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FROM TRADITIONAL TO SMART FARMING: TECHNOLOGICAL DEVELOPMENT IN HARYANA'S AGRICULTURE SECTOR

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ABSTRACT

This study examines the evolution of agricultural practices in Haryana - from traditional methods towards smart farming technologies. We investigate how digital tools, data analytics, IoT devices and precision farming influence productivity, resource usage, and sustainability across different cropping zones. Key objectives include identifying technological adoption levels, assessing benefits and constraints, and proposing policy recommendations to enhance smart farming uptake. The study employs a mixed-methods approach, integrating a survey of 200 farmers and interviews with stakeholders. Statistical analysis (descriptive statistics, chi-square tests) explores relationships between adoption, farm size, and outcomes. Findings reveal that although smart farming shows promise in optimizing inputs, adoption remains uneven due to high costs, digital literacy gaps and infrastructure challenges. Policy interventions are recommended to bolster digital extension services, subsidize hardware and improve rural internet access.

Keywords: *Haryana agriculture; smart farming; precision agriculture; IoT; technological adoption; resource efficiency.*

1. INTRODUCTION

Agriculture has long been the cornerstone of Haryana's economy and identity. Known as the "Green Bowl of India," Haryana played a pivotal role in the Green Revolution of the 1960s and 70s, contributing significantly to India's self-sufficiency in food production. With only 1.4% of India's geographical area, the state produces a substantial share of the country's wheat and rice output, benefiting from fertile soil, a well-irrigated landscape, and an extensive canal network. However, despite these advantages, the state's agriculture sector now stands at a crossroads.

Traditional farming practices, which once formed the backbone of food security, are increasingly seen as unsustainable in the face of modern challenges. Over-dependence on chemical fertilizers, intensive water use, and mono-cropping patterns has led to environmental degradation, falling water tables, and declining soil fertility. Moreover, changing climatic conditions, fluctuating market prices, and rising input costs have further strained the livelihood of farmers. These realities have highlighted the urgent need for innovation and transformation in the agricultural sector.

In this context, the emergence of smart farming—or precision agriculture—offers a timely and potentially transformative solution. Smart farming integrates advanced technologies such as satellite-based monitoring, remote sensing, automated irrigation systems, mobile-based advisory services, GPS-guided tractors, and artificial intelligence. These tools aim to optimize input usage, improve crop yields, reduce waste, and make farming more data-driven and climate-resilient. In contrast to the one-size-fits-all approach of traditional agriculture, smart farming emphasizes field-level decision-making, tailored interventions, and real-time monitoring.

Haryana, with its relatively high rural literacy rates, strong institutional support, and history of agricultural innovation, is well-positioned to lead this shift. Government initiatives, both at the state and national levels, have begun promoting digital agriculture through subsidies, pilot projects, and partnerships with agritech startups. Programs like the Digital India initiative and the Pradhan Mantri Krishi Sinchayee Yojana have created a favorable ecosystem for technological integration.

However, despite these efforts, the actual adoption of smart farming practices in Haryana remains uneven. While some progressive farmers and large landowners have embraced new technologies, small and marginal farmers often face multiple barriers—financial constraints, limited digital literacy, lack of access to reliable internet, and inadequate technical support. This disparity risks creating a digital divide in agriculture, where the benefits of innovation are not equitably distributed.

This research seeks to explore this complex transition from traditional to smart farming in Haryana's agriculture sector. It aims to assess the current state of technological adoption, identify the key challenges and enablers, and evaluate the impact of smart farming on productivity and sustainability. By combining empirical field data with

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insights from existing literature and expert opinions, the study aspires to provide a grounded understanding of Haryana's agricultural transformation and to suggest practical, evidence-based policy interventions that can accelerate the equitable adoption of smart farming across the state.

2. REVIEW OF LITERATURE

The transition from traditional to smart farming has been the subject of growing academic and policy attention over the past decade. A wide range of studies have examined the potential of precision agriculture technologies, their adoption levels, benefits and challenges in various agrarian contexts. This review synthesizes findings from different relevant research studies, focusing primarily on India and Haryana, to frame the current state of knowledge and identify existing research gaps.

2.1 Adoption and Diffusion of Smart Farming Technologies

- **Singh and Kaur (2018)** conducted a district-level study in Haryana on the adoption of drip and sprinkler irrigation. They found that water-saving technologies were adopted by around 30% of farmers, mainly those with medium and large landholdings. Smallholders remained largely excluded due to initial capital requirements and limited technical knowledge.
- **Rao and Ajay (2020)** evaluated the effectiveness of mobile-based agricultural advisory services among wheat farmers in Haryana and Uttar Pradesh. The study showed a 10–12% increase in yield for farmers who regularly followed SMS-based advisories on sowing time, fertilizer doses, and pest control.
- **Patel and Yadav (2024)** explored the adoption of AI-powered decision-support applications (such as Krishi Niti and Kisan GPT) among digitally literate farmers in North India. Their findings indicated that while 60% of users trusted the recommendations, over 40% expressed concerns over inaccuracies, especially during unpredictable weather events.

2.2 Impact of Smart Farming on Productivity and Efficiency

- **Sharma et al. (2019)** studied the use of soil moisture sensors in Punjab and Haryana. The adoption of these sensors improved water use efficiency by nearly 20% and led to a 12% increase in wheat productivity. They highlighted that continuous monitoring enabled more targeted irrigation schedules, reducing water wastage.
- **Jain and Mehta (2021)** examined drone-based crop monitoring systems in Bhiwani and Hisar. Their pilot program found a significant reduction in pest outbreaks (by up to 18%) due to early detection and timely interventions, improving crop health and reducing pesticide use.
- **Verma et al. (2022)** evaluated the effectiveness of satellite-based precision fertilization in Haryana's rice–wheat cropping systems. The study revealed a 15% increase in nitrogen-use efficiency and higher net returns for adopters, highlighting the ecological and economic benefits of smart nutrient management.
- **Das (2025)** conducted a comparative analysis of traditional vs. smart farming methods across four Indian states, including Haryana. The research concluded that while precision farming increased profitability by 18–25%, the gains were more evident in regions with better digital and physical infrastructure.

2.3 Constraints and Barriers to Adoption

- **Rao and Singh (2022)** conducted a field study across five Haryana districts to understand why small and marginal farmers are reluctant to adopt digital tools. Key barriers included high investment costs, low awareness levels, lack of technical support, and poor mobile network connectivity in rural pockets.
- **Saini and Bala (2025)** focused on socio-economic determinants influencing smart farming adoption. Their findings showed that smaller farmers were significantly less likely to adopt smart technologies due to risk aversion and limited institutional credit access.
- **Choudhary (2020)** surveyed awareness levels about Internet of Things (IoT) tools such as smart irrigation controllers and weather-based alerts. Though 40% of farmers had heard of these tools, only 15% reported using them, suggesting a large gap between awareness and adoption.
- **Khan et al. (2023)** examined environmental benefits, showing how sensor-based irrigation systems helped prevent nitrogen leaching and groundwater contamination. However, the study also pointed out the lack of training as a major obstacle to technology diffusion.

2.4 Institutional Support and Policy Interventions

- **Khandelwal and Sharma (2023)** implemented and evaluated a Smart-FARM pilot program in Karnal district. The integrated model included soil sensors, mobile apps, and advisory services. The project recorded

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a 12% increase in crop yield and a 25% reduction in water use. The study recommended state-wide scaling up of such pilot initiatives.

- **Kapoor et al. (2025)** evaluated the impact of digital extension training programs conducted by Krishi Vigyan Kendras (KVKs) in Haryana. The results showed that trained farmers were 40% more likely to adopt at least one smart farming tool within a year compared to those without any exposure.
- **Gupta et al. (2021)** assessed the reach of digital extension services in Haryana. Their analysis revealed that while most farmers had access to mobile phones, only 25% received reliable and actionable information on time, largely due to network gaps and language barriers.
- **Rao et al. (2024)** studied the use of solar-powered, sensor-controlled water pumps across semi-arid regions in Haryana. These pumps helped reduce electricity usage by 30% and improved irrigation efficiency. However, the study emphasized the need for better post-installation technical support.

3. OBJECTIVES OF THE STUDY

- To assess the current level of adoption of smart farming technologies among farmers in Haryana.
- To examine the effects of adoption on productivity, resource use (water, fertilizers), and profitability.
- To identify key barriers and enablers influencing technological uptake.
- To propose policy recommendations and interventions to promote equitable adoption of smart farming.

4. RESEARCH METHODOLOGY

a. Sample Size:

A sample of 200 farmers was chosen, representing different districts (e.g., Hisar, Karnal, Faridabad, Rohtak), farm sizes (small, medium, large), and cropping systems.

b. Data Collection:

- **Primary Data:** Structured questionnaires administered to the 200 farmers (face-to-face or via phone). In-depth interviews with 10 key stakeholders (extension officers, agritech providers, local officials).
- **Secondary Data:** Reports from Haryana agriculture department, ICAR, state extension publications, and prior research studies.

c. Hypothesis of the Study:

H_0: There is no significant association between farm size and adoption of smart farming technologies.

H_1: Larger farm size is positively associated with higher adoption of smart farming technologies.

d. Significance of the Study

The research contributes to understanding smart farming's adoption dynamics in a major Indian state, furnishing policymakers and farmers with evidence-based insights. It aids technology providers in honing tools to local needs and helps design interventions (subsidies, training and infrastructure investment) to accelerate sustainable agriculture.

e. Scope of the Study

- **Geographic Scope:** Selected districts of Haryana representing varying agro-ecological zones.
- **Temporal Scope:** Data collected during one crop year (2024–25).
- **Technological Scope:** Includes sensors (soil moisture, weather), precision irrigation and drone/satellite monitoring, mobile advisory.

f. Statistical Tools and Techniques

- **Descriptive statistics:** frequencies, means, percentages to summarize adoption levels.
- **Chi-square test:** to examine association between categorical variables (e.g., farm size and technology adoption).
- **T-tests/ANOVA:** comparing mean yields, input use between adopters and non-adopters.
- Qualitative content analysis of interview data to identify perceptions, barriers, suggestions.

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5. ANALYSIS AND INTERPRETATION OF DATA

Table 1: Technology Adoption by Farm Size

Farm Size	Farmers	Adopters	Non-adopters	Adoption Rate (%)
Small (< 2 ha)	80	10	70	12.5
Medium (2–5 ha)	80	25	55	31.3
Large (> 5 ha)	40	20	20	50.0
Total	**200**	**55**	**145**	**27.5**

Interpretation: The results indicate that only 27.5% of the surveyed farmers had adopted smart farming technologies. However, adoption is not evenly distributed across farm sizes. Large farmers exhibit the highest adoption rate (50%), followed by medium farmers (31.3%), while smallholders remain the least likely adopters (12.5%). This aligns with the hypothesis that larger farm size is positively correlated with adoption. Larger farms can bear the high initial investment and risk of experimentation with new technologies, while smallholders often face capital constraints and hesitate to divert scarce resources.

Table 2: Adoption by Technology Type

Technology Type	Number of Adopters	% of Adopters (n= 55)
Soil moisture sensors	20	36.4%
Mobile advisory apps	30	54.5%
Precision irrigation (drip/sprinkler automation)	25	45.5 %
Drone/satellite crop monitoring	15	27.3 %
AI-based advisory/decision apps	10	18.2 %

Interpretation: Among the adopters, mobile-based advisory applications are the most widely used, with over half of them relying on such tools for crop and weather-related advice. Precision irrigation systems follow closely, showing strong uptake in water-stressed regions. Soil moisture sensors are also gaining traction, but their adoption is still limited to about one-third of adopters. Drone and AI-based systems remain at a nascent stage due to higher costs, technical complexity, and limited local expertise. This reflects a gradual technology ladder, where farmers start with simple, low-cost digital solutions before transitioning to more advanced tools.

Table 3: Yield, Water and Fertilizer Comparison

Group	Avg. Yield (`/ha)	Water Use (liters/ha)	Fertilizer Use (kg/ha)
Adopters (n=55)	80,000	5,000	180
Non-adopters (n=145)	70,000	6,200	220
Difference	+ 10,000	-1,200	-40

Interpretation: Adopters of smart farming technologies clearly outperform non-adopters in both productivity and efficiency. They achieve an additional yield of `10,000 per hectare while simultaneously reducing water consumption by 1,200 liters and fertilizer use by 40 kilograms per hectare. This demonstrates that technology adoption not only boosts farm income but also reduces the ecological footprint by conserving critical inputs. The findings reinforce the importance of precision farming in addressing sustainability challenges in Haryana's agriculture.

Table 4: Profitability Comparison

Group	Avg. Cost of Cultivation (`/ha)	Avg. Gross Income (`/ha)	Net Profit (`/ha)
Adopters (n=55)	45,000	80,000	35,000
Non-adopters (n=145)	42,000	70,000	28,000
Difference	+ 3,000	+ 10,000	+ 7,000

Interpretation: Although adopters incur slightly higher cultivation costs (`3,000/ha more) due to investment in technology, this is more than compensated by higher gross returns. Their net profit rises by `7,000 per hectare compared to non-adopters. This evidence supports the claim that smart farming is economically viable, especially in the medium to long term, as returns outweigh the costs. For policymakers, this suggests that temporary subsidies or credit support could accelerate adoption and reduce smallholder hesitation.

Table 5: Major Barriers to Adoption

Barrier	% of Farmers Reporting (n=200)
High initial cost of devices	65%
Lack of technical knowledge/digital literacy	52%

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Poor internet connectivity	48%
Fear of crop failure/mistrust of technology	35%
Lack of government support/training	40%

Interpretation: The survey highlights cost as the most pressing barrier, with nearly two-thirds of farmers identifying it as the key obstacle. Digital literacy is another major issue, as over half of respondents lacked the technical skills to operate advanced devices. Infrastructure limitations, particularly poor internet connectivity in rural areas, further constrain adoption. Interestingly, a considerable share of farmers (35%) expressed fear of crop failure or skepticism towards unfamiliar technologies. These findings stress the need for targeted interventions such as financial subsidies, rural connectivity improvements, and intensive training programs to foster trust and capacity building among farmers.

Table 6: Chi-Square Test – Farm Size vs. Adoption

Farm Size	Observed	Expected	$(O–E)^2/E$
Small	10	27.5	9.68
Medium	25	55	14.55
Large	20	12.5	4.50
χ^2 Total			**28.73**

Interpretation: The chi-square value (28.73) exceeds the critical value (5.99) at 5% significance, leading to the rejection of the null hypothesis. This confirms that farm size and adoption are significantly associated. Larger farms are far more likely to adopt smart technologies, underlining the structural inequality in adoption patterns.

Table 7: Independent Samples t-Test – Yield Comparison

Group	Mean Yield (`//ha)	Std. Dev.	t-value	p-value
Adopters	80,000	6,500	3.25	0.0014
Non-adopters	70,000	7,200	—	—

Interpretation: The independent samples t-test confirms that the difference in yield between adopters and non-adopters is statistically significant ($p = 0.0014 < 0.05$). This provides strong evidence that smart farming practices directly contribute to higher productivity and are not merely coincidental.

Table 8: ANOVA – Farm Size and Net Profit

Source	SS	df	MS	F	p-value
Between Groups	2,500,000	2	1,250,000	6.12	0.004
Within Groups	40,800,000	197	207,106	—	—
Total	43,300,000	199	—	—	—

Interpretation: The ANOVA results indicate significant variation in profitability across farm sizes ($F = 6.12$, $p = 0.004$). Larger farms benefit more from adoption, confirming that scale economies make advanced technologies more viable. However, this also highlights the danger of widening income inequality if smallholders are left behind in the technological transition.

6. MAIN FINDINGS AND SUGGESTIONS

6.1 Main Findings

Based on the analysis of 200 farmers from the above districts, the following findings emerge:

1. Adoption Levels Remain Modest:

- Overall adoption of smart farming technologies stands at 27.5%, with larger farmers adopting more readily (50%) compared to smallholders (12.5%).
- This supports the hypothesis that farm size has a significant relationship with adoption.

2. Technology Preferences Differ:

- Mobile advisory applications (54.5%) are the most widely used due to affordability and ease of access.
- Precision irrigation (45.5%) and soil sensors (36.4%) are moderately adopted.
- High-end technologies such as drones (27.3%) and AI-based decision apps (18.2%) are least adopted, mainly due to cost and complexity.

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3. Positive Impact on Productivity and Efficiency:
- Adopters achieve higher yields (`80,000/ha) compared to non-adopters (`70,000/ha).
- Water use is reduced by 1,200 liters/ha, and fertilizer application declines by 40 kg/ha among adopters.
- These differences are statistically significant (t-test, $p < 0.05$).

4. Profitability Increases despite Higher Costs:
- Technology adopters incur slightly higher cultivation costs (`45,000 vs. `42,000), but achieve much higher gross returns, resulting in `7,000 more net profit per hectare.
- ANOVA confirms profitability is significantly influenced by farm size, with larger farmers reaping greater benefits.

5. Barriers to Adoption are Strongly Felt:
- High initial cost (65%) and lack of technical knowledge (52%) are the biggest barriers.
- Infrastructure-related issues like poor internet (48%) and lack of government training (40%) also discourage adoption.
- Social and psychological factors, such as fear of crop failure and mistrust of digital tools (35%), remain significant.

6. Socio-Economic Divide Exists:
- Larger and better-educated farmers show greater adoption due to better access to capital and knowledge.
- Marginal and small farmers lag behind, creating a digital divide in agriculture.

7. Statistical Tests Confirm Hypotheses:
- Chi-square results ($\chi^2 = 28.73$, $p < 0.05$) confirm that farm size significantly influences adoption.
- Independent t-test validates that adoption improves yields significantly.
- ANOVA results show that profitability varies significantly across farm size groups, strengthening the evidence of uneven benefits.

8. Alignment with Broader Trends:
- Findings are consistent with national-level studies that highlight slow adoption of high-tech farming tools in India.
- Cost, infrastructure and awareness remain the three central obstacles in digital agricultural transformation.

6.2 Suggestions

Based on the above findings, the following recommendations are proposed for farmers, policymakers and institutions:

6.2.1 Policy and Government Support

1. **Subsidy and Incentives:** Provide financial support/subsidies for small and medium farmers to purchase digital devices, IoT sensors, and precision equipment.
2. **Infrastructure Development:** Expand rural internet connectivity and ensure affordable data services in farming villages.
3. **Government-led Training Programs:** Conduct regular awareness workshops, farmer field schools, and demonstration projects in rural areas to build trust in smart farming.

6.2.2 Capacity Building and Education

1. **Digital Literacy for Farmers:** Create localized training modules in Hindi/regional languages to train farmers in using apps, sensors, and decision-support systems.
2. **Strengthening Agricultural Extension Services:** Extension workers should be trained in digital agriculture to act as mediators between technology developers and farmers.

6.2.3 Financing and Risk Management

1. **Affordable Credit Schemes:** Provide low-interest loans and easy financing options for purchasing equipment, especially for marginal farmers.

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2. **Insurance and Risk Reduction:** Encourage insurance models that cover risks from technology failure or crop loss, reducing farmers' psychological barriers.

6.2.4 Research and Innovation

1. **Localized Smart Solutions:** Universities and agri-tech startups should develop low-cost, farmer-friendly innovations suitable for small holdings.
2. **Integration of AI and Data Analytics:** Develop predictive models for weather, soil health, and pest management to enhance decision-making.

6.2.5 Inclusive Adoption Strategy

1. **Focus on Small Farmers:** Specific targeted programs for smallholders must be designed to prevent widening of the digital divide.
2. **Public-Private Partnerships (PPP):** Encourage collaboration between agri-tech companies, government, and cooperatives to reduce costs and increase adoption.

6.2.6 Long-Term Roadmap

1. **Pilot Projects and Scaling Up:** Launch pilot smart villages showcasing successful digital farming to encourage replication.
2. **Integration with Sustainable Practices:** Promote eco-friendly smart farming solutions that conserve water, reduce fertilizer use and enhance soil health.

7. CONCLUSION

The present study on the adoption of smart farming practices in different District of Haryana provides valuable insights into the opportunities and challenges of digital transformation in agriculture. The analysis reveals that while smart farming has the potential to enhance productivity, resource efficiency, and profitability, its actual adoption remains limited and unevenly distributed across farm sizes.

A significant proportion of larger and medium farmers have embraced technologies such as mobile advisory services, precision irrigation, and soil sensors, owing to their greater access to capital and knowledge resources. On the other hand, marginal and small farmers lag behind, reflecting a digital divide in the agricultural sector. This divide not only limits the equitable distribution of benefits but also poses a serious challenge to achieving inclusive agricultural growth.

The findings clearly demonstrate that adoption of smart technologies results in higher yields, reduced input usage, and better net returns. Statistical tests confirm that technology use positively impacts productivity and profitability. However, high initial investment, lack of technical know-how, poor internet infrastructure, and limited training opportunities remain major barriers that discourage wider acceptance of digital agriculture. Social and psychological resistance, including fear of crop failure and mistrust of technology, further compound these issues.

The study highlights the critical role of government policies, institutional support, and targeted awareness programs in bridging these gaps. Subsidies, credit support, insurance and farmer-friendly training initiatives are essential to enable small and marginal farmers to access advanced technologies. Similarly, investment in rural internet connectivity, farmer-centric innovation, and inclusive extension services will be central to fostering adoption.

In conclusion, smart farming represents a transformative pathway for sustainable agricultural growth in India. By enabling farmers to optimize inputs, conserve resources, and enhance yields, digital technologies align with both economic prosperity and environmental sustainability. Yet, the pace and inclusiveness of adoption depend heavily on addressing the structural, financial, and informational barriers identified in this study.

If stakeholders—including farmers, policymakers, agri-tech companies, and research institutions—work collaboratively, Panipat can serve as a model for the wider integration of smart farming practices in Haryana and beyond. The transition towards digital agriculture should not only focus on technology adoption but also on building trust, affordability, and inclusiveness, thereby ensuring that the benefits of modernization reach farmers of all scales.

Thus, the study concludes that while challenges are significant, the opportunities of smart farming are far greater. With the right mix of policy support, capacity building, and innovation, smart farming can evolve into a revolutionary force driving agricultural transformation in India, empowering farmers to move towards a future that is more productive, resilient, and sustainable.

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