COMPENDIUM OF BEST PRACTICES

Climate-Smart Agricultural Practices: The Haryana Context

Submitted by

SDGCAC

SUSTAINABLE DEVELOPMENT GOALS COORDINATION AND ACCELERATION CENTRE

OUTPUT- 4 : Green Economy & Climate Friendly Transition

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SUSTAINABLE DEVELOPMENT GOALS COORDINATION AND ACCELERATION CENTRE

Submitted by:
Mr. Pankaj Saini, Green Economy & Climate Friendly Transition Analyst &
Ms. Gurneel Kaur, Economic Research Associate
Supervised by: Mr. Vikas Verma, Head-SDGCAC
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1. Executive Summary

- Climate change is irreversible. Resultant increased weather variability poses a greater threat to agriculture production. Hence, effective and efficient adaptation is necessary.
- As per the Intergovernmental Panel on Climate Change (IPCC, 2023[1]), global temperature increased 1.1 degrees Celsius over the past decade and is rising 0.2 degrees every decade. India's average air temperature has risen by 0.7°C during 1901–2018 largely owing to greenhouse gas emissions and is projected to rise by 2.0-2.8°C by the end of the century. Agriculture is one of the most vulnerable sectors affected by these changes given its intrinsic dependence on the natural environment.
- Agriculture remains a pillar of Haryana's economy, providing livelihoods for 27.5% of the state's workforce and contributing 15.9% to the Gross State Value Added (GSVA), while acting as a critical buffer against inflation and a leader in trade through exports such as Basmati rice.
- Climate projections for Haryana indicate significant warming, with maximum temperatures rising by up to 4.2°C and minimum temperatures by 4.7°C by the end of the century; while annual rainfall is expected to increase by nearly 17% during the same period, it will be accompanied by greater variability and more intense rainfall events.
- Daily income of a typical farming household is only 68% of the World Bank's lower-middle-income benchmark. At the same time, groundwater is being used up at a rate of 17.7 km^3 per year. Additionally, there is an imbalance in state spending, with most of the agricultural budget used for subsidies and relief payments, and limited spending on research and training for farmers.
- Policymakers face a triple challenge of providing food for growing populations and providing livelihoods along the food value chain while building sustainable agriculture.
- Adoption of integrated climate-smart practices such as Climate-Smart Villages (CSV), laser land leveling, Direct Seeded Rice (DSR), zero tillage, crop residue management, and crop diversification, supported by national and global approaches like NICRA and Alternate Wetting and Drying (AWD), can help farmers build resilience, improve resource efficiency, and transition toward sustainable agricultural systems.

[1] Climate change impacts and adaptation options in the agrifood system, FAO 2022.

Introduction

Climate change has become a major global concern, but its impact is severely felt in developing nations where it has profound effects on the agricultural sector. While increasing global food demand (projected at 9.7 billion people to be fed by 2050)[2] is driving agricultural expansion and unsustainable use of natural resources, greater weather variability is decreasing agriculture revenue. Climate change has both direct and indirect effects on agriculture and hence its consequences are more severe in tropical countries where small-scale farmers dominate the sector. Since the phenomenon is inevitable and largely irreversible, timely interventions to mitigate its risk are required. Farmers can adapt efficiently to climate changes given they have timely access to knowledge along with technical and financial capacity.[3] Access to such services can help them make more profitable decisions and can incentivize the transition to low-emission agriculture.

What is Climate Smart Agriculture?

According to the Food and Agriculture Organization, Climate-Smart Agriculture (CSA) refers to the transformation and reorientation of agricultural systems toward green, climate-resilient practices.[4] In essence, it aims to guide agricultural development along pathways that sustain food security under the evolving realities of climate change.

The concept rests on three core pillars: (i) sustainably increasing agricultural productivity and farmers' incomes, (ii) strengthening adaptation and resilience to climate change, and (iii) reducing or removing greenhouse gas emissions where possible. Importantly, this does not imply that every intervention must achieve all three objectives simultaneously. Instead, the emphasis is on minimizing trade-offs and fostering synergies that lead to locally appropriate and socially acceptable solutions aligned with these goals[3]. Furthermore, CSA extends beyond farm-level practices. In addition to on-farm interventions, it incorporates broader institutional, technological, and policy measures, recognizing that agricultural systems operate within diverse local contexts and interconnected value chains.[3]

[2] World Population Prospects 2022, UN
[3] Wreford, Ignaciuk and Gruère, 2017, "Overcoming barriers to the adoption of climate-friendly practices in agriculture"
[4] FAO, 2026

Actions to Implement the CSA Approach Includes:

- **Develop a Robust Evidence Base:** Identify climate vulnerabilities and assess the effectiveness, costs, and emission-reduction potential of various adaptation strategies.
- **Establish Enabling Policies:** Create integrated policies and investment plans that coordinate actions across the agriculture, climate, and land-use sectors.
- **Strengthen Institutional Capacity:** Empower local and national institutions to better support farmers and engage effectively in international climate policy.
- **Expand Funding Mechanisms:** Combine agricultural and climate finance from public and private sources while integrating climate priorities into mainstream state budgeting.
- **Scale Field-Level Implementation:** Work directly with farmers to adapt climate-smart practices to local environmental conditions and specific community priorities.

Impact of Climate Change on Agriculture
Reduced agricultural production (especially at tropical latitudes) affects dietary diversity. Farmers give up producing diversified crops due to climate risk and stick to staples.
Changes in the suitability of land for crop production
Changes in precipitation patterns adversely affects rain-fed agriculture.
Increased temperature results in longer growing seasons in temperate regions. Reduces frost damage in other regions.

What if agriculture is not climate smart?

While climate change affects the agricultural production systems and worsens food insecurity across the world, farmers in developing countries are the first to take the hit in terms of crop losses and related economic consequences.[6] Studies reveal that the impact of high temperatures on agricultural revenue in tropical regions is higher than in countries with temperate climates.[7]

[6] Soubry et al., 2020, "Are we taking farmers seriously? A review of the literature on farmer perceptions and climate change, 20072018"
[7] Mendelsohn, 2008. "The Impact of Climate Change on Agriculture in Developing Countries".

Climate change in Asia is associated with changing monsoon rains and extreme temperatures. These changes delay crop harvesting, reduce crop quality and yields, and increase pest incidence, negatively impacting overall agricultural productivity and food security in Southeast and South Asia.[8]

The Indian Context

India ranked 9th among the ten countries most affected by climate change during 1995–2024[9] and 15th among the twenty most affected countries in 2024. The phenomenon in terms of extreme weather conditions, rising temperature, and erratic rainfall decreases average crop yields and increases food inflation. Frequent extreme precipitation has become common in central and southern parts of the country. Estimating economic losses arising due to soil erosion, crop water requirement, and land degradation remains a challenge.[10]

India's average air temperature has risen by 0.7°C during 1901–2018 largely owing to greenhouse gas emissions and is projected to rise by 2.0-2.8°C by the end of the century.[11] As a result, irrigated rice- yields are expected to decrease by 7% in 2050 and 10% by 2080. Further, wheat and maize yields are estimated to decline by 23 and 25% by 2100 respectively.[12] In the absence of adaptation measures, India is projected to lose 1.8% of its GDP by 2050 and 8.8% by 2100 due to climate change impacts (Ahmed & Suphachalasai, 2014).[13]

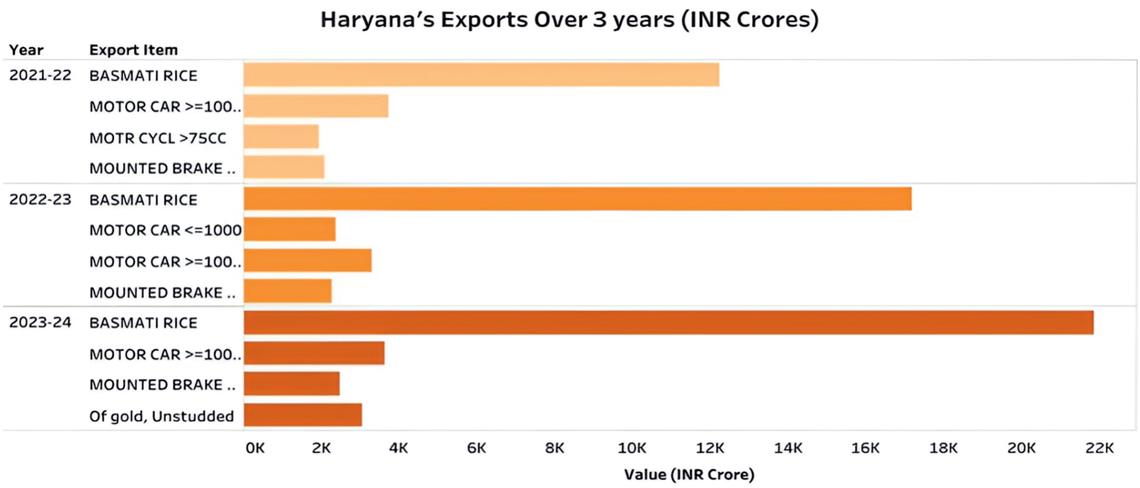
Though India's agricultural production has increased significantly in the last seven decades, the share of farmers in the agriculture chain value remains the lowest. An average agricultural household in India earned USD 1.53 per day in 2018-19 from crop cultivation (77th National Sample Survey on Agricultural Households). When adjusted against inflation, it reveals 8.9% decline between 2012-13 and 2018-19. Moreover, the country stands at a lowly 102 among 123 countries in the Global Hunger Index 2025. Since 63.13% of India's population lives in rural areas (World Bank 2024) and 44% depends on agriculture for livelihood (World Bank ,2023), agricultural distress turns into rural distress. The resultant poverty adds to the huge burden of anaemia and malnutrition, reducing the work capacity of individuals and imposing barriers to the overall progress of the nation.

[8] Thirumalai et al., 2017:"Extreme temperatures in Southeast Asia caused by El Niño and worsened by global warming"
[9] Climate Risk Index 2026
[10] Kumar and Viswanathan, 2019"Weather Shocks, Agricultural Productivity and Farmer Suicides in India,"
[11] Krishnan et. al, 2022, "Extreme wind-wave climate projections for the Indian Ocean under changing climate scenarios"
[12] PIB 2021c
[13] Ahmed, M., & Suphachalasai, S. (2014). Assessing the Costs of Climate Change and Adaptation in South Asia. Asian Development Bank.

Haryana's Rationale

Economic Relevance of Agriculture

Haryana is located in northern India in the Indo-Gangetic Plains and covers about 44,200 km², accounting for roughly 1.4% of the country's geographical area. Despite its relatively small land area, the state has played a critical role in India's agricultural transformation since the Green Revolution due to its fertile alluvial soils, irrigation infrastructure, and adoption of high-yield crop varieties.[14] Haryana's real Gross State Domestic Product (GSDP) grew at an average rate of about 6.3% per year between 2014–15 and 2023–24, slightly higher than the national average growth rate of 6.0% during the same period. Over the longer term, the state's share in the country's nominal Gross Domestic Product (GDP) increased from 2.7% in 1990–91 to 3.6% in 2023–24. In 2023–24, Haryana's nominal per capita income was ₹356,829, which was considerably higher than the national per capita income of ₹188,892.[15]



Source: Department of Commerce, Ministry of Commerce and Industry

The contribution of the agriculture and allied sector to Gross State Value Added (GSVA) has declined over time—from about 60.7% in 1969–70 to 21.3% in 2006–07, and further to around 15.9% in 2024–25.[16] Although the sector's share in output has decreased as the economy has diversified, agriculture remains critical as 27.5% of the workforce remains engaged in agriculture and allied activities.[17] Agriculture is

[14] Statistical Abstract of Haryana 2023-24
[15] Data on Economic Structure are sourced from Ministry of Statistics and Programme Implementation (MoSPI), as of March 2025. First Revised Estimates (FRE) are used for FY 2023-24
[16] Economic Survey 2024-25
[17] NCAER 2025 (Data Repository for States)

also linked to the state's trade performance. The share of agro-food products in the state's exports has increased over the past two decades, with agricultural commodities consistently among the leading export categories. Basmati rice has been the largest agricultural export in the last 4 years. Furthermore, evidence suggests that sustained agricultural growth is essential to control inflation; high overall GSVA growth without agricultural stability risks jeopardizing the broader state economy[14].

A closer look at Farmer's Income in Haryana

Agricultural households in Haryana reported an average monthly income of ₹22,841 during the 2018–19 agricultural year, a figure that is 2.23 times higher than the All-India average of ₹10,218.[19] While Haryana ranks among the highest-earning states, it trails Punjab (₹26,701) and Meghalaya (₹29,348), though it remains significantly ahead of states like Bihar (₹7,542) and Jharkhand (₹4,895)[15.] The composition of this income includes ₹9,092 from crop production, ₹4,020 from animal farming, and a substantial ₹7,861 from wages and salaries. Within the livestock sector, Haryana's receipts are heavily dominated by milk, which accounts for 93.6% of total animal farming produce, compared to the national average of 78.0%[15]. However, when "imputed expenses" (the value of family labor and owned assets) are factored in, the net receipts from animal farming in Haryana drop from a positive ₹4,020 to a negative ₹411, indicating that the sector's apparent profitability relies on the non-valuation of household labor[15].To evaluate whether these earnings represent genuine economic security, they must be compared to international benchmarks. Haryana's average monthly household income of ₹22,841 translates to approximately ₹761 per day per household. Based on the World Bank's lower-middle-income poverty line (applicable to India) of USD 3.20 per person per day [20], a standard household of five members would require a daily income of roughly USD 16.00. Using the 2019 exchange rate (approximately ₹70 per USD), this threshold equates to ₹1,120 per day for a family to maintain a basic middle-income standard of living. At ₹761 per day, the average agricultural household in Haryana, despite being one of the wealthiest in India, reaches only about 68% of the daily income needed to meet the World Bank's lower-middle-income benchmark for a five-member family. Consequently, the reliance on wage labor (₹7,861/month) is not an indicator of an integrated or thriving rural-urban

[18] Trade Intelligence and Analytics Portal, Department of Commerce, Ministry of Commerce and Industry
[19] 77th National Sample Survey (2018-19)
[20] World Bank Poverty and Inequality Platform

synergy, but rather a necessary survival strategy, as the income strictly from cultivation and dairy (₹13,112/month or ₹437/day) is insufficient to keep a standard family above international poverty threshold.

Land Use Dynamics

Haryana's agricultural structure is defined by high land utilization intensity and limited scope for horizontal expansion. According to the Statistical Abstract of Haryana 2023–24, the net area sown (area under crops) stands at 3,585 thousand hectares. This represents 4.52% increase (162 thousand hectares) compared to 1966–67, reflecting the long-term consolidation of agriculture following state formation.

The distribution of cultivated land across districts is uneven. Sirsa district records the highest net sown area at approximately 393 thousand hectares[21], reflecting extensive cultivation under semi-arid irrigated conditions. In contrast, Panchkula district records the lowest net sown area at approximately 22 thousand hectares, largely due to its smaller geographical size, urban expansion, and physiographic constraints in the Shivalik foothill region.

With nearly 80 percent of its geographical area under cultivation[22], Haryana exhibits one of the highest land use intensities among Indian states. Cropping intensity exceeds 180 percent, driven by double-cropping systems supported by irrigation infrastructure[23]. Further, a large proportion of farmland in the state is irrigated, with more than 80% of cultivated land having access to irrigation[24], primarily through groundwater extraction and canal networks[25]. The near saturation of cultivable land implies that agricultural growth is achieved through intensification[26] and higher use of fertilizers and pesticides, with longer term implications for human health and wellbeing[27], soil degradation[28] and ecological damage. This lays down a stronger need for CSA practices as the future agricultural growth will rely predominantly on productivity enhancement, crop diversification, and improved resource-use efficiency rather than expansion of cultivated area.

[21] Statistical Abstract Haryana 2023-24
[22] CEIC Data, 2022
[23] IJELS,2024
[24] Haryana Agriculture Statistics, 2024
[25] Land Use Statistics 2013-14 TO 2022-23 (Table 2.1)
[26] Kumari, M., Swati, Priyanka, K. (2025). A Comprehensive Review on Sustainable Agricultural Intensification and Ecosystem Services
[27] Dhakar, Kumar;2023
[28] Yasir, Muhammad, Abul Hossain, and Anubhav Pratap-Singh. 2025. "Pesticide Degradation: Impacts on Soil Fertility and Nutrient Cycling" Environments 12, no. 8: 272

Agriculture Production Systems

Agriculture in Haryana is structured around agro-climatic diversity and irrigation access. While the rice–wheat system dominates irrigated districts, production systems vary significantly across ecological zones. Haryana is classified into four agro-climatic zones (ACZs) based on rainfall, temperature, soil type, and moisture availability.[29]

Agro-Climatic Zone	Key Districts (Examples)	Dominant Crop Specialization	Distribution & Resource Characteristics
Northern Zone	Ambala, Panchkula, Karnal	Paddy, Wheat, and Jowar (Green Fodder)	Core of the paddy–wheat belt with the highest percentage of fully irrigated holdings (98.13%) and the lowest share of unirrigated area in the state.
Central Zone	Rohtak, Sonipat, Jhajjar, Jind	Paddy, Sugarcane, Wheat, and Cotton (Desi)	Transition belt characterized by high input-intensity agriculture; records the highest yields of sugarcane (74,531 kg/ha) and Cotton (Desi) in the state.
Southern Zone	Mahendragarh, Gurugram, Rewari	Oilseeds (Rape & Mustard), Barley, and Bajra	Relatively drier agro-climatic region with greater crop diversification; emphasis on moisture-efficient crops and oilseeds across irrigated and rainfed areas.
Western Zone	Sirsa, Hisar, Charkhi Dadri	American Cotton, Wheat, Bajra, and Gram	Arid fringe of the state with the highest share of unirrigated area (9.31%); major production hub for American cotton and pulses such as gram.

The northern and central zones, representing the state's core paddy-wheat belt, support highly productive irrigated cereal systems but are simultaneously the most vulnerable to acute groundwater depletion, which historically occurred at a rate of 17.7 km^3 per year, and methane emissions from intensive paddy cultivation. In contrast, the western hot and dry zones, along with the southern tracts, face chronic moisture stress and higher exposure to drought risk, holding the state's largest percentage of unirrigated land (9.31%)[22].

[29] Economics of Farming 2022-23, Issued by DESA in 2025

The distinct agro-ecological diversity of Haryana therefore necessitates zone-specific Climate-Smart Agriculture (CSA) strategies, tailored to local moisture profiles and crop specializations, rather than uniform state-level interventions.

Food Security, Nutrition, and Health

Despite Haryana's steady economic progress and relatively high per capita income, food insecurity and undernutrition remain important public health concerns. Food insecurity, defined as limited or uncertain access to sufficient, safe, and nutritious food, is often aggravated by climatic shocks that disrupt agricultural production and food availability.[30] According to the Census population projections, Haryana's population was 30.6 million in 2024, representing 2.2 percent of India's total population.[31] The projected population growth rate for the period from 2012 to 2036 for Haryana (1.2 percent) is higher than the national average (0.9 percent) as of 2023–24. In Haryana, structural features of agriculture such as small landholdings, income disparities among farmers, and limited crop diversification can further influence household food access and dietary diversity[14].

Malnutrition indicators, although slightly better than the national average, still highlight persistent challenges. According to the National Family Health Survey (NFHS-5, 2019–21), 31.7% of children under five in Haryana are stunted, 17.2% are wasted, and 26.4% are underweight. These outcomes vary across districts, with rural and socio-economically disadvantaged communities often facing higher levels of malnutrition. Undernutrition contributes to maternal and child morbidity, reduced productivity, and weakened immunity.[32] At the same time, Dietary patterns in Haryana reflect heavy reliance on cereals, especially wheat, which dominate caloric intake.[33] Milk and dairy products, abundant in the state, form a significant portion of household food expenditure. However, consumption of fruits, vegetables, and protein-rich foods remains limited, leading to imbalanced diets and micronutrient deficiencies.[34] This imbalance contributes to both undernutrition and rising overweight/obesity rates among women, with nearly one-third of adult women in Haryana classified as overweight or obese[27].

[30] FAO, 2021
[31] "Population Projections for Indian States 2011-2036" by the Technical Group on Population Projections, National Commission on Population, Ministry of Health and Family Welfare, Government of India
[32] UNICEF, 2020
[33] Dey, S., & Bharadwaj, A. (2024)
[34] Kumari & Garg, 2025, Ritchie et al., 2018

Addressing these challenges will require promoting diversified and climate-resilient agricultural systems, alongside strengthening nutrition programmes and improving access to balanced diets, will be essential to improving food and nutrition security in Haryana in the face of increasing climate variability.

Challenges for the agricultural sector

Water availability and usage

Haryana has a population of over 30 million people, comparable to that of several medium-sized countries. The state accounts for about 2% of India's population, and its population[35] continues to grow steadily.

With a rising population and increasing demand for food, Haryana's agricultural systems face pressure to sustain productivity while conserving natural resources. The state plays a significant role in India's food security through large-scale production of wheat and rice under the Green Revolution–driven rice–wheat cropping system. However, meeting the future food and nutritional needs of a growing population will require improvements in productivity, diversification toward more nutritious and high-value crops, and greater efficiency in the use of water, soil, and energy resources. This transition will require strong policy support, investments in sustainable technologies, and coordinated action from government institutions, research organizations, and the private sector.

Projected changes in climate and its impact

The stability of Haryana's food production is increasingly threatened by rising temperatures and climate variability. Climate projections reveal that Haryana will experience a significant rise in temperatures and increasing variability in rainfall over the coming decades. Over 2000-2023, the state recorded warming of about +0.5 °C in maximum and +1.0 °C in minimum temperatures. Beyond temperature, the increased frequency of erratic monsoon rainfall and recurring drought years, such as 2002, 2009, and 2019, has already eroded the groundwater buffers that historically stabilized harvests during weak monsoons29. The warming trend, particularly the rise in night-time lows, has made winters milder and nights warmer, creating conditions that can significantly shorten the cool-season development required for optimal wheat growth.[36]

[35] https://statisticstimes.com/demographics/india/haryana-population.php
[36] Pushpa et al, 2025

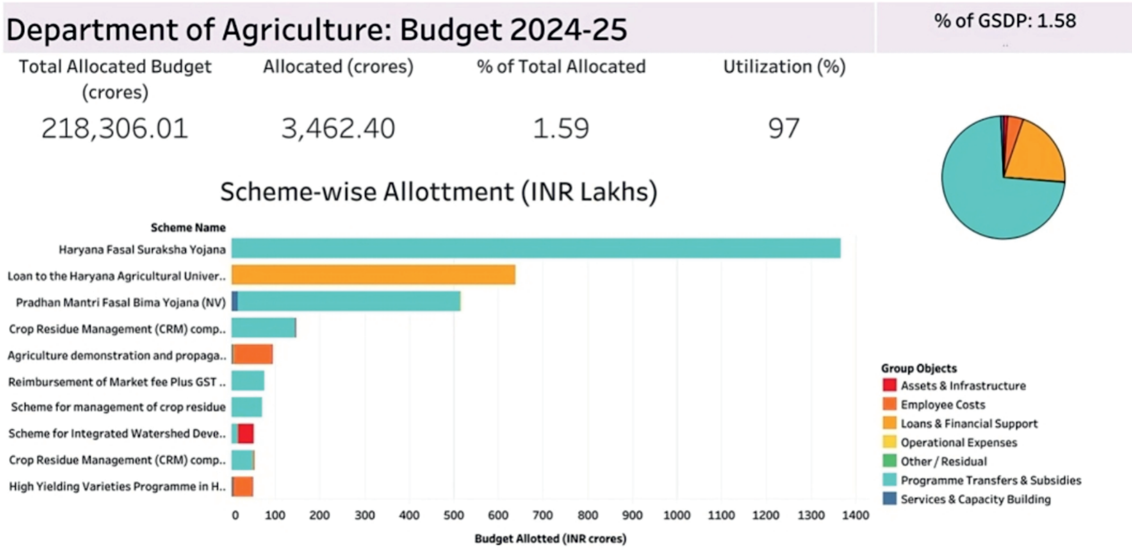
According to the Haryana State Action Plan on Climate Change (SAPCC, 2011), by the mid-century (around 2040–2069), the state's maximum temperature is projected to increase by about 1.3°C, while the minimum temperature will rise by around 2.1°C. By the end of the century (2070–2099), these increases could become more pronounced, with maximum temperatures projected to rise by approximately 4.2°C and minimum temperatures by about 4.7°C. Wheat is sensitive to high temperatures near the end of the growing season, especially during the grain-filling stage. Studies show that an increase of about 1°C in the growing-season temperature can reduce wheat yields if no adjustments are made in farming practices.[37] In March 2022, Haryana experienced an early heat wave during this stage of the crop. An attribution study found that such an event has become about 30 times more likely because of climate change and that it affected wheat production in several parts of India.[38] Rice is affected by warmer nights; empirical work finds 10% yield loss per +1 °C increase in growing-season minimum temperature in the dry season (Peng et al., 2004).

In terms of precipitation, annual rainfall is projected to decline slightly by around 3% by mid-century, but may increase by nearly 17% by the end of the century, although this increase is expected to be accompanied by greater variability and more intense rainfall events.[39] Consequently, the state's long-term food security depends on transitioning to an integrated climate-smart pathway, involving heat-escape sowing windows, heat-tolerant crop varieties, and scaled-up resource conservation technologies.

Research and Capacity Building

Agricultural research in the state has historically prioritized growth strategies centered on the intensification of production, which has successfully pushed cropping intensity to 186% by 2022-2327. However, this intensification has come with the added risk of environmental degradation; the heavy application of 1.44 million tonnes of fertilizers and the alarming depletion of groundwater at a rate of 17.7 km³ per year[27] now threaten to curtail long-term gains while adding to production costs.

[37] Asseng et al., 2015
[38] World Weather Attribution. Climate Change Made Devastating Early Heat in India and Pakistan 30 Times More Likely. May 23, 2022.
[39] Government of Haryana, State Action Plan on Climate Change, 2011



Source: Budget Allocation and Management System 2024-25

Agricultural research and capacity building, although inherently complex, are critically needed to develop robust evidence-based policies and farmer training strategies within a shifting socio-ecological environment.[40] Budgetary analysis indicates a current fiscal imbalance, where the Department of Agriculture and Farmers Welfare allocates the vast majority of its ₹346,240 lakh budget to subsidies and financial relief like the Haryana Fasal Suraksha Yojana, leaving a negligible share for services and capacity building (Departmental Dashboard). To bridge these gaps, future policies must prioritize climate-smart pathways catering to the needs and rights of smallholder farmers, who are majority in the state.

[40] Capacity Building and Education for Climate-Smart Agriculture, 2026

Best Practices in Climate-Smart Agriculture for Haryana

This section presents a curated set of best-practice fiches on Climate-Smart Agriculture (CSA) with relevance for Haryana's agro-ecological, institutional, and policy context. The practices have been selected on the basis of four considerations: strength of available field or research evidence, relevance to Haryana's production systems and climate risks, feasibility of adaptation or scale-up within the state, and alignment with the broad direction of the Haryana State Action Plan on Climate Change.

The fiches are organised in three groups. Section A covers Haryana and locally relevant practices that are already being piloted, promoted, or demonstrated within the state. Section B presents Indian examples that offer programmatic or technological lessons of direct relevance to Haryana. Section C presents selected international experiences that are not intended for direct replication, but provide useful lessons on system design, sequencing, advisory architecture, or enabling conditions. Taken together, these fiches are meant to support informed policy discussion, pilot design, and evidence-led adaptation rather than prescribe a single model for statewide adoption.

A. Haryana and Local Best Practices

A.1 Climate-Smart Villages as a Delivery Model

Category	Delivery model / institutional innovation
Geography	Karnal district, Haryana (piloted 2011 –2014); 500+ villages planned statewide
Problem Addressed	Fragmented technology delivery; low adoption of CSA practice portfolios
Core Intervention	Village-level participatory platform integrating multiple CSA practices with advisory, finance, and institutional support
Haryana Relevance	Very High – addresses rice-wheat system stress, groundwater depletion, residue burning
Scale-up Readiness	High – Haryana government has formally endorsed 500 -village expansion

Why this practice matters: Individual technologies often fail to achieve widespread adoption when they are promoted in isolation. Climate-Smart Villages (CSVs) are important because they provide a village-level delivery model through which multiple climate-smart practices can be combined into a coherent, locally adapted package. Developed through the CGIAR Research Programme on Climate Change, Agriculture and Food Security (CCAFS) in partnership with CIMMYT, the CSV approach was first piloted in Karnal district, Haryana, in 2011.[41] In a state where the rice–wheat system dominates and where groundwater depletion, residue burning, and input-intensive farming increasingly intersect, a systems-based delivery platform has particular relevance.

What the practice involves: A CSV is a village or village cluster in which farmers, researchers, public agencies, and other partners jointly identify, test, and adapt a portfolio of climate-smart interventions suited to local conditions. In the Haryana context, this portfolio has included zero tillage, direct seeded rice, laser land leveling, residue management through Happy Seeder-based approaches, crop diversification, weather-linked services, nutrient management tools, and ICT-enabled advisories. The distinguishing feature of the CSV model is not any one technology, but the institutional architecture through which multiple interventions are selected and implemented in a coordinated manner.[42]

Evidence and outcomes: The Karnal experience provides one of the strongest localized CSA examples available for Haryana. Twenty-eight CSVs were established between 2011 and 2014 under the CCAFS–CIMMYT initiative. The draft cites evidence from Karnal showing adoption rates of 77 percent for laser land levelers and 52 percent for Happy Seeders within CSV settings, with cooperatives and custom hiring centres playing an important role in improving machinery access. It also notes farmer-reported improvements in wheat yield and soil condition where residue retention and zero-till wheat were adopted over multiple years. In addition, the model appears to have generated strong training outreach, including substantial participation by women.

Relevance for Haryana: *The CSV model is highly relevant because it directly addresses the main implementation challenge in Haryana: the need to move from isolated technology promotion to integrated climate-smart delivery. It is especially useful in districts facing a convergence of groundwater depletion, residue management pressures, and climate variability. Rather than focusing only on individual technologies, the CSV model offers a way to connect machinery, extension, farmer institutions, demonstrations, and risk management within one platform. Its relevance is therefore institutional as much as technological.*

[41] CCAFS-CIMMYT (2014), Climate-Smart Villages in Haryana, India. Available at: https://ccafs.cgiar.org/resources/publications/climate-smart-villages-haryana-india
[42] Springer (2024), "Financing Climate-Smart Agriculture: a case study from the Indo-Gangetic Plains." Mitigation and Adaptation Strategies for Global Change. https://link.springer.com/article/10.1007/s11027-024-10127-3

Key enablers: Strong partnerships among research institutions, KVKs, the Department of Agriculture, and farmer groups; functioning Custom Hiring Centres or cooperative service arrangements; demonstration and monitoring systems; ICT-enabled advisories; women's participation; and convergence with state and central schemes supporting water-saving agriculture, mechanization, and climate adaptation.

Risks and cautions: CSVs require sustained coordination across institutions and can lose effectiveness if scaled as a routine administrative scheme without retaining their participatory character. There is also a risk that machinery-intensive benefits may accrue more quickly to better-connected farmers unless smallholders, tenant farmers, and women farmers are explicitly included. The model works best when it remains adaptive and evidence-led rather than becoming a fixed package imposed uniformly across locations.

Scale-up pathway: A practical approach for Haryana would be to expand the CSV model in a phased and district-sensitive manner rather than through simultaneous mass rollout. Initial scaling may focus on priority districts where water stress, residue burning, and rice–wheat system pressures are most acute, with each village or cluster anchored through farmer institutions, machinery access, and technical backstopping from KVKs and research partners. Over time, the CSV platform may serve as the principal field-level architecture through which multiple CSA interventions are sequenced and tested together.

Key Takeaway: *Climate-Smart Villages represent the most thoroughly tested delivery model for bundled CSA in Haryana. Their main value lies in creating an institutional platform through which multiple climate-smart practices can be adapted, demonstrated, and scaled in a coordinated way.*

A.2 Direct Seeded Rice (DSR)

Category	Crop establishment technology / water-saving practice
Geography	Rice-wheat belt: Karnal, Kurukshetra, Kaithal, Panipat, Ambala, Sonepat, Yamunanagar
Problem Addressed	Excessive water use, labour scarcity, and high cost of puddled transplanted rice
Core Intervention	Mechanized dry direct seeding of rice into unpuddled soil, eliminating nursery raising, puddling, and transplanting
Haryana Relevance	Very High – directly addresses the groundwater crisis; Haryana has over 1 million ha under rice
Scale-up Readiness	Moderate to High – technology proven but weed management remains a challenge

Why this practice matters.

Rice is the single largest consumer of irrigation water in Haryana, and the conventional puddled transplanted system places severe pressure on already-stressed groundwater resources. Direct Seeded Rice (DSR) is therefore important because it offers one of the clearest water-saving alternatives within rice cultivation for farmers who continue to grow paddy. The draft notes that Haryan a's groundwater extraction exceeds annual recharge and also cites evidence showing that the irrigation burden of rice is far greater than that of wheat, underscoring why technological change in rice cultivation is central to any serious climate-smart strategy for the state.[44]

What the practice involves: In DSR, rice is sown directly into unpuddled soil using a multi-crop planter, eliminating nurser y raising, puddling, and transplanting. The technical package cited in the draft includes laser land leveling, appropriate sowing windows, calibrated seed rates, seed treatment, and nutrient management using tools such as the Leaf Colour Chart. The system can be used in both prepared and zero-till fields and is particularly suited to mechanized production contexts where labour scarcity and water stress are increasingly important considerations.[45]

Evidence and outcomes: The Haryana evidence base presented in the draft is substantial. CSISA demonstrations across eight districts during 2009–2011 report ed grain yields that were similar to or higher than puddled transplanted rice, with higher net profitability and water savings in the range of 20–25 percent. The document also records expansion in DSR demonstration area during that period, along with reported improvements in the succeeding wheat crop due to better soil structure. At the same time, the draft correctly identifies weed management as the central technical challenge, with success depending heavily on correct herbicide timing and field management.[46]

Relevance for Haryana: *DSR is one of the most relevant climate-smart practices for Haryana because it addresses the core resource constraint in the state's rice–wheat belt: water. Its relevance is greatest in districts where rice remains important but groundwater decline is acute, including Karnal, Kurukshetra, Kaithal, Panipat, and adjoining areas. While crop diversification remains the more structural long-term response to groundwater stress, DSR is highly relevant for those farmers and districts that continue with rice cultivation and require a more water-efficient production pathway.*

[44] Erenstein, O. et al. (2007), "Adoption and Impacts of Zero Tillage as a Resource Conserving Technology in the Irrigated Plains of South Asia." IWMI Comprehensive Assessment Research Report 19, pp. 29, 40.
[45] Kamboj, B.R. et al. (2012), "Direct Seeded Rice Technology in Western Indo-Gangetic Plains of India: CSISA Experiences." CSISA Technical Bulletin 2012/1, IRRI and CIMMYT, pp. 9–14.
[46]

Key enablers: Laser land leveling; access to well-maintained multi-crop planters through Custom Hiring Centres or service providers; trained operators; availability of herbicides and farmer knowledge of integrated weed management; extension support on sowing windows and crop establishment; and convergence with state and centrally supported mechanization and irrigation programmes.

Risks and cautions: The main risks relate to crop establishment and weed control. Poor rainfall immediately after sowing, variable field conditions, mixed weed flora, and micronutrient deficiencies on lighter soils can reduce performance. The draft also points to the limited availability of varieties specifically suited to DSR conditions. As a result, DSR should not be framed as a simple machine-based substitution; it is a management-intensive practice whose performance depends on timely operations and strong field support.

Scale-up pathway: Haryana may continue scaling DSR through a focused district approach in the major rice-growing, groundwater-stressed belt, while ensuring that expansion is tied to readiness conditions rather than area targets alone. A practical pathway would include laser-leveled fields, access to suitable planters, trained operators, pre-positioned weed-management support, and stronger varietal research through relevant state and national institutions. DSR may also be linked with existing water-conservation and crop-planning frameworks where rice remains part of the production system.

The HSAPCC Phase-2 documents specific allocations for Direct Seeded Rice under RKVY during 2015–16 and 2017–18.[47]

Key Takeaway: *Direct Seeded Rice is among the most important water-saving technologies currently available for Haryana's rice-based agriculture. Its value lies in reducing irrigation pressure within continuing rice cultivation, but its success depends on careful management, especially around laser leveling, weed control, and machinery access.*

[47] HSAPCC Phase-2 (2021–30), Government of Haryana, Agriculture Sector Strategy Table, p. 101. Expenditure: Rs 1,369.93 lakh; Allocation: Rs 3,567 lakh.

A.3 Zero Tillage and Conservation Agriculture-Based Wheat Establishment

Category	Crop establishment / resource conservation technology
Geography	Rice-wheat and cotton-wheat belts across Haryana
Problem Addressed	High diesel/cost of wheat land preparation; late planting yield penalty; residue management
Core Intervention	Planting wheat directly into unplowed fields using a tractor -drawn zero-tillage seed drill
Haryana Relevance	Very High – most widely adopted CSA technology; 34.5% of surveyed rice-wheat farmers (2003–04)
Scale-up Readiness	High -mature technology with established manufacturing and service base

Why this practice matters: Zero tillage (ZT) wheat is one of the most established resource-conserving technologies in Haryana and the wider Indo-Gangetic Plains. It matters because it reduces land-preparation costs, saves time and fuel, enables earlier sowing, and can improve profitability in systems where delayed wheat establishment often reduces yields. The evidence cited in the draft shows that ZT substantially reduces tractor operations and input costs, while also generating a modest but statistically significant yield advantage in the Haryana context.[48]

What the practice involves: ZT wheat involves sowing wheat directly into unploughed fields using a tractor-drawn zero-tillage seed drill. In practice, it is most effective when treated not merely as a tillage-saving device, but as part of a broader conservation agriculture pathway that includes residue retention, improved crop sequencing, and better timing of crop establishment. In Haryana, the technology has relevance across both rice–wheat and cotton–wheat systems, although the context and constraints differ between them.

Evidence and outcomes: The draft cites a strong evidence base from Haryana, including survey results from 400 farm hous eholds across ten districts. These findings show significant savings in diesel, tractor hours, and production costs, along with a net revenue advantage and measurable irrigation water savings during the wheat season. The document also notes that the area under ZT in

[48] Erenstein, O.; Farooq, U.; Malik, R.K.; Sharif, M. (2007). "Adoption and Impacts of Zero Tillage as a Resource Conserving Technology in the Irrigated Plains of South Asia." IWMI Comprehensive Assessment Research Report 19, pp. 25–27, 33–34.

Haryana had already reached substantial scale in the early 2000s, underlining that this is not a pilot technology but a proven practice with an existing service and manufacturing ecosystem. At the same time, the evidence also highlights uneven adoption, including stronger uptake among larger farmers and some degree of discontinuation where benefits were not consistently realized.

Relevance for Haryana: *ZT wheat is highly relevant because it is already familiar to Haryana's production systems and addresses both economic and climatic pressures. Its value increases in districts where rice harvest delays the wheat sowing window, particularly in the basmati belt. It is also relevant in cotton–wheat areas where cost-saving and timely establishment matter. However, the real strategic importance of ZT lies in its role as a transition point toward fuller conservation agriculture rather than as a standalone end-state.*

Key enablers: Availability of ZT drills and second-generation equipment through local manufacturers, Custom Hiring Centres, and service providers; operator training; continued institutional support from state and national agricultural institutions; farmer-to-farmer learning; and stronger integration with residue management and crop-sequencing strategies.

Risks and cautions: ZT by itself does not constitute full conservation agriculture. The draft correctly notes that residue retention and crop rotation remain weak points, and that conventional puddled rice can undo many of the soil-structure gains made in wheat. Existing drills may also be unable to handle loose rice residues, making Happy Seeder-type solutions important. Smallholder access can remain constrained where service networks are weak, and the technology may underperform when it is treated as a one-off machine intervention rather than part of a broader system shift.

Scale-up pathway: In Haryana, the next phase for ZT is less about first-time adoption and more about improving quality, inclusiveness, and system integration. A practical pathway would focus on linking ZT with residue-retaining sowing technologies, stronger operator training, better access for smaller farmers through service models, and gradual movement toward double zero-till and diversified conservation agriculture systems where feasible. Districts with lower adoption or weaker service ecosystems may still require focused support, but the broader priority is to deepen the quality of use rather than simply expand numbers.

Key Takeaway: *Zero tillage wheat is Haryana's most mature CSA technology. Its greatest future value lies not in standalone expansion, but in serving as the operational foundation for more complete conservation agriculture pathways built around residue retention, timely establishment, and improved crop sequencing.*

A.4 Crop Diversification – Mera Pani Meri Virasat and Beyond

Category	Cropping system diversification / water conservation policy
Geography	Statewide, with focus on rice-wheat dominant districts
Problem Addressed	Mono-cropping with rice-wheat; groundwater depletion; low system resilience
Core Intervention	Incentive-driven replacement of paddy with less water-intensive crops
Haryana Relevance	Very High -targets the structural driver of the groundwater crisis
Scale-up Readiness	Moderate-policy exists but adoption constrained by procurement guarantees

Why this practice matters: The rice–wheat monoculture occupies a dominant share of Haryana's gross cropped area and is a major structural driver of groundwater depletion, input intensity, and reduced system resilience. Diversification towards less water-intensive crops is therefore important not only as a climate response, but also as a long-term strategy for improving resource-use efficiency and reducing production risk. Unlike practices that improve efficiency within the existing rice system, diversification addresses the underlying pressure on water resources more directly.[49]

The Government of Haryana launched the Mera Pani Meri Virasat (MPMV) scheme in Kharif 2020, providing ₹7,000 per acre to farmers shifting from paddy to alternative crops such as maize, cotton, bajra, pulses, vegetables, and oilseeds. The scheme was expanded in Kharif 2021 to include fallow land under Khet Khali Phir Bhi Khushhali. According to the draft evidence cited here, approximately 25,600 hectares in Kharif 2020 and 20,752 hectares in Kharif 2021 were diversified under the scheme.

The diversification agenda is also supported by research-based alternatives tested in Haryana, including rice–potato–maize, rice–wheat–mungbean, and maize–wheat–mungbean systems under conservation agriculture conditions. These examples suggest that diversification is most viable when it is linked with market access, short-duration crops, and a broader systems approach rather than treated as a one-season substitution exercise.

[49] HSAPCC Phase-2 (2021–30), Government of Haryana, Agriculture Sector, pp. 95–102.

Relevance for Haryana: *Diversification is one of the most strategically important long-term pathways available to Haryana because it addresses the structural dependence of the current production system on water-intensive paddy cultivation. At the same time, the economics of diversification remain constrained by the strong procurement and market assurance available for rice and wheat. This means that diversification is most likely to succeed where water stress is acute, where basmati cultivation already creates some distance from MSP-backed procurement, and where viable alternative value chains can be strengthened. Districts such as Sirsa, Fatehabad, Kaithal, Jind, and Hisar may therefore be particularly relevant for targeted diversification efforts.*

Key enablers: Assured marketing channels for alternative crops; procurement support or price-risk reduction mechanisms; seed availability; extension support on crop planning and agronomy; short-duration crop combinations; custom hiring and mechanization support; and convergence with state water-conservation and crop-planning initiatives.

Risks and cautions: Diversification can remain limited if farmers perceive high market risk relative to paddy and wheat. One-time incentives may encourage initial participation but may not sustain multi-year transition unless supported by procurement, aggregation, storage, processing, and buyer linkages. In some areas, diversification without reliable extension support may also increase production risk for farmers unfamiliar with alternative crop systems.

Scale-up pathway: A practical approach for Haryana would be to treat diversification as a phased district strategy rather than a uniform statewide prescription. Initial scale-up may focus on the most groundwater-stressed paddy districts, with block-level crop planning, demonstration clusters, input support, and market linkage arrangements for identified crops such as maize, pulses, oilseeds, and fodder crops. Over time, diversification efforts may be strengthened by linking incentives with value-chain development, district procurement arrangements, and conservation agriculture-based crop sequencing.

Key Takeaway: *Crop diversification is among the most structurally important long-term strategies for Haryana's agricultural sustainability. Its success, however, depends not only on incentives, but on whether alternative crops are supported by viable markets, local agronomic confidence, and district-specific implementation design.*

A.5 Laser Land Leveling and Precision Water Management

Category	Precision agriculture / water-use efficiency
Geography	Applicable across Haryana; critical for rice-wheat belt
Problem Addressed	Uneven fields causing excess water use, poor crop establishment, and nutrient inefficiency
Core Intervention	GPS/laser-guided precision land leveling for uniform field surfaces
Haryana Relevance	Very High -prerequisite for DSR; 77% adoption in Karnal CSV setting
Scale-up Readiness	High -well-established service market and proven technology

Why this practice matters: Laser land leveling is widely recognized as a foundational enabler for water-efficient and precision-based agriculture in Haryana. Uneven fields lead to non-uniform irrigation, poor crop establishment, inefficient nutrient application, and avoidable water losses. In contrast, precision leveling creates a more uniform field surface, which improves irrigation efficiency, promotes better germination and stand establishment, and supports the performance of other climate-smart practices such as Direct Seeded Rice (DSR), zero tillage, and improved nutrient management.

The evidence cited in this compendium suggests that laser land leveling can reduce irrigation water use substantially while also improving input-use efficiency. In the Karnal Climate-Smart Village context, adoption was reported at 77 percent, with most users accessing the service through providers rather than owning the equipment themselves.[50] This is important for Haryana because it indicates that service delivery models may matter more than ownership models for widespread adoption.

Evidence and outcomes: The literature referenced in the report indicates that laser land leveling is associated with improvements in irrigation uniformity, reductions in water use, and better crop establishment in rice–wheat systems. It also appears repeatedly in the source base as a prerequisite or enabling condition for DSR success. The fact that most users access the technology through custom service arrangements rather than direct ownership suggests that the machinery ecosystem is central to scaling this practice

[50] Springer (2024), Karnal case study; Kamboj et al. (2012), CSISA Technical Bulletin, pp. 8–9; Jat, M.L. et al. (2009)

Relevance for Haryana: *With a high share of cultivated land under irrigation and groundwater extraction exceeding annual recharge, any practice that improves per-hectare water-use efficiency has strategic value for Haryana. Laser land leveling is especially relevant in the rice–wheat belt, where it can support better water management, more reliable DSR performance, and improved fertilizer-use efficiency. Its relevance is therefore not limited to one crop or one scheme; rather, it cuts across multiple CSA interventions.*

Key enablers: Availability of well-maintained laser leveling equipment through Custom Hiring Centres or private service providers; trained operators; field demonstration support; convergence with DSR, precision irrigation, and nutrient management programmes; and district-level extension support to promote correct timing and use.

Risks and cautions: The main risks are operational rather than conceptual. Poor-quality service provision, inadequate operator training, or limited access for smallholders may reduce impact. If the technology is promoted only through ownership-based models, smaller farmers may be left out. In addition, the benefits of precision leveling may be diluted where follow-up crop and irrigation practices remain inefficient.

Scale-up pathway: Haryana may treat laser land leveling as a common enabling platform within CSA implementation rather than as a standalone intervention. Scale-up could focus on ensuring that each Custom Hiring Centre or cluster-level machinery platform has access to laser leveling services, supported by operator training, demonstration plots, and integration with DSR and other water-saving packages in priority districts.

Key Takeaway: *Laser land leveling is a foundational enabling technology for climate-smart agriculture in Haryana. Its value lies not only in direct water savings, but in improving the performance of the wider CSA portfolio built around water efficiency, better crop establishment, and precision input use.*

A.6 Crop Residue Management and In-Situ Incorporation

Category	Residue management / air quality / soil health
Geography	Rice-wheat belt of Haryana, Punjab, and western UP
Problem Addressed	Crop residue burning causing severe air pollution and loss of soil nutrients
Core Intervention	In-situ management using happy seeder, super SMS, mulching, and baling
Haryana Relevance	Very High -Haryana is a major contributor to seasonal crop residue burning
Scale-up Readiness	Moderate to High-machinery available but adoption remains uneven

Why this practice matters: Crop residue burning remains one of the most visible and environmentally damaging challenges associated with Haryana's rice–wheat system. Burning leads to loss of valuable nutrients, deterioration of soil organic matter, and severe seasonal air pollution across northern India. In contrast, in-situ residue management helps retain biomass within the field system, supports soil health, and forms an important bridge from partial zero tillage adoption toward more complete conservation agriculture systems.[51]

The evidence cited in the draft notes that rice straw contains significant quantities of nitrogen, phosphorus, and potassium, all of which are lost when residues are burnt. The Haryana State Action Plan on Climate Change (Phase II) also identifies in-situ residue management as a distinct intervention area and documents major investments in Custom Hiring Centres and machinery distribution for residue handling.

Evidence and outcomes: The examples cited from Karnal's Climate-Smart Village experience suggest that farmers who retained residues and adopted zero-till wheat observed improvements in wheat yield and visible improvements in soil biological activity over time. At the same time, the cited survey evidence indicating residue burning on 56 percent of rice plots in Haryana shows that the challenge remains systemic rather than marginal. This reinforces the point that machinery availability alone may not be sufficient; advisory support, operational timing, and viable use models also matter.

[51] CSISA Technical Bulletin 2012/1, p. 12 (residue mulching); India Climate Dialogue reporting on Taraori CSV.

Relevance for Haryana: *Residue management is highly relevant to Haryana because it sits at the intersection of air quality, soil health, water conservation, and mechanized crop establishment. It is especially important in the rice–wheat belt, where the short turnaround time between rice harvest and wheat sowing often drives burning decisions. In this context, residue management is not only an environmental intervention but a necessary operational condition for advancing towards full conservation agriculture.*

Key enablers: Access to Happy Seeders, Super SMS, mulchers, balers, and related machinery; Custom Hiring Centres and service-provider networks; farmer training on residue retention and sowing logistics; incentives aligned with non-burning practices; and development of biomass use pathways where ex-situ management is appropriate.

Risks and cautions: Machinery distribution without reliable service access, trained operators, or timely field support may limit adoption. Smallholders may face constraints if services are costly or unavailable at short notice. Residue management can also remain incomplete if it is treated as a seasonal compliance issue rather than part of a broader soil-health and crop-establishment strategy.

Scale-up pathway: Haryana may strengthen residue management by moving from a machinery-distribution approach to an integrated service-delivery model. Priority districts in the rice–wheat belt may be supported through cluster-based custom hiring, operational support during the harvest-to-sowing window, demonstration of residue-retained wheat establishment, and stronger convergence with zero tillage, DSR, and biomass value-chain initiatives.

Key Takeaway: *Crop residue management is both an environmental necessity and a systems-level requirement for advancing climate-smart agriculture in Haryana. Its real significance lies in enabling the transition from isolated zero tillage practices to more complete conservation agriculture pathways.*

B. India / National Best Practices

B.1 National Initiative on Climate Resilient Agriculture (NICRA)

Category	National research and demonstration programme
Geography	151+ villages across India; CSSRI Karnal is a NICRA partner in Haryana
Problem Addressed	Climate risk to agriculture; need for location-specific adaptation strategies
Core Intervention	Village-level demonstrations of climate-resilient technologies, weather-based insurance, custom hiring
Haryana Relevance	High-technology portfolio overlaps with Haryana's CSA priorities
Scale-up Readiness	High- institutional infrastructure exists through ICAR-KVK network

NICRA, launched by the Indian Council of Agricultural Research (ICAR) in 2011, is India's flagship programme for climate-resilient agriculture research, technology demonstration, and adaptation support. It operates through village-level demonstration clusters and institutional networks that cover natural resource management, crop production, soil health, livestock, and climate-risk management. In Haryana, the relevance of NICRA lies not only in the technologies it promotes, but also in the demonstration architecture and institutional platform it offers through ICAR institutes, KVKs, and related research systems.[52]

Why this practice matters: NICRA is important because it provides a nationally recognized framework for testing, demonstrating, and refining location-specific climate-resilient practices rather than promoting generic recommendations across agro-ecological settings. Its emphasis on climate vulnerability, adaptive trials, farmer demonstrations, and custom hiring support aligns well with the type of implementation ecosystem required for CSA in Haryana.

Relevance for Haryana: *The programme is highly relevant because its thematic focus overlaps substantially with Haryana's priorities, including water management, climate-resilient crop practices, soil health, advisories, and local demonstration. It may be particularly useful in extending climate-smart agriculture efforts to climatically vulnerable districts where state-led programmes require stronger institutional support and field architecture.*

[52] CAR-NICRA, "National Initiative on Climate Resilient Agriculture." Available at: https://nicra-icar.in/

Key enablers: Effective convergence between ICAR institutions, KVKs, state agriculture departments, and local farmer platforms; district-level identification of climate risks; use of demonstration villages; and alignment with Haryana's broader CSA, SAPCC, and water-management priorities.

Risks and cautions: The main risk is that NICRA may remain institutionally parallel to state programmes unless deliberate convergence is created. Demonstrations may generate useful local evidence, but their wider policy value depends on whether lessons are integrated into district planning, extension systems, and state-supported scaling pathways.

Scale-up pathway: Haryana may use NICRA as a complementary institutional platform for targeted CSA demonstration, especially in districts identified as highly climate-vulnerable. A practical approach would be to align NICRA demonstration villages more closely with CSV-style clusters, KVK extension plans, and state-supported pilot programmes, so that research, demonstration, and scale-up are better connected.

Key Takeaway: *NICRA offers Haryana a ready national platform for localized climate-resilient agriculture demonstration and learning. Its value lies in strengthening the state's evidence base, field validation capacity, and institutional convergence for CSA implementation.*

B.2 Sub-Surface Drip Irrigation in Sugarcane – Maharashtra Model

Category	Precision irrigation / water-use efficiency
Geography	Maharashtra (proven at scale); Haryana sugarcane belt (adaptable)
Problem Addressed	High water consumption in sugarcane; declining water tables
Core Intervention	Sub-surface drip irrigation with fertigation for sugarcane cultivation
Haryana Relevance	Moderate-relevant for sugarcane-wheat districts (Yamunanagar, Karnal, Ambala)
Scale-up Readiness	Moderate-requires investment, farmer training, and supply chain development

Why this practice matters: Sugarcane is among the more water-intensive crops, and experiences from Maharashtra suggest that sub-surface drip irrigation can significantly reduce water use while improving input efficiency and crop performance. For Haryana, this is relevant because parts of the state continue to support sugarcane-based systems even as pressure on groundwater grows. A precision irrigation approach in sugarcane may therefore offer useful lessons for improving water productivity in crop systems that remain economically important but resource-intensive.[53]

What the practice involves: Sub-surface drip irrigation delivers water and nutrients directly to the root zone through buried drip lines, reducing conveyance losses, evaporation, and non-uniform irrigation. When combined with fertigation, the system can also improve nutrient-use efficiency and allow better control over crop-water scheduling.

Evidence and outcomes: The evidence cited in the draft indicates that Maharashtra's experience with sub-surface drip irrigation in sugarcane has shown substantial water savings along with yield gains. While Haryana's agro-climatic and institutional conditions differ, the broad lesson is that precision irrigation can help shift sugarcane cultivation away from flood-based water use towards more efficient resource management.

Relevance for Haryana: *This practice is particularly relevant to Haryana's sugarcane-growing districts such as Yamunanagar, Karnal, and Ambala, where the crop remains important and where improved water-use efficiency may yield both agronomic and resource-conservation benefits. It is best understood not as a universal recommendation, but as a targeted lesson for selected crop systems and districts.*

[53] FAO (2017), "Save and Grow in Practice: Maize, Rice, Wheat." Rome; HSAPCC Phase-2 (2021–30), pp. 96–97; PMKSY-PDMC guidelines for micro-irrigation.

Key enablers: Capital support or credit access for drip systems; technical guidance on installation and maintenance; fertigation support; reliable after-sales service; demonstration plots; and convergence with PMKSY and state irrigation initiatives.

Risks and cautions: High initial investment, maintenance requirements, uneven technical support, and farmer hesitation can constrain adoption. The system may be less attractive where electricity, water pricing, or crop economics do not create a strong incentive for water-saving investment. It may therefore be more suitable for targeted pilots than immediate broad-scale promotion.

Scale-up pathway: Haryana may consider pilot-based introduction of sub-surface drip in selected sugarcane clusters, linked with demonstration, technical handholding, and cost-sharing support. Lessons from these pilots may then inform whether the practice is viable for wider promotion within the state's sugarcane belt.

Key Takeaway: *The Maharashtra model suggests that sub-surface drip irrigation can improve water productivity in sugarcane significantly. For Haryana, its value lies in offering a targeted precision-irrigation lesson for selected districts rather than a one-size-fits-all solution.*

C. Global Best Practices

C.1 Alternate Wetting and Drying (AWD) for Rice – IRRI Global Model

Category	Water management / greenhouse gas mitigation in rice
Geography	Philippines, Vietnam, Bangladesh, Myanmar (proven at scale); India (emerging)
Problem Addressed	Excessive water use and methane emissions from continuous flooding of rice paddies
Core Intervention	Periodic drying of rice fields during non-critical growth stages using observation tubes
Haryana Relevance	High- applicable as transition strategy toward water-efficient rice systems
Scale-up Readiness	Moderate- requires farmer training and integration with existing irrigation scheduling

Why this practice matters: AWD, developed by the International Rice Research Institute (IRRI), reduces irrigation water use by 15–30% and methane emissions by up to 48% in rice paddies without significant yield loss. For Haryana, where both rice irrigation water and methane emissions are critical concerns, AWD offers a complementary strategy alongside DSR. While DSR eliminates puddling entirely, AWD can serve as an intermediate step for farmers not yet ready to shift to DSR, or as a water management refinement where some flooding remains necessary.[54]

What the practice involves: AWD involves installing simple observation tubes (perforated PVC pipes) in rice fields to monitor water levels. Fields are allowed t o dry until water drops 15 cm below the soil surface, then re-irrigated. The cycle is repeated except during flowering. The practice is low-cost, requires no specialized equipment, and is compatible with existing tube-well and canal infrastructure.

Evidence and outcomes: Field studies across Asia and Africa show that AWD can reduce irrigation water use by 15–30 percent while maintaining or even slightly increasing yields. Lampayan et al. (2015) report that AWD adoption in the

[54] IRRI (2021), "Alternate Wetting and Drying." Technical Brief. Available at: https://www.irri.org/alternate-wetting-and-drying; Lampayan, R.M. et al. (2015), "Adoption and economics of alternate wetting and drying water management for irrigated lowland rice." Field Crops Research, 170: 95–108.

Philippines reduced water inputs by 23 percent and lowered pumping costs, while yields remained stable. The same study highlights significant reductions in methane emissions, making AWD a climate-smart practice. IRRI's global trials confirm that AWD is cost-effective, requiring minimal investment in tools and training, yet delivering measurable gains in water productivity.

Relevance for Haryana: *AWD is highly relevant for districts such as Karnal, Kurukshetra, Kaithal, Panipat, Ambala, Yamunanagar, and Sonipat, where rice remains a major kharif crop and groundwater stress is severe. While Direct Seeded Rice (DSR) is a long-term strategy, AWD offers an immediate, low-cost option to save water within transplanted rice systems. It complements Haryana's existing extension structures and can be piloted as a "water-smart rice package" alongside laser levelling and nutrient management tools.*

Key enablers: Farmer training on AWD thresholds and irrigation timing; simple field water tubes or other low-cost monitoring aids; reliable access to irrigation when re-irrigation is needed; integration with laser land levelling and improved nutrient management; demonstration plots in rice-growing districts; and extension support through KVKs, farmer groups, and water-user platforms. Where feasible, AWD may also be linked with local groundwater conservation campaigns to strengthen farmer confidence in water-saving practices.

Scale-up pathway: Distribution of simple field water tubes through KVKs and farmer cooperatives; Training farmers on AWD thresholds and irrigation timing; Integration into block-level water-user groups to coordinate irrigation schedules; Linking AWD demonstrations with climate-smart agriculture platforms (NICRA, ATMA, CSA villages); Policy support to incentivize water-saving practices, especially in groundwater-stressed districts.

Risks and cautions: AWD adoption depends on farmer confidence and timely irrigation scheduling. In areas where farmers equate standing water with crop security, reluctance to adopt AWD is common. Poorly timed irrigation or weak extension support can reduce yields. AWD also requires reliable access to irrigation water when needed; in canal-irrigated systems with rigid schedules, flexibility may be limited.

Key Takeaway: *AWD is a low-cost, globally proven technology for saving water and reducing emissions in rice that can serve as a transition strategy toward DSR for Haryana's farmers who are not yet ready to abandon puddled transplanting.*

C.2 Conservation Agriculture at Scale – Lessons from Brazil

Category	Conservation agriculture system / soil health restoration
Geography	Brazil (32+ million hectares under CA); applicable globally
Problem Addressed	Soil degradation, high tillage costs, low system resilience
Core Intervention	Full CA system: zero/minimum tillage + permanent soil cover + crop rotation
Haryana Relevance	Moderate to High -Haryana has ZT but lacks residue retention and systematic rotation
Scale-up Readiness	Moderate - requires systemic shift beyond individual technologies

Why this practice matters: Brazil is one of the world's most prominent examples of conservation agriculture (CA) at scale, with large areas managed under systems based on minimum soil disturbance, permanent soil cover, and crop rotation. This experience is important not because it can be directly replicated in Haryana, but because it demonstrates what happens when conservation agriculture is treated as a complete production system rather than as a single technology. For Haryana, this distinction is especially relevant: the state has made significant progress with zero tillage wheat, but still has limited residue retention and incomplete crop rotation across much of its farming system.

What the practice involves: The Brazilian CA model is built around three mutually reinforcing pillars: zero or minimum tillage, continuous soil cover through crop residues or cover crops, and systematic crop rotation. Its significance lies in the fact that these elements are treated as an integrated system for soil health restoration, moisture conservation, cost reduction, and long-term resilience. The lesson for Haryana is therefore not simply that no-till works, but that the benefits of resource-conserving agriculture are much greater when tillage reduction is combined with residue retention and rotation rather than practiced in isolation.

Evidence and outcomes: Brazil transformed its agriculture by adopting conservation agriculture on over 32 million hectares, making it the world's se cond-largest CA practitioner after the United States. The Brazilian experience demonstrates that CA requires all three pillars: minimum soil disturbance, permanent organic soil cover, and crop rotation. This is directly relevant to Haryana, which has adopted ZT widely but has not yet achieved the other two pillars.[55]

[55] FAO (2007), Conservation Agriculture website: https://www.fao.org/conservation-agriculture/en/; Hobbs, P.R. (2007), “Conservation agriculture: What is it and why is it important for future sustainable food production?” Journal of Agricultural Science, 145(2): 127–137.

Relevance for Haryana: *This example has moderate to high relevance for Haryana because it helps clarify the gap between current practice and full conservation agriculture. Haryana already has an important entry point in the form of zero tillage, but residue retention remains uneven and crop rotation is still constrained by the dominance of the rice–wheat system and procurement incentives. The Brazil experience is therefore best read as a systems lesson: it suggests that the long-term gains from resource-conserving technologies become greater when they are embedded in a fuller soil-health and crop-sequencing strategy.*

Key enablers: Access to residue-handling equipment and conservation agriculture-compatible drills; institutional support for crop rotation and diversified sequencing; farmer training and demonstration; service-provider networks; soil-health-oriented extension; and policy support that encourages farmers to move beyond single-season tillage reduction toward more integrated conservation systems.

Risks and cautions: The main risk is superficial adoption—treating zero tillage alone as equivalent to conservation agriculture. As the Haryana experience already suggests, tillage reduction without residue retention and rotation may deliver only partial benefits. There is also a risk of over-transferability: Brazil's agro-ecological and farm-structure context differs from Haryana's, so the value of the example lies in strategic learning rather than direct replication.

Scale-up pathway: Haryana may draw on the Brazil lesson by using its existing ZT base as a starting point for gradual system integration. A practical pathway would involve promoting residue-retaining sowing, strengthening crop-rotation pilots such as inclusion of mungbean or maize-based alternatives where feasible, and building district-level conservation agriculture packages that connect machinery, advisory support, and crop planning. In this way, the state may shift from isolated resource-conserving practices toward a more complete conservation agriculture transition.

Key Takeaway: *Brazil's conservation agriculture experience is valuable for Haryana because it highlights the difference between adopting one efficient technology and building a full soil-health-based production system. The main lesson is that long-term resilience gains are likely to be stronger when zero tillage, residue retention, and crop rotation are advanced together rather than separately.*

C.3 Precision Nutrient Management and Water-Smart Rice Cultivation - Lessons from Sri Lanka

Category	Input-use efficiency / water management / rice system optimization
Geography	Sri Lanka (proven in smallholder reservoir systems); adaptable to Haryana's rice-wheat belt
Problem Addressed	High irrigation demand and inefficient fertilizer use in rice cultivation
Core Intervention	Combining alternate wetting and drying, early land preparation, rainwater use, soil testing kits, and Leaf Colour Chart-based fertilizer management
Haryana Relevance	High- directly relevant to groundwater-stressed rice districts
Scale-up Readiness	Moderate to High- techniques are low-cost and can be integrated into existing extension systems

Why this practice matters: In groundwater-stressed rice systems, climate-smart agriculture is not only about changing the crop but also about changing how water and nutrients are managed within the crop. FAO's Sri Lanka case shows that a package combining early land preparation, greater use of rainwater, alternate wetting and drying (AWD), and simple nutrient management tools can significantly improve water productivity while reducing input waste.[56]

What the practice involves: Farmers were trained to begin land preparation earlier at the start of the rainy season rather than waiting for reservoirs to fill. This was combined with AWD to reduce unnecessary irrigation, and with simple nutrient management tools such as soil testing kits and Leaf Colour Charts to guide fertilizer application more precisely. The approach is practical because it does not depend on expensive machinery; instead, it improves decisions on timing, irrigation, and nutrient use.[57]

Evidence and outcomes: The Sri Lanka case reports that farmers were able to expand irrigated land by 15 percent during the dry season because water was saved during the main season through AWD and improved planning. The same case also reports that more precise fertilizer application using soil testing kits and Leaf Colour Charts reduced fertilizer use by 27 percent. These results are especially relevant for Haryana, where overuse of irrigation and fertilizers raises both production costs and environmental stress.[58]

[56] FAO. 2021. Climate-smart agriculture case studies 2021: Projects from around the world. Rome. Case study on Sri Lanka, pp. 23-24.
[57] FAO. 2021. Climate-smart agriculture case studies 2021: Projects from around the world. Rome, pp. 23-24.
[58] FAO. 2021. Climate-smart agriculture case studies 2021: Projects from around the world. Rome, p. 23.

Relevance for Haryana: *This practice is highly relevant for Karnal, Kurukshetra, Kaithal, Panipat, Ambala, Yamunanagar, and Sonipat, where rice remains a major kharif crop and groundwater stress is severe. While DSR is a major long-term strategy, all farmers may not shift immediately. This package therefore offers a practical intermediate pathway: better water scheduling, better fertilizer targeting, and improved rainwater use within existing rice systems. It is also compatible with Haryana's existing advisory, KVK, and demonstration structures.*

Key enablers: Farmer training on AWD thresholds and irrigation timing; block-level soil testing support; distribution and demonstration of Leaf Colour Charts; integration with KVKs, ATMA, NICRA, and CSA village platforms; use of local water-user groups and progressive farmers for field demonstrations.

Risks and cautions: AWD requires timely advisory support and farmer confidence, especially in areas where farmers associate standing water with crop security. Poorly timed irrigation may reduce performance if extension support is weak. Soil testing must be linked with actionable recommendations, not just one-time testing.

Scale-up pathway: This practice should be piloted in selected paddy clusters in Karnal, Kurukshetra, and Kaithal as a “water-smart rice package” for farmers who are not yet ready to shift fully to DSR. Demonstrations should combine AWD, laser leveling where feasible, and simple nutrient tools such as Leaf Colour Charts.

Key Takeaway: Precision nutrient management and water-smart rice cultivation offer Haryana a practical bridge between conventional transplanted rice and more transformative systems such as DSR. The approach is low-cost, advisory-intensive, and highly suitable for rapid field-level scaling.

C.4 Farmer Field Schools as a Climate-Smart Agriculture Extension Platform

Category	Extension and capacity-building model / participatory learning platform
Geography	Senegal, Lao PDR, Moldova and multiple FAO programme countries; adaptable statewide in Haryana
Problem Addressed	Low adoption of climate- smart practices due to fragmented extension and inadequate farmer handholding
Core Intervention	Community-based learning-by-doing through Farmer Field Schools (FFS), combining local knowledge, field demonstrations, and climate adaptation practices
Haryana Relevance	High- highly suitable for district-wise CSA adoption and behaviour change
Scale-up Readiness	High- can be integrated with KVKs, ATMA, NICRA, and Climate Smart Village expansion

Why this practice matters: Many CSA practices fail not because the technology is weak, but because farmers do not receive enough localized, season-long handholding. FAO's case studies show that Farmer Field Schools (FFS) are effective because they use a learning-by-doing approach in which the field itself becomes the site of observation, analysis, and decision-making. This method helps farmers compare their existing practices with improved climate-smart options and adapt them to local conditions.[59]

What the practice involves: In Senegal, FAO used FFS to integrate indigenous knowledge and farmer perceptions of climate change into climate-resilient agriculture planning. The approach emphasized local agro-ecosystem understanding, farmer empowerment, and participatory problem-solving. In Lao PDR, FFS were also used to test and demonstrate labour-saving and climate-smart technologies such as drum seeders for rice, showing that FFS can serve not only as a training platform but also as an innovation-testing platform.[60]

Evidence and outcomes: The Senegal case notes that FFS strengthen the evidence base for CSA by documenting local producer knowledge and climate perceptions, which can then inform more relevant advisory content. The Lao PDR case further shows that farmers who used drum seeders after FFS training reported substantial savings in labour and planting time, while the technology also improved resilience by enabling faster planting and earlier maturity under erratic weather conditions.[61]

[59] FAO. 2021. Climate-smart agriculture case studies 2021: Projects from around the world. Rome, case study on Senegal, pp. 24-25.
[60] FAO. 2021. Climate-smart agriculture case studies 2021: Projects from around the world. Rome, pp. 24-25, 64-66.
[61] FAO. 2021. Climate-smart agriculture case studies 2021: Projects from around the world. Rome, pp. 25, 65-66.

Relevance for Haryana: *Haryana already has strong institutions for agricultural outreach, but the extension system remains more scheme-driven than season-long and practice-based. FFS can strengthen adoption of DSR, AWD, zero tillage, residue retention, diversification, and water-saving irrigation by giving farmers repeated, field-based exposure over a crop cycle. It is particularly useful in districts where behaviour change is as important as machinery access.*

Key enablers: KVK facilitation; partnership with CCS HAU, ICAR institutes, and line departments; farmer-led plots; women's participation; season-long observation protocols; documentation of local practices and farmer feedback.

Risks and cautions: FFS may become routine training events if not designed as genuine field-based learning platforms. They require skilled facilitators and repeated engagement, not one-off awareness sessions. Without inclusion safeguards, participation may skew toward larger and more vocal farmers.

Scale-up pathway: A practical approach would be to adapt the FFS model within Climate-Smart Villages, NICRA villages, and district CSA pilots. Each priority district could identify one crop-climate problem cluster - for example DSR and weed management in Karnal, diversification in Kaithal, or moisture stress in Mahendragarh - and run full-season FFS cycles around those problems.

Key Takeaway: *Farmer Field Schools are one of the strongest globally tested models for converting CSA from a technology list into an adoption process. For Haryana, they can become the missing institutional bridge between research evidence and farmer practice.*

C.5 Gender-Responsive Climate-Smart Mechanization and Women-Centred CSA

Category	Gender-responsive technology / labour-saving mechanization / inclusive CSA
Geography	Lao PDR, Somalia, and FAO just-transition guidance; adaptable across Haryana
Problem Addressed	Women's limited access to climate-smart technologies, decision making, and extension despite their major role in agriculture
Core Intervention	Promoting labour-saving, gender-responsive technologies and women-centred CSA design, with explicit inclusion in training, demonstrations, and resource access
Haryana Relevance	High- especially relevant for women farmers, SHGs, livestock-linked agriculture, and labour-scarce rural areas
Scale-up Readiness	Moderate to High-requires institutional targeting more than technological invention

Why this practice matters: Climate-smart agriculture often assumes a gender-neutral farmer, but women face distinct barriers in access to land, technology, training, finance, and decision-making. The FAO case studies and just transition policy brief make clear that CSA becomes more effective when it is deliberately designed to reduce labour burdens, improve women's access to technology and information, and increase their role in local decision-making.[62]

What the practice involves: In Lao PDR, FAO documented the use of a drum seeder as a gender-sensitive labour-saving technology that could be adapted for use by both women and men. The case notes that one person using a drum seeder could plant one hectare in one day, compared to 29 persons needed for manual transplanting, and that users could recover the technology cost within the first year under certain conditions. At the same time, FAO cautioned that women must be explicitly included in demonstrations and training to avoid their exclusion from the benefits of mechanization.[63]

The FAO just-transition brief broadens this lesson by recommending women's equitable access to land, resources, information, and technology; support for climate-adaptive production practices that reduce women's unpaid labour and care burdens; and stronger participation of women and girls in agrifood decision-making. It also links women-centred climate action with social protection, enterprise development, and access to markets and finance.[64]

[62] FAO. 2021. Climate-smart agriculture case studies 2021: Projects from around the world. Rome, pp. 65-66, 75-77; FAO. 2025. Pathways towards a just transition in agrifood systems: Policy brief. Rome, pp. 7-8.
[63] FAO. 2021. Climate-smart agriculture case studies 2021: Projects from around the world. Rome, pp. 65-66.
[64] FAO. 2025. Pathways towards a just transition in agrifood systems: Policy brief. Rome, pp. 7-8.

Relevance for Haryana: *In Haryana, women contribute substantially to livestock care, seedling preparation, weeding, fodder management, post-harvest handling, and household nutrition systems, yet they are often underrepresented in extension and equipment access. A women-centred CSA approach would strengthen adoption of drudgery-reducing tools, kitchen and nutrition gardens, fodder and silage systems, climate-resilient dairy support, women-led nurseries, and SHG-based custom hiring or service models.*

Key enablers: Dedicated quotas for women in demonstrations and trainings; equipment suited to women's ergonomic needs; SHG and FPO platforms; women extension workers and community resource persons; linking technology access with microfinance and social protection; convergence with women farmer and livelihood programmes.

Risks and cautions: Mechanization can deepen inequality if women are excluded from training or displaced from casual work without alternative livelihood pathways. Token participation without control over assets or decisions will weaken impact.

Scale-up pathway: Haryana may consider including a specific women-centred CSA track within CSVs, NICRA villages, and district demonstrations. Pilot interventions can include women-led seedling and nursery enterprises, drudgery-reducing tools, women-focused fodder and livestock adaptation packages, and SHG-managed machinery services for small-scale operations.

Key Takeaway: *Gender-responsive CSA is not a side issue but a core condition for equitable and effective climate adaptation. Haryana's compendium should explicitly treat women as priority CSA adopters, innovators, and enterprise leaders.*

C.6 Digital and Precision Climate-Smart Agriculture - Lessons from China

Category	Digital agriculture / precision farming / climate-risk management
Geography	China (policy-to-investment scale-up); adaptable to Haryana's progressive agricultural districts
Problem Addressed	High labour intensity, inefficient input use, weak real-time monitoring, and fragmented climate-risk response
Core Intervention	Combining drones, fertigation, agricultural IoT, digital monitoring, early warning systems, demonstration zones, and climate-risk management tools
Haryana Relevance	Moderate to High- especially relevant for progressive districts and pilot-based scaling
Scale-up Readiness	Moderate- requires phased pilots, standards, and institutional support

Why this practice matters: The next generation of CSA is not only about improved agronomy but also about using digital tools to improve timing, precision, and risk response. FAO's China report shows how climate-smart agriculture can move from policy to investment by combining precision technologies, resilient infrastructure, monitoring systems, demonstration zones, and long-term institutional support.[65]

What the practice involves: The China report documents the use of drones for direct seeding, fertilizer application, and pesticide spraying in rice systems. Field evidence cited in the report shows that drone seeding achieved efficiencies far higher than manual or tractor-based operations, reduced labour substantially, and maintained yields comparable to conventional mechanized transplanting. The report also highlights the rapid expansion of agricultural IoT, allowing technicians to monitor soil nutrients, soil moisture, crop growth, pest incidence, and environmental conditions remotely through digital systems.[66]

The report further emphasizes the importance of ecological monitoring, early warning mechanisms, optimized agricultural insurance systems, and comprehensive demonstration zones for scaling climate-smart practices. These institutional supports matter because digital technologies alone do not scale without standards, training, and coordinated public investment.[67]

[65] Chen, F., Yin, X. & Jiang, S. 2023. Climate-smart agriculture in China: from policy to investment. FAO Investment Centre Country Highlights No. 20. Rome.
[66] Chen, F., Yin, X. & Jiang, S. 2023. Climate-smart agriculture in China: from policy to investment. Rome, pp. 44-45.
[67] Chen, F., Yin, X. & Jiang, S. 2023. Climate-smart agriculture in China: from policy to investment. Rome, pp. 14, 82

Relevance for Haryana: *Haryana is already relatively advanced in mechanization and has strong agricultural research and extension institutions. This makes it a suitable candidate for pilot-based adoption of digital CSA tools such as drone-based input application, sensor-based irrigation scheduling, mobile-based advisory, pest surveillance, and weather-linked decision support. These tools are likely to be most useful first in progressive districts such as Karnal, Kurukshetra, Ambala, Hisar, and Sirsa.*

Key enablers: Digital service providers; clear operational standards; farmer training; custom hiring or shared-service models; reliable weather and soil data; integration with KVKs, universities, and private technology providers; district-level demonstration clusters.

Risks and cautions: These technologies can remain elite or pilot-bound if not linked to affordable service models for small and medium farmers. Technology adoption without advisory support may increase costs without improving outcomes. Regulatory clarity for drones and data systems is also important.

Scale-up pathway: A practical approach would be to treat digital and precision CSA as a phased innovation track rather than a blanket recommendation. Initial pilots can focus on drone-based demonstration services, weather-smart advisories, and sensor-based irrigation scheduling in selected districts, followed by evidence-led expansion through demonstration clusters and district innovation platforms.

Key Takeaway: *Digital and precision agriculture can help Haryana move from generic advisories to real-time, location-specific climate-smart decision support. The most effective pathway is pilot-based scaling through demonstration clusters, not immediate mass rollout.*

Cross-Cutting Lessons for Haryana

The practice fiches point to several recurring lessons that are particularly relevant for Haryana's overall approach to climate-smart agriculture.

- **Advisory systems matter as much as technology:** Across the fiches, the performance of climate-smart practices depends heavily on the quality of extension, operational guidance, and follow-up support. Practices such as DSR, AWD, residue retention, and precision irrigation are knowledge-intensive and can underperform if farmers do not receive timely, location-specific advice.
- **Pilot-to-scale design is essential:** The evidence suggests that successful CSA scaling is usually built on phased demonstration, local adaptation, and iterative learning rather than immediate mass rollout. Haryana's approach may therefore benefit from cluster-based pilots, monitored demonstration villages, and evidence-led expansion.
- **District targeting is important:** Haryana's districts differ significantly in groundwater stress, cropping systems, irrigation dependence, and climate vulnerability. This suggests that CSA interventions should be geographically differentiated rather than promoted uniformly across the state.
- **Collective platforms support adoption:** Farmer cooperatives, FPOs, SHGs, and Custom Hiring Centres repeatedly emerge as important intermediaries for access to machinery, services, advisory support, and risk reduction. In highly mechanized CSA pathways, service access is often more important than asset ownership.
- **Water-smart agriculture should be the organizing principle:** Across the Haryana-specific and comparative examples, water emerges as the most binding constraint. The most relevant CSA portfolio for the state is therefore one that combines water-saving crop establishment, precision land management, diversification, and improved irrigation practices.
- **Machinery and service ecosystems are critical:** Many of the most relevant practices for Haryana—ZT, Happy Seeder-based residue management, laser leveling, DSR, and some precision tools—depend on timely access to reliable machinery and trained operators. Adoption is therefore shaped not only by farmer willingness but by service infrastructure.

- **Convergence shapes long-term uptake:** The fiches suggest that the success of CSA depends on institutional convergence across schemes, missions, and delivery systems. Research, extension, machinery support, incentives, water conservation, and farmer organizations need to function in a coordinated way if climate-smart agriculture is to move beyond fragmented pilot efforts.

Taken together, these lessons indicate that Haryana's CSA transition is likely to be most effective when approached as a district-sensitive, water-centred, service-supported, and evidence-led process rather than as a collection of isolated technologies.

Conclusion

The agriculture sector is a core concern globally as its dependence goes beyond mere survival. Its concerns are exacerbated in emerging nations where it is the key to rural households and the economy. Haryana's agricultural sector stands at a critical juncture, where the pressures of climate change, groundwater depletion, and economic vulnerability are converging. While the state has historically been a leader in agricultural productivity, sustaining this success will require a decisive shift toward climate-smart agriculture (CSA). The evidence presented in this compendium highlights that no single intervention is sufficient; rather, a portfolio approach combining water-efficient technologies, conservation agriculture, crop diversification, and institutional innovations is essential.

Equally important is the enabling ecosystem—robust advisory systems, farmer collectives, access to machinery, and policy convergence—which determines the success of these practices at scale. Global and national experiences reinforce that long-term resilience is built through sustained investment, adaptive learning, and farmer-centric implementation. By strategically scaling proven CSA practices and aligning them with local conditions, Haryana can secure its agricultural future while contributing to broader goals of food security, environmental sustainability, and rural prosperity.

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