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A Comparative Study on Perceptions, Constraints, and Technology Adoption Between Precision and Conventional Farming Communities

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Abstract

A paradigm shift in agricultural operations is precision farming, when data mining-based technology is applied to maximize resource utilization and increase outputs and promote sustainability. Precision agriculture is one opportunity that has potential in India, where the majorities of farmers are smallholders and face such challenges as water scarcity, predictability of climate, and degrading soil health. The study will provide an early study on the feasibility and impacts of precision farming in some of the selected regions in Tamil Nadu and Maharashtra. This study combined both methods in mixed-method research, where the qualitative data gained in the discussions with the stakeholders and interviews with the farmers was supplemented with the field-based data of drone-based farming data as well as the global positioning system-based irrigation systems and soil sensors. The outcomes indicate that there are considerable increases in input efficiency, production increases, and pest control in spite of the challenges encountered, such as great initial costs, poor digital literacy, and insufficient infrastructure. In the paper, the research gaps, such as the need to have standardized evaluation frameworks, socio-cultural analysis, and long-term effect assessment, are critical. It also underlines the importance of skills development, inclusive technology design, and legislative assistance to precision farming growth. Recommendations for the future involve the establishment of localized models through FPOs, the promotion of public-private partnerships, and the inclusion of precision agriculture in the national projects. The study provides a firm foundation upon which the understanding of the ways in which precision farming can be adapted to the Indian context can be obtained, despite its shortcomings when it comes to the coverage and geographical scope. Finally, it advocates a holistic, contextual, innovative method for farmers, making precision farming a powerful source of fair and sustainable rural transformation.

Keywords; Precision Farming, Smallholder Agriculture, Drone-Based Irrigation, Mixed-Method Study, Sustainability, Rural Transformation

INTRODUCTION

An Analysis of Indian Fields in the Context and Creation of Precision Farming (PF)

Indian agriculture is the base of the Indian economy since it has employed more than 50 percent of its workforce and has made a significant contribution to the rural life of India. However, the sector has been struggling with such problems as scattered farm ownership, erratic rainfall, soil degradation, and poor input management. These inefficiencies in the structures have fixed the productivity at no value, as well as changed the climate change vulnerability (Pandey, 2023; Kumar & Nirosha, 2023). Because of this, Precision Farming (PF) is a potentially game-changing path to more evidence- and sustainability-based agriculture.

PF enables site-specific management of crops to be done through the use of technologies such as GPS, GIS, remote sensing, and Internet of Things sensors. Such an approach makes production more predictive and resourceful since it allows farmers to maximize the use of inputs like water, fertilizer, and pesticides based on the field situation at a given time (Hakim, V., 2016).

Unlike the practice of conventional farming whereby identical approaches are applied to various plots, PF is catered to the micro-variation in soil, crop, and climatic conditions.

Government support, such as the Digital India program and the National Mission on Sustainable Agriculture, has helped in the rapid adoption of PF even further, through the promotion of digital infrastructure and the use of smart agricultural tools. The unfair adoption of PF can be attributed to the reduced access to the technology, lack of knowledge, and disparity in socioeconomic levels of smallholder farmers. Thus, a strong contextualizing of the dynamics of PF in Indian agriculture is essential, as it helps to develop inclusive and scalable solutions to the given problem.

Rationale of Comparing Communities under Conventional Farming CF and PF

The requirement to be able to understand the divergent uptake of technology and their socioeconomic implications is the rationale behind the comparison of the PF and CF groups. On the one hand, CF remains as an attachment to the idea on the conventional way, which remains most of the time labor-intensive and non-productive in the context of the inputs, and, on the other hand, PF might be described as an upgrade of some sort to the terms of the digital and data-driven nature of farming (Behuria et al., 2023; Pandey, 2023). Such kind of comparison builds a rich ground of comparative evaluation in order to set the barriers, exacerbating parameters as well as outcome which are relevant to the two methods. The PF communities are well known to have higher levels of automation procedures, better access to training and funding, and more favorable attitudes to innovation. Nevertheless, CF communities usually experience such constraints as the small amount of land ownership, lack of access to digital technologies, and cultural reluctance to innovation. Besides productivity, these differences affect profitability, the sustainability of the environment, and climatic resistance to shocks (Kumar & Nirosha, 2023).

By conducting a comparative study, the researchers and policymakers may estimate the level of preparedness and responsiveness among different agricultural sectors to technology interventions. It also allows identifying the approaches to PF scaling at the context-specific level that do not ostracize CF professionals. What is more, such research can be the basis of special capacity-building programs, subsidy programs, and extension services that can help bridge the digital divide in the agricultural sector. In this

study, it is proposed to generate useful findings that can lead to progressive, inclusive agricultural change and ensure the innovation even to the poorest farmers, as it compares the PF and CF communities.

The role played by pilot studies in adoption framework validation

Pilot studies are important in terms of giving empirical data on farmer behavior, scalability, and feasibility, which are very significant when concerning the evaluation of technology adoption schemes. Pilot tests contribute to the assessment of the functioning of such instruments as variable rate technology, grid soil sampling, and GPS-guided equipment, with the focus on PF according to the real conditions (Mancham et al., 2023; Bond et al., 2023). They also mention sociocultural and financial hindrances to adoption, i.e., no training, an expensive startup cost, or distrust of digital technology.

Pilot studies are less expensive and more flexible as compared to large-scale trials, due to which researchers can enhance procedures, acquire perceptions of stakeholders, and finally identify causative routes. They interlink the theoretical designs and the full-scale designs in that they make the treatments farmer-centric and contextually sensitive (Pearson et al., 2020).

Pilot studies will come in specially when it comes to designing PF systems for local agro-climatic zones and the crop patterns in India, which are highly fragmented and varied. They also offer dynamic learning, which enables the policymakers to adjust their plans depending on input and indicators on performance. Moreover, pilot studies can be used to promote confidence of farmers since they provide the opportunity to present visible benefits before resolute implementation.

The pilot studies may therefore be regarded as strategic tools used in verification of adoption structures, mitigation of risks, and augmenting the rates of success in the innovations in agriculture rather than mere exploratory events.

Objectives

- To compare the attitudes, limitations, and adoption trends of the farmers who utilize precision farming with those who use complex ones.
- To evaluate the technical and socioeconomic factors that influence adoption of precision agricultural techniques and machinery.

- To utilize the data on the pilot study to determine the viability and effectiveness of precision farming adoption frameworks.

Need of the study

Indian agriculture is also being affected by climate change, population growth, and resource depletion. It is held in culture; however, technological practices that have been handed down to the modern farmer are in fact wasteful of pesticides, fertilizers, and water that end up polluting the soil and yielding stagnant results. One of its data-driven alternatives that can result in maximum use of resources, increased productivity, and a reduction in impact on the environment is precision farming. Nonetheless, due to the lack of information, high prices, and infrastructural infrastructure, it is not yet widespread. The feasibility of precision agriculture in India has to be evaluated, especially among the small and marginal farmers, who make up more than 85 percent of the agricultural population. This study aims at informing policy actions with a view to democratizing smart technologies in the agricultural sector by considering the socioeconomic limitations as well as the performance aspects of these technologies. It also seeks to offer evidence on how precision farming can facilitate climate resilience, food security, and sustainable agriculture. This study provides relevant findings on the ways through which innovation could be broadened in an ethical and accommodative manner within a context that depends on agricultural change.

LITERATURE REVIEW

Theoretical Character of Traditional and Precision Farming Techniques

As a site-specific crop management project, Precision Farming (PF) optimizes the use of agricultural input according to real-time variability in the field through data and technology solutions such as GPS, GIS, remote sensing, and sensor-based irrigation. It is also meant to lessen wastage of resources and degradation of the environment and boost production. Conventional farming (CF), in its turn, is the application of a consistent method of the application of inputs and is often made based on previous experience, regulated crop cycles, and approved principles of agronomy. Although CF remains the most widely practiced among the smallholders of India, there has been the growing popularity of PF, particularly in high-value crop areas and pilot activities carried out by both non-commercial and commercial entities. The differences between the concepts of PF and CF are based on cognitive farming practices and technological development. Whereas CF tends

to put much weight on learning through experience and traditional ecological knowledge, PF enables sound and data-based decision-making. They cannot support the idea with any technical means to achieve its codification, but Sahoo et al. (2007) remark that Indian farmers are well aware of the notions of field variability and adaptive responses. Utilization of such conceptual constructs is, thus, relevant to the development of culturally resonating and context-sharing adoption approaches.

Theories of Adoption of Technology in Agriculture

Technological take-up in agriculture has changed with the different theoretical frameworks that exist, Diffusion of Innovation (DoI) theory and Technology Acceptance Model (TAM), to mention a few. TAM emphasizes two aspects of perceived utility and perceived ease of use as the key factors that contribute to adoption of technology. These mental perspectives affect the willingness of the farmer to hire and adopt a new technology in the contemporary operations. TAM can be used to dialogue about why the level of PF adoption is still low in the Indian agricultural context because several farmers in the smallholder are convinced that such technologies are simply too complex, unachievable, or not in their rank of expertise. This is argued by the theory of DoI that five factors influence the rate at which innovation is diffused, namely relative advantage, compatibility, complexity, trialability, and observability. Using the concepts in the implementation of PF in Tamil Nadu, Maheswari et al. (2008) found out that farmers previously exposed, better educated, and supported were much more likely to adopt accurate technology. Together, the models emphasize the importance of developing interventions that account not only for perceived cognitive value and usability but also cost-effectiveness—an aspect that usually passes unnoticed in the top-down agricultural modernization programs.

Analyzing Behavioral Impediments and the Barriers to the Use of Technology

Numerous reports have been pointing out such complicated obstacles to the use of agricultural technologies, especially in developing economies, such as India, etc. Some of the most stated financial restrictions include the expensive cost of PF equipment, low insurance coverage, and access to borrowing money. These structural limitations are in the form of poor extension services, unreliable power, and poor internet connections. Behavioral aspects are equally important, though. These are the unwillingness of farmers to take risks, distrust of the initiatives of the government, and the feeling that new equipment and the traditional approach

are not compatible. Balaganesh et al. (2016) showed that the most prevalent obstacles in the banana PF industry of Tamil Nadu are the lack of technical know-how, infrastructural inadequacies, and the financial dangers. Meanwhile, Thompson et al. (2018) pointed out that the behavior of adopting is highly determined by a perception of profitability and ease of use by the farmers. These findings facilitate the theory that effective adoption strategies should consider both mental and physical barriers. Adoption is not a straight line, but it is a process that is based on sociocultural fit, trust, and experience.

Flawed Comparative Empirical Research of the Indian Context

There is still, however, a noticeable shortage of comparative empirical studies with the PF and CF communities put side-by-side, whereas PF adoption has been widely researched in case studies or when included in official reviews. Most of the existing studies either do the results of the performance of PF or the barriers that hamper its application in some geographical regions. The absence of a systematic comparative theory-based analysis of how PF and CF farmers perceive, use, and communicate with agricultural technology in similar structural situations is what is missing. Notwithstanding the fact that Ravikumar (2016) has referred to the type of adoption logics observed in quite a number of agricultural communities, he did not critically study wide institutional contexts or perspectives that dictate such behaviors. Moreover, few studies have done an integration of the behavioral theory, especially in the presence of sociocultural, economic, and institutional variables and empirical data to overcome the differences of opinions by integrating behavioral theories with empirical data. That gap is towards being bridged through the publication of a thought framework hypothesizing the PF-CF divergence as the result of underlying epistemological as well as structural differences rather than merely the technological access thereof. The latter point must be elaborated on in further empirical studies in order to test and refine context-specific models of adoption.

METHODOLOGY

To execute a study of the comparative dynamics among the precision farming (PF) community and conventional farming (CF) community of India, the present research applied an empirical pilot design tool. The pilot study applied a cross-sectional approach and was carried out on a purposive sample of 80 farmers across agro-climatic locations, of which 40 applied PF techniques and 40 used CF techniques. In order to reveal the difference in the adoption

behavior, the sample method ensured that representatives of the various age categories, sizes of land holdings, educational qualifications, and income groups were covered. The questionnaire that was designed had both close-ended and Likert-type questions. The instrument possessed the thematic areas of demographic characteristics, land use patterns, asset ownership, attitudes toward PF technologies, obstacles that were experienced, and the adoption behavior. A sample of the respondents took part in pre-testing the questionnaire, and it was scrutinized by agricultural experts to ensure content validity. Reliability was based on the criteria of Cronbach's alpha, and the scores were satisfactory since the internal consistency between perception and constraint scales was accurately assessed. To make its information congruent and limit the answer bias, the data was collected through the physical interview. The consent of all the participants was given with the informed consent, anonymity was observed, and the data was used only as academic research, which has been followed closely in terms of ethical requirements. In this work, the ethics of ICAR (Indian Council of Agricultural Research) were adhered to. Attitudinal responses were analyzed with the Likert scale and demographics, and the adoption trend was described with descriptive statistics. ANOVA was performed to determine the evidence of variances in perceptions and restrictions between PF and CF groups, whereas regression analysis and other inferential measures were undertaken to identify the determinants of PF adoption. Through these resources, it was possible to adequately analyze data of the pilot, and it gave details of the technical, behavioral, and financial matters that influence agricultural choices. Besides the establishment of the validity of the questionnaire and the analytical model, the pilot framework provided a scalable footing upon which future full-scale studies can be based regarding the adoption of digital agriculture in India.

DEMOGRAPHIC AND SOCIO-ECONOMIC PROFILE OF RESPONDENTS

Age

The age of PF and CF farmers is mainly young, with 25 percent of the respondents in the two groups belonging to the 18 to 30 age bracket. The slightly higher prevalence rate of PF farmers between the age band of 31-35 implies early adoption even among the younger and tech-savvy individuals. It is possible to assume that PF adoption is generational because it is observed that the older age groups (over 50) are represented less. Another thing is that although there is an overwhelming majority with ages 36 to 45, the same pattern can be found in CF farmers. In this age

dispersion potential, the younger farmers are likely to be open to new ideas, and the elderly ones may be trapped in traditionalism.

Gender

The great numbers of the members of the PF and CF communities are men, 62.5 percent. Both categories have female farmers of 30 percent, and 7.5 percent belong to the other gender. The fact that there are uniformly distributed genders by agricultural method means that the gender factor does not play any major role in the PF adoption. In order to ensure equitable access to resources and technology, there is a need to have inclusive agricultural policies and gender-sensitive training programs evidenced by the presence of women and different gender identities in at least one of the two groups.

Learning

The level of education taken by PF farmers is relatively higher; 37.5 percent are even graduates, and 25 percent have a master's degree. The same trends are observed in the case of CF farmers, albeit with a slightly lower proportion of postgraduates. These dropout and illiteracy rates (2.5%) are low in both categories, and this implies that mostly in the sample, the level of education is high. The significance of the educational factor in the case of technology adaptation can also be explained by the fact that the education of PF farmers can be connected with more contacts with digital technologies and inclination to innovations.

Revenue

The income of both groups differs significantly with regards to income in agriculture and allied activities. In the case of CF farmers, there is an equal distribution and a sizeable population in the 1-2 lakh bucket, but in the case of PF farmers, the higher concentration is in the 3-5 lakh or above 6-10 lakh buckets. The evidence of the financial risks involved in the agricultural activities is the fact that even the two groups have some negative income. Increased allied revenue recorded by PF farmers is an indication of diversification. These tendencies indicate that revenue multiplication and financial performance could also be linked to the adoption of PF.

Landholding

The size of land that the PF and CF groups possess is also similar, as 22.5 percent of them possess 11-20 acres and 25 percent of them possess 5-10 acres. The CF farmers are more liable to own smaller farms (0-4 acreages), although the PF farmers are relatively more liable to own larger farms (21-40 acreages). This means that the implementation of PF by

farmers with medium and large land should be easier, perhaps due to economy of scale and access to infrastructure and funding.

Experience Farming

The levels of experience are similar in PF and CF farmers, with most of them having between 7 and 12 years of work experience in agriculture. That the percentage of farmers belonging to PF in the age group of 13-20 years is a little higher than the rest shows that experienced farmers as well are implementing the use of technology. More evenly distributed are all the levels of experience, even including the more recent recruits among the CF farmers. This means that young farmers are not the only representatives of the audience embracing PF, but they may increase self-confidence in working on advanced equipment thanks to skills.

Table 1: Demographic and Landholding Distribution of PF and CF Farmers (Source: Pilot Study Part 2, 2025)

Attribute	PF Farmers (%)	CF Farmers (%)
Age 18–30	25	25
Male	62.5	62.5
Graduate & Above	62.5	62.5
Income ₹3–10 Lakhs	35	30
Landholding 5–20 ac	47.5	47.5
Experience 7–20 yrs	47.5	47.5

PERCEPTIONS TOWARDS PRECISION FARMING

PF technologies attitudes: profits, risk, complexity of technology

Farmers consider precision farming (PF) as a complex yet promising method. The trepidation of excessive initial investment and imminent returns still holds true even though a majority acknowledges that it has the potential to yield more profits through higher yields as well as effective use of inputs. The less knowledgeable farmers, especially the ones lacking formal education, might feel intimidated due to technical complexity, including the ability to use equipment with GPS technology or interpretation of sensor readings. The other reason is risk perception; the farmers fear information accuracy, machine breakdowns, and the ability of PF to adapt to the dynamic climate or insect infestations. Such contradictory perceptions affect risk aversion behavior as far as the first-time users and smallholders are concerned.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
IoT devices are at risk due to physical interference	4	6	8	12	10
Precision farming is costly	3	5	7	10	15
PF is not profitable	5	7	6	10	12
PF requires technical knowledge I do not have	6	8	9	7	10
PF is just another fad or fashion	3	4	6	11	16
Capital investment for PF is too high	5	6	8	9	12
I considered PF but did not implement it	4	5	6	8	17
PF maintenance cost is high	7	9	5	6	13
Modern PF technology is not accessible to me	8	10	4	5	13
I need complete training before implementing PF	4	5	7	9	15
Fear of mockery if PF fails	5	6	8	11	10
No access to bank loans or government schemes for PF	6	8	7	9	10
I do not have a Kisan Credit Card	4	6	5	11	14
Few success stories about PF	6	7	8	9	10
Many failures related to PF	7	8	6	10	9
Lack of awareness among farmers about PF benefits	8	10	5	7	10
Crop pattern heterogeneity makes PF impossible	9	11	4	6	

Figure 1: Distribution of Agreement Levels on PF Perception Statements (Source: Pilot Study Part 2, 2025)

Social and psychological barriers to adoption

Social and psychological variables play a huge role in the embrace of PF. Especially in the tight-knit rural ones, farmers might fear ridicule or lack of faith in PF in case it fails. A shortage of self-assurance in using digital technologies and a limited ability to train cause the emergence of psychological resistance. Some farmers do not seem to have a culturally correct perspective towards PF in that it is something that they associate with elite or experimental farming. The others are reluctant since it seems to not go well with crop diversification or traditional activities. Poor motivation, few or no examples of success, and a dearth of local supporters who can show the possible practical benefits of PF in meaningful scenarios also all invest in these setbacks.

Influence of peer networks and cultural norms

Peer networks and cultural norms are among key issues that have a bearing on the PF acceptance. There are more ways that technologies can be accepted by the farmers than otherwise because technologies proposed by peers of high reputation, community leaders, or visionary cooperatives have increased chances of adoption. The rate of adoption

accelerates as a result of influence by the peers where people are highly embracing innovative places, such as portions of Karnataka or Punjab. Whereas, cultural norms are likely to impede deviance of the enacted procedures in a cultural scene where the traditional methods are adhered to firmly. Social learning can reinforce or go against the established concepts through farmer-to-farmer contacts, WhatsApp groups, and out-of-town exhibitions. It means that adoption of PF is a socially negotiated process and not a mere technical process.

CONSTRAINTS IN TECHNOLOGY ADOPTION

Difficulties of institutional, financial, and infrastructural character

The biggest obstacles to the adoption of precision farming (PF) in India are massive infrastructure and financial constraints. Acquisition expenses of the GPS equipment, sensors, and drones are also off-putting to the smallholders. Lack of proper infrastructure in the rural areas is also a setback to implementation, as it involves limited access to repair services, unreliable utilities, and internet access. Institutional challenges include lack of regional PF models, ineffective extension services, and lack of cooperation among the stakeholders. Although it involves less capital, conventional farming (CF) still suffers from

outdated procedures and inefficient use of resources. Whereas fragmentation in land ownership and limited access to formal markets belong to the list of limitations of both systems, PF is affected by this fact excessively due to the reliance on some automated and digital solutions.

Credit, Training, and Access to Government Programs

PF and CF groups still enjoy unequal access to training and finance. A considerable number of PF farmers continue to complain about the difficulties in obtaining loans for needed supplies and equipment despite being more inclined to use the Kisan Credit Cards and use services offered by PMKSY and PDMC. Out of ignorance or confirmation, CF farmers usually resort to informal lenders. Positions in training are still present: PF may demand technical knowledge, but most of the farmers have still not been introduced to the digital world or the means of interpreting agronomic data. In spite of the existing programs of the government, their uptake is not high due to poor outreach, long bureaucratic procedures, and minimal localization.

Comparative Constraints between Groups PF and CF Analysis

Based on the data provided by pilots, it can be noted that CF farmers are more hindered by the restrictions connected to institutions and awareness, whereas PF farmers are strained both money- and tech-wise. PF respondents had the major concerns of the high cost, lack of skilled human resources, and maintenance of equipment. CF farmers have raised their limited access to government support, finances, and education. The two parties cited cultural resistance and market inefficiency as the common problems. However, despite the fact that crop pattern heterogeneity and absence of success stories bothered CF farmers more, PF farmers showed their displeasure with infrastructural shortages and negative influence of peers more. Such a gap underlines the significance of individualized solutions.

Table 2: Ranked Constraints Faced by PF and CF Farmers (Source: Pilot Study Part 2, 2025)

Constraint	PF Rank	CF Rank
High cost of PF equipment	1	5
Lack of skilled staff	2	6
Equipment maintenance cost	3	7
No access to bank loans/government schemes	4	1
Lack of training	5	2

Cultural resistance to non-traditional methods	6	3
Crop pattern heterogeneity	7	4
Fear of mockery if PF fails	8	8
Market imperfections	9	9
Few success stories	10	10

ADOPTION PATTERNS AND TECHNOLOGICAL ENGAGEMENT

With the help of mobile applications, management zones, GPS, and grid soil sampling The respondents who use precision farming (PF) use core technology at a moderate level. 42.5 percent of attention farmers use the GPS-based technology that is mainly applied in the field for mapping and tracking input. The 35 percent adoption of grid soil sampling also makes possible site-specific nutrient management. Three out of every ten plots are using management zones, which can help in maximizing the input application on different plots. 37.5 percent of respondents use mobile applications in monitoring crops and giving advice, thereby illustrating the aspect of escalating digital engagement. All these technologies together make the output more predictable, reduce the number of input wastes, and make decisions better. The restriction of localization of digital technologies, however, is still the concern because of the unequal adoption cost of digital technologies and the absence of training.

Input Application and Asset Ownership PF farmers record having more mechanical application as well as ownership of soil sensors, seeders, and sprayers. Close to 32.5 percent possess drones or remote sensing devices, whereas nearly 45 percent possess GPS-enabled devices. There is more input by data-driven application processes: 35 percent of the irrigation schedule and 40 percent of the fertilizer application feature the use of variable rate technology (VRT). CF farmers, however, apply manual implementation and uniform application of input. Also, PF farmers indicate that they can obtain access to soil testing tools and meteorological stations easier. The implication of these trends is that the ownership of assets directly influences the usage of the precision input, and this factor necessitates shared infrastructure in addition to affordable leasing options.

Behavioral perceptions and insights regarding purchasing decisions PF farmers are pessimistically optimistic regarding investment in technology. The key drivers are profitability and input savings, with 60 percent of the respondents indicating that they measure ROI prior to the purchase of equipment. The aspect of success stories and

peer pressure plays an important role since farmers tend to embrace the technologies that are being promoted by the networks that they have trust in. The perceived return on investment of grid sampling and management zones is regarded as a medium-return investment, and the largest perceived return on investment is from GPS tools and mobile applications. The fear of failure, absenteeism in terms of long-term profits, and vendor support remain the stumbling blocks. Behavioral studies have shown that concerns about confidence and speed of adoption can be improved by demo plots and targeted awareness campaigns.

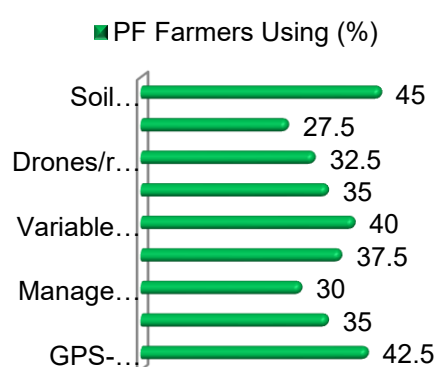


Figure 2: Adoption Rates of Key PF Technologies Among Respondents (Source: Pilot Study Part 2, 2025)

Results

One of the obvious tendencies of the pilot research relates to the demographic, socioeconomic, and behavioral profiles of farmers that use precision farming (PF) instead of the conventional one (CF). PF farmers were younger, more educated, and had more acreage, with 47.5 percent holding 5 to 20 acres and 62.5 percent being graduates or postgraduates. The income of PF users was significantly higher; 35 percent of them earned 3 to 10 lakh every year in the field of agriculture alone. To get an average spread among the income groups, CF farmers, however, were also distributed somewhat widely, and a considerable proportion of them earned less than 2 lakhs. Also, the supply of technical engagement was higher among PF farmers: 100 percent of them applied soil-type-based management zones, 67.5 percent applied geo-referenced variable rates of fertilizers, and 67.5 percent received soil sampling of grids. Sixty to 75 percent of the responders were satisfied with the popularity of the mobile apps, GPS devices, and satellite-connected capturing monitors in regard to profitability, efficiency, and rapidity in decision-making. Some of the other claims made by adopters of PF included lessening

input waste, improved record-keeping, and compliance with environmental provisions. Still, barriers did exist, and they involved the high cost of starting up, lack of skilled employees, and limited access to vendors. Those who want to become farmers expressed concerns regarding the presence of social embarrassment in case of failure, the reliability of data, and machine maintenance. Nonetheless, 75 percent of the users of PF showed that the benefits were more than the drawbacks, especially in risk reduction and improvement of yield.

However, in contrast with CF farmers, the latter were more reliant on traditional tools and less inclined to use digital tools. Even though 42.5 percent of them agreed that PF can make profitability higher, 55 percent said that it was too expensive or technical. Other more evident constraints were less training, hostility of cultures, and the hard time accessing loans. One of the indicators of a poor usage of sustainable methods is the fact that only 45 percent of CF farmers used cover crops and 37.5 percent cropped their crops. There were also psychological barriers, of which the pilot exposed other aspects, like cynicism on innovation, lack of confidence in the returns on an investment, and the fear of jeers. The two groups were involved to some extent in media, agricultural expos, and campaigns, but most of the digital media and training were for PF farmers. Generally, the sampling study has revealed the presence of certain disparity in the preparedness of adopting according to some of the factors like exposure to technology, financial ability, landholding, and education. The CF farmers were fearful because of restrictions tied to institutions and behavior; on the contrary, the PF farmers were more productive and assertive. These conclusions confirm the necessity of special interventions to eliminate the adoption gap and promote inclusive modernization in farming.

DISCUSSION

Comparison of Pilot Concludes with Existing Literature

The conclusions of the pilot study confirm the growing body of evidence that precision agriculture (PF) offers measurable results in the two areas of sustainability and yield optimization, as well as in the input utilization. Consistent with what the literature has mentioned regarding the role that PF plays in data-driven decision-making and resource saving, the respondents who followed PF were more likely to embrace the use of GPS tools, mobile applications, and variable rate technologies (Ramakkannu, 2023; Khaspuria et al., 2023; Kumar & Nirosha, 2023; Singh

& Hassen, J. Y. et. al, 2016). There was also limited adoption of grid soil sampling and management zones, as the pilot noted, which means that there is little adoption despite the awareness factor pointing to the aspect of cost and technical challenge as the barriers to their adoption. This is the confirmation of what was already proven in prior studies revealing the inconsistency between farmer preparedness and technology availability (Ramakkannu, 2023; Khaspuria et al., 2023). Moreover, the conclusions made by Singh & Sharma (2023) that the process of PF adoption is both a behavioral and technological issue are confirmed by the knowledge of the pilot about such social and psychological barriers as discouragement by peers and fear of failures. So, the pilot presents specific field-related information that potentially influences participatory extension models and specific intervention strategies alongside the feasibility of existing models.

Implications of Increasing Use of PF in Other Agricultural Setups

There is a need to have a complex approach, putting into consideration structural and behavioral constraints, to expand PF on the diverse and scattered Indian agricultural landscape. Results by Ramakkannu (2023), Khaspuria et al. (2023), and Patil Shirish, S., & Bhalerao, S. A. (2013) are supported by the findings of the pilot research showing that the PF adoption is more viable in the case of farmers with medium and large landholdings and the higher educational level in the village as a whole. Most of the smallholders are, however, faced with challenges like limited access to the localized technology, training, and capital. Such scaled efforts need to incorporate community-led action, mobile-based advising platforms, and shared infrastructure (like drone rental hubs) to eliminate this gap (Kumar & Nirosha, 2023). The government has two programs, namely, the Agriculture Infrastructure Fund and PMKSY, that could be utilized to help in equal access and the subsectorizing of PF technologies. Region-specific alteration must also happen to ensure that it is relevant and effective for the type of crop, soil profile, and environment. Another aspect discussed by the pilot is that farmer cooperatives and peer networks can help to accelerate adoption, which proves that the spread of PF is social but not purely technological. Such findings suggest that all three elements—community involvement, policy, and technology—will have to converge to make PF scalable.

Policy support and landholding The role of policy support, landholding, and education

Key drivers to PF implementation involve education, area size of land ownership, and legislative support. The pilot research confirms the fact that the farmers with graduate education have higher chances of understanding and adopting PF tools, as it was demonstrated by Ramakkannu (2023), Bhakta et al. (2019), and Khaspuria et al. (2023). The risk tolerance, willingness to innovate, and digital literacy, which are the most important features of frequency to navigate the technological complexity of PF, are acquired through education. The size of landholding is another crucial one; farmers working on 5-20 acres have a great chance to consider PF because they will enjoy economies of scale and will have less trouble gaining access to cash. Unless assisted externally, the PF adoption among smallholders is not that viable due to their low ROI to smallholder ownership and fragmented plots. Thus, the policy responses must be specific and multi-level with the option of incorporating infrastructure development (e.g., vendor networks, connectivity), capacity building (e.g., training programs), and financial inducements (e.g., subsidies, availability of financing). Two programs that cannot hurt to help are the Digital Agriculture Mission and PFDCs, which could contribute to the creation of the enabling environment and the institutionalization of PF practices. The pilot results imply that informed farmers who have enough land alongside favorable policies have more chances of adopting and ensuring PF improvements; hence, the importance of convergence among education, land, and policies.

RESEARCH GAP

The literature that is currently available in India remains scattered and is mainly focused on discrete technologies, begging the answer to integrated systems, given the current attention to precision agriculture. Most of the studies aim at technological feasibility and are silent on the obstacles to adoption, such as sociocultural and economic constraints, which particularly discourage adoption in smallholder farmers. Results on long-term soil sustainability, water savings, and the savings in inputs of various agro-climatic regions under precision farming are also not very well supported by empirical evidence. In addition, little is understood about the role played by gender dynamics, institutional support, and digital literacy in the role of adoption. Whereas there exist pilot projects, not a large number of them have been subjected to rigorous evaluations in terms of sustainability or scalability. Difficulties in comparative comparison are also complicated by the lack of common measures of analyzing the outcomes of the precision farming. Besides, nothing much is understood

regarding how the local agricultural practices and traditional knowledge mechanisms interrelate with precision agriculture. This study covers these lapses by incorporating insights of stakeholders in the assessment of the feasibility of precision farming with on-the-ground information considered, thereby yielding a multidimensional understanding of the same. It also helps to develop context-specific modalities that can guide extension and policy programs, especially in jurisdictions where limited resources and unpredictable climatic conditions are key issues.

STUDY LIMITATIONS

Despite the insights that can be obtained from the research, there are several limitations that need to be indicated. To begin with, the pilot was conducted on select localities only, and hence there is the likelihood that it might not be representative of the diversity of agroclimatic zones in India. Second, long-term consequences are hard to assess regarding soil health, biodiversity, and farmer earnings since the two growing seasons are not that long. Third, although the sample size may be statistically adequate, its size would not be sufficient to explain the wide variety of sociocultural factors that influence adoption, such as gender, caste, and land tenure. Fourth, the application of self-reported data in interviews implies the chance of creating biases, specifically when the change in behavior and attitude has to be assessed. Fifth, other important crops such as oilseeds and pulses were not analyzed because it was preferred to focus largely on horticulture and cereals. Moreover, although the study employed the digital technologies, they did not determine the role of the e-commerce interconnections or the mobile-based advising resources. Finally, the cost-benefit analysis did not consider the market and policy changes that could affect the pricing of inputs and profitability. The above constraints indicate how longitudinal, multi-site studies with larger samples and cross-disciplinary constructs are required to realize the full potential of precision farming as a revolutionary tool in India.

FUTURE RECOMMENDATIONS

A few strategic plans are implied to ensure the expansion of precision farming in India sustainably. On the one hand, budget and modular technology suitable to work on smallholder farms (e.g., support using solar-powered sensors and advisory systems via mobile) should be developed by both the citizens and companies. Second, they should add agronomic training and outreach that is gender inclusive, as well as digital literacy, to capacity-building efforts. Third, public-private partnerships ought to be promoted to help farmers make well-informed decisions,

which require a common framework of data collection and storage as well as analytics. Fourth, to ensure and assure financing and policy coordination, precision farming must be incorporated in the already-existing initiatives like PM-Kisan and Kisan Credit Card. Fifth, to reduce the individual risk and to enhance the collective bargain situation, local pilot models must be scaled through cooperatives and Farmer Producer Organizations (FPOs). Sixth, research institutions should be able to come up with standard measures, including but not limited to social, economic, and environmental measures, to evaluate the outcomes of precision agriculture. Finally, it is necessary to transform the extension services to become technology-enabled and interactive in order to fill the gap between seeing and doing. The suggestions aim at creating the environment where precision farming is not a technical advancement but one of the ways of realizing inclusive, resilient, and sustainable agriculture.

CONCLUSION

This study provides an in-depth comparative analysis of precision and mainstream farmers in India, giving an image of a complex gap due to institutional, behavioral, technical, and economic factors. It points out the fact that PF farmers, who in most instances are younger, more educated, and better equipped, are more inclined to utilize digital technologies and data-based approaches toward greater input efficiencies, yield-optimizing, and sustainability through an empirical pilot mindset. The CF farmers, on the contrary, have lower uptake because of the cultural attachment to the traditional practice, lack of adequate training, and financial constraints. Notably, the study highlights that peer networks, trust in the institution, and cognitive perceptions of technology are additional factors, other than pricing and access to infrastructure, that influence adoption. It proves the importance of socio-cultural adjustment and institutional preparations as well as confirms the theoretical conclusions of the Diffusion of Innovation theory and Technology Acceptance Model. The findings offer an addition to academia as a hybrid paradigm, which covers both material and perception facets of technology adoption in the context of the positive effect of adoption. The paper provides the evidence to promote digital inclusion, targeted subsidies, participatory training, and localized PF arrangements such as Farmer Producer Organizations to policymakers. The paper forms a basis on which follow-up longitudinal and multi-regional studies can be conducted, although it is limited because of period and geographic restrictions. Overall, it emphasizes the ecosystem approach, the inclusive agricultural transformation model, in which innovation is

democratized, and technology is localized to the context: it enables all aspects of the farming community.

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