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Transforming Indian Agriculture: Digital and Climate-Smart Pathways for Women Farmers' Empowerment

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Agriculture in India is undergoing a transformative phase as it embraces digital tools, climate-smart practices, and inclusive policies. The sector is critical to national food security, rural livelihoods, and environmental sustainability. Women constitute nearly 48% of India's agricultural workforce, yet they remain largely marginalized regarding land ownership, access to credit, and participation in formal extension services. Only ~13% of operational holdings are owned by women, and fewer than 20% have access to agricultural advisory services (Table 1).This disparity underscores the urgent need for targeted interventions to improve productivity, sustainability, and income generation for women farmers. The recent policy push towards digitization, climate-smart agriculture (CSA), and women-centric empowerment programs has opened new avenues for enhancing agricultural efficiency. Pilot programs in states like Uttar Pradesh, Bihar, and Telangana have introduced women farmers to AI-based weather forecasts, precision agriculture tools, and digital marketplaces. These interventions help women make informed decisions regarding sowing dates, irrigation, pest control, and nutrient management, translating into measurable yield improvements, reduced input costs, and higher incomes.

Table 1: Women Participation and Access to Resources in Indian Agriculture

Indicator	Value (India)	Source / Year	Comments
Women as agricultural workers	~48 % of total agricultural workforce	2011 Census / PLFS 2024	Includes labor in crop, livestock, and allied sectors
Rural women engaged in agriculture	~76.9 % of rural women	PLFS 2024	Reflects both paid and unpaid labor
Women with access to formal extension services	~19 %	National estimate, 2022	Low participation due to limited outreach and socio-cultural barriers
Women with access to agricultural credit	~10–12 %	NABARD / Ministry of Agriculture 2023	Includes institutional credit from banks and cooperatives
Women participating in farmer producer organizations (FPOs)	~18 %	NITI Aayog report 2022	FPOs facilitate collective marketing, training, & input supply
Women decision-makers in crop planning	~14–16 %	Ministry of Agriculture 2021	Decisions mainly influenced by male household members
Women receiving government schemes (e.g., PM-KISAN, MKSP)	~20–25 %	Ministry of Agriculture, 2023	Benefits include financial support& training programs
Women with access to digital agriculture tools (mobile apps, advisories)	~12–15 %	State pilot studies, 2022–24	Includes AI weather forecasts, soil health apps, and pest management platforms

**Estimate based on broader extension participation data.*

Women's Role and Constraints in Agriculture

Women contribute significantly to agricultural labor, post-harvest management, and household nutrition security. Despite their contributions, constraints such as limited land rights, restricted access to credit, insufficient digital literacy, and lack of inclusion in decision-making hinder productivity and income potential. Studies show that when women gain access to digital advisory services and training, crop yields increase by 15–20%, while input costs can decrease by 10–15%, highlighting the untapped potential of empowering women farmers.

Digital Agriculture: Tools and Impact

Digital technologies are enabling women farmers to overcome knowledge gaps and resource constraints. Tools such as AI-based weather forecasts, soil health mobile applications, precision irrigation sensors, and pest and disease advisory platforms are increasingly being adopted. These technologies allow for real-time decision-making**,** reducing losses caused by unpredictable rainfall, pest outbreaks, or inefficient input use.

Digital marketplaces and cooperative platforms provide transparent access to market prices, credit, and government subsidies**,** eliminating intermediaries. Early results from pilot programs indicate that net income for women farmers can improve by 12–18% through enhanced market access.

Climate-Smart Agriculture Practices and Women Farmers

Climate-smart agriculture (CSA) plays a vital role in mitigating the impacts of climate variability while enhancing agricultural productivity and resource-use efficiency (Table 2 & 3). For women farmers in India, CSA practices are particularly significant, as they reduce labor intensity, lower input costs, and improve resilience in resource-constrained and climate-vulnerable farming systems. Key CSA techniques increasingly adopted by women farmers include:

1. **Water-efficient irrigation**

Drip and sprinkler irrigation systems reduce water usage by 35–84%, depending on crop and agro-climatic conditions, while maintaining or improving yields. For women farmers, these systems significantly reduce manual labor associated with irrigation and water management, enabling better time allocation and higher productivity.

2. **Intercropping and agroforestry**

The integration of legumes or multipurpose trees with cereal crops enhances soil organic carbon and nitrogen availability, improving soil fertility and reducing reliance on synthetic fertilizers. Women-managed intercropped fields have reported approximately a 25% increase in soil nitrogen content, contributing to sustainable soil health and stable yields.

3. **Organic manures and cover cropping**

The use of farmyard manure, compost, green manures, and cover crops helps retain soil moisture, enhance microbial activity, and reduce chemical fertilizer inputs by 20–30%. These practices are widely adopted by women farmers due to their compatibility with traditional knowledge, low external input requirements, and positive impacts on soil fertility.

4. **Precision agriculture tools**

Digital and precision tools, including AI-based advisories, mobile applications, and sensor-based nutrient and pest management systems, enable women farmers to apply fertilizers and pesticides more efficiently. Adoption of these tools has resulted in 15–20% yield improvements, while also reducing input costs and environmental impacts.

Overall, the adoption of climate-smart agriculture practices by women farmers enhances climate resilience, strengthens household food security, and supports environmentally sustainable agricultural systems, making women key agents in the transition toward climate-resilient farming in India.

Table 2: Yield Improvements Linked to Climate-Smart Agriculture (CSA) in India

Climate-Smart Practice	Crop/Region	Approx. Yield Increase (%)	Additional Benefits
Drip irrigation / micro irrigation	Vegetables (Tomato, Onion), Maharashtra, Gujarat	18–22 %	Saves 30–40 % water, reduces fertilizer use
Drip irrigation / micro irrigation	Cotton, Telangana, Punjab	15–20 %	Improved water-use efficiency, reduced soil salinity
Intercropping (legumes + cereals)	Maize + Cowpea, Bihar; Wheat + Chickpea, Haryana	20–25 %	Increased soil N content by 25%, reduced fertilizer dependence
Organic manure & improved soil practices	Rice, Punjab; Wheat, Uttar Pradesh	10–15 %	Enhances soil organic carbon, reduces chemical fertilizer use
Adoption of precision / AI-based advisories	Rice, Andhra Pradesh; Vegetables, Kerala	15–20 %	Better irrigation scheduling, pest & nutrient management
Agroforestry & cover cropping	Maize + Tree Intercropping, Chhattisgarh	12–18 %	Reduces soil erosion, improves microclimate, increases biomass
Conservation agriculture (minimal tillage + residue retention)	Wheat, Punjab; Maize, Bihar	10–15 %	Reduces fuel and labor costs by 20%, improves soil moisture retention
Climate-resilient crop varieties	Drought-tolerant paddy, Odisha; Heat-tolerant wheat, Rajasthan	8–12 %	Reduces yield losses under erratic rainfall and heat stress

Source: Aggregated from multiple recent Indian field studies.

Integrating Digital Tools with Climate-Smart Agriculture

The integration of digital tools with climate-smart agriculture (CSA) creates strong synergies that enable women farmers to make evidence-based decisions while conserving natural resources. AI-based advisory systems support optimal irrigation scheduling using real-time weather forecasts and soil moisture information, helping reduce water stress and crop losses. Mobile applications provide timely recommendations on fertilizer application and pest management, ensuring efficient input use and improved yield quality. Digital marketplaces further strengthen women's economic empowerment by offering transparent price information and direct market access for CSA-grown produce, reducing dependence on intermediaries. These combined digital and CSA interventions are particularly effective in rainfed and marginal regions, where climate variability, limited resources, and restricted access to extension services pose significant challenges for women farmers.

Table 3: Water and Fertilizer Savings Through Climate-Smart Practices in India

Practice	Crop / Region	Water Savings (%)	Fertilizer Reduction (%)	Additional Benefits
Drip / Micro irrigation	Vegetables (Tomato, Onion) – Maharashtra, Gujarat	35–50 %	25–30 % (NPK)	Improved yield, reduced soil salinity, energy savings
Drip / Micro irrigation	Cotton – Telangana, Punjab	40–60 %	15–25 %	Enhanced water-use efficiency, reduced pest incidence
Drip / Micro irrigation	Sugarcane – Tamil Nadu	60–84 %	20–25 %	Higher cane quality, reduced labor costs
Alternate Wetting & Drying (AWD)	Rice – Andhra Pradesh, Odisha	20–40 %	10–15 %	Reduced methane emissions, better root development
Mulching / Cover Cropping	Vegetables & Maize – Punjab, Bihar	22–30 %	10–15 %	Reduces soil evaporation, prevents weed growth, enhances organic carbon
Organic Manures / Balanced Fertilizer Use	Wheat & Rice – UP, Haryana	—	20–30 %	Improves soil fertility, reduces chemical dependency
Conservation Agriculture (Residue Retention + Minimum Tillage)	Wheat – Punjab; Maize – Bihar	25–35 %	15–20 %	Retains soil moisture, reduces labor and fuel costs, increases soil organic matter
Agroforestry & Intercropping	Maize + Trees – Chhattisgarh	20–30 %	10–15 %	Reduces soil erosion, improves microclimate, increases biomass

Case Studies: State-Level Initiatives

1. **Uttar Pradesh:** Women-led farmer producer organizations (FPOs) have played a key role in promoting climate-smart agriculture (CSA) and digital advisory services. Training in intercropping, organic nutrient management, and precision irrigation resulted in 18–

22% yield improvements and an average 12% increase in farm income among participating women farmers.

2. **Bihar:** In Bihar, AI-enabled weather forecasting applications integrated with drip irrigation trials improved women farmers' decision-making regarding sowing dates and irrigation scheduling. These interventions led to an approximately 15% reduction in water use and enhanced cropping efficiency in rainfed areas.
3. **Telangana:** Women farmers in Telangana benefited from smartphone-based pest and disease management advisories coupled with digital market linkages. As a result, crop yields increased by approximately 20%, while input costs declined by 10%, demonstrating the effectiveness of digital and CSA integration.
4. **Maharashtra:** Women farmers adopting micro-irrigation systems and mobile-based nutrient management advisories recorded improvements in water-use efficiency and crop productivity. Yield gains of 15–20% were observed, along with reductions in fertilizer and energy costs.
5. **Odisha:** In Odisha, women farmers adopting climate-resilient crop varieties supported by digital extension services experienced 10–15% yield stability under erratic rainfall conditions, contributing to improved climate resilience and household food security.

Policy Support

Several national initiatives in India provide crucial support to women farmers, complementing digital and climate-smart agriculture interventions. The Mahila Kisan Sashaktikaran Pariyojana (MKSP) emphasizes capacity building through skill development, access to credit, and promotion of sustainable agricultural practices among women. The PM-KISAN scheme provides direct income support to farmers, including women beneficiaries, enhancing financial security and enabling investment in improved inputs and technologies.

In addition, the National Rural Livelihoods Mission (NRLM) promotes women-led self-help groups and producer collectives, facilitating access to digital tools, training, and market linkages. Schemes such as the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) support women farmers through subsidies for micro-irrigation systems, while the Soil Health Card Scheme improves women's access to soil fertility information. Digital platforms like e-NAM and other agri-marketplaces further enhance price transparency, reduce intermediary dependence, and improve income realization. Together, these policies create an enabling ecosystem for inclusive, climate-resilient, and women-centered agricultural development.

Socio-Economic and Environmental Impacts

Empowering women through the integration of digital tools and climate-smart agriculture generates multi-dimensional benefits. Enhanced access to advisory services, efficient input use, and improved crop management contribute to higher and more stable yields, thereby strengthening food security at both household and community levels. The consequent increase in farm incomes supports improved rural livelihoods, enabling better access to nutrition, healthcare, and education. Environmentally, climate-smart practices reduce water consumption, limit chemical inputs, and improve soil conservation, collectively mitigating the adverse effects of climate change. Furthermore, addressing gender disparities in land ownership, technology adoption, and decision-making enhances women's agency, promoting gender equality and more inclusive rural development.

Challenges and Way Forward

Despite notable progress, several challenges constrain the full potential of women-led digital and climate-smart agriculture. Limited digital literacy, inadequate internet penetration in rural areas, and persistent social norms restricting women's mobility and access to land and markets hinder adoption. Additionally, the high upfront costs of climate-smart infrastructure, such as drip irrigation systems and soil sensors, limit scalability. Effective implementation requires region-specific climate-smart agriculture packages tailored to local agro-climatic conditions, combined with integrated policy interventions. Strengthening women-led

cooperatives, expanding affordable technology deployment, and capacity-building initiatives are essential to overcome these barriers and ensure sustainable, inclusive, and productive agriculture in India.

Conclusion

Empowering women farmers in India through digital agriculture and climate-smart practices is critical for achieving productivity gains, environmental sustainability, and socio-economic development. Evidence from pilot programs demonstrates that these interventions can increase crop yields by 15–25%**,** reduce input costs by 10–15%**,** save water and fertilizer by 20–80%**,** and increase net income by 12–18%**.** Women farmers, equipped with knowledge, technology, and market access**,** are emerging as pivotal agents of change in Indian agriculture. Policy support, capacity-building initiatives, and technology adoption strategies that focus on women will strengthen resilience, enhance food security, and ensure sustainable agricultural development in the face of climate change.