, ecological functions are degraded or absent, but forest gardens can help restore these systems by creating habitat for urban wildlife, moderating the urban heat island effect, providing shade, absorbing and slowing stormwater, building soil through biomass accumulation, and improving air quality.

At the same time, many neighborhoods face barriers to accessing nutritious food, where fast food and convenience stores dominate and full-service grocery options are difficult to reach by foot, bike, or public transit. By bringing food production directly into backyards, school grounds, and shared public spaces, forest gardening improves access to fresh, nutrient-dense produce while also reducing transportation costs and the decline in nutritional quality that occurs after harvest.

Around the world, community forest gardens on public land—maintained by local residents—demonstrate the potential of this approach; in the Pacific Northwest, the Beacon Food Forest is a leading example of how community-managed landscapes can produce food while fostering stewardship and shared benefit. In addition to these public projects, forest gardens on privately owned land near cities offer further opportunities, where proximity to markets provides a clear advantage for small-scale producers and helps strengthen resilient, localized food systems.

Farms in rural environments tend to be focused on annual crops. Perennial crops provide permanent cover for the soil, stabilizing the soil and reducing erosion. Tree crops provide for a growing yield over time. Many of the benefits of agricultural systems based on tree crops and perennial plants have been presented in other places in this handbook. Consider the importance of fruit and nuts as well as long lived



Above: Seattle's Beacon Food Forest is a 7-acre urban garden—open for the public's enjoyment and harvest 24 hours a day.

Photo courtesy of Abel Kloster

perennial vegetables in your diet. There are many species and varieties available that can provide nutritious fruit, nuts, vegetables, and herbs over many seasons to the local community and beyond.

Contaminated soil

Historic land use can influence the accumulation of heavy metals, like arsenic, cadmium, and lead, in urban environments. The best way to determine whether heavy metals are a concern is to have your soil tested at an analytical laboratory, particularly in urban or previously developed areas. If elevated levels are found, it is not always necessary to avoid growing in the soil entirely, as the appropriate response de-

pends on the type and concentration of contaminants and the intended use of the crops.

In many cases, management strategies such as using raised beds with clean soil, adding organic matter, adjusting soil pH, or selecting crops that are less likely to accumulate contaminants can effectively reduce risk. For example, leafy greens and root crops tend to accumulate more heavy metals, while fruiting crops like trees and berries generally pose lower risk. With thoughtful management, it is often possible to safely produce food while also improving soil conditions over time.

Graywater and stormwater

Growing food close to home creates opportunities to use water more efficiently by cycling it through the landscape. With thoughtful design, water from sinks, showers, and laundry (commonly referred to as **graywater**) can be redirected to support a forest garden. This gently used household water often contains nutrients such as phosphorus, which supports flowering and fruiting, making it a valuable resource for plant growth. Because graywater is produced year-round, it can help sustain plants during the dry summer months typical of the Pacific Northwest.

For guidance on designing and permitting these systems, **Oregon's Department of Environmental Quality** offers [Reusing Graywater in Your Landscape](#), a helpful resource for homeowners.

Forest gardens can also play an important role in managing stormwater in urban environments. Cities often generate significant runoff from roofs, roads, and other impervious surfaces, especially during the wetter months when plant uptake is lower. Well-designed forest gardens that feature healthy, well-drained soils and layered vegetation can slow, absorb, and store this water, reducing pressure on municipal stormwater systems that may become overwhelmed during heavy rains. Plants and mulch systems can capture and hold moisture, gradually returning it to the soil and making it available later in the growing season.

Rainwater catchment further expands this opportunity: roofs and other hard surfaces can be used to collect and store water for future use in the garden. Together, these strategies turn urban water challenges into assets, enhancing both plant health and broader watershed function.



Above: Allen Hancock points out the many varieties of trees in his forest garden at Duma in Eugene, Oregon.

Photo courtesy of Mitchel Davidovitz

Design

Depending on the size and complexity of the site, it is often most effective to establish a forest garden in a series of intentional stages rather than all at once. A critical first step is investing time in soil preparation before planting trees, as the long-term success of the system depends heavily on early soil conditions.

This may include testing and amending soil, reducing compaction, improving drainage, and building organic matter through compost, mulch, and cover crops. Early soil-building efforts help establish the biological activity, structure, and nutrient cycling that will support long-lived perennial systems.

Following initial soil preparation, a first phase of planting might focus on foundational species like canopy and sub-canopy trees, windbreaks, and nitrogen-fixing support plants, which help to define the long-term structure of the garden. These species

often require the most time to mature, so establishing them early allows the system to develop over time. Subsequent phases can introduce shrubs, herbaceous perennials, groundcovers, and climbers, filling in ecological niches as light conditions, soil health, and microclimates evolve.

Staging also allows for observation and adaptation. By installing the system incrementally, forest gardeners can respond to site-specific conditions, adjust plant selection, and refine layout decisions based on what is working well. It also spreads out labor and financial investment, making the process more manageable.

In this way, phased implementation supports both ecological success and practical feasibility, allowing the forest garden to develop as a resilient, dynamic system over time.

Plant selection

Plant selection in a forest garden is both an ecological and cultural choice, shaped by local conditions, food preferences, and long-term goals. In the Pacific Northwest, this process offers a unique opportunity to draw from a rich palette of native species while also incorporating cultivated plants that provide reliable and abundant yields. By thoughtfully combining these elements, a forest garden can reflect the structure and function of native ecosystems while meeting the practical needs of food production throughout the year.

There are many native plants well-suited to forest gardens in the Pacific Northwest, including:

- **salmonberry** (*Rubus spectabilis*)
- **thimbleberry** (*Rubus parviflorus*)
- **golden chinquapin** (*Chrysolepis chrysophylla*)
- **red and black huckleberry** (*Vaccinium* spp.)
- **blue elderberry** (*Sambucus cerulea*)
- **stinging nettle** (*Urtica dioica*)
- **miner's lettuce** (*Claytonia perfoliata*)
- **osoberry** (*Oemleria cerasiformis*)

These species are generally well adapted to regional conditions and can be managed to increase productivity over time. However, native plants alone do not typically provide a substantial portion of the modern diet. For this reason, forest gardens often replicate the ecological structure of native systems while incorporating cultivated species that occupy similar niches and offer higher yields.

A wide range of cultivated fruits and nuts can thrive in the Pacific Northwest, including:

- **apples** (*Malus* spp.)
- **pears** (*Pyrus* spp.)
- **plums** (*Prunus* spp.)
- **walnuts** (*Juglans* spp.)
- **chestnuts** (*Castanea* spp.)
- **figs** (*Ficus carica*)
- **quince** (*Cydonia oblonga*)
- **mulberries** (*Morus* spp.)



Left: The options for species in forest gardens are incredibly diverse and informed by the gardener's vision—be it year-round yields or maximizing vertical space, as in this multi-layered planting in Eugene, Oregon.

Photo courtesy of Mitchel Davidovitz

Careful variety selection is important, as performance can vary significantly depending on local climate and microclimate conditions, including susceptibility to pests and diseases. Many fruit species also require cross-pollination, making it important to select compatible varieties. Local extension services, fruit-growing organizations, and regional nurseries can provide valuable guidance on appropriate selections.

The Pacific Northwest also has a rich history of fruit cultivation, including many heritage varieties that are now uncommon in commercial markets. Incorporating these older varieties offers an opportunity to maintain regional agricultural heritage while benefiting from cultivars that are often well adapted to local conditions.

With thoughtful planning, plant selection can provide fruit throughout much of the year. In the Pacific Northwest, harvest can begin with honeyberries (*Lonicera caerulea*) and strawberries in May, continue through summer and fall, and extend into early winter with crops such as persimmons (*Diospyros kaki*) and quince. From late fall through spring, storage

varieties of apples and pears can be kept in cool conditions and consumed over time, while preservation methods can further extend availability.

For those interested in commercial production, include a market analysis as part of the process. Look at what is currently available locally, what is in demand, and which crops may offer opportunities because they are not widely produced. These factors can help shape thoughtful and strategic species selection.

Learn which species are best suited to the area by connecting with local county extension offices or fruit-growing groups. As site observations deepen and intentions become clearer, consider including plants that contribute aesthetic value as well as ecological function—such as windbreaks, habitat corridors, pollinator-supporting species, and plants that build soil fertility. Native species are especially valuable in forest gardens, as they are well adapted to local conditions and typically require fewer inputs to thrive.

See **Chapter 8: Species Selection** for a more in-depth approach to this topic.

Native plants provide food and habitat for birds, butterflies, insects and other wildlife. Their relationships with these species promote biodiversity and enhance ecological functions. In urban areas, where the habitat is often more limited, these ecological functions are very important to the populations of local wildlife.

Enhance pest management in a forest garden by supporting populations of natural insect predators, which are often attracted to native plants. Include a diversity of cultivated plants to help reduce reliance on food from off-site sources. When selecting species, consider the unique climate and microclimate of the site, and also account for how conditions may shift over time. Planning with future climate changes in mind can help ensure the forest garden remains productive and resilient for years to come.

The structure of the forest garden

Design a forest garden to be ecologically similar to a woodland forest type, such as a Pacific Northwest oak woodland. Aim for high structural complexity by including multiple layers of diverse, productive species. Look to early successional forests in the region as models for structure and composition, and use those patterns to guide the design of the forest garden.

The early stages of a forest garden are much like an early successional forest where the young trees have lots of sunlight around them, offering ecological niches for growing sun loving species. Over time, the canopy of a forest garden will close, reducing the sunlight and the sun loving plants, creating a new ecological niche for plants that prefer shade or partial shade. Since fruit production is influenced by the quantity of sunlight that each tree receives, it is important to manage for light.

Overstory and understory trees are generally planted on wide spacing to allow for patches of sunlight to enhance the biodiversity that can enjoy the forest garden. Below the understory trees are shrub species. Below the shrub species are herbaceous plants. A groundcover layer protects the soil from erosion and

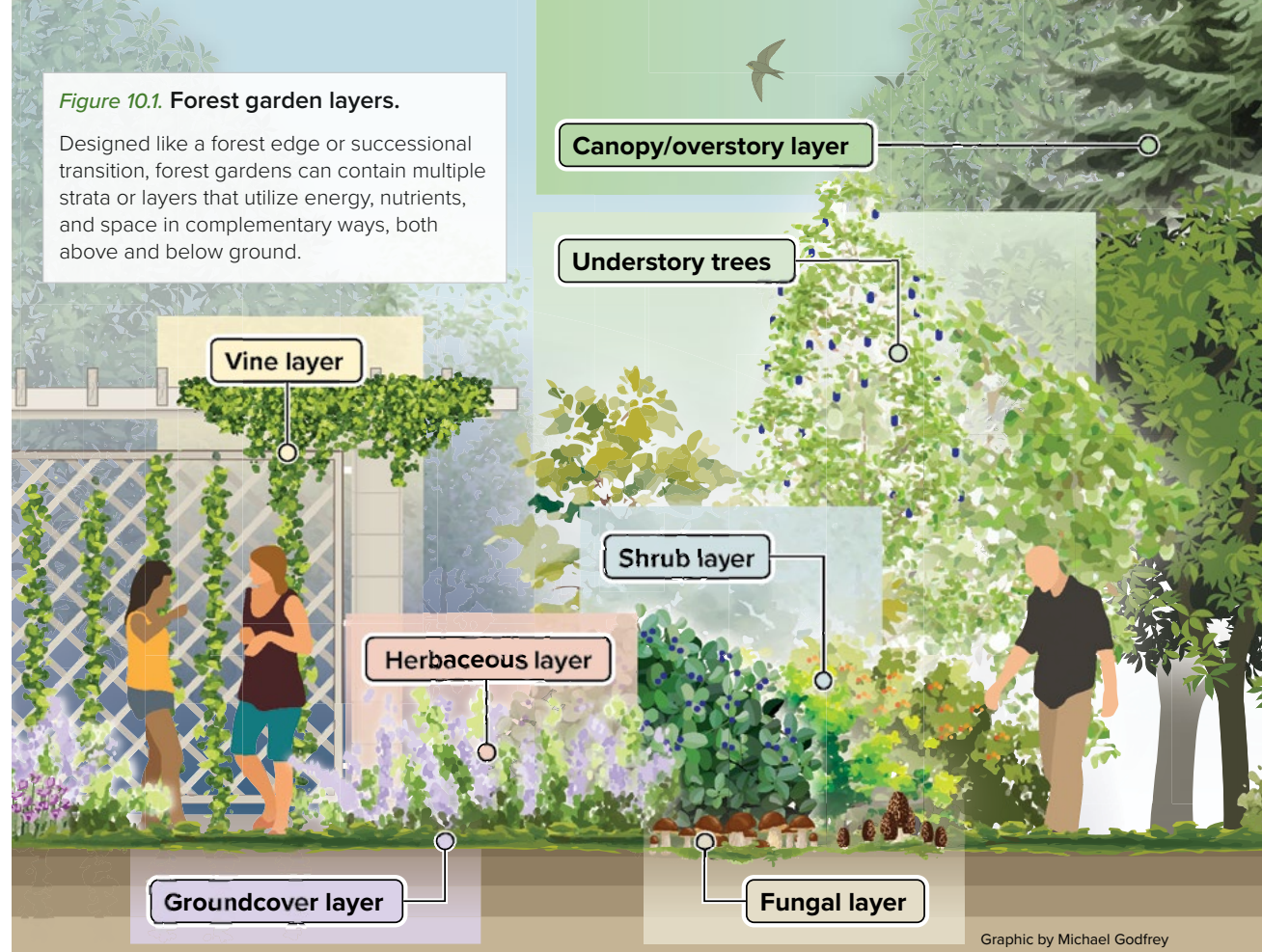


Figure 10.1. Forest garden layers.

Designed like a forest edge or successional transition, forest gardens can contain multiple strata or layers that utilize energy, nutrients, and space in complementary ways, both above and below ground.

compaction. There might be a vine layer growing up a tree. There are fungi and bulbs that comprise the layer known as the rhizosphere.

Each vegetation layer includes plants that have been selected for their ecological function and yield. Some examples include food, medicine, animal fodder, attracting pollinators, enhancing soil tilth, discouraging pests, attracting predator insects, preventing erosion, shading the soil, etc. Plants are selected for their ability to benefit other species in the system. It is ideal to consider each plant featuring at least three functions and having a positive relationship with at least two other species in the design.

Each of the vegetation layers in a native forest can be mimicked in the intentional design of a cultivated forest garden. Some designers choose to have a minimal number of layers and others choose a more complex system. A simple structure can be more beneficial in a production-oriented landscape like a farm. For example, focusing on a limited number of canopy species as a means to establish understory medicinal herb production. Or a focus on highly productive fruit and nut trees could lead to a less diversified understory.

Each layer has inherent properties that might be useful for the community. A breakdown of each of the layers with further information follows:

Canopy/overstory tree layer

Trees are large woody plants that generally have a single trunk. Canopy/overstory trees are often greater than 40 feet tall. They make up the tallest layer in a forest garden and are the most dominant species due to their size and the extension of their roots. As the largest species in the planting, they tend to capture most of the available light for photosynthesis and use the most nutrients and water—especially over time.

Root exudates from these species help shape the soil environment in ways that support the plant's growth, influencing microbial communities, nutrient availability, and soil structure. It is necessary to carefully consider the needs of these trees while choosing understory companions.

Tall trees dictate the quality of light (or darkness) and they can be a primary limiting factor in a forest garden. Overstory trees tend to live for a long time and take at least 5 years to reach bearing age. Most nut trees, including walnuts (*Juglans spp.*) and chestnuts (*Castanea spp.*), would grow in the overstory layer. Standard sized fruit trees would grow in an overstory layer. This layer could also be native trees that already exist on site, or that a steward would want to plant for the future. Examples of native overstory trees include:

- **bigleaf maple** (*Acer macrophyllum*)
- **Western red cedar** (*Thuja plicata*)
- **Douglas-fir** (*Pseudotsuga menziesii*)

Understory trees

Understory trees grow in partial shade from the overstory tree, or they may prefer to grow at the edge of a forest. These trees tend to grow between 15 and 40 feet tall. Examples of trees that like to grow in this type of habitat include:

- **paw paw** (*Asimina triloba*)
- **hazelnut** (*Corylus spp.*)
- **mulberry** (*Morus spp.*) pruned into a bush-like form

Often the location of a forest garden is not conducive to the size and/or life span expected for an overstory tree. In this case, the overstory of a forest garden might only be 15 to 20 feet tall. Semi-dwarf fruit trees would make up the tallest layer in the forest garden in this situation.

Examples of native understory trees include:

- **beaked hazelnut** (*Corylus cornuta*)
- **vine maple** (*Acer circinatum*)
- **red alder** (*Alnus rubra*)

Shrub layer

Shrubs are woody plants that have multiple stems. They grow between 6 and 12 feet tall. There are many types of berries and medicinal herbs that can occupy the shrub layer including:

- **raspberries** (*Rubus ideaus*)
- **elderberries** (*Sambucus spp.*)
- **blueberries** and **huckleberries** (*Vaccinium spp.*)

This layer provides habitat for other species, particularly ground dwelling creatures. Shrubs offer food and shelter for wildlife.

Most food-bearing shrubs will produce more berries in a sunny microclimate. They tend to propagate by layering or underground runners. Examples include:

- **red elderberry** (*Sambucus racemosa*)
- **blue elderberry** (*Sambucus cerulea*)
- **salmonberry** (*Rubus spectabilis*)
- **thimbleberry** (*Rubus parviflorus*)

Herbaceous layer

Plants in the herbaceous layer tend to be 0.5 to 6 feet tall. This layer can also include some species of biennials and self-seeding annuals. Many perennial herbaceous species go dormant in the winter and may not be visible during these months. This is the most diverse layer in the forest garden and it offers many



Above: A lush herbaceous layer of day lily, burdock, and perennial leek grows under an apple tree at the Center for Rural Livelihoods in Cottage Grove Oregon.

Photo courtesy of Mitchel Davidovitz

ecological functions. This layer in the forest garden supports a high amount of insect diversity, attracting beneficial insects and pollinators. Plants in this category may have diverse root systems or taproots that can enhance the receptivity of the soil. Some examples of these plants include:

- **purple coneflower** (*Echinacea purpurea*)
- **elecampagne** (*Inula helenium*)
- **valerian** (*Valeriana officinalis*)
- **evening primrose** (*Oenothera biennis*)

The productivity of the herbaceous layer is driven by abundant light availability, rapid growth rates, and active nutrient cycling near the soil surface. These plants often develop dense root systems that efficiently capture water and nutrients, further supporting vigorous growth. These types of plants are often used for “chop and drop,” meaning that the leaves are cut to leave as mulch on the soil. Some species that can be managed in this way include:

- **comfrey** (*Symphytum x uplandicum*)
- **horseradish** (*Armoracia rusticana*)
- **rhubarb** (*Rheum rhubarbarum*)

Perennial vegetables are grown in this layer include:

- **lovage** (*Levisticum officinale*)
- **chives** (*Allium schoenoprasum*)
- **Jerusalem artichokes** (*Helianthus tuberosus*)

There are many plants that can be grown in this layer that attract beneficial insects including:

- **alyssum** (*Lobularia maritima*)
- **Maximilian sunflower** (*Helianthus maximiliani*)
- **oregano** (*Origanum vulgare*)

Some plants in the herbaceous layer of a forest garden fall into one or more of these categories for ecological functions. Herbaceous native plants include:

- **yarrow** (*Achillea millefolium*)
- **cow parsnip** (*Heracleum maximum*)
- **stinging nettle** (*Urtica dioica*)
- **goatsbeard** (*Aruncus dioicus*)
- **fringecup** (*Tellima grandiflora*)

Vine layer

Vines tend to be 0.5 feet tall or more and grow along the ground unless support is found or provided. Vines are often not encouraged in Pacific Northwest forest gardens. They can decrease the air flow between our plants increasing their susceptibility to fungal diseases. Some vines reduce the host's health and productivity by competing for light and other resources or direct parasitism. However, vines do help to maximize the use of sunlight by using vertical space in the garden.

The shade offered by vines can also provide shelter from the sun for other plants and wildlife. In a Pacific Northwest forest garden, the vine layer is often found on the edges where the growth of a vine will not affect another productive species or where a cooler shaded summer microclimate is desired like over a patio.

Examples of plants for the vine layer include:

- **grapes** (*Vitis spp.*)
- **kiwis** (*Actinidia spp.*)

- **honeysuckle** (*Lonicera spp.*)
- **roses** (*Rosa spp.*)

Native vines include:

- **honeysuckle** (*Lonicera ciliosa*)
- **blackcap raspberry** (*Rubus leucodermis*)
- **trailing blackberry** (*Rubus ursinus*)

Groundcover layer

Groundcover plants cover the surface of the soil, preventing erosion and evaporation and aiding in water absorption. They provide shelter for the soil, enhancing the habitat for soil microorganisms.

Examples of plants for the groundcover layer include:

- **strawberries** (*Fragaria × ananassa*)
- **chamomile** (*Chamaemelum nobile*)
- **sweet woodruff** (*Galium odoratum*)
- **emerald carpet raspberry** (*Rubus pentalobus*)

Native groundcover choices include:

- **wood sorrel** (*Oxalis oregana*)
- **bleeding heart** (*Dicentra formosa*)
- **Pacific waterleaf** (*Hydrophyllum tenuipes*)
- **miner's lettuce** (*Claytonia perfoliata*)

Fungal layer

Fungi enhance the soil structure and help to convert nutrients in the soil into an available form for plants to use. In a forest garden setting, the mycelium of mushrooms aid in water retention, repel saline water, and can protect from frost damage on the roots of plants. Mushrooms help to capture carbon dioxide. Some fungi can counteract disease rot fungi. In the forest garden, mushrooms can be grown in the ground, using wood chips as a substrate.

There are many types of mushrooms that thrive in a forest garden setting in the Pacific Northwest, where shade, consistent moisture, and abundant organic matter create ideal conditions for fungal growth.



Above: The prince (*Agaricus augustus*) grows amidst the groundcover layer in the forest garden at Center for Rural Livelihoods.

Photo courtesy of Abel Kloster

- **King stropharia** (*Stropharia rugosa anulata*), also known as wine cap, are one of the most commonly cultivated species in this habitat and can be easily established in wood chip mulch, garden beds, and pathways. In addition to king stropharia, other saprophytic mushrooms can be inoculated directly into soil-building materials such as wood chips, straw, or buried woody debris.
- **Oyster mushrooms** (*Pleurotus ostreatus*) are highly adaptable and can be grown on a variety of substrates, including logs, straw, and wood chips, often establishing quickly and producing reliably.
- **Blewits** (*Lepista nuda*) can be introduced into leaf litter and compost-rich soils, where they help decompose organic matter while producing edible fruiting bodies.
- **Morels** (*Morchella spp.*), while less predictable, may be encouraged in disturbed soils with woody debris and ash, mimicking post-disturbance conditions.
- **Shaggy mane** (*Coprinus comatus*) can appear in nutrient-rich soils and along garden edges, contributing to decomposition.

Beyond these edible species, incorporating fungal inoculants supports broader soil health by enhancing decomposition, nutrient cycling, and soil structure. Over time, a diverse fungal community can develop within a forest garden, contributing to resilience and productivity while creating opportunities for seasonal harvests.

Mushrooms grown on logs can also be placed in the shade of the forest garden. While not directly interacting with the plants and the soil, log culture provides a way of incorporating pruning of large limbs back into the forest garden system.

Note: The groundcover and fungal layers are often considered part of the **rhizosphere**—the zone of soil near the surface that is strongly influenced by root exudates and microbial activity. Within this active interface, plants, fungi, and microorganisms interact continuously, driving nutrient cycling and supporting regenerative soil processes in a forest garden.

Forest garden planting and layout patterns

Forest gardens can be organized using a range of planting patterns that reflect both ecological function and human intention. The layout of these patterns shapes how plants interact, how resources are shared, and how the space is used over time. Begin by identifying primary species and clarifying goals for the project, as these will guide the selection of patterns that best fit the site. From there, choose from a variety of planting mosaics, each suited to different conditions and outcomes. The following are some common patterns, along with guidance on when they may be most effective.

Edges

An edge describes the interface between two different habitats where the species grown on the edge are able to benefit from the unique characteristics of each space. In a forest garden, plants can benefit by being grown on the forest edge or the edge of a structure.

This location is helpful for plants that want to be sheltered or can benefit from the addition of extra warmth through the insulative effects of being near an established planting area or a structure.

Some plants, such as lilac (*Syringa vulgaris*) or paw paw (*Asimina triloba*), need the shelter of an area like this to help prevent damage from cold winds. An edge can be a sheltered spot for growing young plants. An edge between two habitats can provide more diverse beneficial relationships in regard to pollination, pest control, or other ecological function.

Patch

A patch describes a specific space in an ecosystem that has defined edges and varies from the area around it. Patches may vary in size and texture, but they have a unique successional trajectory from the area around it.

A patch is a basic unit for organizing a plant community in a forest garden. Forest gardens can be made up of one extended patch or many patches.

Guild

A guild is a plant community that has been designed to benefit each other. Generally, they are designed around a primary support species. In a guild, there are multiple plants that provide different ecological functions to help the community benefit as a whole.

There are multiple types of guilds that can be incorporated into a forest garden design.

- For a young forest garden, consider creating a **system establishment guilds** around each young fruit tree. This is a collection of plants that support the growth of young trees. As the tree gets bigger, the companion plants will eventually be shaded out.
- A **community function guild** describes a community of plants that are all offering the same ecological functions. This could be a grouping of plants that are all

attracting beneficial insects or a group of plants that are all helping to improve the soil. This community of plants is oriented around a specific goal.

- A **resource partitioning guild** describes a plant community that has a similar resource need, but can receive it at different times of the year. This plant community partitions valuable resources, which avoids competition, and cultivates harmony between the plants in that area.
- A **mutual support guild** describes a plant community where species work together to provide for the needs of each other. These plants may occupy different layers within the forest garden structure.

Lanes

Lanes describe a forest garden layout organized in rows to support efficient management and harvest. If production is a primary goal, a lane system is a particularly valuable choice, as it allows for easier access, maintenance, and higher overall yields. Access paths or roads can run between rows of trees, making it easier to move people, tools, and equipment through the system. Within each row, fruit or nut trees form the primary structure, and the understory can either be diversified—with flowering herbaceous plants and other supportive species—or simplified, depending on management goals. This approach is similar to alley cropping, but with the addition of multiple vertical layers within each row, creating a more complex and productive system.

Stacking

Stacking refers to layering different types of plants within a forest garden. This approach builds on the vertical structure of the system by arranging species across multiple layers, from groundcover to canopy. By stacking plants in this way, the available space between the ground and the sky is used more efficiently, increasing photosynthetic capacity and overall productivity.

Companion planting

Companion planting describes grouping plants together based on beneficial interconnection. Some information about this practice is documented in scientific research and other information is anecdotal. Both are valuable. In general, plants are matched together based on their characteristics.

Plants that can help attract beneficial insects include:

- **yarrow** (*Achillea millefolium*)
- **coreopsis** (*Coreopsis* spp.)
- **alyssum** (*Lobularia maritima*)
- **dill** (*Anethum graveolens*)
- **alexanders** (*Smyrniololus satrum*)

Another strategy could be to group plants together based on the way that they partition their roots beneath the soil. Select combinations that align with the specific conditions and goals of the site.

Pollination

Most fruiting plants in forest gardens rely on insect pollinators, making pollinator support an essential component of system design. Effective strategies focus on providing continuous sources of nectar and pollen, access to clean water, and suitable nesting habitat throughout the year. Understanding which pollinators are most active and effective for specific crops allows for targeted habitat enhancement.

In the Pacific Northwest, the orchard mason bee (*Osmia lignaria*) is a highly efficient native pollinator of fruit trees, active from early spring through late spring, and benefits from the presence of nesting sites such as drilled wood blocks or natural cavities. In addition to native solitary bees, honeybees (*Apis mellifera*) and bumblebees (*Bombus* spp.) play important roles in pollination and are supported by diverse plantings that provide blooms across multiple seasons.

Maintaining a continuous flowering sequence is key to sustaining pollinator populations. This includes early-season species (such as willows and early fruit blossoms), mid-season flowering shrubs and herbaceous plants, and late-season blooms that extend forage availability into fall.

Incorporating a diversity of plant types, including trees, shrubs, perennials, and groundcovers, helps ensure that nectar and pollen resources are consistently available. Additional habitat features, such as undisturbed soil for ground-nesting bees, woody

debris, hedgerows, and reduced pesticide use, further support pollinator health.

Tracking bloom times across species, such as in a flowering calendar like the Southern Willamette Valley example referenced below, can help identify seasonal gaps and guide future plant selection, strengthening both pollinator presence and overall fruit set within the forest garden.

Table 10.1 is an example of a flowering timetable from the Southern Willamette Valley.

Table 10.1. Flowering timetable for native plants for native pollinators in the Southern Willamette Valley

Species listed are especially good nectar plants for hummingbirds (H) and/or native insects (I). Color bars approximate flower color (□ = white) and flowering time but may occur early or be prolonged depending on weather or irrigation.

Species	H/I	March	April	May	June	July	August	Sept.
Tall Oregon grape <i>Berberis aquifolium</i>	I							
Red-flowering currant <i>Ribes sanguineum</i>	H							
Bleeding heart <i>Dicentra formosa</i>	H/I							
Tall larkspur <i>Delphinium trolliifolium</i>	H/I							
Rosy plectritis <i>Plectritis congesta</i>	I							
Thimbleberry <i>Rubus parviflorus</i>	I							
Riverbank lupine <i>Lupinus rivularis</i>	I							
Red & yellow columbine <i>Aquilegia formosa</i>	H							
Oregon sunshine <i>Eriophyllum lanatum</i>	I							
Nootka rose <i>Rosa nutkana</i>	I							
Oregon geranium <i>Geranium oregonum</i>	I							
Rosy checkermallow <i>Sidalcea malviflora</i> ssp. <i>vigata</i>	I							
Many-leaved lupine <i>Lupinus polyphyllus</i>	I							
Mules' ears <i>Wyethia angustifolia</i>	I							
Lovage <i>Ligusticum apiifolium</i>	I							
Oregon phacelia <i>Phacelia nemoralis</i> ssp. <i>oregonensis</i>	I							
Yarrow <i>Achillea millefolium</i>	I							
Showy milkweed <i>Asclepias speciosa</i>	I							
Mad dog skullcap <i>Scutellaria lateriflora</i>	I							
Douglas aster <i>Symphyotrichum subspicatum</i>	I							

Adapted from a timetable by B. Newhouse, May 2014 posted on the Benton Soil and Water Conservation District at <https://bentonswcd.specialdistrict.org/files/43928b68f/Bloom-Time-Table-of-Pollinator-Plants-2014-05-15.pdf>

Access

Access is an important consideration in forest garden design. Movement of supplies, tools, and harvest materials must be accommodated, particularly during peak management and harvest periods. The size and scale of the system will influence access patterns, including the placement and width of paths or lanes. It is useful to maintain a record of plant species and their seasonal management needs, as this informs how and when different areas must be accessed.

Design access routes to support tasks such as pruning, harvesting, and material transport. Fruit and nut trees often require ladders for pruning and harvest, as well as space to manage and remove cut branches. Although plantings may appear small at first, access should be designed with mature plant size in mind to avoid crowding and inefficiencies over time.

Pathways and access corridors should be sized and arranged to accommodate ongoing maintenance, movement of materials, and ease of harvest, while also contributing to the overall functionality and spatial organization of the system.

Animals and pest control strategies

Fruit production in a forest garden often attracts wildlife and insect pests, making ongoing observation and management essential for maintaining a reliable harvest. Regular monitoring throughout the year, especially as fruit begins to ripen, helps identify potential issues early. In areas with significant wildlife pressure, fencing may be necessary; for example, an approximately 8-foot-tall double fence is commonly used to deter deer, while smaller animals such as squirrels and raccoons are more difficult to exclude and may require additional strategies.

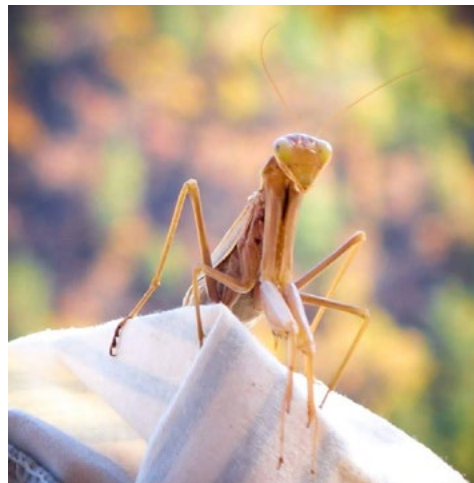
A wide range of pests can affect fruiting crops, some generalists and others species-specific. Careful observation and identification of pest damage allows for informed responses based on each organism's life cycle and habitat preferences.

Integrated Pest Management (IPM) provides a framework for managing these challenges through a combination of ecological and cultural practices. These include supporting beneficial insects, improving habitat conditions, and maintaining healthy plant systems. Enhancing soil health and ensuring adequate airflow can reduce plant susceptibility to pests. Sanitation practices including removing fallen or damaged fruit are especially important, as many pests complete part of their life cycle on the ground before emerging in the following season. In some systems, integrating animals such as poultry can assist with this cleanup.

Beneficial organisms play a key role in regulating pest populations. Predators and parasitoids can significantly reduce pest pressure when supported by appropriate habitat. These include:

- **praying mantises** (*Mantodea*)
- **lady beetles** (*Coccinellidae*)
- **parasitoid wasps** (*Hymenoptera*)
- **spiders** (*Araneae*)
- **lacewings** (*Neuroptera*)

Designing understory plantings that provide nectar, pollen, and shelter throughout the year helps maintain these populations and contributes to a more balanced and resilient forest garden system.



Left:
Praying mantis.

Right:
Lady beetles.

Photos courtesy
of Michael Godfrey

Disease control—design for airflow

Poor airflow, both above and below ground, can contribute to fungal disease in a forest garden. Common examples in the Pacific Northwest include **fire blight**, **powdery mildew**, **anthracnose**, **scab**, **canker**, and various **rots**. Good drainage and soil structure are critical for preventing disease below ground, so soil preparation prior to planting is essential.

Conducting a percolation test can help assess drainage conditions. Applying clean, disease-free wood chip mulch supports soil health while reducing pathogen spread. Above ground, annual pruning improves air circulation through the canopy, and adequate spacing between plants helps reduce humidity and disease pressure. These combined practices create conditions that are less favorable for fungal development and support overall plant health.

Disease control guidance from OSU Extension:

- [PNW Insect Management Handbook](#)
- [Managing Diseases and Insects in the Home Orchard](#)

Establishment and management considerations

Forest gardens can range from highly complex ecosystems to more simplified systems, depending on management goals and capacity. Critical tasks such as soil preparation, planting, pruning, pest and weed control, thinning, and harvesting are carried out differently than in conventional production systems.

High species diversity and structural complexity can limit mechanization, so many forest gardens rely on hand labor or small-scale equipment. However, when designed in conjunction with other agroforestry patterns such as alley cropping, some mechanized access can be incorporated. On larger sites, equipment access can aid in fruit collection, debris removal, and transporting bulk materials.

Regular observation is essential for maintaining system health and productivity. Management often emphasizes anticipating potential challenges and addressing them through design, using plant selection, spatial arrangement, and ecological relationships to reduce the need for reactive interventions over time.

Designing for the ultimate size

Plan for the mature size of plants when designing a forest garden. In the early stages, sunlight between young trees creates opportunities to grow sun-loving understory species. As trees and shrubs mature, the canopy reduces available light, and many of these sun-adapted plants will decline as part of natural succession. Although this results in the loss of some earlier yields, it is offset by increased production from the intended long-term species.

Establishing companion plants early, particularly those that attract beneficial insects, supports the development of stable predator and pollinator populations before pest pressures increase. Similarly, incorporating plants grown for mulch and biomass in the early phases helps build soil organic matter and fertility, supporting long-term system productivity.

Soil building

Plan forest garden installation in stages based on site size and complexity, with early emphasis on soil preparation. Establish soil conditions before planting trees by assessing nutrient availability and addressing any deficiencies through appropriate amendments. Soil testing provides essential baseline information, and local extension services can offer region-specific guidance.

Fruit and nut trees generally perform well in soils supported by woody mulch, which encourages fungal-dominated decomposition. Mulch derived from disease-free deciduous trees is preferred, while bark mulch is less effective for moisture retention. Avoid mulch from species known to produce allelopathic compounds that inhibit plant growth. Deep mulching can enhance microbial activity and nutrient cycling, and these processes can be further supported by incorporating plants with deep taproots and high biomass production that can be periodically cut and left in place as mulch.

Where existing vegetation such as grass is present, sheet mulching can be used to prepare planting areas. This involves layering cardboard over the ground to suppress vegetation, watering each layer, and covering it with wood chips. Over a period of six months to one year, the materials decompose, improving soil structure and fostering microbial activity in preparation for planting.

During early establishment, annual crops can be used to take advantage of higher light availability. Sprawling species such as winter squash can function as living groundcover, producing biomass while suppressing weeds. Trees are often planted with establishment guilds—plant communities designed to support early growth. These typically include nitrogen-fixing species such as:

- **lupine** (*Lupinus spp.*)
- **clover** (*Trifolium spp.*)
- **fava beans** (*Vicia faba*)

pollinator-supporting plants such as:

- **sage** (*Salvia spp.*)
- **lavender** (*Lavandula spp.*)

and dynamic accumulators or soil-conditioning plants such as:

- **comfrey** (*Symphytum x uplandicum*)
- **burdock** (*Arctium lappa*)
- **daikon radish** (*Raphanus sativus var. longipinnatus*)

Together, these species enhance soil fertility, improve structure, and support the successful establishment of long-term plantings.

Animals

Animals can be used during site preparation and system establishment, depending on existing conditions.

- **Chickens** can disturb annual vegetation and grasses through scratching, and when concentrated in an area, can remove surface vegetation while contributing manure that supports soil fertility. They should be removed prior to planting to allow trees and other perennial species to establish.
- **Goats** can be used to clear dense or woody vegetation, such as blackberry thickets, but will also browse on desirable plants, including fruit trees, and should be excluded before planting begins.

Animals can also be integrated into established forest garden systems under controlled conditions. Their use is typically managed through rotational grazing to align with seasonal needs and plant growth stages. When properly timed and stocked, animals can assist with weed suppression, pest reduction, nutrient cycling, and cleanup of fallen fruit.

Management considerations include preventing damage to plant roots, minimizing compaction, and protecting vulnerable plantings. Animal access is generally most appropriate after harvest or prior to key growth periods, when the risk of damage to crops is reduced.

Pruning

In the Pacific Northwest, fruit and nut trees generally require annual pruning to maintain structure and ensure adequate airflow through the canopy, which helps reduce disease pressure. For pome fruits such as apples, pears, and quinces, late winter (typically late January through February) is a common time for pruning, after the heaviest rains have passed and before buds break dormancy. These species can also be pruned in summer, with winter pruning typically promoting vegetative growth and summer pruning used to refine structure and manage size.

Stone fruits in the *Prunus* genus, including plums, cherries, and peaches, are more susceptible to fungal infections when pruned during wet conditions and are therefore best pruned in the summer.

Proper sanitation is important when pruning. Tools should be cleaned and sterilized between cuts or between trees to reduce the risk of spreading disease. A range of pruning techniques and systems exist for different species and management goals, and detailed guidance is available in specialized horticultural resources.

Suggested references from WSU Extension include:

- [Training and Pruning Your Home Orchard](#)
- [Pruning Equipment for Home Gardeners](#)

Irrigation

Watering is typically required during the summer months, especially during system establishment. The amount of water needed varies based on tree size and soil type. Increasing soil organic matter significantly improves water retention; for example, approximately two inches of organic matter in the top foot of soil can greatly reduce irrigation needs. This highlights the importance of soil preparation at the outset.

Soils with high organic matter content and a protective mulch layer require less supplemental water during dry periods. Companion plants and guilds can further support moisture retention by shading the soil surface and contributing organic material through leaf drop. Wood chips are commonly applied and replenished as needed to maintain soil cover and improve long-term water-holding capacity.

Several options exist for delivering water in a forest garden, with the appropriate system depending on available resources and management preferences. Hand watering is low-cost but labor-intensive and allows for close monitoring of plant needs. Overhead irrigation systems can be adapted to diverse plantings, while drip irrigation offers targeted water delivery with greater efficiency. As soil health improves and plant systems mature, overall irrigation requirements typically decrease.

Seasonality

Forest gardens in the Pacific Northwest experience distinct seasonal changes that shape management activities throughout the year.

In **winter**, much of the landscape appears dormant, though some species such as primroses (*Primula* spp.) and witch hazel (*Hamamelis virginiana*) may be in bloom.

Late winter is generally the preferred time to prune pome fruits such as apples and pears to encourage vigor, while pruning of stone fruits is avoided due to increased risk of disease in wet conditions. This period is also suitable for applying nutrients to support growth as daylight increases.

In **spring**, herbaceous plants and early perennials emerge, including stinging nettle, miner's lettuce, rhubarb, and sorrel (*Rumex acetosa*). If fungi have been introduced, mushrooms may also be present. Fruit

trees begin to bloom, and pollinators such as mason bees become active. Early monitoring for disease is important as buds break, allowing for timely intervention if needed. Mulch is ideally applied before the end of the rainy season to retain moisture and moderate soil conditions heading into the dry summer months.

Through **late spring** and **summer**, many perennial species continue to grow and flower. Plants selected for biomass production can be cut and used as mulch, supporting soil health and moisture retention. Early fruit harvest begins with strawberries, honeyberries (*Lonicera caerulea*), and salmonberries, followed by a wide range of tree fruits and nuts through the summer.

In **late summer** into **autumn**, apples and pears ripen with certain varieties suitable for storage into the winter months. During this period, management focuses on irrigation where needed, harvesting, and maintaining plant health. In some systems, animals may be rotated through areas after harvest to assist with weed control and nutrient cycling.

In **autumn**, as rainfall returns, conditions may support a flush of mushrooms if fungal species are present. This is also a suitable time for sowing cover crops ahead of winter, particularly when rainfall is forecast. Slow-release mineral amendments, such as rock-based inputs, can be applied during this season, allowing time for gradual integration into the soil. Mulching is typically renewed to protect soil through the winter, supporting long-term soil development and system resilience.

Table 10.1. Temperate climate food forest maintenance calendar

January — Plan for the future	February — Tend to the soil	March — Planting begins
• Map out food forest and dream of the future • Finish seed processing • Weed as needed • Prune fruit trees, berry bushes, and vines; remove any old fruit to prevent rot spores from spreading • Take live cuttings from grapes, kiwis, and <i>Ribes</i> species before they leaf out. Gather branches of forsythia, quince, and flowering cherry to force indoors. • Propagate berry bushes by root layering and dividing • Harvest root vegetables (Jerusalem artichokes, parsnips, potatoes, etc.) and medicinals (elecampagne, comfrey, marshmallow, etc.) • Divide and transplant perennials, strawberries; fertilize • Gather scions • Plant bare-root trees; graft rootstocks • Rake up any diseased leaves and ensure good airflow around woody plants to prevent fungal diseases • Collect windfall branches; compost or create habitat piles; burn if diseased • Inspect stored fruit and cycle out damaged stores • Clean and sharpen tools • Build mason bee homes	• Prune berry bushes; prune and train grapes • Prune <i>Pome</i> fruit trees for production and to stimulate new growth; allow for open branching structure to maximize sunlight collection and air flow • Compost and amend soil • Fertilize, divide spring ephemerals, e.g. rhubarb, asparagus • Add a new layer of woodchips to encourage soil fungi • Remove any diseased wood from the site • Take live cuttings from grapes, kiwis, and <i>Ribes</i> species before they leaf out • Propagate berry bushes by root layering and dividing • Inoculate mushrooms in logs and in the ground • Divide and transplant perennials, strawberries • Gather scions • Plant bareroot trees; graft rootstocks • Repair any damaged trellises • Test soil • Collect windfall branches; compost or create habitat piles; burn if diseased • Inspect stored fruit and cycle out damaged stores	• Record bloom dates for fruit trees • Renew woody mulch as needed • Begin to transplant new plants into the garden • Compost and amend your soil • Sprinkle borax as needed • Prune and fertilize berry bushes • Inoculate mushrooms • Divide and transplant strawberries, raspberries • Graft rootstocks. • Build trellises for vining plants • Train blackberries and raspberries on their supports • Protect plants from the deer and other wildlife • Fertilize bamboo • Patrol for slugs • Divide spring ephemerals, e.g. rhubarb, asparagus • Sow hardy annual flowers and vegetables • Weed while ground is soft/warm and weeds are young • Tend to mason bee homes • Fertilize spring bulbs • Spray compost tea
April — Tend to leaves	May — Celebrate pollinators	June — You reap what you sow
• Record bloom dates for fruit trees • Plant perennial vegetables • Harvest leafy greens, spring ephemerals, e.g. rhubarb, ramps, and spring garlic • Compost and amend soil; spray with mycorrhizal inoculant • Inoculate mushrooms • Weed while ground is soft/warm and weeds are young • Mulch to prevent weeds and prepe for the dry season • Build trellises for vining plants • Protect plants from deer and other wildlife • Patrol for slugs • Transplant perennials and young starts • Dry herbs for tea • Record last frost date • Control foliar disease by using compost tea • Apply compost tea for scab, fireblight, bacterial blast, and powdery mildew • Patrol for currant worms on gooseberries and currants • Prune spring flowering shrubs after they are finished blooming	• Harvest leafy greens, edible flowers • Record bloom dates for fruit trees • Place dropcloths under any trees or shrubs that might be infested with larvae to discourage pupation • Hang sticky traps as needed • Weed • Do the last of your transplanting. • Thin fruit as needed, once it is as big as a thumbnail • Build trellises for vining plants • Protect plants from deer and other wildlife • Amend soil • Harvest bamboo shoots • Patrol for slugs • Weed while ground is soft/warm and weeds are young • Mulch to prevent weeds and prepare for the dry season • Plant insectary plants to attract beneficial insects • Prune woody plants • Harvest leafy vegetables to encourage more production • Dry herbs for tea • Release beneficial insects if needed to control pests	• Harvest strawberries • Cut back comfrey and other dynamic accumulators for mulch • Harvest medicinal leaves and flowers • Protect plants from deer and other wildlife • Continue to mulch and cut back understory plants for good airflow • Train grapes, kiwis, blackberries, and raspberries on trellises • Prune grapes and kiwis to discourage excessive growth • Remove water sprouts from trees • Inspect plants for insect problems. Hang sticky traps as needed • Water deeply as needed (ample water encourages good, juicy fruit production) • Cut back flowers to encourage more blooms • Harvest leafy vegetables to encourage more production • Set out any scare tactics to prevent birds and squirrels from eating berries • Set out traps for insect pests • Dry herbs for tea

Table 10.1 continued

July — Eye on the bounty	August — Celebrate the harvest	September — Save seeds
• Harvest berries • Preserve surplus berries for winter • Cut back comfrey and other dynamic accumulators for mulch • Harvest medicinal flowers and fruits • Inspect plants for insect problems; hang sticky traps as needed • Water deeply as needed (ample water encourages good, juicy fruit production) • Cut back flowers to encourage more blooms • Dry herbs for tea • Gather any fruit drops and patrol for disease • Harvest early apples, plums, and pears	• Harvest fruit and put up for the winter as needed • Record harvest dates • Summer prune stone fruit trees, <i>Pome</i> fruits for structure and to limit new growth • Begin bud grafting • Provide support for heavy branches on fruit trees • Cut back comfrey and other dynamic accumulators for mulch • Water deeply as needed (ample water encourages good, juicy fruit production) • Inspect plants for insect problems; hang sticky traps as needed • Cut back flowers to encourage more blooms • Begin to collect seeds • Dry herbs for tea • Scatter seed of winter salad plants (chervil, mâche, chickweed) • Prune raspberries and blackberries once they are done fruiting • Control for aphids to prevent black sooty mold on plants • Gather any dropped fruit and patrol for disease	• Save seeds • Harvest fruit and put up for the winter • Record harvest dates • Plant spring flowering bulbs • Run chickens below fruit trees and berry bushes to help with fruit clean-up • Inoculate mushrooms • Water deeply as needed • Prune raspberries once they are finished fruiting • Dry herbs for tea • Remove any diseased plant material • Plant cover crops • Clean up fallen fruit often
October — Nourish the roots	November — Prepare for winter	December — Assess the past year
• Harvest fruit and put up for winter • Winterize irrigation and protect tended plants as needed • Run chickens below fruit trees and berry bushes to help with fruit clean-up • Clean up fallen fruit often • Inoculate mushrooms • Prune raspberries once they are done fruiting • Save seeds • Patrol for slugs • Cut back plants that have died back • Mulch with ramial woodchips • Remove any diseased plant material • Begin to propagate and divide perennials • Divide strawberries • Rake leaves and apply as mulch or add to compost pile • Record harvest dates and the first frost • Add lime as needed	• Save and process seeds • Harvest fruit and put up for the winter • Do not leave any fruit in the trees • Destroy diseased fruit • Rake and compost leaves • Inoculate mushrooms • Harvest medicinal roots • Divide and transplant strawberries • Mulch • Plant spring blooming bulbs • Eat the bounty • Mulch berry bushes for winter protection • Transplant trees and shrubs • Apply lime as needed • Drain outside hoses and store in a warm area • Record first frost • Dig dahlias and yacón to bring inside for the winter	• Harvest roots • Divide and transplant strawberries • Map out food forest and dream of the future • Remove any old fruit still on trees, shrubs, and vines to prevent rot spores from spreading • Transplant perennials as long as the ground is not frozen • Plant spring blooming bulbs • Process seeds • Eat the bounty • Divide and transplant rhubarb • Tend to the compost pile, cover to prevent it from getting too much water • Clean and sharpen tools • Make repairs • Check trellises and any supports to ensure stability in the winter

Summary

Forest gardens are a valuable agroforestry practice for increasing both food production and ecological function in urban and rural settings. They can reflect the structure of native ecosystems while incorporating species that provide meaningful yields and ecological benefits. By drawing from regional plant communities, forest gardens can support wildlife, improve soil health, and enhance site conditions. In the Pacific Northwest, native edible plants offer a diverse template for designing productive and resilient systems.

In agricultural contexts, forest gardens provide an opportunity to diversify into perennial production systems that contribute to long-term soil carbon storage while generating marketable yields. These systems can produce a wide range of fruits, nuts, perennial vegetables, and herbs while also helping to reduce pest and disease pressure, contributing to both ecological stability and economic resilience.

In urban environments, forest gardens improve stormwater infiltration and reintroduce food production into densely populated areas. Perennial systems can produce substantial yields over time, contributing fresh produce to communities where access may be limited. These systems can be integrated into a variety of spaces, including schools, places of worship, residential areas, and public rights-of-way, while also supporting urban biodiversity and habitat.

Forest gardens are inherently site-specific, shaped by environmental conditions and management goals. When designed effectively, they provide long-term benefits in the form of food production, ecological restoration, and enhanced landscape function across a wide range of contexts.

Additional resources

- Community Food Forests. <https://communityfoodforests.com/community-food-forests-map/>
- The Community Food Forest Handbook (2018) by Catherine Bukowski and John Munsell. Chelsea Green Publishing, LLC. <https://www.chelseagreen.com/product/the-community-food-forest-handbook/>
- Creating a Forest Garden—Working with Nature to Grow Edible Crops (2010) by Martin Crawford. Green Books, UK.
- Edible Forest Gardens, Vol. 1 (2005) by Dave Jacke and Eric Toensmeier. Chelsea Green Publishing, LLC. <https://www.chelseagreen.com/product/edible-forestgardens-volume-1/>
- Edible Forest Gardens, Vol. 1I (2005) by Dave Jacke and Eric Toensmeier. Chelsea Green Publishing, LLC. <https://www.chelseagreen.com/product/edible-forestgardens-volume-ii/>
- Forest Gardening: Cultivating an Edible Landscape, 2nd Edition (1996) by Robert Hart. Chelsea Green Publishing, LLC.
- Perennial Pathways: Planting Tree Crops: Designing & Installing Farm-Scale Edible Agroforestry. Savanna Institute. Champaign, IL. <https://www.savannainstitute.org/planting-tree-crops/>
- Urban Agroforestry Technical Guide (2023) by Katherine Favor, Hannah Hemmelgarn, and Kelsi Stubblefield. <https://attra.ncat.org/publication/urbanagroforestry/>
- USDA NRCS PLANTS Database. <https://plants.usda.gov/home>

FOREST GARDENS

at Sweetwater Farm

Whidbey Island, Washington

By Katherine Favor, *National Agroforestry Center*

Jake and Aja Stewart are owners and operators of Sweetwater Farm, a 24-acre farm on Whidbey Island. Sweetwater Farm is highly diversified, with orchards, vegetable gardens, livestock, and a food forest.

Food forests (also called forest gardens) are a type of forest farming system. The NRCS defines forest farming as the management of stands of trees or shrubs in coordination with understory plants or nontimber forest products.^[1]

While there are many ways to design forest farming systems, food forests in particular are characterized by their multiple layers of overstory and understory vegetation, managed together to create an integrated system that mirrors the structure of an early-succession forest while producing harvestable products.

At Sweetwater Farm, the food forest consists of layers of food- and medicine-producing trees, shrubs, berries, forbs, herbs, mushrooms, and other crops, all planted beneath the canopy of a managed native forest. “We’re basically working with the existing forest to add food production capacity,” explains Jake. The various species in the food forest produce a diversity of harvestable crops while also providing ecological functions that support the system as a whole.

How it started

Jake and Aja began their farming journey 15 years ago in Austin, Texas. However, when their well went dry, their farm income dried up as well. Seeking a place with more abundant water, they eventually settled on Washington’s Whidbey Island, which receives an average of 31.6 inches of rain per year.^[2]



Above: Sweetwater Farm’s diversified production system includes orchards, vegetable gardens, livestock, and a food forest managed under the shade of a native forest canopy.

Photo courtesy of Jake Stewart

There they started Sweetwater Farm. “We named it after the sweet water that we were pursuing,” explains Jake. “We consider ourselves voluntary climate migrants in a way. We came here seeking water, and that’s what we found.”

Today, Sweetwater Farm’s food forest produces an abundance of food that is sold at their farm stand and through a local cooperative. The Stewarts designed their farm to rely on few external inputs, and to provide benefits to the ecosystem as a whole, including the wildlife that call Whidbey Island home.

Design and establishment

Sweetwater Farm is primarily composed of forested land with native tree species such as Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), cedar (*Cedrus spp.*), bigleaf maple (*Acer macrophyllum*), and alder (*Alnus spp.*). “We have other areas of the farm where we cultivate rows of vegetables, but our main strategy for food production is incorporating harvestable crops into our forest,” says Jake. Working with nature is a central goal at Sweetwater Farm. “It looks wild and unruly, but that’s because our production systems are fitting into the natural landscape. We’re trying to tuck production into the existing ecosystem, not keep them separate.”

The first step in this process was identifying and creating open spaces in the forest where food-producing trees could be planted. Jake and Aja began by deciding which existing tree species to retain and which to remove. When they first bought their property, some pockets of the forest had already been cleared by the previous owner for timber harvesting. These openings were the first locations where they planted fruit and nut trees.

They conducted a detailed forest inventory and chose to leave some standing dead trees, or snags, as habitat for wildlife such as native bees and great-horned owls. They also felled several cedar trees, which they milled into lumber to build their home, fence, and other farm structures. Most of the remaining dead, diseased,

and lower-quality trees were also removed, creating additional gaps of light in the forest canopy.

Rather than removing the felled biomass, the Stewarts chipped most of the small diameter logs and branches in place with a tractor-mounted wood chipper. The resulting mulch created a thick, moisture-retaining layer that fostered the growth of beneficial mycorrhizal fungi. They planted food-producing trees directly into these newly-opened, mulched areas. They also chose to leave some downed logs intact, which they then inoculated with oyster (*Pleurotus ostreatus*) and shiitake mushrooms (*Lentinula edodes*).

In the understory, Jake and Aja cultivate a diverse mix of crops. Small trees like Szechuan pepper (*Zanthoxylum piperitum*), and shrubs like goji berry (*Lycium barbarum*), grow under the partial shade of taller fruit trees, while casting their own shade on other crops below. Blackberry brambles (*Rubus spp.*), salal (*Gaultheria shallon*), and native evergreen huckleberry shrubs (*Vaccinium ovatum*) fill the mid-story layer, helping maximize vertical growing space beneath the tree canopies. Nitrogen-fixing shrubs like sea buckthorn (*Hippophae rhamnoides*) are also planted in this layer. In addition to producing medicinal berries, sea buckthorn also enriches the soil by fixing nitrogen, reducing the need for external fertilizer inputs.

Vines such as grape (*Vitis spp.*) and hardy kiwi (*Actinidia arguta*) climb high into the canopy, using the trees and shrubs as natural trellises. In the lower layers of the food forest, the Stewarts grow oyster and shiitake mushrooms on downed logs, and they forage for naturally occurring chanterelles (*Cantharellus cibarius*) on the forest floor.

Above right: Huckleberry, salal, and trailing blackberry grow under a managed native forest overstory.

Right: Sheep graze resident vegetation and add fertility to the outer edges of the food forest, which contain apple, Italian plum, and hawthorn trees.

Photos courtesy of Jake Stewart



Climate risks and adaptation strategies

Warmer winters

Tree species selection was an important part of the Stewarts' farm design process. To guide their decisions, they used the USDA Plant Hardiness Zone Map—a tool that maps the average annual extreme minimum winter temperature across different regions—to determine which perennial species would be suitable for their site. Currently, Whidbey Island is classified as Zone 8b, meaning average minimum winter temperatures range between 15 and 20°F.^[3] However, climate models project that by the end of the century, the region may shift to Zone 9a, with coldest average temperatures ranging from 20 to 25°F.^[4]

Because trees can live for several decades or even centuries, Jake and Aja prioritized long-term climate adaptability in their planting choices. “We’re leaning into the next plant hardiness zone to prepare for what the conditions might be here in the future,” says Jake.

The Stewarts selected species that are expected to thrive in both Zones 8b and 9a. On the sunnier edges of their forest, they planted sun-loving trees and shrubs suited for both of these zones. These include:

- **apple** (*Malus domestica*)
- **Washington hawthorn** (*Crataegus phaenopyrum*)
- **Italian plum** (*Prunus cocomilia*)
- **European chestnut** (*Castanea sativa*)
- **walnut** (*Juglans regia*)
- **American hazelnut** (*Corylus americana*)
- **pistachio** (*Pistacia vera*)
- **jujube** (*Ziziphus jujuba*)
- **pineapple guava** (*Acca sellowiana*)

In more shaded interior areas of the forest, they chose tree species that can tolerate partial shade, such as:

- **honeyberry** (*Lonicera caerulea*)
- **pawpaw** (*Asimina triloba*)
- **mulberry** (*Morus spp.*)
- **aronia** (*Aronia melanocarpa*)

Some of these species have not yet been widely cultivated in Washington, but Jake and Aja are excited to experiment and observe how they perform.

“A lot of what we’re planting is a bit of a gamble,” says Jake. “We’re letting die what wants to die. And we’ll plant more of what does well.”

Management

One of the Stewarts' primary goals is to promote healthy soil, with a particular focus on supporting the mycelial network that underpins the food forest's ecosystem. “Focusing on the soil food web is a big part of our philosophy,” says Jake. “This means protecting the soil structure, reducing compaction, preserving the topsoil layer by preventing erosion, and keeping the topsoil covered.”

To support these goals, the Stewarts incorporate animals into their system at certain times of the year. Rotationally grazed sheep help manage weeds. Ducks, turkeys, and chickens lightly disturb the soil surface as they forage, without disturbing deeper mycelial networks. After livestock are rotated through, any remaining weeds are cut by hand or with a weed whacker, leaving root systems intact to maintain soil structure and microbial life. The livestock also contribute to soil fertility and help control pest

populations—particularly snails and slugs—thereby reducing the need for nutrient inputs and pesticides.

“Our goal for our children one day is that the soil they inherit will be richer than what it started as, and that the farm’s input costs go down,” says Jake. “We’re trying to bank nutrients instead of spending them, while using as few external inputs as possible.”

Conclusion

At Sweetwater Farm, Jake and Aja Stewart are building a resilient, ecologically-grounded food system through thoughtful design, climate-adaptive species selection, and soil-focused management. By integrating multiple layers of tree crops, shrubs, vines, mushrooms, and other crops into their food forest, they can produce food while supporting the surrounding forest ecosystem.

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RIPARIAN FOREST BUFFERS

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Definition

A riparian forest buffer is an intentional agroforestry practice consisting of a managed area of trees, shrubs, and other plants growing alongside a body of water.

Riparian forest buffers protect the integrity of stream channels and shorelines, reduce the impacts of upland pollution on waterbodies, and restore the integrity of critical aquatic and terrestrial habitat for a wide variety of wildlife. More than three-quarters of Washington and Oregon's land-based species use riparian forest buffers as habitat. Because of their positions in the landscape, riparian forest buffers play a critical role in the movement of water and non-point-source pollution through watersheds. They also provide shade, as well as large woody debris, which in turn fosters habitat and refugia for fish.

Riparian areas typically have a high-water table and can be subject to periodic flooding and influence from the adjacent water body. Riparian areas are found adjacent to perennial, intermittent, and ephemeral streams, lakes, and estuarine shorelines. Riparian habitats represent a nexus of biodiversity where species richness and abundance are disproportionately high compared to nearby terrestrial habitats.

Unfortunately, riparian areas are some of the most degraded habitats across the United States. More than half of U.S. wetlands and up to 90 percent of riparian areas have been extensively altered and degraded.

Riparian degradation negatively impacts rivers and streams as they lose their ability to support fish and wildlife, reduce flooding impacts, purify water, along with negative impacts on a whole host of other functions. In the Pacific Northwest nearly 85 percent of historical wild salmon populations are either extinct, endangered, threatened, or of special concern. The decline of fish and other wildlife is intimately linked to the degradation of riparian forest buffers.

The true loss of riparian and wetland habitat in the Northwest complex is not known, but estimates exist

Above: Riparian forest buffer at Nehalem River Ranch in the Coast Range of Oregon.

Photo courtesy of Mitchel Davidovitz

based upon historical survey documents and maps. Since the settlement of Washington by non-Indigenous peoples began in the early 1800s, between 50 and 90 percent of the region's riparian ecosystems have been lost or heavily modified.

Restoring and protecting riparian forest buffers in Washington and Oregon is a critical step in recovering threatened wild salmon populations and other wildlife, protecting farmlands from flooding damage, and for producing foods and medicines from intentional tending of these spaces. Replanting native vegetation and removing invasive species like Himalayan blackberry can stabilize eroding stream banks and filter runoff before it pollutes regional waterways.

Although the knowledge and use of riparian forest buffers is relatively new as an agricultural practice in the United States, riparian areas have a long history of stewardship and utilization by Indigenous cultures. In the Pacific Northwest, Indigenous peoples are deeply tied to riparian ecosystems through salmon, recognized as a **Cultural Keystone Species**, whose lifecycles depend on intact, functioning riparian forests.

The depth of this relationship is reflected in local Indigenous oral histories and place names, and archaeologically; roughly half of the nearly 200 state-registered prehistoric sites in King County, Washington are located within 200 feet of waters of statewide significance, including major village sites.^[1]

Riparian areas are natural producers of berries, seeds, roots, herbs, and other plant parts used by Indigenous communities, and the abundance of wildlife species within these zones complemented the fisheries resources of the adjacent streams and lakes.

Indigenous communities used a variety of management practices included burning, irrigating, coppicing, pruning, selective harvesting, sowing, and weeding to manage the production of foods, medicines, and materials, making riparian forests some of the most intentionally shaped and modified ecosystems

Benefits and challenges

Benefits

- Reduce sediment, organic material, nutrients and pesticides in surface runoff
- Reduce nutrients and other chemicals in shallow groundwater flow
- Create wildlife habitat and provide wildlife corridors
- Create shade and lower water temperatures to improve habitat for aquatic organisms
- Provide a source of detritus and large woody material for aquatic and terrestrial organisms
- Provide a harvestable crop of timber, fiber, forage, fruit, nuts, berries or other crops consistent with other intended purposes
- Stabilize eroding stream banks and reduce scour erosion in the floodplain
- Increase carbon storage in plant biomass and soils
- Reduce water energy and soil deposition onto working lands from flood events
- Enhanced aesthetics

Challenges

- Different management techniques compared to adjacent working land
- Loss of crop ground or pasture
- Challenges with artificial subsurface drainage systems (tiles)
- May reduce available soil moisture for crops immediately adjacent to the buffer
- Provides shade which may reduce growth of crops immediately adjacent to the buffer
- Provides habitat for wildlife that may feed on adjacent crops

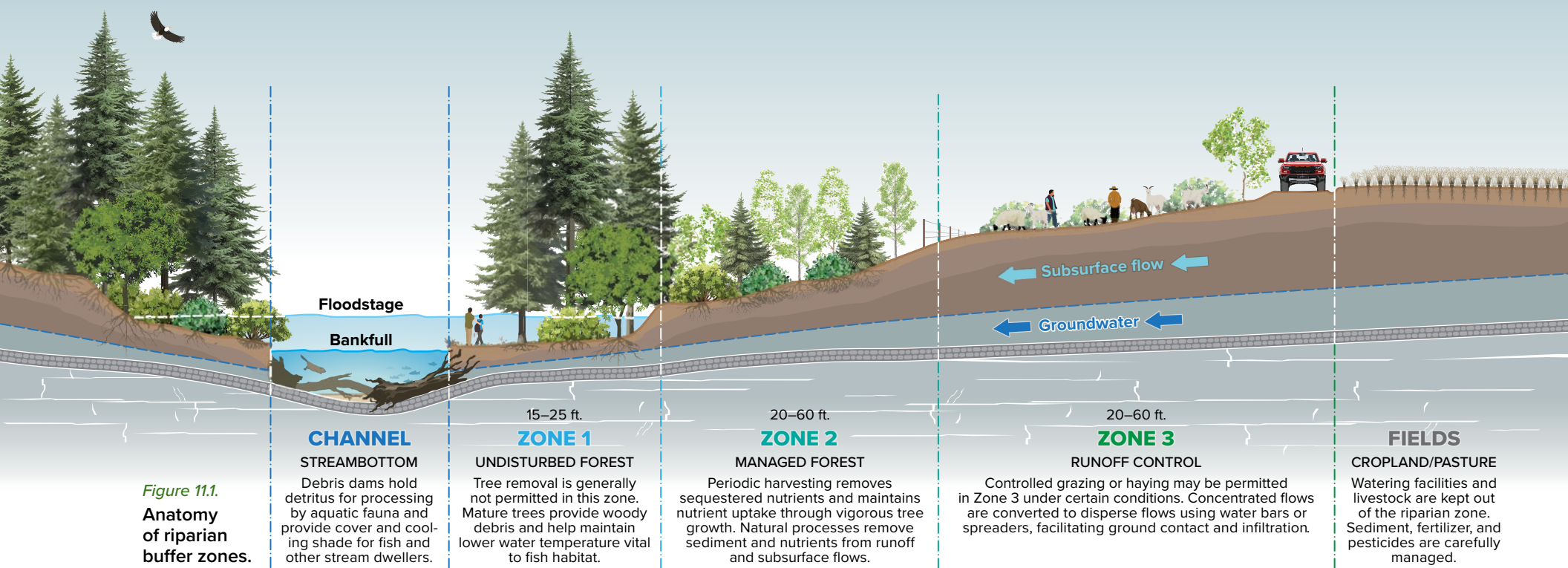
under Traditional Ecological Knowledge systems. For instance, in the Pacific Northwest, Indigenous communities in the Puget Sound region tended riparian patches of salmonberry (*Rubus spectabilis*), crabapple (*Malus fusca*), and willow (*Salix spp.*) along river margins to encourage vigorous growth, maintain productive patches, and enhance wildlife habitat.^[2]

Along the Columbia River communities managed floodplain productive zones of willows, Indian hemp (*Apocynum cannabinum* L.), and hazelnut (*Corylus cornuta* var. *californica*) for food, weaving materials, and cordage, demonstrating intentional shaping of riparian plant communities. Across these landscapes, culturally important species were maintained in

productive patches, creating semi-domesticated “ethnoecosystems” that remained stable and highly productive for centuries.

Indigenous land management practices also shaped riparian ecosystems through large engineered structures such as fishing weirs and platforms, which functioned as living components of waterways and shorelines, influencing hydrology, sediment movement, and habitat complexity.

Significant colonization began in Oregon in the early 1800s and increased into Washington in the 1850s. By the end of the 19th century, the Industrial Revolution ushered in the mechanization of natural resource



extraction, which had significant impacts on forested riparian ecosystems along most of the major rivers in the region.

Beginning in the 1950s and 1960s, concerns about damage to fish habitat and water quality as a result of continuous timber harvesting led policy makers to consider best management practices to mitigate the negative effects of forestry activities.

By the late 1960s, retaining buffer strips of existing riparian forest, commonly referred to as streamside management zones, were encouraged with the primary objectives being provision of shade and minimization of streambank erosion.

In the 1980s, researchers began to document that existing and planted riparian forest buffers could reduce nonpoint source pollution in agricultural landscapes. Riparian forest buffers became a recognized USDA practice in the 1996 Farm Bill.

In addition to being used in forested and agricultural landscapes, riparian forest buffers are also being implemented in suburban and urban landscapes to address issues including water quantity and quality, recreation, and biodiversity. Historically, riparian forest buffers were viewed primarily as a conservation practice; however, increasing recognition of their production potential has led to growing interest in multifunctional riparian buffers that provide both ecological and economic benefits.^[3]

Special assessment considerations

Riparian areas are active landscapes that are frequently subject to flooding and other natural disturbances. The success of a riparian forest buffer is dependent upon selecting and managing for suitable species that can thrive in this dynamic riparian environment while delivering the desired functions and purposes. This section covers general attributes

and considerations for identifying plant species that can grow and thrive in a riparian forest buffer as well as other important factors to consider when selecting species.

Different vegetation communities occur in riparian zones due to varying soils and hydrologic conditions. One of the most important considerations is to match species with the hydrology and flooding regime. While not all riparian areas will have each of the zones depicted in **figure 11.1**, this cross section provides a conceptual layout for understanding species locations relative to streambank position and water table and can provide a guide for riparian forest buffer design. Depending upon the desired objectives, a riparian forest buffer may not extend the complete width of the riparian floodplain.

Design

Designing an effective riparian forest buffer requires acknowledging that these are active, dynamic landscapes. When considering riparian buffer design it is important to understand farmer/landowner objectives and concerns, major functions of the buffer, present land-use, soils, geology, and water table location. There are many considerations in design and many good resources exist to help in design based on a wide range of factors.

A thorough site assessment and a good conversation with the site steward is always the best place to start. Consider your ecological zone, and assess existing native plant species growing and adapted to the area.

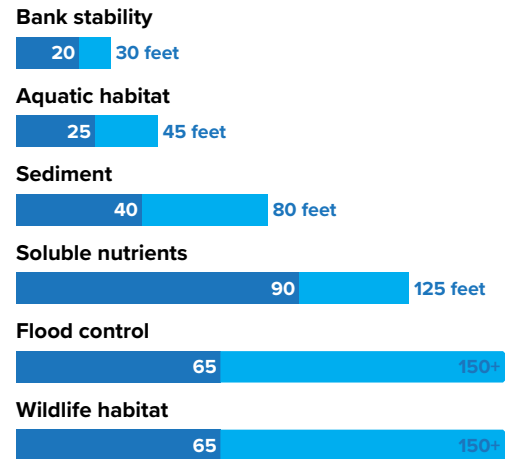
The width of the buffer is an important factor into how effective the buffer is at performing ecological functions. The width required also depends on the specific ecological function, as shown in **figure 11.2**. For example, riparian buffers used for flood control require substantially more area, as there needs to be room for the water to flow into the buffer and for the energy of flowing water to be dissipated by the vegetation. Narrow buffers will suffice for fulfilling goals of provisioning of aquatic habitat and shade.

There are additional considerations that need to be evaluated before incorporating species into a riparian forest buffer for harvestable products. Key factors to consider include harvesting methods, timing and labor demand, processing, and whether markets exist for products. In addition, general attributes to consider avoiding include species that are allelopathic (plant inhibits the growth of another), dispersive (too successful at propagating by seed), expansive (spreading vigorously), allergy-inducing (hay fever, etc), persistent (hard to get rid of once planted), sprawling (vigorous vines), and other undesirable attributes such as stinging and thorns.

Other factors to evaluate include whether buffer species may play a role in hosting pests or diseases of adjacent cropping areas.

Figure 11.2.

Recommended minimum and maximum riparian buffers based on conservation goal



Adapted from Schultz, R.C., T.M. Isenhardt, J.P. Colletti, W.W. Simpkins, R.P. Udawatta, and P.L. Schultz. 2009. Riparian and Upland Buffer Practices. Chapter 8 In: H.E. Garrett, (Ed.) North American Agroforestry: An Integrated Science and Practice, 2nd Ed. American Society of Agronomy, Madison, Wis.

When considering growing and selectively harvesting products from a riparian forest buffer, care must be taken not to negatively impact water quality, terrestrial and aquatic habitat, and other functions. Removal of plant parts and the harvesting process can change the structural characteristics and functional diversity of the riparian forest buffer, which may lead to undesirable changes in other functions. Take care to design a riparian buffer that accounts for access for harvest and occasional maintenance to minimize potential damage.

Figure 11.1 above demonstrates the riparian forest buffer planting zones:

- **Zone 1** is an unmanaged woody zone nearest the stream which is followed by Zone 2.
- **Zone 2** is a woody zone that can be managed for income and is bordered by Zone 3.
- **Zone 3** consists of shrubs and herbaceous plants.

These zones become areas where specific plants and management are combined to create a forested riparian buffer that is highly effective at improving and maintaining water quality and aquatic habitat.

Key areas for consideration

Stream channel

Assessment of stream condition includes evaluating channel morphology, streambed substrate composition, and the form and stability of streambanks. Channelized or straightened segments create issues both upstream and downstream of the altered reach.

Historically, many stream channels were straightened, dredged, or otherwise channelized to improve agricultural drainage, reduce localized flooding, or make land available for cultivation or development. While these modifications achieved short-term objectives, they altered natural stream processes and reduced channel stability over time.

Straightening a stream channel increases channel slope, which in turn increases water velocity and the erosive force exerted on the streambed and banks. The increased energy often causes channel down-cutting, or incision, as the stream cuts deeper into its bed both upstream and downstream of the channelized reach. As incision progresses and reaches more resistant bed material, or as bank heights exceed the structural stability of the soil, streambanks begin to collapse. This widens the channel and can result in the loss or degradation of adjacent riparian areas.

Channel stabilization measures, such as boulder weirs and bioengineering techniques, can help reduce erosion and restore channel stability. Because in-stream restoration activities can significantly affect stream processes and aquatic habitat, they should be designed and implemented under the guidance of qualified stream restoration professionals and in accordance with applicable permitting requirements.

Adjacent to the stream (Zones 1 and 2)

Plants growing immediately adjacent to and in direct contact with the upper edge of the streambank can both stabilize bank erosion and serve as a living filter. This area also functions to slow flood waters, filter flood debris, and provide both upland and aquatic wildlife habitat. Selection of the species to provide and augment these functions will depend on their ability to withstand the frequency, magnitude and length of the flooding regime of the site and the depth to the water table during the growing season.

In **Zone 1** (as shown in **figure 11.1**), deep rooted plant species provide bank stability along deeply incised channels. Longer lived woody roots provide reinforcement of the bank soils, shade, and organic matter inputs to the stream channel. If the channel is incised, fast growing riparian trees (such as willow, cottonwood, bigleaf maple, and red alder) should occupy the first two rows adjacent to the channel to allow rapid stabilization of stream banks. These two rows of trees should be allowed to mature and die without removal to provide continuous shade and organic matter for the aquatic ecosystem, unless they are along streams with drainage tiles or other drainage roles. If drainage tile outlets are present, these rows of trees should be allowed to reach maturity but should be harvested to reduce the chance of contributing large woody debris to the channel thereby restricting drainage.

Where woody plant inputs to the channel are not desired, shrubs or deep-rooted grasses and forbs can be planted, although they do not provide the same strength to incised streambanks because of their more rapid growth and decomposition. On streambanks with slopes of 3:1 or gentler (three horizontal feet for every one vertical foot of rise), grasses and forbs can provide effective bank stabilization.

The next two or three rows of trees or shrubs (Zone 2) can consist of riparian or upland species along deeply incised channels where the water table during the growing season is an average of 4 or more feet (1.2 m) below the surface.

Table 11.1. Function and management of buffer zones

Buffer zone	Function	Management
ZONE 1 Beginning near the edge of the stream (fast-growing trees and shrub species)	- Shade the stream and moderate water temperature - Provide bank stabilization - Enhance aquatic habitat with organic matter - Final filter of material moving through the buffer - Reduce velocity of over-the-bank flood waters	- Unmanaged zone, trees allowed to mature and fall into stream contributing important large woody debris - Large woody debris not allowed in streams with tile drainage or other specific drainage functions - Use selective harvest, with replacement from planting or coppice resprouting - Logging equipment excluded - Grazing is excluded
ZONE 2 Beginning at the edge of Zone 1 (fast and slower growing trees and shrub species)	- Provide maximum infiltration - Uptake of non-point source (NPS) nutrients and chemicals - Storage of NPS pollutants - Breakdown NPS pollutants - Provide forest-grown products - Enhanced wildlife habitat - Slow down over-the-bank flood waters - Trap debris moving in flood waters to keep it out of crop fields	- Active management encouraged - Marketable products encouraged from trees and shrubs where feasible - Harvest should stimulate new growth - Avoid soil compacting activities - Grazing excluded - Wildlife activities such as bird watching or lease hunting
ZONE 3 Beginning at the edge of Zone 2 (grass and forb species)	- Slow surface runoff converting concentrated flow to sheet flow - Slowed runoff drops most sediment/debris at outside edge of zone - Remaining sediment is filtered from sheet flow - High infiltration of water delivering NPS nutrients and chemicals to soil filter - Uptake of nutrients and chemicals	- Maintain vigorous vegetative growth - Remove biomass—mow and bale so as not to smother remaining plants - Remove biomass—flash grazing possible with fencing of woody zones - Remove biomass—burn on 3- to 5-year cycle - Work accumulated sediments away from the buffer edge back into the field
On non-recreational or non-incised streams, Zones 1 and 2 are often combined, and management becomes more closely aligned to that of Zone 2 alone. In each of the zones, it is important to recognize the role that buffer health plays in maintaining function. Healthy and actively growing vegetation provides the best capture and utilization of problem NPS nutrients and chemicals prior to their entering waterways.		

Adapted from the Training Manual for Applied Agroforestry Practices, 2024, p. 56.

Where flooding is frequent and flood waters carry significant debris, several rows of multi-stemmed shrubs should be planted at the outer edge of the woody zone (Zone 2) to trap the debris and keep it from being deposited on the grass/forb outer zone or the adjacent crop field or pasture.

Examples of this are:

- **black hawthorn** (*Crataegus douglasii*)
- **black twinberry** (*Lonicera involucrata*)
- **Nootka rose** (*Rosa nutkana*)
- **salmonberry** (*Rubus spectabilis*)

Select species adapted to the soil conditions on the site. Depending on landowner objectives, trees and shrubs that provide potential marketable timber or specialty crops can be used. Use a mix of tree and shrub species either by planting a different kind in each row or by block planting. A mixture prevents loss of benefits if one species fails and provides a more diverse wildlife habitat.

In areas with frequent flooding, trees and shrubs should also be less densely planted so a ground cover of grasses and forbs can be established. Where the trees and/or shrubs completely shade the soil, surface erosion from flood waters can be extensive and counterproductive to the function of the buffer system. It is therefore important to maintain a woody plant spacing that allows enough sunlight to reach the soil to support a substantial understory cover. This spacing depends on species and is usually wider than that recommended for planting timber trees, but narrower than widths suggested for major nut growing plantations.

Management practices such as limbing or thinning may be necessary to maintain adequate sunlight penetration to the ground surface. A balance needs to be established between maximizing tree growth and volume with maximizing the understory growth.

Outer edge (Zone 3)

This zone provides the initial treatment of direct runoff from adjacent land uses. This runoff often occurs as concentrated flow associated with ephemeral gullies, whereas sheet flow or broad, shallow flow is relatively uncommon in cultivated field settings. As a result, the intercepting plant community must form a dense, stiff barrier capable of slowing concentrated flow, promoting flow dispersion, and facilitating sediment deposition.

Reducing flow velocity through Zones 2 and 3 also enhances infiltration, allowing runoff to enter and be filtered by the soil profile. Mixtures of grasses and forbs can be used effectively if the zone is wide

enough. Width will depend on the length and slope of the adjacent crop field. If the grass zone has been established on previously cultivated riparian soil, it will take at least 5-10 years to redevelop the maximum infiltration potential of undisturbed soil.

Where Zone 3 intersects a grassed waterway, a wider, triangular-shaped transition area should be established to create an apron that allows runoff to spread evenly before entering the buffer. Native warm- and cool-season grasses, along with associated forbs, are particularly well suited for this zone because they remain upright under flowing water and typically develop deeper root systems than introduced cool-season grasses. Much of this root biomass is renewed annually, contributing substantial organic matter to the soil. Increased organic matter improves soil structure by promoting the formation of stable soil aggregates and large macropores, which enhance water infiltration and support microbial processes involved in nonpoint source pollution treatment.

Economic opportunities and production

Restoring ecosystem functions in degraded riparian areas can be costly and financially challenging for producers and landowners. Financial incentive programs are available to help cover costs of riparian forest buffers; however, purely monetary incentives are not achieving the scale of riparian restoration necessary in most U.S. watersheds.

Riparian landscapes across the globe have been shaped by human forces for thousands of years. Indigenous communities have managed and harvested products from riparian areas in a reciprocal relationship of providing ecosystem services to the riparian system in return for harvesting of food and medicines. Through species selection and management, riparian forest buffers can provide products for economic purposes while also supporting and maintaining other ecosystem services. This paradigm offers incentives of agency in riparian ecosystems that are often more appealing to landstewards.

Several products from riparian forest buffers have established markets and there are emerging opportunities for novel crops and products. In addition to providing economic value, productive riparian forest buffers can offer cultural and value-based benefits. Riparian forest buffers planted with a rich diversity of native fruits, nuts, and florals can offer a special connection with local tradition, culture, and folklore. Culturally significant plants can contribute directly to people's health, wellbeing, and food sovereignty.

Some of the economic and cultural products that riparian forest buffers can provide include:

- edible and non-timber forest products
- timber products
- fodder and mast for livestock

There are several categories of non-timber forest products that can be grown in riparian forest buffers including edible parts for human consumption (berries, nuts, leaves, roots), floral and crafting uses (bows, leaf structure, branches with vivid color or interesting form, materials for cordage or weaving), and cultural usage (Tribal significance, spiritual, medicinal, first foods. Products can also be produced indirectly from riparian plants such as honey.

Key flowering trees and shrubs that support honey production include:

Spring

- **bigleaf maple** (*Acer macrophyllum*)
- **vine maple** (*Acer circinatum*)
- **Pacific willow** (*Salix lucida*)
- **evergreen huckleberry** (*Vaccinium ovatum*)
- **salal** (*Gaultheria shallon*)

Summer

- **black hawthorn** (*Crataegus douglasii*)
- **cascara** (*Frangula purshiana*)
- **Pacific madrone** (*Arbutus menziesii*)
- **oceanspray** (*Holodiscus discolor*)

Food and medicine products that are native to Pacific Northwest riparian forests include::

- **beaked hazelnut** (*Corylus cornuta*)
- **black hawthorn** (*Crataegus douglasii*)
- **blue elderberry** (*Sambucus nigra ssp. caerulea*) on dry edges
- **Bog Labrador tea** (*Rhododendron groenlandicum*)
- **cascara** (*Frangula purshiana*)
- **evergreen huckleberry** (*Vaccinium ovatum*)
- **Nootka rose** (*Rosa nutkana*)
- **osoberry** (*Oemleria cerasiformis*)
- **Pacific crabapple** (*Malus fusca*)
- **salal** (*Gaultheria shallon*)
- **salmonberry** (*Rubus spectabilis*)
- **stinging nettle** (*Urtica dioica*)

Depending upon the species, riparian trees and shrubs may also provide nutritional fodder (leaves and branches) or mast (nuts, fruits, seed pods) for livestock. There are several native trees that can be coppiced for livestock fodder. Systems that rely on cutting and carrying fodder to livestock may be particularly useful in riparian forest buffers to minimize potential negative impacts of livestock grazing.

Careful and intensive management is necessary if considering grazing livestock in a riparian zone. Livestock should be seen as a tool for riparian forest management as opposed to the riparian forest being viewed as grazing land. Palatability and nutritional aspects, toxicity concerns, and season of fodder and mast availability are important factors to consider in species selection and are often specific to livestock type. Unfortunately, research on species specific factors is limited.

Species that provide fodder and mast include:

- **bigleaf maple** (*Acer macrophyllum*)
- **black cottonwood** (*Populus trichocarpa*)
- **Oregon white oak** (*Quercus garryana*)
- **Pacific crabapple** (*Malus fusca*)
- **red alder** (*Alnus rubra*)
- **vine maple** (*Acer circinatum*)
- **willow species** (*Salix spp.*)

Riparian forest management should prioritize native species; however, regional ecotypes are also capable of supporting a variety of high-value crop species with established or emerging market potential.

Integrating non-native species should be first considered at the margins or riparian forests as transitions between the riparian zone and adjacent land uses (farming, forestry, recreation).

Integrating non-native species further into the riparian zone should only be done with careful consideration in management, ecological function with the ecosystem, habitat impacts (positive or negative), verifying potential for invasiveness, and checking any regulatory considerations that may apply. Consult with a local agroforestry specialist before planting non-native species within a riparian forest.

Non-native species that have economic potential in riparian forests in the Pacific Northwest include:

- **American persimmon** (*Diospyros virginiana*)
- **aronia berry** (*Aronia melanocarpa*)
- **cider apples** (*Malus spp.*)
- **English walnuts** (*Juglans regia*)
- **goldenseal** (*Hydrastis canadensis*)
- **quince** (*Cydonia oblonga*)
- **ramps** (*Allium tricoccum*)
- **tea** (*Camellia sinensis*)
- **wasabi** (*Eutrena japonicum*)

Sequester carbon in soils and perennial biomass

Riparian forest buffers can sequester atmospheric CO₂ in above ground biomass or wood and below-ground in roots and in soil. Despite their relatively small spatial footprint, riparian forest buffers often have favorable growing conditions that can lead to accumulating carbon stocks at a faster rate than upland forests, particularly in the earlier stages.

Establishing riparian forests can substantially increase carbon storage within both vegetation and soils. Research has shown that converting degraded

Table 11.2. Effectiveness of different vegetation types for providing specific benefits

Benefit	Vegetation type		
	Grass	Shrub	Tree
Stabilize bank erosion	low	high	high
Filter sediment	low	high	high
Filter nutrients, pesticides, microbes			
... sediment-bound	high	low	low
... soluble	medium	low	medium
Aquatic habitat	low	medium	high
Wildlife habitat			
... pasture/prairie wildlife	high	medium	low
... forest wildlife	low	medium	high
Economic products	medium	low	medium
Visual density	low	medium	high
Flood protection	low	medium	high

Adapted from Dosskey, M.G., Shultz, R., & Isenhardt, T. (1997) How to Design a riparian buffer for agricultural land (Agroforestry Notes 4). Lincoln, NE: National Agroforestry Center.

or intensively managed riparian areas to forested buffers can triple soil carbon stocks over time. In addition to improving soil carbon storage, mature riparian forests commonly store between 68 and 158 megagrams of carbon per hectare (Mg C/ha) in aboveground and belowground biomass. These forests therefore play an important role in long-term carbon sequestration while also providing benefits such as improved water quality, bank stabilization, wildlife habitat, and floodplain resilience.

Primary functions riparian vegetation can influence:

- sequester aboveground carbon in woody biomass
- sequester belowground carbon in roots and soils
- reduce the energy associated with flooding events thereby minimizing soil disturbance and carbon losses

Buffers with woody species will have higher potential for carbon sequestration than grass or herbaceous only buffers. Large tree species with substantial trunk diameters will offer the greatest carbon storage, sequestering up to 1000 times more carbon than small trees or shrubs.

Temperate zone buffers with deciduous trees will generally provide higher biomass and soil carbon concentrations than buffers planted with coniferous species. Growth rate is a nuanced criterion. Faster growing tree species will sequester more carbon quickly, but slower-growing species can store more carbon over their longer lives. Selecting tree species with higher wood densities can also increase carbon density and storage.

Native species that are low maintenance and disease resistant will be better suited for sequestering carbon since they are adapted to the environmental conditions, will generally thrive, and not require any fossil fuel-based inputs or management.

Some tree species that are especially good at storing carbon include:

- **bigleaf maple** (*Acer macrophyllum*) shorter lived, but fast growing and large
- **Douglas-fir** (*Pseudotsuga menziesii*)
- **Oregon white oak** (*Quercus garryana*)
- **ponderosa pine** (*Pinus ponderosa*)
- **Sitka spruce** (*Picea sitchensis*)
- **Western hemlock** (*Tsuga heterophylla*)
- **Western larch** (*Larix occidentalis*)
- **Western red cedar** (*Thuja plicata*)

From a plant community perspective, the carbon sequestration potential can be optimized by planting riparian forest buffers that are functionally and structurally diverse. Using a mix of plant species in a buffer will provide more diverse rooting structures and organic inputs that will generally support higher storage of soil carbon. Species that can minimize erosion from flooding events and increase deposition will help protect and store soil carbon.

Wood products harvested from a riparian forest buffer can also sequester carbon for a long time period. Wood used in single family residential construction

has an estimated half-life of around 100 years, 30 years in furniture, and 6 years in pallets. Hence, tree and shrub species that can be processed into durable wood products offer benefits for long-lasting carbon storage.

Carbon stored in wood is only released back to the atmosphere when it is burned or decays. While selective harvesting in a riparian forest buffer may be done, it should be carefully considered to avoid or minimize effects on other desired functions.

While riparian forest buffers can serve as a carbon sink, they may also be a source of other greenhouse gases (GHGs). Increases in the frequency of floodplain inundation can result in more frequent anoxic soil conditions that may increase methane (CH₄) and nitrous-oxide (N₂O) emissions in buffers that are prone to regular flooding. Research on these GHG emissions in riparian forest buffers is still emerging, and there is a lack of scientific guidance regarding species selection and management to affect these GHGs.

Enhance aesthetics and visual quality

The aesthetics of riparian buffers can be an extremely important consideration of whether landowners adopt the practice on their private land. The aesthetic values that private landowners hold can be incorporated into riparian restoration, and in turn offer increased support for restoration. There is no universal aesthetic when it comes to streams and rivers.

Sociological studies on the preferences for certain aesthetics show a wide range of what different people find aesthetically pleasing. It has also been noted that differing values on nature and the environment contribute to what people find aesthetically pleasing in landscapes. Therefore, it is difficult to find a riparian buffer design that pleases all landowners or the general public overall.

In general, riparian buffer designs that incorporate trees, maintain selective views of water, and avoid an unmanaged appearance are generally preferred aesthetically, with strategically placed view corridors and shrub plantings carefully balanced to support both visual appeal and ecological function.

Riparian restoration efforts should be developed in close collaboration with landowners to ensure that planting designs align with site conditions, management goals, and the aesthetic preferences of the property owner.

Provide outdoor recreation opportunities

Riparian areas can support numerous outdoor recreational opportunities including wildlife viewing, hunting, fishing, aquatic sports, and hiking. Riparian plant communities can influence the type and magnitude of recreational opportunities and the species selection and management should match the desired recreational activities. For instance, plant species should be selected to support the habitat needs of the desired animal species for wildlife-based activities.

Aquatic-based activities including fishing benefit from clean water and appropriate stream temperatures. Refer to previous sections on selecting plants for these purposes.

Vegetative structure may also influence human movement and activities on the site and may be a selection criterion when planning for recreation. Plant selection criteria for recreational opportunities can be highly variable and should be considered in conjunction with the other desired purposes and functions, especially since recreational activities can have adverse impacts on other goals

Establishment and management considerations

There are many reasons to establish a riparian forest buffer, including stabilizing eroding streambanks, and filtering sediment, nutrients, or chemicals from agricultural runoff. Establishment and management of these systems involves numerous considerations, including short- and long-term management strategies, available government support programs, and market opportunities for potential buffer products.

Stabilizing eroding stream banks requires plants both on and adjacent to the bank that have deep and fibrous roots that help to stabilize soil.

Some species that can provide bank stabilization are:

- **black cottonwood** (*Populus trichocarpa*)
- **red alder** (*Alnus rubra*)
- **Pacific ninebark** (*Physocarpus capitatus*)
- **red osier dogwood** (*Cornus sericea*)
- **native willows e.g. Scoulers willow** (*Salix scouleriana*)
- **Nootka rose** (*Rosa nutkana*)
- **yarrow** (*Achillea millefolium*)
- **slough sedge** (*Carex obnupta*)

Many streams are deeply incised and are no longer in contact with their floodplain. Along these kinds of channels, upland as well as riparian tree and shrub species can be planted, depending on both functional and market objectives of the farmer/landowner.

Buffers created for filtering sediment and associated chemicals and nutrients from agricultural runoff work best by slowing surface runoff, and improving soil quality that supports rapid infiltration, so water

can move through plant root zones before it enters the adjacent waterbody. This can be accomplished by establishing stiff stemmed grasses and forbs.

Species that provide this function include:

- **small-fruited bulrush** (*Scirpus microcarpus*)
- **slough sedge** (*Carex obnupta*)
- **spirea** (*Spirea douglasii*)
- **snowberry** (*Symphoricarpos albus*)

Considering desired outcomes for a buffer is a first step in creating a functional design. Landowners are strongly encouraged to work with a natural resource professional to design the buffer and identify problem areas, such as severe bank erosion, channeled waterways and gullies that exit into the existing perennial riparian plant community, drainage tiles, etc.

Trees, shrubs, grasses and forbs should then be planted in appropriate zones to accommodate any unique problem areas. For example, trees, shrubs, and deep-rooted native grasses and forbs should not be planted directly above field drainage tile lines. Shallow rooted, native or non-native grasses are more appropriate for these sites.

It is also important to realistically assess the time available for managing vegetation within buffer systems. On many large-scale row crop and livestock operations, the labor required for buffer maintenance and harvesting may coincide with periods of intensive farming activity, limiting management capacity. In these situations, appropriate strategies may include selecting lower-maintenance plant species, choosing crops that can be managed outside the primary row-crop season, or contracting a natural resource management professional to oversee buffer maintenance.

Summary

Riparian forest buffers connect working lands with nearby streams and floodplains. They can protect water quality, stabilize streambanks, moderate water temperatures, and provide habitat for aquatic and terrestrial species. Some buffers may also support harvestable or culturally important products.

Because riparian areas change with flooding, sediment movement, and shifting water tables, effective buffers must be designed with local hydrology, soils, channel conditions, surrounding land use, and landowner goals in mind. With thoughtful design and management that can be sustained over time, riparian forest buffers can strengthen watershed health while remaining a practical part of diversified and functional working lands.

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RIPARIAN FOREST BUFFERS at Nehalem River Ranch

Nehalem, Oregon

Above: Trees and shrubs planted in multiple rows form a riparian forest buffer between Nehalem River Ranch and the Nehalem River.

Photo courtesy of Mitchel Davidovitz

By Katherine Favor, *National Agroforestry Center*

Nehalem River Ranch is a 100-acre diversified ranch along the Nehalem River in Northwest Oregon, owned and managed by Jared Gardner. Jared has implemented several agroforestry practices, including silvopasture, windbreaks, and riparian forest buffers—managed areas of trees and shrubs located between agricultural production zones and waterways for the purpose of water quality protection, streambank stabilization, and wildlife habitat.^[1]

“Being stewards of 100 acres along a river is really magical, but it also comes with a responsibility,” says Jared. “We are excited to do our part to keep the river as clean as possible.”

Focusing on diversity, Jared raises grass-fed and finished Angus-Hereford cross beef and Gloucestershire Old Spot cross pigs, and he also keeps bees for honey. Additionally, he partners with tenant farmers who lease shared pastureland and graze poultry in

rotation behind his cattle and pigs. They also grow flowers, and, in years past, raise goats and sheep and grow vegetables.

Along the river’s edge, the ranch’s riparian forest buffer serves as a barrier between the pastureland and the Nehalem River. The buffer filters runoff, reduces nutrient pollution, and stabilizes the riverbank to prevent erosion. It also supports Jared’s honey operation by providing a year-round supply of flowers for his honeybees.

Jared’s goals for his land are to produce healthy, local meat and honey, and to foster a biodiverse landscape that supports both his farm and the surrounding Nehalem River watershed. “This has been a really important ecological site, culturally and historically,” says Jared. “It’s our responsibility to think about the river, the riparian zone, and how we steward animals and plants in relation to the riparian ecosystem.”



How it started

Shortly after Jared purchased Nehalem River Ranch in late 2014, the Nehalem flooded and exposed a lack of resilience from significant ecological degradation on the banks. Much of the native woody perennial vegetation had been removed and converted into more pasture for cattle.

Over time, much of the riverbank was overtaken by Japanese knotweed (*Polygonum cuspidatum*)—a bamboo-like invasive forb. The roots of Japanese knotweed are connected to weak rhizomes that easily break apart.^[2] Without the stronger roots of woody perennials to stabilize the soil and hold it in place, streambank erosion became a significant issue.

Motivated to address the erosion and invasive species issues, Jared began a large-scale restoration effort. In partnership with several local organizations, he removed the knotweed through targeted, intensive grazing, and planted in its place over 5,000 native trees and shrubs to rebuild the river's natural riparian buffer and stabilize the soil.

Jared's restoration efforts also aimed to improve habitat for terrestrial and aquatic wildlife. The woody perennials in the riparian forest buffer provide shelter and food to many terrestrial animals like elk, deer, and birds. The riparian forest buffer also filters

runoff and reduces the amount of nutrients that end up in the river. This helps to prevent eutrophication—an accumulation of nutrients that leads to increased growth of algae, which can deplete oxygen levels and harm aquatic life. By reducing nutrient overload from livestock waste, the buffer protects aquatic organisms.

Jared was also interested in planting trees along the river to cast shade and lower water temperatures, further improving aquatic habitat. He recognizes that improving wildlife habitat does more than just benefit the environment—it also benefits the ranch itself.

“The more trees we plant, the more birds of prey we have. The more birds of prey we have, the less gopher holes and tripping hazards for our cows,” Jared explains. “So, it's little, simple things like that that are a win-win for both the ecology and our production.”

Design

The riparian forest buffer at the ranch spans the entire length of the river border—over 7,000 linear feet in total. The trees and shrubs were planted in rows varying from two to six rows wide, depending on topography. Within rows, trees were planted close together—just six to 10 feet apart—to account for expected losses to elk browsing and other pressures.

“We over-planted instead of using protective cages,” says Jared. “We know that we will need to thin some trees down the line, but when we did the math, this method was more cost effective than having to pay for caging.” All in all, over ten of Nehalem River Ranch's 100 acres are planted to riparian forest buffers.

Species selection was an important part of the design process. In the rows closest to the river, Jared chose native plants with deep roots that could tolerate seasonally saturated soils, like:

- **Western hemlock** (*Tsuga heterophylla*)
- **red currant** (*Ribes triste*)
- **willow** (*Salix* spp.)

In the rows farther from the river, he chose taller species that not only help filter nutrient load and slow runoff, but that also act as windbreaks. These species include:

- **Sitka spruce** (*Picea sitchensis*)
- **red osier dogwood** (*Cornus sericea* L.)
- **Western red cedar** (*Thuja plicata*)
- **bigleaf maple** (*Acer macrophyllum*)

As a beekeeper, Jared was intentional about selecting tree and shrub species to support his honeybees, along with other pollinators. To do so, he selected native species that flower at different times of the year, to ensure a continuous source of nectar and pollen. About 3,000 of the total 10,000 trees and shrubs planted were chosen specifically for their pollinator value, including species such as:

- **oceanspray** (*Holodiscus discolor*)
- **twinberry** (*Lonicera involucrata*)
- **Pacific ninebark** (*Physocarpus capitatus*)
- **red-flowering currant** (*Ribes sanguineum*)
- **thimbleberry** (*Rubus parviflorus*)
- **Western crabapple** (*Malus fusca*)
- **red elderberry** (*Sambucus racemosa*)

“These trees are doing all sorts of things for the environment, but they also give us another product that we can sell—honey,” explains Jared.

Establishment

Through multi-agency and non-profit collaborations, Nehalem River Ranch's riparian forest buffers were begun in 2021 and now include 5 years of maintenance and data collection to improve efforts across the region. The project was partially funded through a grant provided by the Oregon Watershed Enhancement Board by way of the Lower Nehalem Watershed Council. The Lower Nehalem Watershed Council, along with Resilience Permaculture, also provided technical assistance to help Jared develop a design, planting, and management plan.

NRCS funded the purchase and establishment of the pollinator support species through the Environmental Quality Incentives Program (EQIP). The Tillamook Estuaries Partnership (TEP) provided many of the trees and much of the labor, contracting with a crew to plant and maintain the trees during the initial few years. In total, TEP provided roughly 10,000 trees and shrubs. The rest were planted by Jared along with local community and customer volunteers, including two middle school educational field trips.

Prior to planting trees, the first step in the establishment process was to remove Japanese knotweed. Because the ranch uses organic practices, it was important not to use herbicides. "We don't want any toxins to run off into the water, and we don't want our cows to graze anything that has chemicals on it," Jared explains. "It's really important to us as a family, and also for our customers." Instead, TEP provided contract labor to manually mow down knotweed in steeper areas of the riparian sector while he used flash grazing with goats and cattle to make quick work of the Japanese knotweed and stunt its growth.

Once invasive plants were under control, native tree and shrub saplings were planted. To protect newly planted trees, Jared installed fencing to exclude livestock. This also prevents cattle from entering the river and causing streambank erosion.

After a few years, the woody perennials have grown tall enough that they are almost above the height of



Above: Newly planted trees and shrubs provide shade, slowing outcompeting the invasive Japanese knotweed.

Photo courtesy of Mitchel Davidovitz

mature knotweed and can start to shade it out without manual mowing. While this is an ongoing process that requires regular intensive weed management, Jared is hopeful that one day the area will be dominated by native perennials in place of invasives, replicating areas on the property with mature mixed canopies which have diverse native shrubs spreading naturally.

Management

Nehalem River Ranch grazes multiple species of animals in successional rotation, one after another. While the cattle and hogs are managed by Jared, the poultry are managed by tenant farmers.

"It's a complementary system," explains Jared. "Because there are multiple managers, no one person needs to learn all the skillsets needed to manage a diversified operation." Because livestock management is shared, a shared grazing plan was important to prevent overgrazing and to maximize the benefits of animal impacts. The plan is centered around rotational grazing principles, where animals are rotated into different paddocks every few weeks. Much of the pasture is in silvopasture, with native trees interspersed in the grassland, providing shade and shelter for the animals as they graze.

In the riparian forest buffer, vegetation management is an ongoing task, particularly for Japanese knotweed. For these first few years, much of the weed whacking and mowing was done by the Tillamook Estuaries Partnership, but Jared also uses animals to help with weed control.

The tenant farmers' 800 chickens have access to fenced off paddocks within the riparian forest buffer for two days at a time before being moved to the next grazing section. The chickens help clear surrounding weeds by scratching, while also fertilizing the trees. All in all, Jared estimates that the chickens supply the equivalent of \$10,000 in fertilizer throughout the ranch, helping him save money on inputs.

Jared considers wildlife when making management decisions. While mowing and weed whacking are critical tasks to prevent competition, some birds and other wildlife species depend on grassland habitat. "So, we mow in cycles," he explains. "We'll mow this part of the land one month, and another part of the land another month, so that there's always some grassland habitat available."

Replanting trees and shrubs is another major management task, but one that was expected. “We always knew we were going to lose some trees, so we overplanted and also planned and budgeted to replant,” says Jared.

Climate risks and adaptation strategies

Despite the region’s high annual rainfall—an average of 10 feet per year—summers in Nehalem are typically drier, with an average of 6.5 inches of rain between June and August.^[3] In the last 10 years, Jared notes that Nehalem River Ranch has experienced several summer seasons that have had periods of no rainfall lasting longer than 80 days. Oregon’s temperatures have also increased by 2.2°F per century since 1895,^[4] and they are projected to increase by 4.7°F to 10.0°F by 2080.^[5] High temperatures, combined with periods of little to no rainfall, can put stress on newly planted trees. To improve survival without installing irrigation, Jared applies woodchip mulch, which helps conserve moisture as well as prevent weeds.

Heavy rains in winter are another concern. From November through January, Nehalem receives an average of 57.5 inches of rain, which can lead to significant streambank erosion and flooding. Nehalem River Ranch’s riparian forest buffer has helped significantly reduce streambank erosion, helping to conserve soil and nutrients.

Climate models project that both the frequency and intensity of extreme precipitation events are likely to increase in Oregon in the coming years.^[6] This concern has further incentivized Jared’s decision to plant a riparian forest buffer. “You can either lose your production land to planting a riparian forest buffer, or you can lose it to erosion from the river,” he explains. “I’d rather have a riparian forest buffer, because of all the additional benefits it provides to our ranch and the surrounding ecosystem.”



Above: Nehalem River Ranch’s riparian forest buffer helps prevent land loss from streambank erosion and flooding during heavy rain events.

Photo courtesy of Mitchel Davidovitz

Conclusion

Nehalem River Ranch’s riparian forest buffer is multifunctional, preventing erosion, filtering runoff, preventing nutrient overload, providing shade to aquatic wildlife, and supporting terrestrial wildlife as well. At the same time, the buffer promotes income generation by preventing land loss, and by providing a source of food to Jared’s bees for his honey business.

To ensure long-term protection, Jared is working with the Oregon Agricultural Trust to establish a conservation easement on the property. “By having a conservation easement, we have a longer-term framework to ensure that these trees do live to 100 years and beyond,” says Jared. “There are trees on this property that I benefit from that were planted intentionally by someone a century ago. Now it’s my responsibility to pay it forward for the next 100 years.”

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Climate Hubs

U.S. DEPARTMENT OF AGRICULTURE

CHAPTER

12

SILVOPASTURE

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Definition

Silvopasture is the deliberate integration of livestock with trees and forages suitable for grazing.

Author Note: This chapter is based in part on original narrative developed by Dusty Walter and Ashley Conway for the University of Missouri and used with permission. The chapter has been revised, expanded, and updated by Mark Batcheler for this publication.



Silvopasture differs from other woodland grazing due to the intensive management of the three primary components: livestock, trees, and forages. However, not all combinations of trees, forage, and livestock constitute silvopasture.

Allowing livestock access to woodlands without consideration for tree and soil health, environmental impacts, or forage composition and availability will result in a degradation of resources. It is important to manage silvopasture system components collectively to prevent negative impacts.

In silvopasture management, livestock are commonly rotationally grazed using multiple temporary or permanent paddocks in managed tree stands, orchards, or vineyards. Grazing occurs during periods when forages are growing and are sufficient in quantity to sustain the grazing events based on herd size. Trees are spaced to allow for sufficient light to promote

the establishment and growth of understory forages, which are predominantly composed of grasses and legumes that are adapted to reduced light levels and meet the nutritional requirements of livestock.

Tree species may include those grown for timber, fodder, fruit or nut crops. In some situations, the trees are intended almost exclusively to provide shade with little emphasis on additional products. In most of the farms in the Pacific Northwest, silvopasture represents only a portion of grazing management systems and is combined with open pastures along with other land management systems.

Above: Sheep grazing in silvopasture.

Photo courtesy of Mitchel Davidovitz

Benefits and challenges

A well-managed silvopasture can provide a wide variety of ecological, economic, and social benefits. Ecological benefits may include reducing soil erosion, enhancing wildlife habitat, sequestering carbon, reducing livestock heat stress, and prolonging forage growth. Economic benefits may include multiple revenue streams, increasing forage production throughout the year, increasing livestock weight gain, and milk production. Social benefits may include improved aesthetics, and enhanced recreation activities such as hunting, foraging and wildlife viewing.

The primary challenge of silvopasture is the inherent complexity of managing trees, livestock and forage production on the same land. Establishment and continued maintenance often require additional infrastructure, equipment and increased labor. These establishment costs can be prohibitive and may require cost-sharing grants or funding. Silvopasture systems do not have the same carrying capacity for livestock as open and irrigated pastures.

Special assessment considerations

For most producers in the Pacific Northwest, silvopasture may be only a portion of their grazing system and are part of a more complex farm management system. Often the combination of open pastures and silvopasture are part of the livestock grazing plan. This allows landowners to graze silvopasture later in the summer due to the continued growth of forages and as a method to protect livestock from heat stress. Prior to establishing a silvopasture system, it is important to consider site assessment and suitability as discussed in **Chapter 4** of this handbook.

In general, silvopasture can be established on lands that can support tree and forage growth simultaneously and where site conditions are appropriate for grazing. Site variables such as erodible and hydric soils, slope, aspect, forage and tree species should be evaluated prior to grazing. In addition, all parts (livestock, trees, forage) of the system must match the climate and other aspects of the land, and thus species combinations may be quite different from one region to another.

There are many pathways for establishing silvopasture. However, typically in the Pacific Northwest the two primary methods involve either establishing trees in existing pastures or thinning existing forest or woodland stands and managing for preferred forage species.

Design

Due to the complexity of establishing a silvopasture system, it is important to design a system that matches your objectives and site-specific conditions. For successful implementation, a thorough site assessment and well designed management plan are critical. Working with conservation districts, foresters, and grazing and forage specialists can be useful in assessing site suitability and designing a management plan.

Components of silvopasture

Each component of a silvopasture system—livestock, trees, and forage—needs to be considered in terms of how its characteristics will influence silvopasture function and effectiveness. Components must be considered in the context of a specific site given the potential effects of microclimate, soils and available infrastructure.

In addition, the components and their characteristics change and interact with each other over time such that management is not a static or set activity. To be successful, practitioners will need to actively engage in managing each component to maintain a functional system.

Table 12.1. Considerations for silvopasture components

Livestock	Trees, shrubs, or vines	Forage	Site conditions
- species - breed - age/class - social learning - stocking rate and duration - water use - seasonal timing of grazing	- pasture conditioning height - canopy width and density - rooting depth - phenology (leaf, fruit, nut emergence and drop) - leaf/needle/fruit/nut form - water use - planting/thinning configuration	- annual/perennial - cool, warm season - seeding density - nutrient use and requirements - adaptability to grazing - water use - shade tolerance	- elevation - aspect - soil type - infrastructure - topography - water holding capacity - climate

Adapted from MacFarland, K.; Feibel, S.; Batcheler, M.; Moore, A.; Smith, M.M.; Joslin, A. 2025. Silvopasture: an agroforestry practice. Agroforestry Note 8. [Revised]. Lincoln, NE: U.S. Department of Agriculture, Forest Service, National Agroforestry Center.

Livestock

From a management perspective, livestock are the most dynamic component of silvopasture systems and will require the most time and effort. Selecting livestock species and breeds, determining appropriate stocking rates and monitoring carrying capacity (defined as the number of animals that be grazed for a specific time period), and establishing a grazing management plan is critical to a well-functioning silvopasture system.

In addition, having the appropriate infrastructure to manage livestock is necessary. Examples of infrastructure include portable or permanent stock tanks, permanent cross fencing between paddocks and temporary electric fencing appropriate for the livestock species. In addition, protecting trees from livestock should be considered.

Rotational grazing

A component of silvopasture is the use of rotational grazing which benefits from a comprehensive grazing management plan that gives producers the capacity to manage grazing frequency, intensity, and duration. Moving livestock from grazed to ungrazed paddocks prevents overgrazing, which reduces plant density and overall forage production.

In addition to a grazing management plan, producers need a plan for both permanent and temporary fencing, and placement of watering facilities to maintain a productive silvopasture.



Above: Cows graze in the shade of white oak trees at Kime Ranch near Eugene, Oregon.

Photo courtesy of Mitchel Davidovitz

Livestock selection

Multiple livestock species are grazed in silvopasture systems in the Pacific Northwest. Although cattle and sheep are the most common livestock, other animals such as goats, pigs and poultry can also be incorporated. Selecting appropriate livestock will help landowners to achieve their economic and ecological objectives.

From a financial outlook, producers may benefit from considering livestock species that match available markets and provide suitable returns. This can be informed by studying local and regional livestock markets and selecting livestock species that are resistant to pests and parasites, are efficient grazers, have good weight gains, and are well-adapted to the forage and tree species.

Livestock should be selected based on the carrying capacity of the land. Carrying capacity is an estimated measurement of how much forage is produced in a given area (meters, acres, hectares), which determines stocking rate.

The stocking rate is informed by the amount of forage required by one **animal unit for one month (AUM)**. The estimated AUM of a pasture can be used as a measure of potential forage production in pounds or tons per acre. AUM is based on an animal intake of 2.5 to 3 percent of body weight per day on a dry matter basis, that is adjusted for moisture content of feed. To determine both the carrying capacity and stocking rate, it may be useful to work with a grazing specialist in your region.

Trees

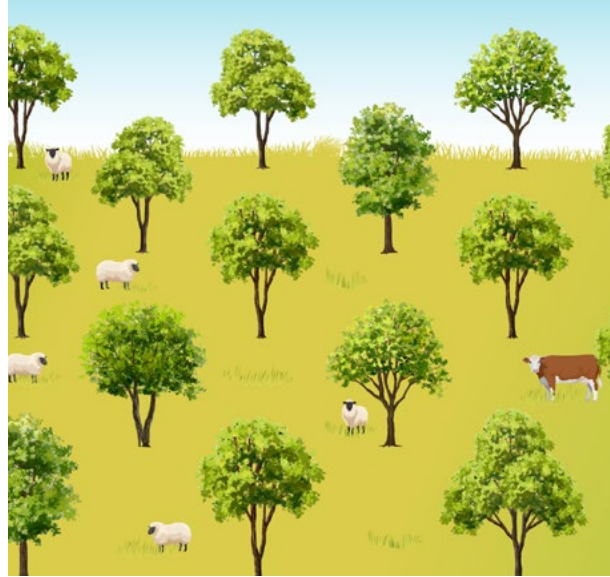
Selection and management of trees depends on a host of factors including tree age, establishment, species and intended goals and uses (shade for livestock, timber products, non-timber products, fruit/nut production, etc.). When selecting which trees to establish or maintain, consider species suitability for site conditions, including soil types and landscape position (slope and aspect influence species composition).

Consider management activities such as thinning, pruning and harvesting in conjunction with livestock grazing and managing forage production.

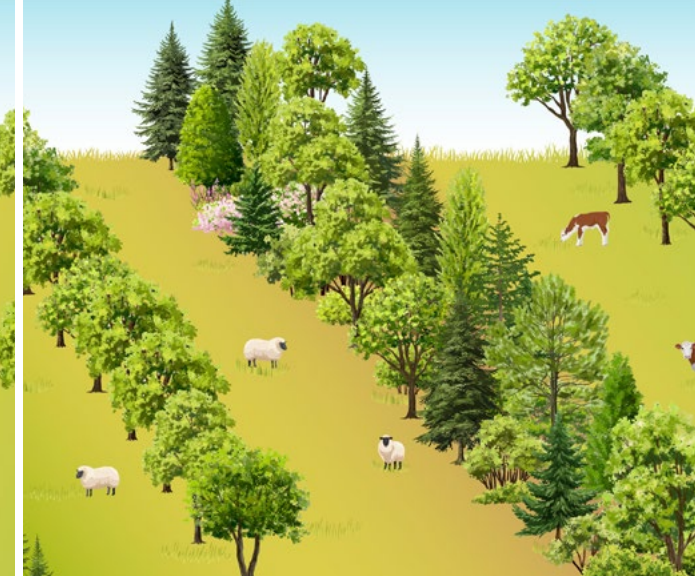
Tree establishment and management

Whether establishing trees or thinning an existing stand, it is important to consider the structure of the stand. Several considerations will influence tree spacing and configuration.

- **Equipment size:** For a silvopasture design that plans for occasional forage removal by mechanical means it is important to provide space between the trees so that equipment can move freely. The alley between tree rows should be wide enough to allow clear passage of the widest piece of equipment and should be organized to allow for full passes of the equipment. Ultimately, the best designs plan for the branch and crown development that occur over time for a given tree species and the products desired from those trees. For example, when planting trees for nut production, where large crowns are desirable, planners may wish to include wider space between tree rows.
- **Forage:** Closer tree spacings may be designed for forages which are more shade tolerant, keeping in mind equipment requirements. However, most forages need a minimum of 50 percent light, so plan to manage tree densities to produce adequate light for forage growth.



Left: Uniform tree spacing.



Right: Trees spaced to create paddocks between rows.

Figures courtesy of G. Steffan, Washington State University, College of Agriculture, Human, and Natural Resource Sciences (CAHNRS).

- **Changes through time:** Increased shading occurs as trees mature. As this happens, a change toward a more shade tolerant forage will be necessary to maintain suitable yields. These changes can also be offset by timely thinning of lower quality trees and through pruning that reduces branch density in a tree's crown.
- **Timely thinning** can be used to maintain semi-open crown conditions. While used as a tool to manage the light available for forage production, thinning also serves to increase the resources (light, water, and nutrients) available to the remaining higher value trees and therefore, should enhance their growth rate. Another dual-purpose management practice is pruning. Proper pruning of the lower branches, to develop a high-value log, can increase tree value and increase the space available for the operation of equipment. At the same time, this also increases sunlight available to the forage.
- **Competition for light at the canopy level:** Trees like oak, ponderosa pine, and sugar pine prefer little to no crown competition while other trees like alder, cherry, and walnut tolerate some degree of crown competition. Trees more closely spaced in silvopasture systems may be managed for straight saw logs while those spaced further apart may encourage nut and fruit production or simply to provide the light necessary for continued growth.

- **Crown density:** Trees with more fine needles and leaf patterns allow more light through their canopy and may supply adequate light to the understory despite closer spacing. These include ponderosa pine, black locust, and honey locust.

Livestock interaction

When perennial vegetation such as trees, shrubs, vines are established and livestock are allowed to graze adjacent to them, it is important to manage interaction to prevent livestock from damaging trees and crops. The combined use of tree tubes and electric fencing is a good solution if grazing exclusion is not achievable. In addition, consider integrating smaller livestock whose grazing habits may be more conducive to newly established trees and or crops.

Forages

Forage growth and initial yields vary substantially by the chosen path of establishment; however, producers can expect that shade's impact on forage yields will be minimal when planting trees into pasture for the first several years. Eventually, forages will begin to decline as tree canopy cover approaches 30 to 50 percent.

Forage establishment

Establishing forage under an existing tree canopy may be challenging and take longer to fully establish. For example, forage growth under deciduous trees, such as Oregon white oak, may be delayed due to undecomposed litter layers. Similarly, establishing forages under conifers may be slowed by light availability. However, silvopasture with relatively low shading may produce similar forage yields to conventional pastures after 2 or 3 years if the right species are chosen and adequate light is maintained at ground level.

Considerations for establishing and managing forage:

1. Evaluate forage availability before tree establishment by clipping and weighing or using a rapid method for estimating forage availability. Test the soil to determine whether soil amendments such as lime or fertilizer could benefit the silvopasture.
2. Consider how existing forage will change as shade increases. Do different forages need to be established or existing forages enhanced? Generally, pasture renovation is not necessary for pasture-to-silvopasture establishment. Over time more shade-adapted species may occur in the silvopasture.
3. When selecting how many trees to plant, consider the balance between forage production and shade. Tree spacing and orientation can influence forage quality and quantity.
4. Regularly estimate forage availability to adapt grazing intensity and management.



Above: Lush summer forage in the oak woodland understory at Kime Ranch near Eugene, Oregon.

Photo courtesy of Mitchel Davidovitz

The forage component of silvopastures is primarily influenced by the composition of forage species, the stocking rate of the livestock and the density and canopy cover of the trees, shrubs, or vines and thus requires greater management than is often used in typical pasture systems.

However, silvopasture also allows for the opportunity to create different ecotypes which can support a broader array of forages which help extend forage growth during warmer and drier seasons.

Learning to establish, manage and monitor forage in silvopasture systems are necessary steps to ensure your silvopasture stays productive.

Forage management

Managing forages is accomplished through a well-designed plan which monitors forage species composition, planting density, stage of growth, forage age, nutrient and water requirements, and defoliation as result of grazing. In addition, silvopasture systems have the added feature of trees, shrubs and vines which, as they mature, influence available light and will alter forage composition growth, yield, and nutritional content. Thus, measuring canopy density and maintaining a balance of forage and tree/shrub/vine composition is another component of forage management. Additional components of a forage plan may include fertilization and nutrient management, pest management, and measuring stocking density.

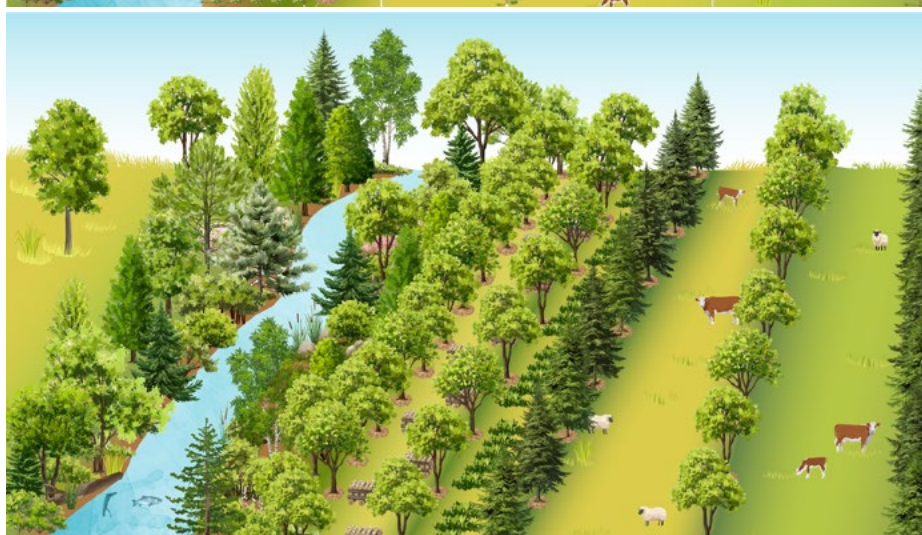
Site conditions

It is important to assess site conditions in both the establishment and management phases. Variables such as shade and soil pH, aspect, slope, and elevation influence which tree and forage species can be successfully established and maintained. Conducting soil tests to determine pH and assess soil nutrient deficiencies, soil compaction will add in understanding forage growth, yield and nutritional content.

Monitoring the structure and composition of shrubs, vines, and trees is a necessary component as they affect forage. For trees, measuring the canopy density using tools such as densitometer aids in determining the amount of shade which influences forage species composition and growth rates. Canopy density can be managed by pruning lower limbs or thinning trees to allow increase available light to reach the ground.

Forage species in silvopasture systems will change over time due to changes in grazing pressure, trees per acre, tree canopy density, tree species and changes in seasonal precipitation. In order to determine appropriate grazing density or establish preferred forage species, it is beneficial to determine which species of grasses and legumes are present and the yield (typically measured in tons per acres) of preferred species. To determine forage composition and assess livestock utilization, conduct a survey of pastures. There are multiple ways to conduct forage surveys. Contact your local extension, conservation district or NRCS staff for support.

See **Chapter 7: Species Selection** for a sample method to evaluate forage.



Above:
Newly established silvopasture. Trees arranged in rows with nearby with riparian forest buffer.

Left:
Mature silvopasture. Trees arranged in rows with nearby riparian forest buffer.

Graphics courtesy of G. Steffan, WSU College of Agriculture, Human, and Natural Resource Sciences (CAHNRS).

Monitoring growth rates and nutritional qualities of forage are essential for livestock aspects of silvopasture systems. Forage growth rates are influenced by soil conditions and available nutrients.

This fact makes soil testing essential to determine available nutrients in the soil for forage growth and how much fertilizer is needed to optimize forage yield and quality. Assessing forage quality is helpful to determine the protein and fiber content will aid in determining the nutritional content.

Finally, it is essential to monitor forage production which is the first step in determining how many livestock are appropriate for a given silvopasture. Knowing how, when and where to measure forage yields requires simple tools that provide accurate assessment of forage yield as expressed in ton per acre.

Methods such as the [grazing stick](#) or the [hoop method](#) are proven methods for evaluating forage quantity for the purpose of determining the carrying capacity and stocking rates for livestock grazing.

Infrastructure

The establishment and management of the silvo-pasture components (trees, forage and livestock) are informed by the infrastructure that is used to intentionally integrate these components. Infrastructure is site specific and may vary between silvopasture operations. However, similar to the components of silvopasture there are commonly used components such as temporary electrical fencing, permanent cross fencing, and water tanks

Electrified fencing

An effectively designed fencing system allows for the establishment of temporary or permanent paddocks, promotes the ease of livestock movement and minimizes the hazard of livestock damaging trees.

- The design of a temporary electrified fence using polywire, netting or single strand etc. is determined by the landscape, producer goals, and livestock type. Electrified fences are primarily a psychological barrier and can only be effective if the fence carries enough current to deliver a “deterrent” shock. Alternating current (AC) powered units are generally the best choice for energizing a fence if 220- or 110-volt power is available. For remote areas, battery powered systems with solar recharge may be necessary. In a silvopasture, falling branches or trees increase the potential of damaging the system.
- To ensure effective operation, the energized fence should have a proper-sized energizer. Generally, one-joule output per mile of fence is sufficient. Be properly grounded with a minimum of three feet of ground rod per joule output. Be protected from lightning by installing a surge protector at the power source, a lightning choke at the fence, and an additional ground rod every 3,000 feet of fence.
- High tensile wire is best when using energized fences for border areas and is also used for cross fencing. The number of strands depends upon the type of livestock being grazed. Generally, a minimum of four to six



Above: Tree protection and livestock exclusion using netted electrified fencing and tree tubes

Photo courtesy of Mark Batcheler

strands is recommended for border fencing and one to three strands for cross-fencing cattle. Other livestock require special considerations such as distance above the ground of the bottom wire, and distance between wires for smaller livestock like goats and sheep.

- Polywire or polytape can be used for temporary or portable cross-fencing to create smaller paddocks for intensive grazing or to allocate stockpiled pastures for winter grazing. This enhances the manager’s ability to provide optimum, forage recovery periods.
- Livestock can do significant damage by stepping or rubbing the bark off newly established trees. Generally, trees are most susceptible when less than 16 inches

tall, and during the period of rapid growth in early spring. Trampling damage causes deformation and weakening of the stem and may also provide an entry point for pests and disease.

- Consider using a variety of tree protection methods that best suit livestock type and operation. Examples may include rigid tree cages using hog fencing secured with a T-post for widely spaced trees. Use plastic tree tubes with a single fiberglass post for smaller livestock such as sheep or goats. For more closely spaced trees, it may be more economical to use energized polywire that is attached to plastic tree tubes and is high enough to allow livestock to pass under the wire.

Establishment and management considerations

Success with establishing silvopasture in a pasture is dependent upon the establishment techniques that allows you to carry on a profitable livestock operation while creating a long-term investment in timber and/or forest products. The establishment of trees provides shade and wind protection will enhance livestock performance, yet eventually reduce forage production.

Success and longevity of the practice hinges on three primary factors: proper establishment and maintenance of young trees (necessary for early tree development); management or introduction of preferred forages; and protecting trees from livestock interactions.

Success with establishing silvopasture in a forest stand is dependent upon creating a forest management plan that will act as a guide in determining the number, age class, and species of trees that will be thinned. In addition, the resulting stocking level of trees should be spaced appropriately to ensure adequate forage production. Though no metric has been established for trees in this region, research on thinned hardwood forests suggest 30% of the full stocking basal area or approximately 50% canopy closure is appropriate for a productive silvopasture system. The tree stocking density will depend greatly on the tree species and age class.

Further evaluation of silvopasture in different forest types is necessary to determine an appropriate tree stocking density for each site. Work with a forester who is supportive of integrating livestock in the stand.

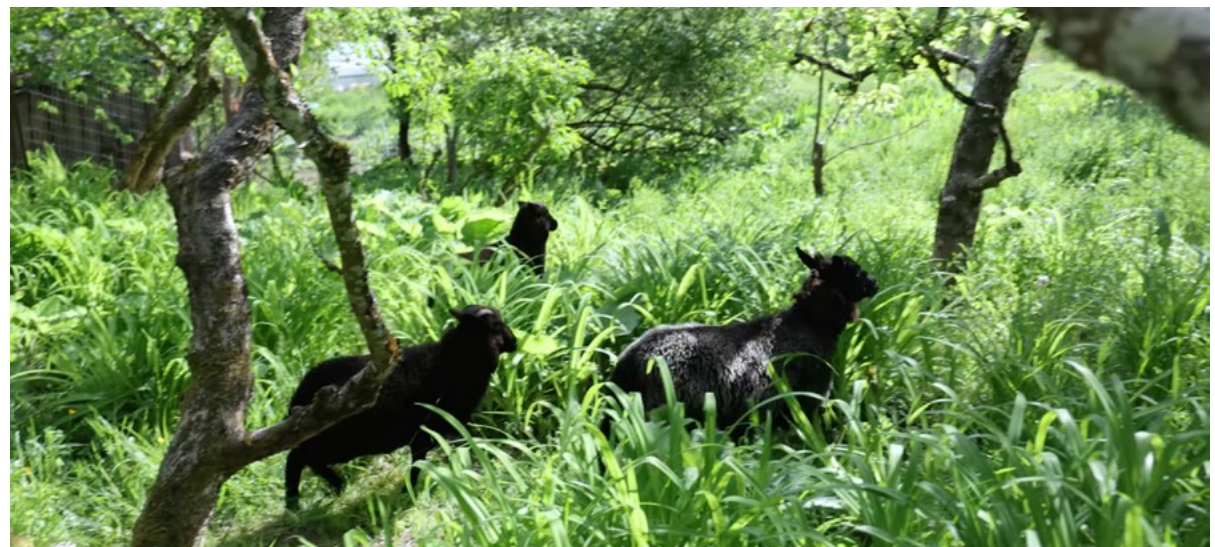
Right:
Sheep grazing in an orchard at the Center for Rural Livelihoods.

Photo courtesy of Mitchel Davidovitz

Table 15.2. Silvopasture establishment methods

Method	Livestock	Trees	Forage
Pasture to silvopasture	- Monitor tree/livestock interaction to prevent tree damage - Establish appropriate infrastructure (water tanks, permanent and/or temporary fencing) - Plan rotational grazing	- Determine tree configuration and trees per acre - Select trees that are suitable to site conditions and non-toxic to livestock - Use tree tubes, electric fencing or other methods to protect trees	- Control vegetation around newly planted trees - Defer grazing until forage is well established and is of sufficient height to be grazed - Monitor forage utilization and yields
Forest to silvopasture	- Establish appropriate infrastructure (water tanks, permanent and/or temporary fencing) - Include silvopasture in the rotational grazing plan	- Determine preferred trees per acre - Remove downed woody debris - Selectively thin trees to allow more light penetration and prevent windthrow and epicormic branching	- Evaluate forage composition prior to seeding - Consider herbicide application on invasive and noxious weeds.
Orchard to silvopasture	- Determine animal management needs (fencing, water access) - Include orchard silvopasture in rotational grazing plan	- Determine the timing of crop harvest and animal exclusion requirements - Ensure crops are not toxic to livestock	- Determine forage/fodder availability to determine livestock stocking - Identify suitable pastures to graze during periods of exclusion in the orchard

Adapted from MacFarland, K.; Feibel, S.; Batcheler, M.; Moore, A.; Smith, M.M.; Joslin, A. 2025. Silvopasture: an agroforestry practice. Agroforestry Note 8. [Revised]. Lincoln, NE: U.S. Department of Agriculture, Forest Service, National Agroforestry Center.



Summary

Silvopasture systems can vary depending upon the combinations of livestock, trees, and forage. This system can work well with both small and large land agricultural and forest operations when well designed and managed.

Variation in environmental conditions, resource availability, and the spatial configuration of land cover types can increase species diversity and serve important ecological functions. However, the success of silvopasture management in addressing specific resource concerns and/or achieving conservation benefits depends on individual site conditions, landscape composition and structure and the management approach a producer pursues.

During the planning and establishment phases, it is critical to align the specific ecological context of a selected site with the goals of the producer. Working with a team of knowledgeable technical assistance providers can help determine timelines of establishment and management for livestock, trees, and forage. Finding a balance in managing these different but connected components can be a challenge. However, with clear short- and long-term goals, teamwork, and an integrated design plan for each component, silvopasture can bring many lasting benefits.

Additional resources

- Agroforestry Note #8, [Silvopasture: An Agroforestry Practice](#). (MacFarland et al 2025)
- Agroforestry Note #23, [Converting a Pasture to Silvopasture in the PNW](#). (Sharrow et al 2003)
- Agroforestry Note #31, [Silvopasture Tree Pruning](#). (Robinson et al 2006)
- Agroforestry Note #46, [Forest Grazing, Silvopasture, and Turning Livestock Into the Woods](#). (Brantly 2014)
- Agroforestry Note #50, [Considerations for Establishing Silvopastures on Wooded Sites](#). (Chedzoy et al. 2022)
- [Plants Poisonous to Livestock](#). (Cornell University 2024)
- [Introduction to pasture and grazing management in Western Oregon](#), OSU Extension Service. (Fery et al 2020)
- [Silvopasture: An Agroforestry Practice](#), OSU Extension Service. (Agnima 2009)

SILVOPASTURE

at Spencer Shadow Ranch

Eugene, Oregon

By Katherine Favor, *National Agroforestry Center*

Spencer Shadow Ranch is a 340-acre property in Eugene, Oregon where owners and operators Doug and Sookjae McCarty transitioned an unmanaged forest to a silvopasture system, with cattle rotated under the shade of trees. Doug McCarty identified risks such as low soil fertility, high heat, and limited rainfall, and took action by integrating livestock with native trees such as Oregon white oak (*Quercus garryana*) and valley ponderosa pine (*Pinus ponderosa*).

By implementing silvopasture through strategic thinning and rotational grazing, the ranch is mitigating heat stress in cattle, improving forage resilience, and improving soil fertility.

Oak woodlands and savannas like those found on Spencer Shadow Ranch provide important ecological functions to numerous species that depend on this ecosystem.^[4] By implementing silvopasture, the McCartys are conserving this habitat while increasing the productivity of their ranch.

How it started

Doug and Sookjae McCarty purchased Spencer Shadow Ranch in 2014. What started out initially as an investment opportunity quickly turned into what Doug now sees as his life's legacy. As Doug started spending more time on the land and studying permaculture design (a design framework for sustainable food production), stewarding the ranch became his full-time passion and he never turned back.



Above: The landscape at Spencer Shadow Ranch has been intentionally designed to have patches of trees interspersed with patches of open pasture in a grid-like pattern.

Photo courtesy of Mitchel Davidovitz

“When we took over ownership, the land was in bad shape,” says Doug. Parts of the land had been operated as a hay farm for years, relying on heavy inputs to stay viable. Other parts of the land were unmanaged, overgrown forests that posed a fire risk. The soil was compacted from heavy equipment use and severely lacking in microbiological life.

The McCartys invested in livestock, believing that well-managed grazing would help improve soil structure fertility, structure, and water holding capacity, to support more production. “Divots from cattle hooves create thousands of mini-ponds that collect water,” explains Doug. “This helps water infiltrate slowly.

Cattle also take forages and transform them into nutrient-rich manure that goes back to the soil and provides nutrients in a plant-available form.” Because of this, cattle can help improve soil fertility when rotated regularly and when managed intensively.

The McCartys now have a complete herd (calves, cows, and bulls) consisting of 140 head of Aberdeen Lowline Angus and Dexter steer—all grass fed and finished. To address the risks of high heat and limited water availability, the McCartys are practicing silvopasture, defined by the USDA as the establishment of trees, livestock, and forage on the same unit of land.

Climate risks and adaptation strategies

Extreme temperatures

Both high and low temperatures pose challenges for livestock. Eugene's USDA Plant Hardiness Zone is 8b, and while temperatures can drop down to 15°F in the winter, they regularly climb into the high 90s in the summer. Since 1900, temperatures in Oregon have risen 2.5°F.^[2] They are projected to increase another 4.7 to 10°F by the end of the century, depending on whether greenhouse gas emissions are curbed or increased in the coming years.^[2]

Much of the McCarty's land slopes to the south, which exposes plants and livestock to even more heat. Because cattle begin experiencing heat stress as low as 75°F,^[3] Doug understood the importance of designing a system that would address this risk.

One of the ways that Spencer Shadow Ranch is managing livestock heat stress is by implementing silvopasture. In silvopasture systems, trees provide shade to livestock, reducing temperatures by up to 2.5°F and reducing solar radiation exposure by 14 to 58 percent.^[4] This can reduce heat stress in cattle, resulting in increased feed intake, faster weight gain, improved fertility, and lower mortality rates.^[5]

Trees also provide protection to cattle during cold winter months. "The beauty of trees is that they provide shade and cooling in the summer, and they also provide protection from the worst of the winter," explains Doug. Of the McCarty's 340 total acres, 120 acres are now managed as silvopasture, with native white oaks and valley pine strategically spaced and integrated with pasture in the understory.



Limited water availability:

Limited summer precipitation and regulations that limit irrigation are additional challenges that Spencer Shadow Ranch experiences. While Eugene receives around 46 inches of rain a year, it typically gets 0 to 5 inches from July 1 to November 1. Four months with limited rainfall can prove challenging when trying to sustain cattle on pasture. Limited water may prove even more of a challenge in the coming years, as climate change models project that summer precipitation may decrease in Oregon, and water stress will be exacerbated by increasing temperatures.^[6]

The McCartys are addressing the challenge of limited water by planting pasture into thinned wooded areas, as shade from trees can help pastures maintain soil moisture longer by reducing evapotranspiration. This can enhance forage production during times of limited rainfall.^[5]

Establishment

Silvopasture is often established either by planting trees into existing pastures, or by thinning trees in an existing forest and planting preferred forages under the thinned canopy. Achieving the right balance of trees and pasture is important; some shade from trees is beneficial, but too much shade can prevent pasture from growing.

To achieve the proper canopy density, Doug thinned his forested land strategically. Originally, the forested parts of the McCarty's land held dense stands of Oregon white oaks (*Quercus garryana*), valley ponderosa pine (*Pinus ponderosa*), cedar (*Cedrus spp.*), and Douglas-fir (*Pseudotsuga menziesii*). Doug started thinning the forest by first removing dead and dying trees. He also logged mature, economically valuable trees from an overstocked stand, including some older white oaks, which he sold as lumber for flooring.

Left: Trees provide shade and relief from heat stress to livestock below.

Photo courtesy of Mitchell Davidovitz



Finally, he removed most of the Douglas-firs and cedars, because their dense canopies cast too much shade, encroaching significantly on oak and pine trees and reducing the amount of light that reaches the understory.

Douglas-firs can also be susceptible to drought and heat stress, and were therefore identified as the most at-risk species in the face of limited summer precipitation and increasing summer temperatures. Most of the healthy pines and oaks were left because Doug considers them “good neighbor species” that don’t compete excessively with pasture for light or water.

Design

At Spencer Shadow Ranch, Doug opted to create islands of trees laid out in a “patchwork” design. In his design, there are 1- to 2-acre patches of well-spaced trees interspersed with 4- to 5-acre patches of

treeless meadows in a grid across 120 acres of landscape. Each paddock that cattle pass through contains both open pasture and stands of thinned trees. This allows cattle the freedom to access shade for relief from the heat when needed, and to also access open pasture, which often can support more forage.

By creating a patchwork pattern of treed areas and open grassland areas, Doug has also enhanced the “edge effect” on his land. The “edge effect” is a phenomenon in ecology in which biodiversity richness increases where two or more habitats meet. “If you look at a forest ecosystem, the edges of the forest—where the forest meets another kind of ecosystem—are where most of the species interaction occurs,” explains Doug. “That edge is a hotspot for wildlife. A goal of mine with this silvopasture design was to create more of that ‘edge effect’ on the land.” Although the ranch itself is only half a square mile, Doug has created roughly 20 miles of “edge” ecosystems with

Above: NRCS helped finance some of the management activities associated with thinning the forest.

Photo courtesy of Mitchel Davidovitz

his careful design which he says has allowed wildlife to flourish. “It’s kind of a magic trick,” he says.

Another benefit of this patchwork design is sustained forage production in each paddock at different times of the year. During summer, the growth rate of forage exposed to direct sun can be inhibited by high heat. When forage is grown under the partial shade of trees, however, heat stress can be alleviated, which allows forage growth to continue. In cooler times of the year, however, shade from trees can limit forage growth, so during cool months, it’s important to have some areas of pasture that are exposed to direct sun. By concentrating trees in patches and leaving some open pasture, Doug can extend the forage growing season using the same paddocks all year.



Management

While management is intensive, Doug has designed his silvopasture system to rely on as few inputs as possible. Rather than using herbicides to manage weeds in the forest, vegetation is mostly managed by cattle, which eat many of the undesirable species when rotated using adaptive grazing principles. After rotating cattle through first, Doug then follows with his herd of sheep, which eat the vegetation that cattle don't like, including poison oak, hawthorn, young cedar trees, and blackberry.

Restoring the native oak woodland is an ongoing project that is very labor-intensive, and that requires regular thinning of trees with the use of specialized equipment. Doug cuts down most trees by hand with chainsaws and removes them with a skid steer that has a log grapple attachment, which can lift up to 4,000 pounds.

High-quality logs are sold, while dead and dying trees are hauled to a slash pile where they are burned. Once trees are logged, the remaining woody debris on the forest floor is cut up with a brush cutter. Finally, the

ground is raked over with a tractor, and vegetation is allowed to grow. Native grasses and clover come up naturally, but Doug also broadcasts native perennial grasses into these areas.

Rotational grazing is a critical part of silvopasture management to ensure that cattle promote soil health instead of damaging it. When cattle are rotationally grazed and the land is allowed to rest in between periods of grazing, animals can improve soil fertility, microbiological activity, infiltration rates, and soil water holding capacity.^[7]

At Spencer Shadow Ranch, Doug monitors pasture growth carefully to determine when it is time to rotate cattle to a new paddock. In his larger, 50- to 100-acre paddocks, the timing of these rotations comes out to about every two to four weeks. In the smaller, 15- to 20-acre paddocks, cattle sometimes need to be rotated as often as every three days. Once cattle leave an area, that paddock is allowed to rest for a minimum of 40 days before animals are allowed back in.

Above left: A skid steer with a log grapple attachment is used to remove trees to create more pasture areas.

Above right: Cattle grazing at Spencer Shadow Ranch.

Photos courtesy of Mitchel Davidovitz (left) and Douglas McCarty, Spencer Shadow Ranch (right)

Challenges

Fencing infrastructure can be important both to conduct rotational grazing and to protect cattle from predation. However, fencing can be expensive and time consuming to maintain, and Doug has identified this as one of his biggest challenges.

One of Doug's land stewardship goals is to promote biodiversity across the broader landscape by increasing the species-richness of the land. He recognizes the role of wildlife in ecosystem health, and he welcomes diversity and abundance of fauna of all kinds—even predators like coyotes and mountain lions. Rather than kill these animals or eliminate their habitat, Doug's strategy to protect his cattle while also promoting wildlife has been to exclude predators with multiple layers of fencing, including electric fencing and a perimeter border of taller nonelectric fencing.

By having multiple exclusionary barriers in place, Doug has been able to reduce the threat of predation without hurting predators.

Eventually, Doug would like to invest in more fencing to establish smaller paddocks for optimized rotational grazing as well. Spencer Shadow Ranch's existing paddocks range from 15- to 100-acres, but Doug's goal is to divide the land into smaller 20-acre paddocks, so that cattle can be rotated through quickly at a higher stocking density. "The overall goal is to have 20-acre paddocks, each with roughly 6 acres of woods and 14 acres of meadows," explains Doug. "This will allow enough canopy cover for weather protection, while providing enough open space to invite abundant grazing."

This type of rotation also promotes even pasture growth and allows each paddock to receive longer periods of rest between rotations. Paying for and maintaining fencing infrastructure is a challenge, but Doug feels it will be worth it. This infrastructure will support improved rotational grazing, which will benefit soil health, protect his cattle, and protect other wildlife as well.

Implementation

The NRCS helped fund much of Spencer Shadow Ranch's initial forest thinning through a financial assistance program called the Environmental Quality Incentives Program (EQIP). Doug worked with an NRCS Technical Service Provider to develop a Forest Management Plan, which helped inform which trees to thin and which trees to keep. Doug invested in equipment to implement the Forest Management Plan, and some of these costs were reimbursed through financial assistance from NRCS.

Conclusion

Doug and Sookjae McCarty's implementation of silvopasture at Spencer Shadow Ranch is helping them address challenges such as limited soil fertility, extreme temperatures, and limited water availability, to improve their cattle production in the face of changing climate conditions. By adopting silvopasture, the McCartys are also able to conserve their oak woodland and savanna habitat and protect biodiversity. While challenges inevitably come up, Doug considers them as part of the journey. "There are no mistakes—just activities that give you results that you weren't expecting," says Doug. "It's all a learning opportunity."

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Climate Hubs
U.S. DEPARTMENT OF AGRICULTURE

CHAPTER
13

WINDBREAKS & HEDGEROWS

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Definitions

A windbreak is a barrier, such as a row of trees, shrubs, or fence, designed to decrease wind speed, reduce soil erosion, and shelter crops, livestock, or structures.

A hedgerow is a linear planting of trees, shrubs, grasses and forbs designed to provide multiple conservation, production, and landscape functions.

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Windbreaks and hedgerows are closely related agroforestry practices that use linear plantings of trees, shrubs, grasses, and other perennial plants to improve agricultural and ecological function across farms, ranches, roadsides, and rural landscapes. Windbreaks are usually designed primarily to modify wind, while hedgerows often serve a broader set of conservation, production, and landscape functions.

Many plantings combine elements of both, providing wind protection while also supporting soil and water conservation, crop and livestock systems, wildlife habitat, pollinators, screening, boundaries, and useful plant products.

To be effective, windbreaks and hedgerows should be designed with a clear understanding of the site, the intended function of the planting, and the interactions between the woody and herbaceous plants and the adjacent land use. With proper layout, species selection, and long-term management, these plant-

ings can maintain their effectiveness over time and sustain their contributions to the farm or ranch.

A windbreak's major function is to reduce wind velocity in order to reduce soil erosion, shelter crops and livestock, and enhance production. Windbreaks can also help prevent pesticide drift and mitigate the spread of livestock odors.

A windbreak must be 2.5 feet or higher to have a significant effect. Many kinds of materials can be used for a windbreak, including trees, shrubs, and tall perennial or annual plants, such as switchgrass or sunflowers, that attain sufficient height to create the desired wind shadow. The terms windbreak and shelterbelt are often used interchangeably.

Above. Hedgerows are often planted with a diverse mix of trees, shrubs, and forbs to support pollinator habitat.

Photos courtesy of Erica Guttman, WSU Extension

Hedgerows were historically used to demarcate property lines, but they are now widely used to meet conservation and production objectives. They can provide wildlife habitat on farms, particularly for pollinators, produce food and other useful products, and serve as privacy screens or living boundaries.

Generally speaking, hedgerows tend to be shorter, more diverse, and include more shrubs, grasses, forbs, herbs, vines, and flowers than windbreaks, which often feature fewer species and are more frequently composed of trees.

Windbreaks and hedgerows can also reduce energy costs in homes and other structures by mitigating exposure to cold winds in the winter and providing shade in the summer. When placed along roadways, they can prevent snow drift and improve public safety as living snow fences.

This chapter discusses both windbreaks and hedgerows, with technical guidance for wind protection as well as broader design and establishment considerations for multifunctional hedgerow plantings.

Historical context

Windbreaks and hedgerows have long histories as working landscape features. Hedgerows developed as living fences and multifunctional farm boundaries. In medieval Europe, hawthorn cuttings were planted, allowed to grow, and then bent and trained to fill gaps, creating dense living fences known as hedges. As birds settled in the hawthorns and dropped seeds, more plant species became part of these living boundaries. Today, many farms in England are still surrounded by ancient hedgerows that shelter beneficial organisms and conserve soil and water.

Windbreaks have also been used for generations to protect farms, roads, and livestock from wind and drifting snow. In North America, windbreaks became especially important during the Dust Bowl era, when severe wind erosion contributed to widespread soil loss across the Great Plains. In response, the **USDA's Shelterbelt Program** supported large-scale tree plant-

ing during the 1930s to reduce wind erosion, protect farms, and improve rural living conditions.

Hedgerow plantings were less common in the early United States, although renewed interest in sustainable farming, pollinator habitat, biodiversity, and multifunctional conservation practices has brought new attention to this age-old practice. Today, both windbreaks and hedgerows are used to protect soil and water, shelter crops and livestock, support wildlife and pollinators, buffer land uses, and add long-term value to farms and rural landscapes.

Benefits and challenges

Windbreaks and hedgerows can provide multiple benefits at once, including crop and livestock protection, soil conservation, water management, wildlife habitat, pollinator support, screening, air-quality improvement, and diversified farm products. Their value depends on how well the planting is matched to the site, the landowner's goals, and the surrounding farm or ranch system.

Benefits

The following sections describe these benefits in relation to soil and water protection, crop and livestock systems, biodiversity and pollinator habitat, buffers and screening, and diversified farm products.

Soil and water protection

Windbreaks have been widely recognized as a key tool to reduce wind erosion. When wind speed is reduced, the wind erosion process cannot start. Wind erosion can rob land of precious topsoil containing nutrients and organic matter. This loss can lead to reduced productivity and the need to add more nutrients.

Wind erosion potential is greatest when fields are wide and the soil is bare and smooth. Windbreaks combined with other wind erosion control measures, such as reduced tillage and herbaceous wind barriers, create a conservation approach to tolerating wide weather extremes.

With careful species selection, both windbreaks and hedgerows can be designed to maximize soil benefits. Deep-rooting trees enhance nutrient cycling and add nutrient-rich organic matter from leaf litter, particularly deciduous trees. Nitrogen-fixing trees and shrubs add nitrogen to the soil around them and may increase available nitrogen for adjacent crops. Trees and other woody perennials naturally provide carbon sequestration benefits and help support soil biota. Planting wider windbreaks and hedgerows with a diversity of species will enhance this effect.

Hedgerow plantings can also reduce soil erosion within a landscape by increasing surface water infiltration, improving soil structure around the root zone, and slowing sediments and organic material that may otherwise flow from farm fields into waterways. Decaying matter from the roots, stems, leaves, and branches of hedgerow plants increases soil organic matter over time, which improves the ability of soil to absorb and retain water.

Hedgerows can also support aquatic habitat when they are planted near riparian areas. Shade from trees and tall shrubs can reduce water temperatures, limit evaporation, and improve watershed quality. The degree of benefit depends on the hedgerow's location, stream aspect, leaf density, and height of vegetation.

Crop and livestock protection

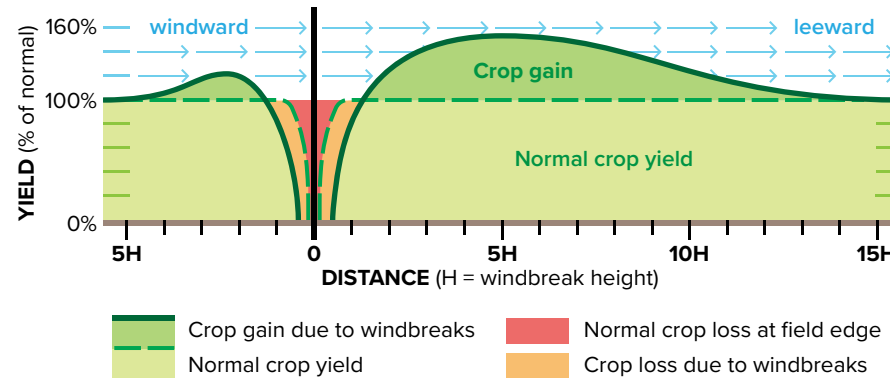
Windbreaks improve crop production and quality by modifying the microclimate and reducing wind erosion. They can protect crops from wind stress, improve irrigation efficiency by reducing evaporation losses, manage snow drifting to increase soil moisture, and reduce physical damage to plants.

When field windbreaks are suggested to landowners, they often have a mental image of crop reduction and/or loss adjacent to the windbreak and from the space occupied by the windbreak. What is often not recognized is the potential for increased crop quality and quantity on the leeward side of the windbreak.

Figure 13.1.
Crop yield response.

Crop yields may decline immediately adjacent to the windbreak because of competition and unplanted field edge area, but yields often increase on the leeward side where wind protection improves growing conditions.

Adapted from Read (1964) and Helmers and Brandle (2005)



Many years of field research have shown there is a yield advantage for many crops when protected by a windbreak. This yield increase generally occurs on the leeward side of the windbreak, where reduced wind speed improves the growing environment. The amount of yield increase will vary from year to year due to weather conditions, soils, and the types of trees used in the windbreak. Less competitive trees generally result in greater gains.

The yield advantage is normally more than enough to offset the decrease in yield immediately adjacent to the windbreak and the land occupied by the windbreak. Some landowners plant a deep-rooted crop such as alfalfa adjacent to the windbreak in the area most affected by competition and are able to gain good quality forage.

In addition to traditional commodity crops, windbreaks are also used to protect a variety of horticultural crops including fruit trees and vegetables. Some of the key benefits of protecting these crops include improved quality from reduced bruising, better pollination from insects due to less wind, and earlier crop maturity, which may create marketing advantages.

Windbreaks around orchards are also being examined for their use in preventing off-site drifting of pesticides. Many orchards and other farms are being engulfed by housing developments. Windbreaks can help buffer potential land-use conflicts.

Windbreaks provide valuable protection to livestock, especially young animals and those exposed to cold northerly winds in winter and early spring. Reducing wind stress lowers animal stress and improves health, resulting in better livestock production by increasing feed efficiency and weight gains, improving survival of newborns, and increasing milk production.

Windbreaks and hedgerows can also provide living screens to separate incompatible uses, such as livestock facilities from suburban residences. Hedgerows are sometimes used in place of fencing to contain livestock or separate paddocks in rotational grazing systems. In the process, they can provide valuable fodder to enhance livestock nutrition and ‘finish’ animals for meat products. These plantings can also provide shelter for livestock from cold winds, heat, and other inclement weather.

Biodiversity, pollinators, and pest management

Windbreaks and hedgerows enhance wildlife habitat by adding tree, shrub, and herbaceous cover to agricultural landscapes. They can provide food, cover, nesting sites, perches, and travel corridors for mammals, birds, reptiles, amphibians, insects, and other species. Dense or thorny shrub thickets can offer songbirds refuge from predators, while trees can provide nesting sites and perches for raptors that help control rodents.

Hedgerows provide undisturbed refuge for species of all kinds, creating wildlife corridors, travel lanes, or habitat islands. These corridors are especially important in fragmented landscapes, such as where a single crop is grown. Hedgerows help protect wildlife from predators and can offer sheltered access to riparian zones or other water sources.

Planting a variety of flowering trees, shrubs, forbs, and perennial plants provides insect habitat, nectar, and pollen sources throughout the year for beneficial insects and pollinators. Increasing plant habitat for pollinator species can improve fruit set, size, and quality, as well as general biodiversity.

Pollinator habitat also attracts beneficial insects that prey on many crop pests. Plants in the family Umbelliferae, such as coriander, dill, fennel, parsnip, parsley, and carrots, attract parasitic wasps, hover flies, lacewings, ladybeetles, and true bugs such as ambush bugs and minute pirate bugs. These plants are useful in the kitchen and are attractive to pollinators. Increasing the number of beneficial insects can help farmers manage crop pests and reduce insecticide use.

Windbreaks and hedgerows can also help manage invasive weeds. Hedgerows planted along roads or between crop fields may prevent weed seeds from blowing into the field. As hedgerows mature, these plantings can displace invasive weeds. If well maintained, this weed management benefit can last for the lifetime of the hedgerow.

Buffers, screening, and community benefits

Windbreaks and hedgerows can improve air quality and reduce conflicts between neighboring land uses by capturing airborne particulates, including dust, smoke, pesticide droplets, and odors. As plantings mature and become dense, they can also reduce noise, chemical drift, and other pollutants.

Open-canopy trees can be effective barriers for dust and pesticides because particles in the air slowly filter through them instead of depositing in concentrated

clouds on the other side of the hedge. Planting hedges as close as possible to areas where pollutants are a concern can help alleviate neighborhood conflicts where agriculture borders urban or suburban areas.

These plantings can also serve as attractive borders, privacy screens, and living fences along roads, field edges, livestock areas, and property boundaries. Evergreen plants can provide year-round screening, while diverse plantings add seasonal beauty through flowers, fruit, foliage, bark, and structure. When placed along roadways, windbreaks and hedgerows can prevent snow drift and improve public safety as living snow fences.

Windbreaks and hedgerows can also reduce energy costs in residential homes and other structures by mitigating exposure to cold winds in the winter and providing shade in the summer. In rural communities, these benefits extend beyond the farm by improving comfort, visibility, safety, and landscape appearance.

Products, income, and aesthetics

Both windbreaks and hedgerows can be designed to produce valuable crops and materials, including fruits, nuts, berries, leaves, flowers, seeds, bark, medicinal herbs, fiber, basketry materials, tree syrups, firewood, timber, nursery stock, floral materials, and cuttings for propagation.

Trees can also be planted for secondary wood products such as lumber, veneer, firewood, chips for bedding, or mulch. Willows and other flexible-stemmed shrubs can provide craft material and basketry products. Fruits, berries, nuts, and edible leaves can provide food for humans, livestock, and wildlife. Some plantings may also support beekeeping or increase pollination rates in adjacent crops.

By combining conservation functions with useful products, windbreaks and hedgerows can diversify farm income while enhancing the beauty, productiv-

ity, and biodiversity of the landscape. These benefits often increase over time as the planting matures.

Hedgerows in the landscape add continuous beauty, especially when designed for year-round interest. The color and texture of leaves and bark, bloom color and timing, fruit, evergreen or deciduous structure, and layered plant forms can create attractive effects in every season.

Challenges

Despite these benefits, windbreaks and hedgerows require careful planning and long-term management. The same trees, shrubs, and herbaceous plants that provide conservation and production benefits can also create challenges if they are poorly placed, poorly matched to the site, or not maintained during establishment.

Windbreaks and hedgerows may remove land from annual crop production, require specialized equipment for tree and shrub management, and need regular attention to weeds, irrigation, replanting, pruning, and protection from wildlife. Financial returns may increase gradually as the planting grows, but they are rarely immediate.

Poorly designed plantings can compete with adjacent crops for light, moisture, and nutrients. They may also interfere with equipment access, create gaps that funnel wind, or harbor harmful crop pests, weeds, or diseases if not properly managed. In some settings, root or canopy pruning, mowing, mulching, or thinning may be needed to maintain the desired balance between the planting and adjacent crops or pastures.

These challenges can usually be reduced through clear goals, careful site assessment, appropriate species selection, proper spacing and orientation, and a realistic maintenance plan. Windbreaks and hedgerows are long-term investments, and their success depends on matching the design to the site and the intended function.

How windbreaks function

Windbreaks function primarily by changing wind speed, turbulence, snow movement, and microclimate. Hedgerows may provide some of these same wind-modifying functions, but they are often designed more broadly to create habitat, filter runoff, buffer land uses, produce useful products, and increase landscape diversity.

Windbreak height

Height (referred to as 'H') is the most important factor determining the downwind area of protection. The windbreak 'H' is the height of the tallest row of trees in the windbreak.

The windbreak will reduce wind speed for 2 to 5 times the height of the windbreak (2H to 5H) on the upwind side and up to 30H on the downwind side of the barrier. The area protected is a direct result of the height and density.

Windbreak density

Density is the ratio of the solid portion of the barrier to the total area of the barrier. Wind flows through the open portions of a windbreak, thus the more solid the windbreak, the less wind passes through. By adjusting windbreak density, different wind flow patterns and areas of protection are established.

Density level is manipulated by choice of plant materials (e.g., deciduous vs. conifer); and plant arrangement. By combining low growing shrubs with medium and tall deciduous trees, dense plant material is provided at three levels (low, middle and upper) of the windbreak during the growing season.

However, during the winter, the density would decrease due to the loss of foliage. Consequently, a conifer component would be desirable for year-round protection.

The term windbreak **porosity** may also be used to characterize this structural element. The percentage of porosity is the amount of open spaces in the windbreak when viewed perpendicular to the windbreak as shown in **figure 13.2**. In other words, porosity is the inverse of density, i.e., a 60% dense windbreak would be 40% porous.

Degree of **density** impacts the extent of the protected area and magnitude of protection (see **figure 13.3**)

- **Solid, 100%:** Provides maximum wind reduction, but the area of wind reduction, known as a wind shadow, is shorter than with a dense tree windbreak.
- **Dense, 60-80%:** Protects a larger area and the magnitude of wind reduction is as good as the solid structural fence or wall.
- **Moderately dense, 40-60%:** The magnitude of wind reduction is somewhat less, but the wind shadow is at its maximum.
- **Under 40%:** The effectiveness of the windbreak begins to decline. However, low-density windbreaks are very effective for even distribution of snow across a field for moisture management. This density level is not as good for stopping wind erosion.

Windbreak orientation

Windbreaks are most effective when oriented at right angles to prevailing or troublesome winds (see **figure 13.4**). The best orientation for each windbreak depends on the objectives for the windbreak. A key point to remember is that although the troublesome wind may occur primarily from one direction, it rarely blows exclusively from that direction. As the wind changes direction and is no longer blowing directly against the windbreak, the protected area decreases.

Windbreak length

Although the height of the windbreak determines the extent of the protected area downwind, the length of a windbreak determines the amount of total area receiving protection. For maximum efficiency, the uninterrupted length should exceed the height by at least 10:1 (i.e., a 30-foot-tall windbreak needs to be at least 300 feet long). The ratio reduces the influence of end-turbulence on the total protected area.

Windbreak width

The width primarily serves as a means to manipulate the desired density of the windbreak. The number of rows, the distance between trees, and species composition are factors controlling windbreak density. Increasing the number of rows or decreasing the distance between trees increases density and provides a more solid barrier to the wind. A wider windbreak can also increase the value of the windbreak for wildlife and offers opportunities to produce products.

Windbreak continuity

Continuity influences efficiency. Gaps in a windbreak become funnels that concentrate wind flow, creating areas on the downwind side of the gap in which wind speeds often exceed open field wind velocities. Gaps will decrease the windbreak's effectiveness. Access lanes through a windbreak should be avoided or minimized.

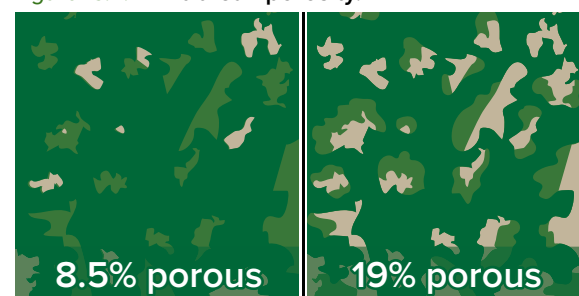
Windbreak cross-sectional shape

Some windbreak guides call for a “hip-roof shape” to assist in “lifting” the wind. However, the cross-sectional shape of windbreaks with equal densities has minimal influence on wind velocities within 10H of the leeward side of a barrier. Beyond 10H, straight sides provide slightly more protection than slanted sides because more wind passes through the trees and extends the protected area farther to the leeward.

Choosing a windbreak, hedgerow, or hybrid design

In practice, many plantings fall between a windbreak and a hedgerow. A planting designed mainly to reduce wind speed, control snow, or protect crops is usually planned as a windbreak. A planting designed primarily for habitat, pollinators, products, privacy, or field-edge biodiversity may be planned as a hedgerow. Many farms and ranches benefit from hybrid designs that use windbreak principles of height, density, continuity, and orientation while also incorporating the species diversity and habitat value of hedgerows.

Figure 13.2. Windbreak porosity.



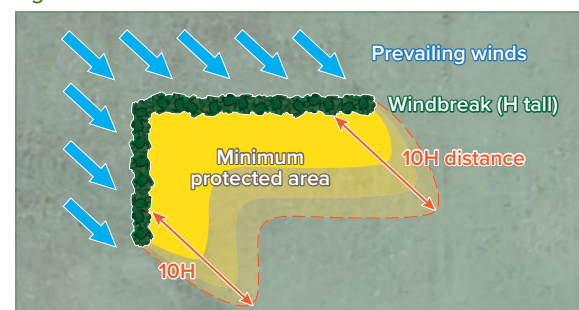
Graphic adapted from Cameron C Dunn

Figure 13.3. Windspeed reduction.

H-distance from windbreak	Open wind speed at 22 mph			
	Deciduous windbreak 25-35% density	Conifer windbreak 40-50% density	Multi-row windbreak 60-80% density	Solid fence 100% density
5H	11 mph 50%	7 mph 30%	6 mph 25%	6 mph 25%
10H	15 mph 65%	11 mph 50%	8 mph 35%	16 mph 70%
15H	18 mph 80%	13 mph 60%	15 mph 65%	20 mph 90%
20H	19 mph 85%	17 mph 75%	19 mph 85%	21 mph 95%
30H	22 mph 100%	21 mph 95%	21 mph 95%	22 mph 100%

From Univ. of Missouri Center for Agroforestry, *Training Manual for Applied Agroforestry Practices*, 2024.

Figure 13.4. Windbreak orientation.



Special assessment considerations

Key assessment questions include:

- What needs to be protected: crops, orchards, soil, livestock, buildings, roads, or other infrastructure?
- How important are additional benefits such as wildlife habitat, pollinator support, carbon sequestration, privacy screening, or diversified farm products?

Determining the purpose

As noted previously, windbreaks and hedgerows can serve a variety of purposes, ranging from crop protection to pollinator habitat. The design of a windbreak or hedgerow depends on that purpose, the owner's objectives, and the physical characteristics of the site.

The first step in design is to identify the primary and secondary objectives for the planting. A structured assessment process can help clarify these objectives.

Crops

- Has wind erosion occurred in the fields? If so:
 - When did it occur?
 - From which directions does the wind cause the most problems?
 - Are other wind erosion control practices being used, such as reduced tillage?
- Did wind or blowing soil cause the crop damage? If so:
 - When did it occur?
 - From which directions does the wind cause the most problems?
 - What wind-sensitive crops are being grown?
- Are pollination-dependent crops present?

Livestock

- When do livestock need the most wind protection?
- Which pastures, lots, or structures need protection?
- Is summer air movement needed in the livestock area?
- Which access roads need to be kept clear of snow?
- Are there drainage concerns with rain or snowmelt?

Wildlife

- Are there target wildlife species the planting is intended to support? If so:
 - What habitat do those species require?

- Will buffer size affect their ability to use the space?
- Are pollinators a priority? If so,
 - What time of year is pollination most important for crop production?
 - What times of year are food sources scarce?
 - What species can be selected to provide nectar, pollen, or other food sources during those periods?
- Is crop damage by wildlife occurring? If so:
 - What animals, insects, or other organisms are responsible?
 - Can habitat be provided for predators that may help reduce crop damage?
 - Can alternative food sources be provided to reduce crop damage?

Site evaluation

The next step is to evaluate site conditions that may affect windbreak or hedgerow design and application. A conservation plan map, aerial photo, or field sketch can be used to identify fields in need of protection, existing windbreaks, soil problems, utilities, prevailing erosive winds, property lines, roads, and access lanes.

- Identify all areas needing protection based on troublesome wind direction or directions.
- Inventory soils, including areas that may pond seasonally, and begin a starter list of species adapted to those soil conditions.
- Observe topography to identify drainage concerns into or away from the windbreak, especially snowmelt and feedlot runoff.
- Locate property lines, overhead and underground utilities, and existing trees or shrubs within or adjacent to the proposed planting area.
- Identify access roads or lanes that could create breaks in the windbreak.
- Locate the windbreak to avoid obstructing winter sun or traffic visibility near driveways.
- Identify protection needs for the planting, such as fencing to exclude livestock.
- Observe existing plant species that may be alternate hosts for pathogens, such as cedar-apple rust.
- Inventory existing wildlife habitat and wildlife species so the windbreak or hedgerow can complement surrounding habitat.

Design

Design begins with the goals of the land manager and the site conditions that shape what a planting can realistically accomplish. The following considerations move from overall purpose and site fit to rows, spacing, species selection, production goals, and Pacific Northwest plant options.

Designing windbreaks and hedgerows requires the planner to manipulate structural components in order to achieve the desired effect. Climatic and physical effects such as wind speed, apparent air temperature, snow deposition, and evapotranspiration are modified by the structural characteristics of the windbreak or hedgerow.

Designing for crop protection

- For crop protection, crop production, and/or uniform snow distribution, windbreak-to-windbreak intervals should be 15 to 20H. For crops highly susceptible to wind damage or small amounts of wind-blown soil during part of the growing season, a spacing interval of 6 to 10H provides a high degree of protection.
- For erosion control purposes, NRCS uses a general rule of "no erosion out to 10H leeward," leading to a windbreak-to-windbreak interval of 10H plus the distance protected by the agronomic system, such as standing crop, crop residues, cropping pattern, or ridging.
- Different design densities and heights result in different snow drift patterns. For example, if the goal is to spread snow evenly across a field to improve soil moisture, the windbreak design density should range from 25 to 35%. This is roughly equivalent to a single row of widely spaced deciduous trees without leaves. If soil erosion is a potential concern while the windbreak is at this density level, additional conservation measures will be needed.

Designing for livestock benefits

- Greatest wind protection occurs from 2 to 5H leeward of the tallest tree row.
- For wind and snow protection, the most windward row should be 100 to 200 feet from the windward edge of the primary protection area.

- Allow room for snow deposition outside the feeding area. Drainage from clean water runoff, snowmelt, and feeding areas should also be considered. Effluent from feeding areas can harm or kill trees and shrubs.
- Critical temperatures for beef cattle are determined in part by coat condition. Below or above the critical temperature, livestock must expend more energy to keep warm or cool.
- Select species that can grow to a sufficient diameter to tolerate some livestock interaction, typically 4 to 6 inches. If smaller trees, shrubs, or forbs are used, select species that are resilient to browse and potential compaction damage. Avoid species that may have adverse effects on livestock. For example, ponderosa pine (*Pinus ponderosa*) can cause abortion in cattle, and conifers that drop sap may damage sheep wool. Species that produce fodder or other consumable products can also be selected to supplement or enhance livestock nutrition. Fruits and nuts may add value to livestock products.

Designing for wildlife and pollinator benefits

- Plant a diversity of species that occupy all vertical strata, including understory, midstory, and overstory, to provide adequate cover for wildlife. Adding a shrub row 50 to 100 feet windward of the main windbreak as a snow trap can improve wildlife protection on the leeward side. Species that provide good winter thermal protection, such as cedar and spruce, may be useful.
- Consider planting or retaining herbaceous vegetation, such as grasses, legumes, standing grain, or crop residues, as a 20- to 50-foot border along the edges of the windbreak or hedgerow. If grasses or legumes are used, they should be separated from new tree plantings to avoid competition. This cover can provide nesting, loafing, and foraging habitat for a number of species.
- Plant wider hedgerows and windbreaks to allow animal movement and serve as wildlife corridors. Where possible, design plantings to connect with larger habitat blocks, such as woodlots. Plantings that intersect with or run alongside riparian areas can provide covered access to water. (see **Chapter 11: Riparian Forest Buffers** for more information on riparian plantings).
- Check the bloom period of proposed species and select a mix that provides food sources for pollinators throughout the growing season.

- Plant fruit- and nut-producing trees and shrubs to provide food for wildlife and potential human use. Additional crops can also provide fiber, decorative materials, and medicinal products.
- Select some taller tree species, even when wind protection is not a priority, to provide habitat for birds of prey. This may help reduce small mammal pests in crops and structures.
- To reduce pollinator exposure to pesticides, plant trees and shrubs that are less attractive to pollinators close to fields where pesticides may be used. Pollinator-preferred species can be planted in the interior or on the opposite side.

Designing for structures, roads, and energy conservation

Windbreaks and hedgerows can reduce energy consumption by reducing wind exposure, limiting air infiltration into buildings, and decreasing heat loss during cold weather. They can also reduce snow accumulation around buildings, roads, driveways, and other infrastructure, lowering the need for snow removal and improving access and safety.

For wind protection alone, the tallest row should generally be located 2 to 5H from the primary area needing protection, where H is the height of the tallest row. Areas and objects more than 10H from the windbreak will receive reduced wind protection.

For combined wind and snow protection, the most windward row should generally be located 100 to 200 feet from the windward edge of the primary protection area. This spacing allows room for snow storage while still providing wind protection. Once this distance is met, the protected area should be checked to determine whether it remains within the desired 2 to 5H protection zone.

To protect structures, the windbreak should generally have a density of 60 to 80% during the season when maximum protection is needed. To achieve this density, plant at least three rows of trees and shrubs, with at least one row composed of conifers where year-round protection is desired.

The windbreak should extend at least 100 feet beyond the structures needing protection to reduce end turbulence and snow drifting at the ends of the planting. Access roads should generally be located 100 to 500 feet from the ends of the windbreak. If a lane must pass through a windbreak, it should cross at an angle to the prevailing wind to reduce wind funneling and snow drifting.

In the Pacific Northwest, windbreaks and hedgerows used near homes, barns, and other structures should also be planned with wildfire preparedness in mind. Defensible space should be created and maintained by carefully selecting and managing vegetation near buildings and other infrastructure.

For more information, consult guidance from:

- [National Fire Protection Association](#)
- [Washington Department of Natural Resources](#)
- [Wildfire Readiness](#), OSU Extension Service

Additional design applications

In addition to protecting crops, livestock, soil, and habitat, windbreaks and hedgerows can be designed for broader community, transportation, and land-use compatibility goals. These applications rely on the same basic design principles of height, density, orientation, continuity, and species selection, but they are planned around roads, homes, farmsteads, livestock facilities, or rural-urban edges.

Community windbreaks and hedgerows

Planned community windbreaks and hedgerows can provide protection for entire developments, neighborhoods, roads, and public spaces. They may also increase property values by improving comfort, aesthetics, privacy, and landscape quality.

Community windbreaks and hedgerows can also reduce conflicts in the rural-urban interface. Where agricultural land borders residential or commercial development, well-designed plantings can help reduce blowing dust, windblown soil, pesticide drift,

odors, noise, and loss of privacy between land uses. High-quality windbreaks between agricultural fields and communities can also reduce snow movement and improve safety and comfort for nearby residents.

For more information, see:

- [Working Trees for Communities](#), USDA National Agroforestry Center

Living snow fences

Blowing and drifting snow can affect public safety, emergency services, business access, road maintenance costs, and wildlife movement. Living snow fences are windbreaks designed specifically to trap and manage snow before it reaches roads, driveways, buildings, or other areas needing protection. Compared with structural barriers, living snow fences can be cost-effective over time and can also provide wildlife habitat, visual screening, carbon storage, and other conservation benefits.

Design tips:

- To achieve maximum snow accumulation, windbreak density should generally range from 60 to 80%.
- The furthest windward row should be located at least 100 feet from the area being protected to prevent unwanted snowdrifts. This distance may vary from 100 to 300 feet depending on location, winter severity, wind exposure, and the amount of snow storage needed.
- A trap row of shrubs or dense conifers can be located 50 to 100 feet windward of the main windbreak to create a snow trap.
- For road protection, adequate space should be allowed for the leeward drift. In many cases, the windward row of the windbreak should be located 200 to 300 feet from the center of the road.

For more information, see:

- [Living Snow Fences](#), USDA National Agroforestry Center
- [Windbreaks for Snow Management](#), University of Nebraska Extension
- [Davenport Living Snow Fence Demonstration: Fifteen-Year Survival and Growth Update](#), WSU Extension

Livestock odor reduction

Windbreaks and hedgerows placed around livestock production facilities can reduce the movement of odors and dust generated. Urban expansion has placed more people in closer contact with agricultural operations, while large-scale livestock confinement systems can concentrate odor emissions across landscapes with few natural barriers.

Windbreaks and hedgerows alone will not eliminate odor concerns, but they can help intercept and dilute odor-laden air, reduce dust movement, and improve the visual screening of livestock facilities. These effects can reduce negative perceptions and help improve compatibility between livestock operations and neighboring homes or communities.

Design tips:

- Windbreaks for odor reduction should generally include one to three rows of conifer and deciduous species.
- Two to three rows of trees can provide an effective density of approximately 60%, or 40% porosity, for odor interception and air mixing.
- Shrubs are generally planted in the outside or inside rows, followed by conifers, with deciduous hardwoods toward the middle or along the downwind side where they can grow efficiently.
- Tree species, row placement, and density should be managed to maximize odor interception, increase dilution of moving air, and reduce odor movement away from the source.
- Where site and facility conditions allow, plantings can be placed around the full perimeter of the odor source. Where a full perimeter planting is not possible, a strategically placed windbreak or hedgerow on one side of the facility can still provide benefits.

For more information, see:

- [Windbreaks: A “Fresh” Tool to Mitigate Odors from Livestock Production Facilities](#), Iowa State University

Rows, spacing, and access

- Avoid creating gaps with access roads cut through a windbreak. Wind flow increases through gaps decreasing windbreak effectiveness. Where needed, design the opening at an angle to prevailing winds. Lanes or roads through single-row barriers should be avoided; where necessary, locate them 100 to 500 feet from the ends of the windbreak.
- Locate new rows of trees 50 feet from existing trees.
- Stay away from subsurface drain fields and overhead utilities.
- Avoid locating windbreaks within 200 feet of road intersections to prevent poor driver visibility.

Species selection and planting design

Tree and shrub species differ in growth rate, mature height, density, site adaptation, and function. Available soil moisture during the growing season and soil aeration are two important factors affecting tree and shrub growth. Seasonal ponding can also significantly affect species selection. These factors are largely determined by soil texture, soil depth, drainage, and climate.

For agroforestry in frequently ponding areas, see:

- [Wet Feet Farming Guide](#) from Better Ground, the Puget Sound Conservation District Caucus

Conservation tree and shrub suitability groups can help identify species adapted to different soils and climates, predict height growth at 20 years, and estimate effectiveness. These guides are available through the [NRCS Field Office Technical Guide](#).

Plant information is also available through the [USDA PLANTS database](#). WSU Extension's [Hedgerows Toolkit for Rural and Working Lands](#) also provides support for selecting regionally appropriate species, planting templates, and guidance for western Washington and northwest Oregon.

In addition to being adapted to climate and soil, selected plants should have strong potential to meet land manager objectives. For windbreaks, the primary objective is often to provide the desired level of wind

protection within a reasonable time, often within 10 years. This means selecting species that provide the appropriate density and height for the site. For example, conifers should be considered where year-round wind protection is desired.

Other objectives, including wildlife habitat, pollinator support, soil health, carbon sequestration, crop production, privacy screening, and products for sale or personal use, will also influence species selection.

Multifunctional hedgerow design

Whether in rural or urban settings, the principles of planning a hedgerow are similar: evaluate the site, determine the desired functions of the planting, match the right plant with the right place, and properly prepare the site.

There are many essential components to consider when designing a multifunctional hedgerow. The first step is to observe the site where the hedgerow is to be planted and consider the ecological and environmental conditions that will influence plant selection, layout, location, and the size of the area to be planted.

Although a single line of trees or shrubs can provide some benefits, wider and more diverse plantings generally provide greater benefits for wind protection, water and soil conservation, wildlife habitat, pollinator support, and biodiversity. Four or more rows of plants are often optimal where space allows. When appropriate, place the tallest plants at maturity in the center row, with shorter plants interplanted between and along the edges. A diverse selection of plant sizes, forms, and functions is generally most beneficial.

When wind protection is one of the goals, rows are most effective when oriented perpendicular to prevailing winds. Hedgerows that follow land contours can create meandering lines on the landscape, produce a more natural appearance, reduce erosion, and create larger buffer areas for wildlife habitat.

If pollinator habitat is a primary goal, reserve approximately one-half acre of hedgerow or other pollinator habitat for every 40 acres planted in crops.

Hedgerow plant selection

Hedgerow plant selection should be guided by both site conditions and the intended functions of the planting. A successful hedgerow usually includes a diverse mix of trees, shrubs, forbs, grasses, and other perennial plants that occupy multiple layers, provide seasonal habitat and food resources, and

remain manageable over time. Species should be well adapted to the site's soil, water, light, and climate conditions, while avoiding invasive plants or species with serious pest, disease, toxicity, or maintenance concerns. **Table 13.1** provides a checklist for evaluating plant options before finalizing a hedgerow design.

Table 13.1. Selection factors for hedgerow plants.

Selection factor	Questions to consider
Origin and range	- Is the plant native, indigenous, naturalized, or introduced? - Is it appropriate for the region and site?
Hardiness and climate	Is the plant suited to the local hardiness zone, frost dates, heat exposure, and seasonal weather patterns?
Light requirements	- Does the plant require full sun, partial shade, or shade? - How will light conditions change as the hedgerow matures?
Mature size and growth habit	What height, width, form, and growth rate will the plant have at maturity?
Soil conditions	Is the plant adapted to the soil type, pH, fertility, compaction, and erosion risk?
Drainage and water needs	Can the plant tolerate the site's drainage, seasonal wetness, drought, irrigation pattern, and water movement?
Seasonal function	When does the plant bloom, fruit, leaf out, or provide seasonal interest?
Productivity	Does the plant provide food, fodder, fiber, medicine, floral materials, biomass, or other useful products?
Stress tolerance	Can the plant tolerate heat, cold, drought, salt, pollution, wind, browsing, or livestock pressure?
Evergreen or deciduous	Is year-round screening, winter density, or seasonal light penetration desired?
Plant structure	What form, texture, leaf type, bark character, thorniness, or branching pattern does the plant provide?
Safety and toxicity	Are any plant parts poisonous to people, livestock, pets, or wildlife?
Pest and disease resistance	Is the plant susceptible to common local insects, diseases, or pathogens?
Cost and availability	Is the plant available in the needed size, quantity, and provenance?
Maintenance needs	Will the plant require pruning, coppicing, irrigation, containment, pest control, or frequent harvesting?
Allelopathy and compatibility	Does the plant release compounds that may inhibit germination or growth of nearby plants?
Plant associations	Can plants with similar soil, water, sun, and drainage needs be grouped together?

Table 13.2. Design considerations for hedgerows.

Design consideration	General recommendation
Spacing within rows	Plant trees and shrubs approx. 6 to 8 feet apart, adjusted by species size and function.
Spacing between rows	Space rows approx. 8 to 10 feet apart where equipment access and site conditions allow.
Layering	Use one or two rows of taller trees flanked by shrubs, forbs, grasses, or low-growing plants.
Width	Hedgerows generally provide greater wildlife value when they are wider than 20 feet.
Winter wind protection	A winter windbreak may include at least two rows of evergreen trees and one row of deciduous trees or shrubs.
Summer wind protection	A summer windbreak may include at least one row of tall deciduous trees and one row of deciduous shrubs.
Planting hole preparation	Holes should be deep and wide to accommodate roots without crowding or bending.
Establishment watering	New plantings should be watered in thoroughly and supported with irrigation as needed during establishment.

General hedgerow layout recommendations

The layout of a hedgerow should translate plant-selection goals into a functional structure on the ground. Row spacing, planting width, layering, and species arrangement will determine how well the hedgerow provides habitat, screening, wind protection, access, and long-term maintenance.

Table 13.2 summarizes general layout recommendations that can be adjusted based on site conditions, available space, equipment access, and the primary purpose of the planting.

Productive windbreaks and hedgerows

For most of the other agroforestry practices, a marketable product is typically produced from the woody component. Windbreaks have historically been a conservation practice that focuses on providing benefits to the adjacent area by reducing wind impacts.

In windbreaks planted in the 1930s and 1940s, plants were chosen that could provide fruit for home consumption and trees were cut for use as fence posts and rough lumber on the farm. It is also common for hedgerows to include a variety of species that can be used as food, fiber, and medicine for the landowners.

Windbreaks and hedgerows are not commonly managed to sell a product, but it is a viable option for interested landowners. For example, nut and fruit producing plants could be incorporated into a windbreak design with the intent of harvesting the fruits/nuts as a product.

Some commonly harvested fruits include:

- **currants** (*Ribes* spp.)
- **hazelnuts** (*Corylus* spp.)
- **chestnuts** (*Castanea* spp.)
- **salal** (*Gaultheria shallon*)
- **huckleberries** (*Vaccinium* spp.)
- **elderberries** (*Sambucus* spp.)
- **Oregon grape** (*Mahonia nervosa*, *Mahonia aquifolium*)
- **rose hips and flowers** (*Rosa* spp.)

All are harvested for home use, but they are also gathered for commercial use as fresh fruit, jams, jellies, syrups, juices, concentrates, confections, and wines.

A second enterprise is decorative woody florals. Any woody plant species that has a colorful or unusually shaped stem, bud, flower, fruit or even leaf can become a decorative floral product. Some plant examples include stems from red and yellow-stemmed dogwoods; and curly, pussy, flame and basket willows.

A number of native trees and shrubs in the Pacific Northwest are used for floral greenery, including Western red cedar, noble fir, and salal. When collecting boughs and foliage for these products, do not overharvest or compromise the wind protection benefits.

With these enterprises, careful advanced planning is needed. Unique challenges include understanding available markets, mechanizing harvest, perishability, available labor, wildlife pressure, year-to-year production, etc. Once these issues have been resolved, decide how to incorporate the plants into the windbreak design. If the plants that will be harvested are primarily shrubs, they can be included in the easily accessible outer or inner rows.

Growing specialty forest products in windbreaks can provide supplemental income while at the same time improving the environment. Another advantage is that windbreaks or hedgerows receive more management and could result in a longer lasting planting.

For more information on productive windbreaks, see:
 → [Productive Conservation: Growing Specialty Forest Products in Agroforestry Plantings](#) from USDA's National Agroforestry Center

Pacific Northwest species considerations

The following functional species list (**table 13.3**) provides starting points for Pacific Northwest windbreaks and hedgerows. It is not exhaustive. Final species selection should reflect site conditions, water availability, exposure, mature size, wildlife pressure, desired function, and local invasive species concerns.

Species should be selected first for site adaptation, then for function. A planting designed for year-round wind protection may require dense evergreen trees and shrubs. A planting designed for pollinator habitat should include species with overlapping bloom periods. A planting designed for farm products may emphasize fruits, nuts, berries, floral materials, basketry materials, or other non-timber forest products.

Establishment and management

Successful windbreak and hedgerow establishment depends on careful site preparation, appropriate planting methods, reliable moisture during establishment, weed control, and protection from wildlife or livestock damage. Management during the first several years is especially important because young trees and shrubs are vulnerable to drought, competition, browsing, girdling, and poor root development.

Site preparation

Site preparation is an important first step to support successful survival of trees and shrubs in windbreaks and hedgerows. The goal is to maximize available moisture and minimize weed competition. The type of site preparation used depends on the soil, slope, existing vegetation, weed pressure, erosion risk, and scale of the planting.

Site preparation can be accomplished mechanically, chemically, biologically, or through a combination of methods. Mechanical preparation may include tillage equipment such as a chisel plow, disc, rototiller, or scalper. Where herbicides are used, pre-emergent or post-emergent applications should follow label directions and avoid impacts to waterways, desirable vegetation, and sensitive habitat. With sandy soils, care should be taken to avoid wind erosion. On sloping sites, precautions should be taken to prevent water erosion.

On smaller sites, planting areas in existing grass or pasture can be prepared by applying a thin layer of compost or manure, followed by several layers of cardboard and mulch such as straw or leaves. Over winter, soil organisms help decompose the grass and add organic matter to the planting area. This method may not be practical at larger scales.

On larger sites, the area may be prepared by tilling in spring and planting an early cover crop such as crimson clover, followed by buckwheat. In late summer, the cover crop can be tilled or disced in and replanted with an overwintering cover crop such as crimson clo-

ver, field peas, or vetch. Cover crops can improve soil fertility, reduce weeds, stabilize soil, and attract beneficial insects. The area can then be prepared again the following spring before planting trees and shrubs.

Another option for sites with high weed pressure is solarization. The ground is closely mowed and covered with UV-stabilized plastic in midsummer for several weeks to suppress weeds. Solarization can be followed by fall planting where climate and soil moisture conditions are suitable.

Timing of planting

In more temperate environments, fall planting allows roots to become established before foliage emerges and takes advantage of winter rains. In colder climates or sites with harsh winter conditions, early spring may be the preferred planting time. At planting, amendments such as compost or manure may be applied as a top dressing where appropriate, based on site conditions and soil needs.

Planting methods

Tree and shrub planting can be completed with a tree planting machine or by hand. For either method, several planting techniques are important:

- Avoid planting on hot, windy days.
- Prevent roots from drying out before or during planting.
- Do not plant when temperatures are freezing or below.
- Plant seedlings vertically, with the root collar approximately 1 inch below the soil surface.
- Prepare a trench or planting hole deep and wide enough for roots to spread naturally.
- Avoid "J-rooting"; prune roots as needed so they fit properly in the planting hole.
- Pack soil firmly around roots to eliminate air pockets.

In arid areas where trees are difficult to establish, shrubs or tall native grasses may be used to provide crop protection, control wind erosion, and capture snow for crop production. Woody mulch around the base of trees and shrubs can help retain soil moisture and reduce weed competition.

Table 13.3. Functional species list for Pacific Northwest windbreaks and hedgerows.

Dense and lower foliage	
Douglas-fir <i>Pseudotsuga menziesii</i>	Evergreen structure; useful for wind protection
Evergreen huckleberry <i>Vaccinium ovatum</i>	Evergreen shrub; also provides berries
Grand fir <i>Abies grandis</i>	Evergreen structure
Incense cedar <i>Calocedrus decurrens</i>	Evergreen structure; drought-tolerant once established
Nootka rose <i>Rosa nutkana</i>	Deciduous; dense shrub; wildlife value
Salal <i>Gaultheria shallon</i>	Evergreen groundcover/shrub; berries and greenery
Shore pine <i>Pinus contorta</i> var. <i>contorta</i>	Evergreen; coastal and exposed sites
Sitka spruce <i>Picea sitchensis</i>	Evergreen; good for moist coastal sites
Sword fern <i>Polystichum munitum</i>	Evergreen understory cover
Tall Oregon grape <i>Mahonia aquifolium</i>	Evergreen shrub; flowers, berries, medicinal use
Thimbleberry <i>Rubus parviflorus</i>	Deciduous shrub; wildlife and berry value
Vine maple <i>Acer circinatum</i>	Deciduous; layered structure
Western red cedar <i>Thuja plicata</i>	Evergreen structure; moist sites
Western spiraea <i>Spiraea douglasii</i>	Deciduous shrub; wet sites and pollinator value
Pollinators	
Bigleaf maple <i>Acer macrophyllum</i>	Early flowers; large tree
Black hawthorn <i>Crataegus douglasii</i>	Flowers, fruit, wildlife value
Blue elderberry <i>Sambucus caerulea</i>	Flowers, berries, wildlife value
Cascara <i>Frangula purshiana</i>	Flowers and fruit; wildlife value
Evergreen huckleberry <i>Vaccinium ovatum</i>	Flowers, berries, evergreen cover
Oceanspray <i>Holodiscus discolor</i>	Summer flowers; dry-site tolerance
Pacific crabapple <i>Malus fusca</i>	Flowers, fruit, wet tolerant
Red-flowering currant <i>Ribes sanguineum</i>	Early flowers; pollinator value
Red elderberry <i>Sambucus racemosa</i>	Flowers and fruit; wildlife value

Irrigation and moisture management

A general establishment schedule for hedgerow plantings is to irrigate weekly during the heat of the first summer, every two weeks during the second year, and monthly during the third year. Adjust intervals based on rainfall, soil moisture, and plant condition.

Watering should be deep enough to encourage deep root growth. Water can be supplied by swales, furrows, flood irrigation, drip irrigation, hand watering, or by extending nearby crop irrigation where appropriate.

Protection during establishment

One of the biggest challenges in establishing windbreaks and hedgerows is keeping competing vegetation from overwhelming young plantings. Weed control during establishment reduces competition for moisture, nutrients, and light and can reduce future maintenance needs.

Alleys between plant rows can be left for mowing, cultivation, or mulching until plants are well established. Ideally, an area 6 to 8 feet wide around the hedgerow or windbreak should be mowed, flailed, mulched, or tilled for weed management, fire protection, and rodent control. Mulching with at least 3 inches of leaves, straw, sawdust, wood chips, or cardboard around each plant can help suppress weeds and retain soil moisture.

As trees and shrubs mature, they may shade out many annual weeds. At that point, low-growing, shade-tolerant plants can be added to fill gaps where appropriate.

Young plants may also need protection from livestock, deer, elk, rabbits, voles, mice, beaver, nutria, or other animals. Fencing, tree shelters, hardware cloth, plastic-coated guards, or partially buried trunk protection may be needed depending on the site. If pesticides are used, label directions should be followed carefully, especially near rivers, creeks, ponds, wetlands, or other riparian areas.

Managing a hedgerow or windbreak in the first few years is similar to managing a crop. Effective establishment management generally results in stronger plant survival, faster canopy closure, and less labor to control weeds in later years.

Cost and phasing

Establishment costs vary based on site preparation, planting size, plant materials, irrigation, mulch, protection, labor, and maintenance.

Seedling plants are often available at relatively low cost, and some species can be propagated from existing plantings. Larger plants, such as dormant bare-root stock or one-gallon potted plants, can establish a screen more quickly but usually cost more and often require summer irrigation.

Planting can also be phased over multiple years. Phasing may be useful when budgets are limited, when long plantings are being established, or when site conditions require staged preparation. Government programs, conservation cost-share programs, tax exemption programs for riparian zones, and wildlife habitat conservation programs may help support windbreak or hedgerow establishment.

Establishment timeline

Windbreaks and hedgerows are long-term investments. With proper planning and care, a hedgerow may take approximately four to eight years to become well established and 30 or more years to reach maturity. Windbreak effectiveness also increases over time as trees and shrubs gain height, density, and continuity.

A phased establishment plan can help match planting activities to available labor, funding, irrigation capacity, and management goals. Over time, well-managed windbreaks and hedgerows can provide increasing benefits for farms, ranches, rural communities, and ecosystems.

Table 13.3. Functional species list (cont.'d)

Pollinators (cont.'d)	
Salal <i>Gaultheria shallon</i>	Flowers, berries, evergreen cover
Strawberry tree <i>Arbutus unedo</i>	Flowers and fruit; non-native, site-specific use
Tall Oregon grape <i>Mahonia aquifolium</i>	Early flowers; berries
Thimbleberry <i>Rubus parviflorus</i>	Flowers and berries
Western redbud <i>Cercis occidentalis</i>	Showy flowers; dry-site tolerance
Western serviceberry <i>Amelanchier alnifolia</i>	Flowers, berries, wildlife value
Willows <i>Salix</i> spp.	Early pollen; wet tolerant
Non-timber forest products	
Bigleaf maple <i>Acer macrophyllum</i>	Tree sap, edible flowers
Blue elderberry <i>Sambucus caerulea</i>	Berries, natural dyes
Douglas-fir <i>Pseudotsuga menziesii</i>	Douglas-fir tips
Evergreen huckleberry <i>Vaccinium ovatum</i>	Berries
Nootka rose <i>Rosa nutkana</i>	Rose hips, flowers
Red alder <i>Alnus rubra</i>	Shiitake logs, natural dyes, tree sap
Salal <i>Gaultheria shallon</i>	Berries, greenery
Sitka spruce <i>Picea sitchensis</i>	Spruce tips
Tall Oregon grape <i>Mahonia aquifolium</i>	Medicinal tinctures, berries, natural dyes
Thimbleberry <i>Rubus parviflorus</i>	Berries
Western red cedar <i>Thuja plicata</i>	Boughs, natural dyes
Western serviceberry <i>Amelanchier alnifolia</i>	Berries
Willows <i>Salix</i> spp.	Basketry material
Drought tolerance	
Bitter cherry <i>Prunus emarginata</i>	Dry-site tolerance once established
Blue elderberry <i>Sambucus caerulea</i>	Drought tolerant once established
Evergreen huckleberry <i>Vaccinium ovatum</i>	Site-specific; prefers moisture but tolerates dry shade
Nootka rose <i>Rosa nutkana</i>	Resilient shrub; wildlife value

Operation and maintenance

The goal of operation and maintenance is to maintain the health and vigor of individual trees and shrubs while preserving the overall structure and function of the windbreak or hedgerow. With proper care, windbreaks and hedgerows can provide long-term protection, habitat, and production benefits.

Weed and grass control

Weeds and grasses should be minimized during the first three to five years, especially in a band about 3 to 4 feet on each side of tree or shrub rows. This reduces competition for moisture, nutrients, and light while young plants become established.

The area between rows can be planted to an annual cover crop, such as oats, millet, wheat, rye, or sunflowers, where appropriate. Cover crops can help suppress weeds, provide wildlife cover, protect young seedlings from soil or wind abrasion, and reduce erosion. Cover crop selection should avoid excessive competition with young trees and shrubs.

Supplemental irrigation

Supplemental irrigation may be needed when soil moisture is extremely low at planting or during prolonged drought after planting. Irrigation should be applied deeply enough to support root growth and adjusted based on soil texture, rainfall, mulch, plant condition, and species needs.

Replanting

Trees and shrubs that fail should be replanted to fill gaps in the windbreak or hedgerow. Replanting should occur annually for at least three years after the initial planting, or until a full stand is established. Maintaining continuity is especially important in windbreaks because gaps can funnel wind and reduce effectiveness.

Animal protection

Appropriate fencing or other protection may be needed to prevent damage from livestock, deer, elk, beaver, nutria, rabbits, voles, mice, and other animals. Protection methods may include exclusion fencing, tree shelters, trunk guards, hardware cloth, repellents, traps, or seedling protectors such as photodegradable tubing or mesh netting. Local wildlife or extension specialists can provide guidance on appropriate control measures.

Pest and disease monitoring

Periodic inspection of trees, shrubs, crops, and adjacent vegetation is recommended to detect insects, diseases, weeds, or other pest concerns before they become severe. In some cases, pheromone traps or other monitoring tools can help determine whether corrective action is warranted. Pest management should be designed to minimize impacts on beneficial insects, pollinators, wildlife, and nearby water resources.

Pruning

Pruning may be needed to remove broken, dead, diseased, or storm-damaged limbs and tops. Hail, wind, snow, and ice can cause branch breakage or damage to main stems. Pruning can also be used to maintain access, improve visibility near roads or driveways, manage shade on adjacent crops, reduce equipment interference, maintain desired density, and support production goals such as fruit, nut, floral, or wood quality.

Pruning should preserve the intended structure of the windbreak or hedgerow. Excessive pruning can reduce wind protection, habitat value, and plant vigor.

Table 13.3. Functional species list (cont.'d)

Drought tolerance (cont.'d)	
Oregon white oak <i>Quercus garryana</i>	Drought tolerant; wildlife and savanna value
Ponderosa pine <i>Pinus ponderosa</i>	Drought tolerant; avoid livestock risk in cattle systems
Quaking aspen <i>Populus tremuloides</i>	Site-specific; often needs seasonal moisture
Red-flowering currant <i>Ribes sanguineum</i>	Drought tolerant once established
Snowberry <i>Symphoricarpos albus</i>	Hardy shrub; wildlife cover
Shore pine <i>Pinus contorta</i> var. <i>contorta</i>	Exposed and coastal sites
Strawberry tree <i>Arbutus unedo</i>	Non-native; site-specific use
Tall Oregon grape <i>Mahonia aquifolium</i>	Evergreen; dry-site tolerance
Western juniper <i>Juniperus occidentalis</i>	Dry inland sites
Western larch <i>Larix occidentalis</i>	Inland sites; deciduous conifer
Western redbud <i>Cercis occidentalis</i>	Dry-site ornamental and pollinator value
Western white pine <i>Pinus monticola</i>	Site-specific; disease resistance should be considered
Wet soils	
Black cottonwood <i>Populus trichocarpa</i>	Wet soils and riparian areas
Black hawthorn <i>Crataegus douglasii</i>	Moist soils; flowers and fruit
Nootka rose <i>Rosa nutkana</i>	Tolerates moist sites
Oceanspray <i>Holodiscus discolor</i>	Generally adaptable; confirm site fit
Oregon white oak <i>Quercus garryana</i>	Tolerates seasonal wetness but needs summer drainage
Pacific crabapple <i>Malus fusca</i>	Wet soils; flowers and fruit
Red alder <i>Alnus rubra</i>	Moist soils; nitrogen-fixing
Red-osier dogwood <i>Cornus sericea</i> ssp. <i>occidentalis</i>	Wet soils; dense shrub structure
Snowberry <i>Symphoricarpos albus</i>	Adaptable shrub
Willows <i>Salix</i> spp.	Wet soils, basketry, early pollen

Fertilization

Fertilization of windbreaks and hedgerows is generally not recommended unless a specific nutrient deficiency has been identified. In most cases, fertilization is not practical, economical, or necessary. It may be justified for a small, high-value planting on soils with documented nutrient deficiencies. Fertilizer should be applied according to soil test results to avoid overapplication, leaching, runoff, and unnecessary expense.

Summary

Windbreaks and hedgerows can protect crops, soil, livestock, and infrastructure while also improving air and water quality, providing wildlife and pollinator habitat, producing useful plant products, and enhancing the landscape. A successful planting begins with a clear understanding of the landowner's goals and the site conditions that will shape design and management. From there, planners can determine the appropriate structure, spacing, density, orientation, and species mix. With careful planning and long-term management, windbreaks and hedgerows can provide lasting benefits for crop production, livestock health, conservation, habitat, and farm resilience.

Additional resources

- How to Choose Wind Break Trees. Utah State University Extension. <https://www.youtube.com/watch?v=AQthhHnv3gU>
- Benefits of hedgerows on farm field edges. University of California Cooperative Extension. <https://www.youtube.com/watch?v=n8blexfznQQ&t=15s>
- Trees Against the Wind, Pacific Northwest Extension Publication. <https://pubs.extension.wsu.edu/trees-against-the-wind>
- Eastern Oregon windbreak trees and shrubs : observations of various species over a period of 22 years. https://ir.library.oregonstate.edu/concern/administrative_report_or_publications/m326m2745
- WSU Extension Hedgerows Toolkit for Rural & Working Lands. <https://hedgerows.extension.wsu.edu/>
- WSU Extension Davenport Living Snow Fence Demonstration: Fifteen-Year Survival and Growth Update. <https://pubs.extension.wsu.edu/davenport-living-snow-fence-demonstration-fifteen-year-survival-and-growth-update>
- Plant selection for windbreaks in Central Oregon. <https://extension.oregonstate.edu/gardening/flowers-shrubs-trees/plant-selection-windbreaks-central-oregon>
- USDA National Agroforestry Center, Windbreak Series, Agroforestry Notes. <https://www.fs.usda.gov/nac/practices/windbreaks.shtml>
- University of Wisconsin, Windbreaks: Trees as Technology for Protecting Wisconsin's Topsoil. <https://cias.wisc.edu/uncategorized/windbreaks-trees-as-technology-for-protecting-wisconsins-topsoil/>
- Using Windbreaks to Reduce Odors Associated with Livestock Production Facilities—USDA NRCS-MOIS-MO380. <https://www.fs.usda.gov/nac/assets/documents/agroforestrynotes/an41w04.pdf>
- USDA NRCS, Windbreak/Shelterbelt Establishment or Renovation, <https://www.nrcs.usda.gov/resources/guides-and-instructions/windbreakshelterbelt-establishment-and-renovation-ft-380>



WINDBREAKS & HEDGEROWS at Heart Culture Farm

Eugene, Oregon

By Katherine Favor, *National Agroforestry Center*

Heart Culture Farm is a 33-acre community farm in the Long Tom Watershed in Eugene, Oregon. Home to 25 people, the farm's primary goal is to provide food for its residents. Kara Huntermoon is one of the principal stewards of this land and, with the help of many community members and volunteers, she is successfully growing about half of the community's food, despite resource limitations and climate challenges. She estimates that, once the trees mature, the farm will be able to produce as much as 90 percent of the food required for 25 residents.

The farm integrates a diverse array of production systems, including a fruit and nut orchard, vegetable fields, sheep, goats and poultry. To enhance resilience and productivity, Kara has implemented several agroforestry practices, including hedgerows—linear vegetative buffers that serve multiple functions across the landscape.

The hedgerows at Heart Culture Farm are designed specifically to help the farm adapt to challenges such as high wind, limited seasonal rainfall at certain times of the year, excess rainfall at other times of the year, and pest pressure. The NRCS defines hedgerows as dense perennial vegetation in a linear design to achieve a conservation purpose, often related to providing habitat. The terms “windbreak” and “hedgerow” are sometimes used interchangeably because they can be designed for overlapping purposes. Hedgerows are often structurally similar to windbreaks and can be designed to satisfy many of the same goals.

At Heart Culture Farm, these goals include reducing wind speed, preventing soil erosion, attracting beneficial insects for improved integrated pest management, fencing in animals, producing fodder for livestock, and providing food and other resources to the community.

Above: Heart Culture Farm's fruit and nut orchard is bordered to the north by a diverse native plant hedgerow and to the east and west by living fence hedgerows planted with willow.

Photo courtesy of Mitchel Davidovitz



“When designing, we’re thinking about how many different types of yields we can get from this landscape,” explains Kara. Beyond simply food production, Kara considers other kinds of “yields,” such as fencing, wind protection, livestock forage, medicinal plants, building materials, wildlife habitat, nitrogen fixation, and pest control.

“I need species that support pollinators, fix nitrogen, accumulate minerals, and bring beauty to the landscape,” Kara explains. “At the same time, I’m thinking about how to add shade, fodder, and wind protection. So, there’s a ‘multiple functions’ theme here when we’re designing.”

Because they are designed to be multifunctional, Heart Culture Farm’s hedgerows are helping the farm adapt to multiple challenges while producing other valuable benefits, to support both climate resilience and community self-sufficiency.

Challenges and adaptation strategies

High winds

To protect the farm’s diversified fruit and nut orchard from strong summer winds, Kara established a hedgerow designed to reduce wind speed and prevent moisture loss. “Part of the reason I planted a hedgerow here is because in the summer, we’ve got these really hot, punishing winds that come across,” says Kara.

Before the hedgerow was planted, Kara says that even irrigated fruit tree saplings struggled to survive, turning brown on the wind-exposed side. “It’s really difficult to get young fruit trees to establish in that situation.” To address this challenge, Kara planted a hedgerow to the north of the orchard in an east to west orientation, perpendicular to the prevailing summer winds that come from the north.

She designed the hedgerow to be four rows wide, with one row of tall trees and three rows of shorter trees and shrubs. Each row is spaced two feet apart to achieve around 60% density, which is an effective

Above left: A hedgerow to the north of the diversified fruit and nut orchard protects young trees from wind damage.

Above right: Hedgerow plants are planted into a raised berm next to a swale, to prevent “wet feet” during periods of extreme precipitation.

Photos courtesy of Mitchel Davidovitz

density for slowing down wind. After establishing the hedgerow, Kara observed a significant reduction in wind speed, and her young orchard trees no longer showed signs of moisture stress.

Pest pressure

Heart Culture Farm produces an abundance of vegetable, fruit, and nut crops for the community, and like any farm, they deal with pest pressure. Crops are grown in close proximity to people’s homes, so spraying conventional pesticides is not an option they are interested in. Instead, Kara relies on native plant hedgerows to attract beneficial insects, including natural predators that eat harmful insects.

The hedgerows also attract and support natural enemy predators like bats, parasitic wasps, spiders, green lacewing (*Chrysoperla sp.*), lady beetles (*Coccinellidae sp.*), and others, that help keep pests in check.

By selecting native species that flower at different times of the year, Kara ensures a continuous supply of pollen and nectar for beneficial insects. She planted a diverse mix of native trees and shrubs with the goal of supporting natural enemies for improved pest control. Some of the species she planted include black cottonwood (*Populus balsamifera L. spp.*), native Scouler's willow (*Salix scouleriana Barratt ex Hook*), Oregon white oak (*Quercus garryana*), Oregon ash (*Fraxinus latifolia*), Oregon crabapple (*Malus fusca*), red alder (*Alnus rubra*), and redosier dogwood (*Cornus sericea L.*).

Since establishing the hedgerows, she has observed increases in the number of butterflies, parasitoids, and birds in the hedgerows, many of which contribute to pest management on the farm.

Heavy winter rainfall

Heavy winter rainfall is common in Eugene. The region receives around 46 inches per year, but much of this rain falls during the months of November to February.^[1] This seasonal concentration of rainfall leads to standing water in parts of Heart Culture Farm, causing soil saturation, waterlogging, runoff, and erosion—all of which impact production during the rainy season.

Heavy rain may prove even more challenging in the coming years. Climate models project that winter precipitation in Oregon may increase from 5.7 to 12.3 percent by the end of the century, with rainfall intensity on wet days also expected to rise.^[1]

Given Eugene's seasonal shifts between wet winters and dry summers, it was important for Kara to choose hedgerow species that can thrive in both conditions. In general, many native Oregon species are well-adapted to fluctuating soil moisture levels, including the ability to withstand “wet feet” during prolonged periods of saturation. For this reason, Kara prioritizes

native species when designing hedgerows. “Any time you have the chance to fulfill your needs with a native plant, it's better to choose natives,” she explains.

Another way that Kara deals with heavy winter rainfall is by creating extensive “earthworks” (embankments made of earth) in and around hedgerow plantings. In parallel lines, she dug a row of one-foot-deep swales for water to flow into, and next to it she piled up one-foot-high berms of dry soil. She then planted hedgerow trees and shrubs into the raised berms.

The berms elevate the plant roots slightly above the seasonal water table, which allows them to buffer the effects of excess water, which Kara says has greatly increased their survival rate. They also divert excess water away from tree roots and into the swales, allowing tree roots to stay drier than they would otherwise. Tree roots in turn help stabilize the soil, preventing erosion. During the rainy season, swales act as natural reservoirs, allowing water to slowly infiltrate the soil, which improves moisture retention for drier months down the line.

Limited summer rainfall

One of the key functions of the hedgerows at Heart Culture Farm is to provide supplementary food to livestock during periods of limited rainfall. While Eugene receives around 46 inches of precipitation per year, summer rainfall is minimal, with an average of 3.5 inches from June 1 to October 1.^[2] By August and September, most of the farm's pasture grasses have dried up due to a lack of rain, leaving the farm's sheep and goats with little grass to eat.

Climate projections suggest that this challenge may intensify in the coming years. While winter precipitation and total annual precipitation in Eugene will likely increase by the end of the century, summer precipitation is projected to decrease by between 9.8 and 17.2 percent.^[1]

Below: During periods of limited rainfall when grass has dried up, Kara prunes trees and shrubs and feeds the fodder to livestock.

Photo courtesy of Mitchel Davidovitz



To deal with this challenge, Kara planted hedgerows with tree and shrub species that can be used as supplemental livestock forage. “Unless you irrigate the grass, it’s done being available for food in August, but the trees still have green leaves. So that increases the on-farm food sources for the sheep and the goats.”

In the hedgerow to the north of the fruit and nut orchard, Kara planted fodder trees and shrubs like alder (*Alnus spp.*), black locust (*Robinia pseudoacacia*), common linden (*Tilia spp.*), cottonwood (*Populus spp.*), honey locust (*Gleditsia triacanthos*), mulberry (*Morus spp.*) and willow (*Salix spp.*). These plants are rich in nutrients and provide a source of nutrition to livestock when grass is not available.^[3,4]

Kara also selected fodder plants for their ability to provide other functions to the farm. For example, Kara chose cottonwood not only for its nutrient-dense leaves, but also for its ability to grow tall quickly,

which has helped protect the orchard from wind in a short amount of time. Black locust was chosen for its high protein content and its ability to fix nitrogen, enriching the soil. Mulberries were selected because their protein- and mineral-rich leaves provide nutrition to livestock, while berries provide a source of food to the community.

On the eastern and western edges of the fruit and nut orchard, Kara planted hedgerows that are comprised of basket willows (*Salix purpurea*) like ‘Polish Purple,’ woven tightly together to form a living fence. This willow hedgerow provides a source of nutrition to livestock during periods of limited rainfall. It also slows down wind and is used to contain some of the farm’s animals, including sheep, ducks, and geese.

To construct the living fence, Kara wove together willow stems using a method called “pleaching,” which involves planting long strands of willow stakes

diagonally eight inches apart, crossing them in a diamond pattern, and tying them together. Once tied, the willows fuse together to form what functions as a connected, living organism in the shape of a fence.

“A living willow fence can provide a lot of the same habitat benefits that you would expect from a hedgerow, but it’s just tighter and more controlled, and it forms a denser boundary in your system,” explains Kara. While these fences can effectively contain livestock once they mature, Kara notes that it does take many years for them to grow tall and strong enough to withstand animal impacts, and they are not recommended for containing larger livestock, like cattle.

Below left: A living fence hedgerow made of willows woven together using a method called “pleaching.”

Below right: A fully grown living fence hedgerow made from ‘Polish Purple’ basket willow (*Salix purpurea*).

Photos courtesy of Mitchel Davidovitz



Management

One of Kara's guiding philosophies is to provide the farm with what it needs while relying as little as possible on inputs sourced from outside of the farm. One way she achieves this is by integrating livestock into the farm in strategic ways to help with management tasks, including vegetation control, pest management, and fertilization. Sheep are rotated through the orchard to graze cover crops and resident vegetation, while chickens and ducks are used to control orchard pests, such as snails and slugs. In addition to these roles, livestock contribute valuable manure, enhancing soil fertility.

Managing and protecting animals is a labor of its own, however. To prevent overgrazing and excess nutrient accumulation, Kara divides the farm into 12 different paddocks and rotates animals through at regular intervals. While the farm's living willow fences help contain livestock on one side of the property, mobile electric fencing is needed elsewhere. Moving this fencing and rotating animals is labor intensive, but it is a vital part of using livestock in a beneficial way.

Kara notes that protecting newly-planted trees and shrubs from livestock is critical to prevent trampling, debarking, and defoliation. She uses mobile fencing to exclude livestock completely from young trees and shrubs, but she notes that there are still benefits to allowing animals to graze nearby.

"Even though I'm fencing the animals away from the trunks of the younger trees, the roots extend out past the trunks," explains Kara. "Because livestock are still able to perform weed control and defecate on areas adjacent to trees, the benefits remain." Kara has observed that hedgerow plants and adjacent cover crops grow earlier, greener, and taller since incorporating animals five years ago. "I can visually see the difference between areas where I have run the animals and where I have not yet started running the animals," she says.

Conclusion

Heart Culture Farm's multifunctional hedgerows are an example of how one agroforestry practice can be used to satisfy multiple goals. Kara Huntermoon designed the farm's hedgerows with climate adaptation in mind, to enhance resilience in the face of challenges such as high winds, pest pressure, heavy winter rainfall, and limited summer moisture.

Through careful species selection, the hedgerows are providing resources for livestock, community members, and the broader environment, such as pest control, wildlife habitat, food, fodder, medicine, and other products for the community.

Kara designed the orientation and composition of the hedgerows to delineate field boundaries, fence in livestock in desired areas, and also slow prevailing winds. She used berms and swales to capture excess water and increase the survival rate of hedgerow plants. She is also using animals to help with weed control, pest control, and fertilization.

Heart Culture Farm's use of hedgerows is one way that they are strengthening resilience while also contributing to community self-sufficiency.

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V

- 14 ECONOMIC BUDGETING
FOR AGROFORESTRY**
- 15 MARKETING AGROFORESTRY
PRODUCTS**
- 16 INCENTIVES FOR
AGROFORESTRY**

ECONOMIC CONSIDERATIONS

Budgeting, marketing, and incentives are three of the most important economic considerations when analyzing an agroforestry practice. Even if the goals of the landowner do not include managing the agroforestry practice for income, the landowner should be aware of ways to minimize the costs associated with establishing and maintaining that practice.

There are many economic benefits to incorporating agroforestry practices into agricultural landscapes. The six agroforestry practices discussed in Part IV provide opportunities for generating income from a wide array of alternative products. These practices also provide valuable environmental services for producers, such as soil health improvements, beneficial insect habitat, extreme weather mitigation, and carbon sequestration at a low cost.

Chapter 14 focuses on budgeting for the costs and revenues of any agroforestry enterprise. Monitoring the economic costs and benefits is essential for analyzing a practice's economic success or failure.

Chapter 15 focuses on the special marketing considerations for agroforestry products that may be diverse and likely mature at different times of the year.

Chapter 16 provides a summary of incentive programs and grants available for the planning and implementation of agroforestry in the Pacific Northwest.

CHAPTER 14

ECONOMIC BUDGETING FOR AGROFORESTRY

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Author Note: This chapter is based on original narrative developed by Larry Godsey, PhD for the University of Missouri and used with permission. Minor editorial revisions have been made by Badege Bishaw and Abel Kloster for formatting, consistency, and integration with this publication.



Photos courtesy of Tao Orion (left, middle) and Mitchel Davidovitz (right)

Agroforestry budgeting differs from conventional agricultural budgeting because agroforestry systems combine multiple enterprises—such as trees, crops, forages, and livestock—each with different production timelines and management needs. Unlike annual crops, agroforestry systems often operate on long planning horizons due to the tree component, with costs and returns occurring over decades rather than within a single growing season. In addition, revenues and expenses may occur irregularly over time, making financial planning more complex.

These characteristics require budgeting approaches that account for long-term investment, variable income streams, and the interactions among multiple system components.

Economic evaluation is an important part of agroforestry planning because it helps estimate financial feasibility, identify trade-offs among multiple benefits, and assess long-term efficiency. Budgeting is the primary tool used in this process.

Economic budgeting is a very flexible process. However, effective application of budgets requires an understanding of the crop and practice to which it is being applied. Agroforestry poses some unique economic budgeting problems because it involves multiple enterprises with varying production cycles, such as trees, row crops, forages and/or livestock.

First, unlike most agricultural commodities, agroforestry has a **planning horizon** of greater than one season due to the tree component. A planning horizon is simply a time period in which all costs and revenues for a given practice are realized. For soybeans, a planning horizon may be six months to a year. For agroforestry, a simple planning horizon may be as long as 60-80 years when the timber value of trees is taken into consideration.

Second, because of agroforestry's long planning horizon, many revenues and costs do not occur at regular or predictable intervals, but occur irregularly.

Finally, because agroforestry practices typically incorporate a fixed tree component, the crop or livestock component may change over time. For example, an alley cropping practice may start out as high value medicinal herbs grown between rows of chestnut trees, but by the time the trees are producing nuts, only the most shade-tolerant herbs may be growing between the rows of trees because of the closed canopy.

These three characteristics of agroforestry require a specific type of budgeting that will be flexible enough to allow for variable crop and/or livestock components, as well as comprehensive enough to show annual cash flows for the entire planning horizon.

Agroforestry budgeting

Agroforestry budgeting generally involves two steps: developing enterprise budgets for each component of the system, then integrating those budgets into a comprehensive cash flow plan.

An enterprise budget is a complete, detailed listing of all the costs and revenues expected for each single enterprise, such as medicinal herbs, livestock, or nut and timber trees.

A cash flow plan combines the details from the different enterprise budgets in the agroforestry practice and adds a time dimension. The enterprise budget provides a framework for reporting and monitoring the profitability of each enterprise, and the cash flow plan provides the information necessary to assess and forecast the economic feasibility of the agroforestry practice over time.

Developing enterprise budgets

The development of an enterprise budget is a three-step process.

The first step is to list all possible sources of revenue for an enterprise. For the tree component of an agroforestry practice, it is important to list not only the sources, but also the timing of those revenues. For example, a riparian buffer planting with pawpaw trees may receive Conservation Reserve Program (CRP) payments for the first 10 years of the planning horizon but not after that period. Income from fruit production may start at year 5 and be in full production by year 10 and continue for 30 years.

Examples of revenues:

Cost share payments (e.g. EQIP or CSP)	\$.
Scionwood and cuttings sold	\$.
Fruit sold	\$.
Nuts sold	\$.
Meat sold	\$.
Tours	\$.
Hunting leases	\$.

The second step is to identify and itemize all potential sources of variable costs.

Variable costs are expenses associated with the productive use of resources and are generally categorized as either cash or non-cash costs. Variable cash costs include direct expenditures related to establishment, maintenance, harvesting, and marketing activities. Variable non-cash costs do not require an immediate cash payment but represent opportunity costs—the value of the next best alternative use of a resource.

Examples of variable costs:

1. Establishment	\$.
a. Site preparation (e.g. tilling)	\$.
b. Amendments	\$.
– Fertilizer	\$.
– Lime	\$.
– Rock dust	\$.
c. Planting	\$.
– Seedlings	\$.
– Labor	\$.
– Equipment	\$.
d. Irrigation infrastructure	\$.
e. Protection (e.g. livestock fencing)	\$.
2. Maintenance	\$.
a. Fertilization	\$.
b. Mowing	\$.
c. Weeding	\$.
d. Watering	\$.
e. Pruning	\$.
f. Labor	\$.
3. Establishment	\$.
a. Labor	\$.
4. Establishment	\$.
a. Labor	\$.
b. Equipment (e.g. washing station)	\$.
5. Establishment	\$.
a. Advertising	\$.
b. Packaging	\$.
c. Transportation	\$.

For example, labor provided by family members may not involve a direct expense, yet it still has economic value and should be included in the analysis.

Report variable costs with enough detail to show what the expense is, how much it will cost, and when it is expected to occur. This includes identifying the source, the estimated amount, and the timing or frequency within the production cycle. For example, tree thinning may cost \$50 per acre and be scheduled to occur during years 21 and 25 of the project.

The third and final step in preparing an enterprise budget is to identify and account for all fixed costs.

Fixed costs are generally associated with resource ownership and are incurred regardless of the level of production or management activity taking place. Fixed cash costs commonly include property taxes, insurance, interest on intermediate- or long-term debt, and lease payments.

Fixed non-cash costs, particularly depreciation and land costs, are also important to include in investment analyses because they can significantly affect taxable income and long-term financial performance. Although fixed costs tend to change less frequently than revenues or variable costs, some increases may be predictable over time, such as annual increases in property taxes.

When reporting fixed costs, it is important to identify the source of the cost, the estimated amount, and any anticipated changes over the planning period.

Examples of fixed costs:

Property tax	\$.
Insurance	\$.
Interest payments	\$.
Leases	\$.
Management	\$.

From enterprise budgets to cash flow plans

Once enterprise budgets are created, a cash flow plan for the agroforestry practice can be developed. It is important to understand that an agroforestry practice may include more than one enterprise. For example, a well-established alley cropping practice may combine a tree enterprise with a hay, livestock, or other small crop enterprise. As mentioned earlier, often the tree enterprise is fixed while the crop or livestock enterprises vary over time.

Cash flow planning has two characteristics that make it useful for agroforestry economic analysis:

- **It accounts for multiple enterprises:** Agroforestry systems often combine trees, crops, livestock, and other products within the same operation. Cash flow planning allows revenues and expenses from these different enterprises to be evaluated together.
- **It incorporates a time dimension:** Agroforestry systems involve costs and returns that occur at different times, often over many years or decades. Cash flow planning helps track when expenses and income are expected to occur throughout the life of the system.

Using a cash flow plan in conjunction with an enterprise budget can simplify the process of economic analysis by allowing the enterprise budgets to reflect the detailed information and let the cashflow plans use minimal data to provide the analysis.

Evaluating the economic performance of agroforestry systems

There are several common indicators used to analyze an agroforestry practice for economic performance. Supplementing these common economic indicators with some very basic indicators of economic performance can help both producers and economists understand the economic performance of agroforestry practices.

Net present value (NPV) is a common economic analysis technique that can be conducted given the information provided in a good cashflow plan. Net present value is simply all future net income streams from the practice discounted to reflect their current or present value. This indicator is useful only as a basis for comparison. The NPV of the agroforestry practice can be compared to the NPV of other alternatives, such as a soybean monoculture, to see which practice is the most economically profitable. Assuming each practice is discounted using the same period of time and the same discount rate, the highest NPV would indicate the best alternative.

Internal rate of return (IRR) is the internal rate at which an investment is expected to grow. For example, a savings account pays 3 percent per year; therefore, an investor who puts money in a savings account is expecting to earn 3 percent on that investment. If an agroforestry practice has an IRR of 6 percent, then a rational investor would choose the agroforestry practice over the savings account earning 3 percent. However, the internal rate of return does not always capture the uncertainty of returns over time. Using the savings account example, an investor is assured that the money put into a savings account is relatively risk free; however, investment in agroforestry practices may face uncertainties that were not predicted or planned.

Annual equivalent value (AEV) is another common indicator of economic performance that can be derived from a cashflow plan. The AEV is an estimate of a level income stream that would have the same net present value as the actual income streams. Actual income streams for agroforestry practices may be positive one year and negative another; however, with the AEV, a level income estimate is established. The annual equivalent value can be used to compare alternative practices with the agroforestry practice to see which has the highest expected income potential.

Additional measures of financial feasibility

All three of the common indicators can be used to evaluate the economic success of agroforestry practices. However, there are easier ways to help evaluate the economic feasibility of agroforestry practices without complicated discounting equations.

By using a cash flow budget, three supplemental economic indicators can be derived:

- Frequency of negative cash flow
- Duration of negative cash flow
- Magnitude of positive and negative cash flows

The **frequency of negative cashflow** is simply determining the number of years in a planning horizon in which a practice will have a net loss. For many landowners, a practice that appears to be economically profitable according to a NPV analysis may not be feasible due to several periods of net loss.

Similar to frequency, **duration of negative cashflow** reflects the length of time that the practice returns a negative cashflow, or net loss. While frequency would describe a practice as having negative cashflow four out of 15 years, duration may indicate that three of those four years occurred consecutively. A landowner may not be concerned about having a negative cashflow occasionally. However, a continuous net loss may make a practice undesirable and infeasible.

The **magnitude of positive and negative cashflow** reflects the range of fluctuations that occur from year to year and throughout the planning horizon in net income. For example, one practice may have a very large net loss the first two years for startup costs, followed by several years of small net incomes. Over the long run, this practice may have a positive internal rate of return, but the periods of large net losses may make the practice infeasible. On the other hand, expected large net income in the future may make periods of small net losses tolerable.

The three supplemental indicators of frequency, duration and magnitude require no special training in finance or math and may have more influence on the decision process. The common indicators of net present value, internal rate of return and annual equivalent value are still important to help compare the agroforestry alternative to other possible alternatives. Using both types of economic indicators can help “fine tune” the economic analysis and aid in the decision process.

There are many other benefits to agroforestry besides those measured by economics. Environmental and social benefits also may have value to the decision maker. These benefits are often difficult to quantify. With economic analysis, these benefits can be considered in light of financial considerations.

Economic analysis as an ongoing process

Economic analysis is not meant to be—nor is it designed to be—a one-time activity. Economic analysis is designed to be a road map for a dynamic and living system. Reassessment takes the information gathered in the economic analysis and combines it with other information to change the original goals or fine tune the design so that it is more successful at meeting those goals. Reassessment is the continuous loop that helps redefine goals, adjust designs and modify indicators. Economic analysis is just one part of the reassessment loop.

Conclusion

Agroforestry economic analysis provides a framework for evaluating the long-term financial feasibility, risks, and profitability of complex, multi-enterprise systems. By combining enterprise budgets, cash flow planning, and economic performance indicators, landowners and practitioners can better understand how costs, revenues, and management decisions interact over time. While economic measures are important tools for decision-making, they should be considered alongside the ecological, social, and conservation benefits that agroforestry systems can provide. Because agroforestry systems evolve over time, economic analysis should remain an ongoing and adaptive process that supports continual reassessment and informed management decisions.

CHAPTER
15
**MARKETING
AGROFORESTRY
PRODUCTS**

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Marketing agroforestry products requires special consideration because of the diversity of outputs and the timing of their availability over the life of the system. Agroforestry systems often produce multiple products with different maturation periods, harvest schedules, and sales windows. As a result, producers should evaluate available sales channels, anticipated demand, pricing opportunities, and potential sales volumes for each product over time.

The following are some of the characteristics to consider when marketing agroforestry products.

- 1. Location and transportation:** Farms located far from buyers or distribution centers may face higher transportation costs. For example, if a farm is located 50–60 miles from a market, transporting products can significantly increase overall marketing expenses.
- 2. Consumer interest and product values:** Consumer demand may be influenced by preferences for sustainably produced, locally grown, organic, or socially responsible products. Producers should consider whether their products align with these values and how those attributes may affect pricing, demand, and marketing opportunities.
- 3. Compatibility with local markets and food systems:** Producers should evaluate whether agroforestry products align with local market demand, existing food systems, processing infrastructure, and regional distribution networks. Understanding local consumer preferences and supply chain opportunities can help improve product viability and market access.
- 4. Public awareness and consumer education:** In some regions, agroforestry may be unfamiliar to consumers or local communities. Producers may need to explain what agroforestry is, how products are grown, and the environmental or social benefits associated with these systems in order to build consumer understanding and support.
- 5. Export and niche market potential:** Some agroforestry products may have opportunities in export or specialty markets, particularly when they are high quality, regionally distinctive, sustainably produced, or targeted toward niche consumer preferences. Producers should assess whether their products meet the quality standards, certifications, or supply requirements needed to access these markets.
- 6. Market coordination and information sharing:** Limited coordination among producers and lack of reliable market information can make it difficult to price and sell agroforestry products effectively. Collaborating with other local producers and sharing information about production volumes, pricing, and buyer demand can help improve market access, strengthen supply chains, and support more competitive pricing strategies.



Photos courtesy of Mitchel Davidovitz (left, far right) and Tao Orion (middle left, middle right)

The goal of agroforestry marketing is to maximize the long-term profitability and successful sale of products over time. Several marketing approaches can be considered to improve economic performance:

1. **Diversification versus specialization:** Producers may choose to market a diverse range of products or specialize in a smaller number of products. The most appropriate approach depends on regional conditions, available markets, production capacity, and the types of products being produced.
2. **Direct marketing:** Products may be sold directly to consumers through outlets such as farmers markets, roadside stands, community-supported agriculture (CSA) programs, or online sales. Direct marketing can increase returns by reducing intermediaries and strengthening connections with consumers.
3. **Cooperative marketing:** Working collaboratively through cooperatives or producer groups can reduce costs, improve bargaining power, expand market access, and increase value of agricultural products.
4. **Value-added marketing:** Processing raw products into higher-value goods may increase profitability. However, producers should carefully evaluate the additional costs associated with processing equipment, labor, regulations, and marketing before investing in value-added production.

The potential benefits, costs, and feasibility of these marketing approaches should be evaluated to determine whether they improve system efficiency and long-term profitability.

Agroforestry products and market opportunities

Unlike other types of conservation practices where land is taken out of production, agroforestry is “productive conservation.” Agroforestry practices enable farmers to generate income from the production of a wide range of conventional and specialty products while simultaneously protecting and conserving soil, water, and other natural resources.

Products produced through agroforestry practices, including specialty or non-timber forest products, are produced from trees and shrubs, within forests, or in combinations of trees or shrubs, crops and/or animals. Many of these products have proven economic value but have been ignored or are unknown to agricultural and forest landowners and managers.

In North America, such products include: edibles (e.g., mushrooms, chestnuts, pecans, hickories, hazelnuts, persimmon, pawpaw, Asian pears, cornelian cherry, Kiwi fruit, aronia, elderberry, mayhaw, goji berry, other berries); herbal medicinals (e.g., ginseng, goldenseal, witch hazel, elderberry); specialty wood products (e.g., diamond willow canes, red cedar closet liners, live edge wood slabs); floral and greenery products (e.g., sword fern, salal, cedar boughs); fiber and mulch (e.g., cedar pet bedding, pine straw); and recreation (e.g., agritourism, fee hunting, forest bathing).

Agroforestry enterprises often produce niche or specialty products that serve relatively small or unfamiliar markets. In many cases, limited information is available about how these products move through the supply chain, who purchases them, and what factors drive consumer demand. This uncertainty is sometimes referred to as the “black box” of agroforestry marketing.

For producers, important questions may include how to access markets, identify customers, estimate costs and returns, secure supplies and inputs, understand competitors, and anticipate changes in demand or pricing. Additional uncertainty may arise from limited knowledge about distribution channels, value chains, and the number of intermediaries involved before products reach final consumers.

Unlike commodity markets, which often have established pricing systems and widely available market data, niche agroforestry markets may lack reliable information and established infrastructure. As a result, producers and small businesses engaged in agroforestry enterprises often need to conduct market research to better understand supply chains, consumer preferences, pricing opportunities, and competitive conditions. Improving access to market information can help reduce uncertainty and support more informed production and marketing decisions.

Market research and information needs

Data collection

The first step in any market research process is data collection. It starts with investigating publicly available data (secondary information sources) and continues with information gathered specifically for the market(s) of interest (primary information sources).

Primary information sources

- personal interviews with consumers, producers, and other persons involved in the value chain
- observations, e.g. visiting farmer's markets, retail outlets, production facilities, as well as attending farmer field days, trade shows, and marketing conferences)
- online, mail or phone surveys
- focus groups

Secondary information sources

- published reports and studies
- online information sources, such as websites, newsgroups, and electronic bulletin boards
- trade magazines and journals, newspapers, books and literature from competitors, business directories

This list is not exhaustive, but it provides examples of potential sources of market information that can support analysis of the business environment, industry conditions, and market opportunities for agroforestry products.

Table 15.1. Marketing examples for forestry, agroforestry, and natural resources

Forestry and alternative forest products			
Enterprise	Retail or direct market	Wholesale market	Niche market
Firewood	Delivery to homeowner, roadside piles for campers	Broker, garden center, landscape contractors	Convenience store bundles
Fence posts and/or rails (black locusts, cedar or Osage orange hedge)	Homeowners	Landscape contractors, garden stores	Nature stores
Wood chips for cooking and smoking (hickory, apple, maple)	Homeowners and businesses	Convenience stores	Fairs and festivals
High-value sawtimber and veneer		Sawmills through traditional sales process	Sell harvested logs directly from log deck to buyers, sell to the export market
Custom sawmilling	Craft artisans, hobbyists	Other sawmills	Cut lumber at landowner's property
Drying lumber	Craft artisans, hobbyists, cabinetmakers	Local lumber store, chain stores, planing mil	Unique species or products such as crotch wood, matching panels
Value-added wood products (hardwood and grapevine baskets, bowls, utensils, etc.)	Craft fair, tourist sites, internet and catalog sales	Broker	Custom-shaped and custom-sized baskets, gift baskets
Christmas trees	Choose-and-cut or parking lot trees	Garden stores, non-profit organizations that sell trees for fundraising	Super large trees, tabletop trees, and select species; combine with sleighride and other activities or onsite sales
Holiday greenery (wreaths and roping from pine trees and grapevines)	Choose-and-cut or parking lot sales	Broker, non-profit organizations that sell trees for fundraising	Decorated greenery at holiday craft fair
Native vegetation collection for floral and food markets on a sustainable basis (moss, ferns, colored twigs, mushrooms, twigs, etc.)	Florist shops, craft artisans, fairs	Brokers for floral markets and edibles, stores, restaurants	
Mushrooms (shiitake, oyster, etc)	Farmers market, CSAs	Broker, specialty stores, restaurants	Dried mushrooms and other unique products

Evaluating products and markets

Analytical tools such as SWOT analysis and Porter's Five Forces (covered in **Chapter 6: System Selection**) help agroforesters evaluate market opportunities, competitive conditions, supply chain constraints, and long-term business viability. These frameworks are particularly useful for niche and specialty products where market information may be limited and supply chains are still developing.

In agroforestry markets, producers may face challenges due to limited processing infrastructure, seasonal supply, perishability, specialized handling, limited propagation material, or unfamiliarity among consumers. Evaluating these factors can help identify potential barriers to market entry as well as opportunities for differentiation and value-added production.

Customer research is also important because agroforestry markets are often highly segmented. Consumers may differ in preferences, purchasing habits, values, and willingness to pay for products that are locally produced, sustainably grown, regionally distinctive, or otherwise differentiated. Understanding customer segments helps producers develop more effective pricing, distribution, and promotion strategies.

Marketing strategies used to differentiate agroforestry products may include:

- offering locally produced or sustainably grown products
- processing products into value-added goods
- introducing uncommon or regionally distinctive crops
- extending seasonal availability
- emphasizing quality and customer relationships
- promoting products through labels of origin or production methods

These approaches can help reduce price competition, strengthen customer loyalty, and improve profitability in niche and specialty markets. Once target markets and differentiation opportunities have been identified, producers can begin developing marketing strategies that align products, pricing, distribution methods, and promotional activities with customer needs and business goals.

Table 15.1. continued

Agricultural products			
Enterprise	Retail or direct market	Wholesale market	Niche market
Field crops (corn, soybeans, grains, etc.)	Livestock farmers	Elevator, cooperative	Popcorn, edible soybeans, fuel for heating stove, organic
Vegetables	Farmers markets, roadside stands, pick-your-own, CSAs	Broker, auction, cooperative, restaurants	Ethnic markets, organic
Hay	Farmers, small-farm owners, horse owners	Auction	Special hay mixes for specific livestock
Herbs (echinacea, basil, etc.)	Farmers markets, roadside stands	Broker, stores, restaurants	Organic, medicinal, special product combinations, heirloom varieties
Ginseng / goldenseal		Broker	Ginseng jams or other specialty products at specialty stores
Bramble fruit crops (berries, currants, etc.)	Farmers markets, roadside stands, pick-your-own, CSAs	Stores	Organic, heirloom varieties
Wine and table grapes	Farmers markets, CSAs	Stores, wineries, restaurants	Organic, special and heirloom varieties for wineries
Greenhouse	Homeowners, local businesses	Garden centers, brokers	Specialty plants for a specific market
Native plant nursery	Homeowners, local businesses	Landscape contractors doing residential and restoration work, garden centers	Specific in-demand species that are difficult to grow
Value-added food processing (bakery, canning, microdairy, slaughterhouse)	Farmers markets, roadside stands, fairs and festivals	Specialty stores, restaurants, brokers	Organic, specialty products
Animals			
Enterprise	Retail or direct market	Wholesale market	Niche market
Sheep and goats (milk, meat, and fiber)	Farmers, 4-H groups, and other individuals and groups	Auction	Ethnic meat markets, organic markets
Exotic livestock (emu, fallow deer, ostrich, etc.)	Farmers, 4-H groups, and other individuals and groups	Auction	Ethnic meat markets, restaurants
Honey	Individuals, roadside stands, farmers markets	Stores, restaurants, cooperative	Stores, restaurants, cooperative, organic, honeycomb

Developing marketing strategies

A marketing strategy outlines what products or services will be offered, how they will reach customers, how they will be priced, and how their benefits and value will be communicated to target audiences.

Product strategy and differentiation

Product strategy focuses on identifying products and services that meet the needs and preferences of target customers. In agroforestry enterprises, product differentiation is one of the most common approaches for creating market value and appealing to specific consumer groups. Differentiation may include emphasizing local production, sustainability, quality, regional identity, unique varieties, or value-added processing.

Adding value through processing, packaging, branding, or customer service can increase product appeal and improve returns from the same amount of raw material. For small landowners and diversified producers, value-added products can significantly improve profitability and expand market opportunities.

Evaluating feasibility of value-added products

Although value-added processing can improve profitability and product differentiation, it is not always the most practical or economically viable option. Producers should carefully evaluate whether sufficient financial resources, labor capacity, technical expertise, infrastructure, and long-term supply are available to support value-added production.

Important considerations may include:

- available financing, training, or processing equipment
- long-term access to adequate raw materials
- market demand and competition for value-added products
- regulatory requirements and food safety standards
- distribution and marketing challenges
- time to recover processing and equipment costs
- additional risks associated with processing, storage, and product marketing

Table 15.1. continued

Recreation and tourism			
Enterprise	Retail or direct market	Wholesale market	Niche market
Recreational agriculture (harvest, festivals, corn mazes, petting zoos)	Individuals, organizations and groups		Combine with value-added products, roadside stand, and other unique offerings
Recreational natural resource events (forestry, logging, heritage, wildlife, maple syrup festivals or field days, forestry skill competitions)	Individuals, organizations and groups		Combine with value-added forestry products and other unique offerings
Recreational trails (bird watching, hiking, cross-country skiing, horseback riding)	Individuals, nature and conservation groups, church and school groups	Broker	Special arrangements
Hayride or sleigh ride (with bonfire combinations)	Individuals, nature and conservation groups, church and school groups	Broker	Special holiday programs and promotions (e.g. Halloween, Thanksgiving, Christmas)
Nature-based bed and breakfast	Individuals, couples, small groups, internet platforms (e.g. Airbnb, Vrbo, HipCamp)	Broker	Special program offering
Vacation cabin	Individuals, families, hunt clubs, internet platforms (e.g. Airbnb, Vrbo, HipCamp)	Broker	Combine with fee hunting, campground or other recreational access enterprises
All-terrain vehicle (ATV) and mountain-biking access	Individuals and groups	Broker	Special races, events, and promotions
Hunting lease	Hunting clubs and groups	Forester or other outlers to act as your broker	Combining hunting lease with cabin rentals

In some cases, selling raw products through intermediaries or existing processors may involve lower financial risk and management complexity than developing independent value-added enterprises.

As with any business decision, careful market research, financial analysis, and assessment of available resources are important before investing in value-added production.

Distribution and transportation strategies

Successfully connecting agroforestry products with buyers involves three related considerations:

- **Distribution:** the sales channels through which products move to customers,
- **Location:** where products are sold,
- **Transportation:** how products are delivered to buyers.

Distribution and sales channels

Agroforestry products may move through several possible sales channels before reaching the end user. The most appropriate channel depends on factors such as:

- existing distribution systems for the product,
- demand at different points in the supply chain,
- available labor and marketing capacity,
- product perishability and storage requirements,
- and the scale and consistency of production.

Two broad distribution approaches are commonly used:

Direct marketing involves selling products directly to consumers through outlets such as farmers markets, on-farm stores, community-supported agriculture (CSA) programs, roadside stands, or online sales. This approach is often well suited to agroforestry products because it allows producers to retain a larger share of the final sale price while also communicating information about production practices, product quality, sustainability, or local origin directly to customers.

Consumer interest in locally produced, sustainably grown, and high-quality products has increased demand for direct marketing opportunities. Direct interaction with producers may also help build customer trust, product awareness, and long-term loyalty.

Intermediary distribution involves selling products through wholesalers, brokers, cooperatives, distributors, retailers, or processors. These channels may provide access to larger markets and reduce some of the marketing responsibilities carried by producers. However, intermediary markets often require larger

and more consistent product volumes, standardized quality, and reliable delivery schedules.

Additional challenges may include storage requirements, transportation costs, maintaining freshness or product integrity throughout the supply chain, and meeting certification or handling standards. In many cases, intermediaries also assume part of the financial and marketing risk associated with reselling products to downstream buyers.

In general, sales channels that place producers closer to consumers may offer higher returns but often require greater labor, marketing effort, and business risk. Evaluating alternative distribution strategies can help identify opportunities to improve profitability, reduce costs, expand market access, or develop new business opportunities over time.

Sales locations and market outlets

When products are sold directly to consumers, several possible sales locations may be considered depending on the type of product, target market, accessibility, and available infrastructure.

Common locations for marketing agroforestry products include:

- on-farm sales locations
- roadside stands
- farmers markets
- craft or specialty markets
- cooperative marketing arrangements with other businesses such as nurseries, retail stores, bed-and-breakfasts, or seasonal vendors

Farmers markets and urban direct-sale venues may provide particularly strong opportunities for specialty, locally produced, or value-added agroforestry products.

Some enterprises may also use remote or mail-order sales systems, including telephone, email, online ordering platforms, or subscription-based sales models. Products may then be delivered directly by the producer or through shipping and delivery services.

For specialty foods, crafts, and other shelf-stable products, internet sales may provide access to broader regional or national markets beyond the immediate local area.

These approaches generally require products that can be packaged, stored, and transported reliably while maintaining quality and product integrity throughout delivery.

Transportation options

When products are sold through channels where customers are not purchasing directly at the production site, transportation and delivery logistics become important considerations. Factors that may influence transportation decisions include shipping costs, distance to markets, reliability and timeliness of delivery services, and the handling requirements of perishable or specialty products.

Additional considerations include whether transportation costs are absorbed by the producer or passed on to buyers, as well as how freight expenses affect overall profitability. Comparing transportation providers, negotiating freight terms, and evaluating multiple shipping options may help reduce costs and improve efficiency.

For some products, cooperative shipping arrangements or shared distribution systems with other producers may reduce transportation expenses by increasing shipment volume. Opportunities may also exist to use “back-haul” freight services, where trucks returning from distribution centers carry products that would otherwise travel on empty return trips.

Developing a list of available transportation options, associated costs, delivery timelines, and handling requirements can help determine whether specific products can be marketed profitably in particular regions or distribution channels.

Pricing strategy

Pricing agroforestry products can be challenging because many niche and specialty products are not traded within standardized commodity markets. Unlike commodity producers, who often accept prevailing market prices, agroforestry producers may have greater flexibility to develop pricing strategies based on product differentiation, production costs, market demand, and customer preferences.

The primary goals of pricing are to:

- cover production and operating costs
- generate profit
- encourage customer purchases

Two general pricing approaches are commonly used:

Market-based pricing involves evaluating current prices for similar products and using that information to establish a competitive price range. Pricing information may be obtained from retail outlets, farmers markets, wholesalers, buyers, online marketplaces, catalogs, or other producers. In many cases, prices within niche markets are negotiable and may vary according to product quality, seasonality, availability, and market demand.

Obtaining pricing information for agroforestry specialty products can sometimes be difficult because markets are often small, regionally variable, or still developing. Direct communication with buyers, distributors, and other producers may therefore be especially important when evaluating potential prices.

Cost-based pricing focuses on ensuring that prices cover all production, processing, transportation, labor, overhead, and marketing expenses while also providing an acceptable profit margin. Producers may initially rely on market-based pricing and later transition toward more cost-based pricing as production costs become better understood.

If comparable products are available at lower prices, additional product differentiation—such as sustainability, local origin, specialty processing, or unique product characteristics—may be necessary to justify higher prices.

Timing can also influence pricing opportunities. Products harvested or sold when supplies are limited may command higher prices, particularly for seasonal or perishable products. Processing, storage, or season-extension strategies may help increase marketing flexibility and allow products to be sold during periods of stronger demand.

A basic pricing formula is:

$$\text{Price per unit} = \text{Total production costs per unit} + \text{Desired profit per unit}$$

Price setters and price takers

The degree to which producers can influence prices depends on several factors, including:

- the scale and structure of the market,
- the level of product differentiation,
- product quality and consistency,
- reputation and reliability within the industry,
- and negotiating ability.

Commodity products traded in large regional or international markets are often subject to externally determined pricing. In contrast, niche and value-added agroforestry products may provide greater opportunities for producers to influence pricing through branding, differentiation, quality, customer relationships, and specialized marketing strategies.

Ultimately, pricing decisions are strongly influenced by customer willingness to pay, market demand, and the perceived value of the product. Marketing and product promotion can also affect how consumers perceive product value and pricing.

Promotion and consumer education

Promotion strategy

Promotion plays an important role in building product awareness, educating consumers, and increasing recognition of agroforestry products within the marketplace. An effective promotion strategy typically considers three components:

- the message being communicated,
- the methods used to communicate that message,
- and the costs associated with promotional activities.

Promotional messaging

Promotional messaging should communicate the characteristics, benefits, and distinguishing qualities of the product. Because many agroforestry products are unfamiliar to consumers, educational information may help increase consumer interest and willingness to purchase. Messaging may emphasize attributes such as freshness, local production, sustainability, small-scale production methods, ecological benefits, specialty qualities, or health-related characteristics.

Promotional tools and delivery methods

A variety of communication tools may be used to promote agroforestry products, including newspapers, magazines, flyers, catalogs, radio, television, websites, social media, online marketplaces, and in-store displays. Publicity and community engagement may also provide lower-cost promotional opportunities through participation in fairs, festivals, workshops, farm tours, farmers markets, community-supported agriculture (CSA) programs, charitable events, and educational outreach activities.

Free product samples, demonstrations, informational displays, fact sheets, and direct interaction with consumers can help increase familiarity with niche products and build customer trust. Educational materials may be especially important for products with unique uses, unfamiliar preparation methods, or less widely recognized health or ecological benefits.

Promotional costs and branding

Promotional activities may involve costs related to advertising, branding, packaging, graphic design, signage, website development, or participation in events and markets. Cooperative advertising or shared promotional efforts with other farms or businesses may help reduce individual marketing expenses.

Branding can also help distinguish agroforestry products from competing products by emphasizing qualities such as local origin, environmental stewardship, sustainability, craftsmanship, or product quality. In many niche markets, promotional efforts focus on creating a recognizable product identity and communicating the values associated with the product and production system.

Conclusion

Successful marketing of agroforestry products requires careful consideration of product characteristics, customer demand, pricing, distribution, transportation, and promotional strategies. Because many agroforestry products are sold in niche or emerging markets, producers often benefit from combining market research, product differentiation, value-added processing, and consumer education to improve competitiveness and profitability.

Developing effective marketing strategies can help strengthen market access, build customer relationships, and support the long-term economic viability of agroforestry enterprises.

Additional resources

Marketing publications and Webpages:

- Oregon Food Innovation Center, <https://fic.oregonstate.edu/>
- WSDA Handbook for Small and Direct Marketing Farms, <https://agr.wa.gov/departments/business-and-marketing-support/small-farm/the-green-book>
- WSU Extension Food Systems Program, <https://foodsystems.wsu.edu/>

Productive conservation:

- Growing Specialty Forest Products in Agroforestry Plantings. University of Nebraska, Lincoln. <https://ilforestry.org/Resources/Documents/Publications/Prod%20Cons.pdf>
- Agricultural Marketing Resource Center. Business management resources. <https://www.agmrc.org/business-development>
- *Break-even Pricing, Revenue and Units*, Univ. of Missouri Extension. <https://extension.missouri.edu/publications/g648>
- *Selecting an Appropriate Pricing Strategy*, Univ. of Missouri Extension. <https://extension.missouri.edu/publications/g649>
- Missouri Department of Agriculture. Food Safety, Farmers' Market Handbook. <http://agriculture.mo.gov/connect/foodsafety.php>

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CHAPTER 16

INCENTIVES FOR AGROFORESTRY

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Agroforestry incentives can originate from a variety of sources. For some landowners, the environmental benefits, including improved soil health, water quality, and biodiversity, provide sufficient motivation to adopt agroforestry practices. However, other producers may require substantial financial support before making the investment. As a result, the most common funding incentives are programs that help reduce or offset the upfront costs associated with establishing agroforestry systems, making adoption more economically feasible for landowners.

Funding incentives can come from at least three major sources: **federal**, **state**, and **private** conservation programs.



Photos courtesy of Tao Orion (left) and Abel Kloster (right).

Federal programs

Federal conservation programs are those initiated by major legislation, such as the Farm Bill. These programs offer cost share payments, land easement payments, and other incentive payments to farmers who adopt environmentally responsible land use practices.

The NRCS provides technical assistance and funding to landowners interested in agroforestry and other conservation practices, and is an important program for any landowner interested in adopting agroforestry. It leverages Farm Bill funding to provide cost-share support for implementing and maintaining agroforestry systems through these programs:

The **Environmental Quality Incentives Program (EQIP)** is one of the primary federal programs supporting landowners interested in adopting agroforestry practices. EQIP is a voluntary program that provides both financial and technical assistance to agricultural producers through contracts that may extend for up to ten years. These contracts offer cost-share funding to help plan, establish, and maintain conservation practices that improve soil, water, air, plant, animal, and related natural resources on agricultural lands and nonindustrial private forestlands.

EQIP supports a range of agroforestry practices, including alley cropping, riparian forest buffers, windbreaks, silvopasture, forest farming, and other tree-planting systems. Additional conservation programs, including the **Wildlife Habitat Incentives Program (WHIP)**, the **Wetlands Reserve Program (WRP)**, and the **Conservation Stewardship Program (CSP)**, also encourage agroforestry adoption through cost-share assistance and conservation easement payments. These programs commonly support practices such as riparian buffers, tree planting, and forest management, while CSP may also provide assistance for alley cropping and silvopasture systems.

Federal programs provide vital resources that make it possible for professionals to provide the assistance that supports planning and establishment of agroforestry practices. Besides the NRCS, other USDA assistance helps advance agroforestry adoption, including the **Sustainable Agriculture Research and Education (SARE)** program, which offers grants to farmers, ranchers and agricultural professionals for on-farm research, education, and professional and community development. Within **Western SARE**, the program that covers all of the Western US, most grants require that producers work with some form of technical advisor to apply (an extension agent, conservation district,

etc.). One exception is the farmer/rancher grant program, which allows producers to apply directly for funding innovative producer-driven research.

The **National Agroforestry Center**, a department within the U.S. Forest Service, collaborates on technical transfer of information and research. The center has a library of free publications, online tools and training resources, and sometimes provides funding to local universities, non-profits, and other entities to support research, demonstration, and agroforestry efforts.

State programs

State programs can be equally as important and effective to supporting landowner adoption of agroforestry. They can be more relevant to local needs and environmental concerns, and often require less administration than federal funding.

Conservation districts can be a key local resource for landowners interested in agroforestry by providing technical assistance and/or cost share programs. In many cases, conservation districts work closely with the NRCS to help implement programs like EQIP or CSP on the ground. They can help landowners navigate the process and better leverage the funds, especially where NRCS agent capacity is limited. However, their ability to provide agroforestry expertise can vary significantly by county and local priorities.

Other resource-focused entities, such as watershed councils, watershed partnerships, and regional restoration organizations, can also provide technical assistance and grant funding to support agroforestry adoption. Resources from entities like these will often be contingent on the project addressing a specific resource concern (e.g. water quality, wildlife habitat).

Fortunately, agroforestry systems can often be designed to support ecosystem services and landowner production goals, and state and local agencies are increasingly coming to see it as a natural solution to issues like salmon recovery and climate mitigation.

Table 16.1. Federal incentive programs.

Program	Agency	Description	Eligible practices
Conservation Technical Assistance (CTA)	USDA NRCS	Technical assistance to clients to address opportunities, concerns, and problems related to the use of natural resources.	Alley cropping, riparian forest buffer, windbreak, silvopasture, forest farming
Environmental Quality Incentives Program (EQIP)	USDA NRCS	Financial assistance to promote agricultural production, forest management, and environmental quality as compatible goals.	Alley cropping, riparian forest buffer, windbreak, silvopasture, forest farming
Conservation Stewardship Program (CSP)	USDA NRCS	Financial assistance to encourage producers to undertake additional conservation activities or to improve, maintain, and manage existing conservation activities.	Alley cropping, riparian forest buffer, windbreak, silvopasture, forest farming
Conservation Reserve Program (CRP)	USDA FSA	Financial assistance to help agricultural producers safeguard environmentally sensitive land and to convert marginal cropland to long-term conservation cover, either grass or trees. The land is bid into the program on a competitive basis and ranged based on environmental benefits and cost.	Tree planting that can be used to support future agroforestry practices after contract period has expired.
Conservation Reserve Enhancement Program (CREP)	USDA FSA	Special financial initiative within CRP to address agricultural resource problems, targeting priority environmental needs and providing additional incentives for conservation	Riparian forest buffer, windbreak
Forest Stewardship Program (FSP)	USDA Forest Service	Technical assistance to nonindustrial private forest landowners to develop comprehensive, multiresource conservation plans for their forests.	Alley cropping, riparian forest buffer, windbreak, silvopasture, forest farming
Sustainable Agriculture Research and Education (SARE) Program	USDA NIFA	Competitive producer grants for landowners and practitioners who want to try new agroforestry enterprise concepts.	Alley cropping, riparian forest buffer, windbreak, silvopasture, forest farming, system research
Partners for Fish and Wildlife (PFW)	USFWS	Financial and technical assistance to help conserve, protect, and enhance fish, wildlife, and plants and their habitats on private lands.	Riparian forest buffer, tree planting

FSA = Farm Service Agency; NIFA = National Institute of Food and Agriculture; NRCS = Natural Resources Conservation Service; USDA = U.S. Department of Agriculture; USFWS = U.S. Fish and Wildlife Service.

Oregon

Oregon currently lacks incentive programs designed specifically for agroforestry. However, existing conservation funding programs can often be leveraged to support agroforestry planning, establishment, and management when these practices address identified conservation objectives.

The **Oregon Conservation Strategy** establishes statewide and regional priorities for conserving habitats and species of greatest conservation need and is administered by the **Oregon Department of Fish and Wildlife (ODFW)**. These priorities are organized around key habitat types and their associated strategy species, providing a framework for directing conservation investments across the state.

Agroforestry's greatest potential lies where conservation priorities intersect with actively managed agricultural and forested landscapes. The Oregon Conservation Strategy designates priority geographic areas as **Conservation Opportunity Areas (COAs)**, while the NRCS identifies **Conservation Implementation Strategy (CIS)** areas. Although COAs focus on habitat and species conservation, CIS areas emphasize conservation goals on working farms, ranches, and forestlands. Together, these frameworks highlight landscapes where agroforestry practices can simultaneously advance agricultural production and conservation outcomes.

Many of Oregon's most pressing conservation challenges, including habitat degradation, water quality concerns, soil erosion, climate resilience, and biodiversity loss, cross habitat boundaries and occur throughout the state. The Oregon Conservation Strategy and NRCS conservation priorities collectively provide the overarching framework that guides conservation investments in Oregon. Within this framework, agroforestry offers a powerful set of tools for integrating habitat enhancement, ecosystem services, and natural resource conservation into working agricultural and forest landscapes, creating benefits for both landowners and wildlife.

Washington

Although Washington does not currently offer funding programs dedicated to agroforestry, landowners can access a variety of state programs that can be used to establish and manage agroforestry practices. Many of these programs are administered through the **Washington State Conservation Commission (WSCC)** in partnership with local conservation districts.

One of the most significant sources of support is the **Sustainable Farms and Fields (SFF) Program** funded through Washington's Climate Commitment Act. SFF provides grants and technical assistance to farmers and ranchers implementing climate-smart agricultural practices. Due to their carbon sequestration and climate resilience benefits, practices such as silvopasture, riparian buffers, windbreaks, and alley cropping are often highly competitive within the program.

Other programs such as the **Riparian Grant Program, CREP**, and **Voluntary Stewardship Program (VSP)** help landowners protect sensitive natural resources, particularly riparian areas and aquatic habitats. These programs can support agroforestry approaches that maintain productive land uses while achieving conservation objectives, including working riparian buffers, silvopasture, alley cropping, or forest farming systems. These programs typically coordinate through local conservation districts and often involve a competitive application or proposal process.

The Washington Department of Natural Resources' **Service Forestry Program** offers technical assistance and cost-share funding to nonindustrial forest landowners for practices that improve forest health and resilience, including thinning, fuels reduction, pest and disease management, and restoration of degraded forest stands. These resources may be particularly useful for landowners engaged in forest farming, silvopasture, or other tree-based production systems.

The **Washington State Department of Agriculture (WSDA)** also offers programs that benefit diversified agroforestry operations. For example, the **Local Food System Infrastructure Grant Program** provides

direct funding to producers for food processing and value-added infrastructure, along with assistance in obtaining equipment, permits, and licenses needed to process and market specialty agricultural products.

Some opportunities are tied to regional conservation priorities. For example, the **Chehalis Basin Strategy**, administered by the **Washington Department of Ecology**, provides funding and technical assistance to support riparian restoration and buffer establishment on agricultural lands.

Available programs and funding opportunities vary by region, and growing interest in agroforestry among landowners, conservation organizations, and state agencies is likely to increase support for agroforestry implementation over time. Landowners interested in exploring available resources should contact their local extension office or conservation district, which can help identify relevant programs and funding opportunities in their area.

Private programs

Organizations can provide educational services, farmer technical and financial support, and channel other resources toward agroforestry initiatives. Private funding sources with applications for agroforestry often center on organizations that promote game animals or forestry. Private sources include groups such as **Pheasants Forever**, **Ducks Unlimited**, **Quail Unlimited**, and the **National Wild Turkey Federation**. These organizations offer cost-share programs and land easement payments to producers who manage their land in a way that improves the habitat of the game animal they represent.

Landowner organizations such as Farm Bureau chapters and woodland owner associations may have financial resources to support agroforestry directly or indirectly. These organizations can also sometimes provide marketing and technical assistance through cooperative models.



Photos courtesy of Abel Kloster (left, middle right) and Carrie Brausieck (middle left, far right)

Tax incentives

Another incentive for agroforestry adoption may be the income tax benefits that a producer could receive.

There are three basic ways to substantially reduce your tax burden: **increased deductions**, **reduced tax rate**, and **tax credits**.

The current Internal Revenue Code (IRC) offers at least four areas where a producer can reduce their potential tax burden by establishing an agroforestry practice. The IRC offers tax benefits for reforestation, conservation, business investment, and capital gains.

A. Reforestation incentives

Section 194 of the IRC describes the reforestation deduction and amortizable basis deduction. This deduction allows a producer to deduct the first \$10,000 of reforestation expenses from taxable income and then amortize and deduct the remaining expense over an 84-month period.

B. Business investment incentives

Section 179 allows a producer who is managing the agroforestry practice as an active business to deduct a large amount of expenses incurred for personal property used more than 50% in the business. Qualifying property includes agricultural fences, machinery, and equipment, business property (printers etc.), livestock, single purpose livestock or horticultural structures (mushroom structures, drying sheds, etc.). Most buildings do not qualify for this deduction.

C. Conservation incentives

Section 175 describes the conservation deduction that allows a producer to deduct certain conservation expenses up to 25% of the gross income earned from the farming business. These conservation expenses must be incurred in accordance with a plan approved by the NRCS or a similar agency

Section 126 details how to exclude cost-share payments received from approved federal or state conservation programs from taxable income.

Oregon programs

The **Forestland Program** offers a reduced annual tax rate, below the real market value of the forestland, in exchange for management of that land for timber production. Forest owners must apply through their assessor's office. This program may be compatible with agroforestry practices like forest farming or silvopasture if adequate stocking rates are maintained.

The **Oregon Riparian Lands Tax Incentive** offers a property tax incentive to property owners for improving or maintaining qualifying riparian lands. Under this program, property owners receive complete property tax exemption for their riparian property. This can include land up to 100 feet from a stream.

Washington programs

Designated Forest Land (DFL) is a tax deferral program for private forest owners in Washington State that provides a reduced annual property tax rate in exchange for paying an excise tax during timber harvest. To qualify, forest owners must manage land entered in the program for commercial timber harvest. Agroforestry practices such as forest farming or silvopasture may be compatible with DFL if minimum stocking rates of native commercial tree species are maintained. Designated Forest Land is managed at the county level by an assessor's office, so rules and requirements may vary slightly by county.

Open Space is a similar program that preserves rural land such as farms and forests by providing a reduced annual tax rate in exchange for keeping the land undeveloped. The tax reduction is not as significant as in DFL, but agricultural properties are eligible and there are fewer restrictions on land management.

Individual counties may offer additional programs and incentives that benefit agroforestry practitioners. County assessor offices can provide information on local tax incentive programs and other opportunities that may support agroforestry implementation and management.

Table 16.2. NRCS Environmental Quality Incentives Program (EQIP) practices for agroforestry systems

Alley cropping	Forest farming	Forest gardens	Riparian forest buffers	Silvopasture	Windbreaks & hedgerows	Code	Practice	Description
Planning systems								
●	●	●	●	●	●	CPA 106 DIA 165	Forest management plan	Site-specific conservation plan that contains planned forest related conservation treatment activities for one or more resource concerns.
				●		110	Grazing management plan	Site-specific conservation plan developed for a client which addresses one or more resource concerns on land where grazing related activities or practices will be planned and applied
●	●	●	●	●	●	CPA 138 DIA 140	Organic transition plan	Site-specific conservation plan that contains planned conservation treatment activities for resource concerns resulting from the transition of conventional to organic production systems
Agroforestry practices								
●						311	Alley cropping	Trees or shrubs are planted in sets of single or multiple rows with crops produced in the alleys between
●	●	●	●			379	Forest farming	Establishment and/or management of desired trees and forages
					●	380	Windbreak and shelterbelt establishment/renovation	Establishing, enhancing, or renovating windbreaks, also known as shelterbelts, which are single or multiple rows of trees and/or shrubs in linear or curvilinear configurations
				●		381	Silvopasture	Establishment and/or management of desired trees and forages
			●			391	Riparian forest buffer	An area predominantly covered by trees and/or shrubs located adjacent to and up-gradient from a watercourse or water body
●			●		●	422	Hedgerow planting	Establishment of dense perennial vegetation in a linear design to achieve a conservation purpose
Supporting practices								
	●		●	●		314	Brush management	Special financial initiative within CRP to address agricultural resource problems, targeting priority environmental needs and providing additional incentives for conservation
			●			326	Clearing and snagging	Management or removal of invasive and/or noxious plants
	●	●	●	●		327	Conservation cover	Removal of select vegetation and in-stream obstructions
●						331	Contour orchard and other perennial crops	Establishing and maintaining permanent vegetation and cover
	●			●		338	Prescribed burning	Planned fire for brush control and forage management
●			●			340	Cover crop	Grasses, legumes, and other forbs planted for seasonal vegetative cover
	●	●	●	●		382	Fence	Exclusion of animals or people
			●	●		383	Fuel break	Strip or block with vegetation and litter reduced to control or diminish the spread of fire
	●		●	●		384	Woody residue treatment	Slash treatment of material from management activities or other disturbance
●	●		●			386	Field border	Strip of permanent vegetation established at the edge or around the perimeter of a field
			●			390	Riparian herbaceous cover	Establishing vegetation in the transitional zone between upland and aquatic habitats

Table 16.2. continued

Alley cropping	Forest farming	Forest gardens	Riparian forest buffers	Silvopasture	Windbreaks & hedgerows	Code	Practice	Description
			●			393	Filter strip	Strip or area of herbaceous vegetation that removes contaminants from overland flow
			●			395	Stream habitat improvement and management	Improve, restore, or maintain the ecological functions of a stream and its adjacent floodplain and riparian area
			●			396	Aquatic organism passage	Modification or removal of barriers that restrict or impede movement of aquatic organisms
●	●	●	●		●	430	Irrigation pipeline	Pipeline and appurtenances installed to convey water for storage or application as part of an irrigation system
●	●	●	●		●	441	Microirrigation	Irrigation system for frequent application of small quantities of water on or below the soil surface
●	●	●			●	449	Irrigation water management	Determining and controlling the volume, frequency, and application rate of irrigation water
			●	●		472	Access control	Temporary or permanent exclusion of animals, people, vehicles, and equipment from an area
●			●			484	Mulching	Applying plant residues or other suitable materials to the land surface
●	●	●	●	●	●	490	Tree / shrub site preparation	Enhance the success of natural or artificial regeneration of trees and/or shrubs
				●		512	Pasture and hay planting	Establishing adapted and compatible plants for pasture or hay
				●		516	Livestock pipeline	Livestock and wildlife water supply lines
				●		528	Prescribed grazing	Managing vegetation with grazing and browsing animals to achieve specific ecological, economic, and management objectives
			●			533	Pumping plant	Pressurize and transfer water from a surface or underground source to irrigated land and livestock
				●		561	Heavy use area protection	Stabilization or protection of an intensively used area
	●	●				575	Trails and walkways	A constructed path with a vegetated, earthen, gravel, paved, or other hard surface to facilitate the movement of animals, people, or off-road vehicles
●						600	Terrace	An earth embankment or a combination ridge and channel, constructed across the field slope.
●	●	●	●	●	●	612	Tree-shrub establishment	Establishing woody plants by planting, direct seeding, or through natural regeneration
			●	●		614	Watering facility	Store drinking water for livestock or wildlife
			●			643	Restoration of rare or declining natural communities	Reestablishment of conditions necessary to support rare or declining assemblages of native plants and animals
			●			656	Constructed wetland	An artificial wetland ecosystem with hydrophytic vegetation for biological treatment of water
●	●	●	●	●		660	Tree-shrub pruning	The removal of all or parts of selected branches, leaders, or roots from trees and shrubs
	●			●		666	Forest stand improvement	Managing tree and shrub species composition, structure, or density

Summary

Agroforestry encompasses a diverse set of land-use practices that integrate agricultural production with environmental stewardship. From an economic perspective, agroforestry can enhance the diversity and resilience of farm income by incorporating a wide range of conventional and specialty products into existing agricultural and forestry operations.

Evaluating the financial performance of agroforestry systems requires a combination of enterprise and cash flow budgeting. Enterprise budgets help estimate the costs and returns associated with specific products or practices, while cash flow budgets provide a broader view of revenues and expenses over time. Together, these tools capture both the short- and long-term implications of agroforestry investments.

Because many agroforestry practices require substantial upfront investments and may not generate significant returns for several years, careful financial planning is particularly important. Establishment costs can create barriers to adoption, especially before productive yields are realized. To help offset these costs, landowners may be eligible for assistance through federal, state, and private programs that provide cost-share funding, grants, conservation easements, or other incentives for implementing agroforestry and related conservation practices.

Additionally, the Internal Revenue Code may offer tax advantages to landowners investing in reforestation, conservation, and businesses that depend on the sustainable management of natural resources. These incentives can improve the long-term viability of agroforestry systems and should be considered as part of a comprehensive financial planning strategy.

Additional resources

- Direct Marketing for Agroforestry Producers <https://www.fs.usda.gov/research/publications/an/direct-marketing-an27.pdf>

Financial decision support tools and calculators

- Chestnut, Elderberry, Pawpaw, and Black Walnut Financial Decision Support Tools, University of Missouri Center for Agroforestry. <https://centerforagroforestry.org/resources/>
- Cropping Systems Calculator, Land Stewardship Project. <https://landstewardshipproject.org/stewardshipfood/chippewa10croppingsystemscalculator>
- Grass Fed Beef Calculator, Pasture Project at the Wallace Center. <https://pastureproject.org/financial-calculators/test-2/>

Economic budgeting publications and webpages

- Agroforestry publications, University of Missouri Agricultural Business and Policy Extension. <https://extension.missouri.edu/programs/agricultural-business-and-policy-extension/publications>

Funding and tax incentive publications and webpages

- USDA Farm Service Agency. <http://www.fsa.usda.gov>
- USDA Natural Resource Conservation Service. <http://www.nrcs.usda.gov>
- Sustainable Agriculture Research and Education (SARE). <http://www.sare.org>
- National Timber Tax Website. <https://www.timbertax.org/>
- Internal Revenue Service. <http://www.irs.gov/>
- Building Better Rural Places, USDA, The Michael Fields Agricultural

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About the Center for Rural Livelihoods

CRL's mission is to create and strengthen pathways to rural livelihoods that harmoniously advance social, economic and ecological resilience. Its agroforestry program works toward an equitable, biodiverse, and climate adaptive farm and forest economy rooted in the regeneration of ecosystems and the enhancement of livelihoods through agroforestry. Our work is accomplished by supporting and advancing land based projects, collaborating across networks of mutual support to elevate agroforestry adoption, developing educational materials and workshops, and undertaking research across the region. Through regional networks that stretch across multiple states, we also partner to advance agroforestry across the range of the maritime, Mediterranean, and desert climate zones of the West Coast.

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