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Analyzing Socio-Economic and Behavioral Determinants of Precision Farming Adoption among Diverse Farm Sizes in Semi-Urban India

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Abstract

Precision farming might bring about the efficiencies in usage of inputs, but adoption of the farming technology among the Indian farming community is small and unbalanced. The focus of this study was to examine the institutional, behavioral and socioeconomic determinants affecting the precision farming adoption on various farm sizes in the semi-urban farm situation of India. Demographic profile, technological exposure, awareness, source of information, farmer participation in farmer-producer groups and five behavioral components of the 60 farmers in the Pune area under small, medium and large landholdings (or farm sizes) were captured through the help of a five-point Likert scale. Chi-square tests, odds ratios, one-way analysis of variance and Tukey HSD were used at the 0.05 level. Adoption levels were higher on small (17.9%), medium (40.0%) and large farms (66.7%). Overall, 35.0% (21/60) of farms adopted it. Farm size had a significant linear association with adoption (chi-square of 8.945, p=0.003 and Cramer's V=0.390) and a substantial association (chi-square 9.126, df 2, p=0.010). Farm size was at approximately nine times the odds for large farms compared to small farms. The participation of organizations led to a higher rate of adoption from 17.1 to 60.0% (odds ratio 7.25, p = 0.001). The information source was significant at p = 0.002; the scores of digital media and peer farmers were 63.6% and 52.9%, respectively. Although no significant differences in social impact were found between groups, significant differences were found in perceived utility (F = 2.98, p = 0.058), ease of use, risk perception and self-efficacy. High initial costs were the most prominent limitation to small farms, while absence of technical knowledge was the most crucial limitation with medium-sized farms.

Keywords: *Precision Farming; Technology Adoption; Farm Size Determinants; Farmer Producer Organizations (FPOs); Perceived Usefulness; Semi-Urban Agriculture.*

INTRODUCTION

Precision agriculture, or farming, uses GPS, sensors, drones and data analysis to create more accurate applications of agricultural inputs, though it's not yet evenly distributed in developing countries. A detailed review of adoption studies reveals that adoption is sometimes determined by the size of lands and many seemingly beneficial technologies are not widely adopted [3]. Being a smallholder, Indian farmers face significant technological, social, behavioral, operational, economic and implementation constraints to precision agriculture through UAV [1]. Perception surveys indicate that, although some respondents are positive about the use of precision agriculture approaches, the use of these practices doesn't always translate into the field [2]. Since the process of adopting innovation, particularly with respect to precision farming (PF), is intrinsically complex and social and impacted by producers, change agents, societal norms and organizational pressure, adoption is also molded by social and institutional circumstances [4]. Studies conducted in Tamil Nadu (5) and Punjab (6) reveal that use of precision tools is found to be related to institutional support, awareness and information availability. Most research focuses on either farm size or institutions or behavior. This study examines survey data from sixty farmers, tabulates the data and tries to analyze the socio-economic, institutional and behavioral determinants influencing the adoption of precision farming among the small, medium and large farmers in semi-urban India.

LITERATURE REVIEW

The take-up of precision farming is often explained by institutional, psychological and structural aspects. Farm size, availability of the resources, perceived need for technology features, technology compatibility, social influence, competitive pressure and government support were identified as factors that encouraged PA adoption at the farm level. Individual-level relative advantage, observability, trialability, farmer familiarity with technology, innovativeness and risk-taking were favorable and age and technology complexity were obstacles to PA adoption [7] at the individual level. According to behavioral studies, farmers' social environment and perceived dangers have a big impact on their intents and cognitive constructions and informal modes of information transmission might be crucial for the spread of technology [8]. The findings in the Indian context of smart farming reveal that perceived risk negatively affects the adoption of smart farming, while relative advantage, compatibility, ease of use, attitude, agriculture extension communication effectiveness and government support positively influence the adoption of smart farming [9]. Research in Tamil Nadu, India, revealed that in India, agriculture is the primary industry and hence the use of precision agriculture is generally more appropriate to fulfill the Indian producers' needs [10]. Overall, these findings suggest that size of the farm can't explain adoption and that checks of institutional and perceptual factors are of comparable importance.

METHODOLOGY

A descriptive and analytical approach to the research was adopted, using a primary survey with sixty farmers selected from semi-urban zones of Pune district through Maharashtra state and collecting data till Dec. 2023. Farmer selection was made using purposive sampling and the farmers were categorized into three farm size classes: small (< 2 ha), medium (2-5 ha) and big (> 5 ha) for direct comparison of each farm size class. A structured questionnaire was developed in the local language and included the demographic and socioeconomic profile of the respondent, farm characteristics and technology exposure, awareness and information source and five behavioral constructs measured on a five-point scale. With respect to the actual use of precision farming tools, respondents were asked whether or not these tools were used. The schedule underwent changes and pretests with non-sample / pilot farmers (not included in the main sample) prior to the main survey. The construct items' internal consistency was assessed using Cronbach alpha. SPSS was used to input and process the data. Cramer's V, odds ratios with 95% confidence intervals, one-way ANOVA with Tukey HSD post hoc analysis, percentages, cross tabulations, chi-square tests (adjusted for Fisher's exact test when expected counts were 5 or less) and effect sizes were used, with a significance level of 0.05.

OBJECTIVES

- To investigate the connection between semi-urban farmers' adoption of precision farming and farm size.
- To analyze the influence of institutional membership (FPO/cooperative), awareness and information sources on the adoption of precision agriculture.
- To assess differences between small, medium and large farms with regard to behavioral and perceptual variables such as perceived usefulness, ease of use, risk perception, social impact and self-efficacy.

HYPOTHESES

- **H1:** There are non-significant correlation between the adoption of precision agriculture and farm size.
- **H2:** Precision farming is not significantly related to awareness, knowledge source, or membership within an FPO/cooperative.
- **H3:** There are no significant differences between the farm-size groups regarding behavior constructs (PU, PEOU (Perceived Ease of Use), risk perception, social impact, self-efficacy).

RESULTS AND ANALYSIS

Table 1: Demographic and Socio-Economic Profile of Respondents (N = 60)

Variable	Category	Frequency (n)	Percentage (%)
Age group	Young (< 35 years)	14	23.3
	Middle-aged (35–50 years)	26	43.3
	Old (> 50 years)	20	33.3
Education	Up to primary	12	20.0
	Secondary / Higher secondary	22	36.7
	Graduate and above	26	43.3
Primary occupation	Farming only	38	63.3
	Farming + allied activities	12	20.0
	Farming + business/service	10	16.7
Annual income (₹)	Low (< 2 lakh)	16	26.7
	Medium (2–5 lakh)	28	46.7
	High (> 5 lakh)	16	26.7
Farm size	Small (≤ 2 ha)	28	46.7

Variable	Category	Frequency (n)	Percentage (%)
	Medium (> 2–5 ha)	20	33.3
	Large (> 5 ha)	12	20.0

Source: Primary survey data

Table 2: Farm Characteristics and Technology Exposure by Adoption Status

Variable	Category	Adopters (n = 21)	Non-adopters (n = 39)	Total (N = 60)
Awareness of PF	Aware	21 (100.0%)	29 (74.4%)	50 (83.3%)
	Not aware	0 (0.0%)	10 (25.6%)	10 (16.7%)
Primary source of information	Extension agents	5 (23.8%)	12 (30.8%)	17 (28.3%)
	Peer farmers	9 (42.9%)	8 (20.5%)	17 (28.3%)
	Digital media	7 (33.3%)	4 (10.3%)	11 (18.3%)
	Others / none	0 (0.0%)	15 (38.5%)	15 (25.0%)
FPO / co-operative membership	Member	15 (71.4%)	10 (25.6%)	25 (41.7%)
	Non-member	6 (28.6%)	29 (74.4%)	35 (58.3%)

Source: Primary survey data

Table 3: Behavioral and Perceptual Constructs by Farm Size (Mean Scores, 5-point Likert Scale)

Construct	Overall (N = 60)	Small (n = 28)	Medium (n = 20)	Large (n = 12)	F-value	Sig. (p)
Perceived usefulness	3.82	3.54	3.95	4.25	4.12	0.021*
Perceived ease of use	3.15	2.89	3.25	3.58	3.45	0.039*
Risk perception (higher = higher risk)	3.68	3.96	3.55	3.25	4.89	0.011*
Social influence	3.46	3.21	3.60	3.83	2.98	0.058 (n.s.)
Self-efficacy	3.26	2.96	3.40	3.75	5.21	0.008**

Note: 1 = Strongly disagree, 5 = Strongly agree. *p < 0.05; **p < 0.01; n.s. = not significant. Overall means are weighted means of the three groups.

Table 4: Adoption Status and Constraints by Farm Size

Farm size	n	Adopters n (%)	Non-adopters n (%)	Primary constraint (n)	Secondary constraint (n)
Small (≤ 2 ha)	28	5 (17.9%)	23 (82.1%)	High initial cost (18)	Lack of technical knowledge (15)
Medium (> 2–5 ha)	20	8 (40.0%)	12 (60.0%)	Lack of technical knowledge (8)	High initial cost (6)
Large (> 5 ha)	12	8 (66.7%)	4 (33.3%)	High initial cost (4)	Labour shortage (3)
Total	60	21 (35.0%)	39 (65.0%)	–	–

Note: Constraint counts refer to non-adopters only.

Table 5: Cross-tabulation and Chi-square Test of Farm Size and PF Adoption

Farm size	n	Adopters: Observed (Expected)	Non-adopters: Observed (Expected)	Adoption rate (%)	Adj. std. residual (adopters)
Small	28	5 (9.8)	23 (18.2)	17.9	–2.60
Medium	20	8 (7.0)	12 (13.0)	40.0	+0.57
Large	12	8 (4.2)	4 (7.8)	66.7	+2.57
Total	60	21 (21.0)	39 (39.0)	35.0	–
Test statistic	Test statistic	Value	df	p-value	
Pearson χ^2	Pearson χ^2	9.126	2	0.010	
Linear-by-linear (trend) χ^2	Linear-by-linear (trend) χ^2	8.945	1	0.003	
Cramér's V	Cramér's V	0.390	–	Moderate-to-strong effect	

Note: One cell (16.7%) has an expected count below 5 (minimum = 4.2). Residuals beyond ±1.96 are significant at 5%.

Note: Total df = 59. η^2 = SS between / SS total (0.01 small, 0.06 medium, 0.14 large). *p < 0.05; **p < 0.01.

Table 6: Association of Awareness, Information Source and FPO Membership with PF Adoption

Variable	Category	n	Adopters (n)	Adoption rate (%)	χ^2	df	p-value	Effect size
Awareness of PF	Aware	50	21	42.0	6.462	1	0.011 (Fisher exact p = 0.011)	φ = 0.328
	Not aware	10	0	0.0				
FPO / co-op membership	Member	25	15	60.0	11.774	1	0.001 (0.0006)	φ = 0.443
	Non-member	35	6	17.1				OR = 7.25 (95% CI 2.21–23.80)
Primary information source	Extension agents	17	5	29.4	14.681	3	0.002	Cramér's V = 0.495
	Peer farmers	17	9	52.9				
	Digital media	11	7	63.6				
	Others / none	15	0	0.0				

Table 7: One-way ANOVA of Behavioral Constructs across Farm-Size Groups

Construct	Source	SS	df	MS	F	p-value	η^2
Perceived usefulness	Between groups	4.752	2	2.376	4.12	0.021*	0.126
	Within groups	32.871	57	0.577			
Perceived ease of use	Between groups	4.311	2	2.156	3.45	0.039*	0.108
	Within groups	35.615	57	0.625			
Risk perception	Between groups	4.752	2	2.376	4.89	0.011*	0.146
	Within groups	27.695	57	0.486			
Social influence	Between groups	3.784	2	1.892	2.98	0.058 (n.s.)	0.095
	Within groups	36.188	57	0.635			
Self-efficacy	Between groups	5.792	2	2.896	5.21	0.008**	0.155
	Within groups	31.682	57	0.556			

Table 8: Tukey HSD Post-hoc Comparisons of Farm-Size Groups

Construct	Comparison	Mean difference	SE	q-statistic	Cohen's d	Decision
Perceived usefulness	Small – Medium	–0.41	0.157	2.61	0.54	n.s.
Perceived usefulness	Small – Large	–0.71	0.185	3.83	0.93	$p < 0.05$
Perceived usefulness	Medium – Large	–0.30	0.196	1.53	0.40	n.s.
Perceived ease of use	Small – Medium	–0.36	0.164	2.20	0.46	n.s.
Perceived ease of use	Small – Large	–0.69	0.193	3.58	0.87	$p < 0.05$
Perceived ease of use	Medium – Large	–0.33	0.204	1.62	0.42	n.s.
Risk perception	Small – Medium	+0.41	0.144	2.84	0.59	n.s.
Risk perception	Small – Large	+0.71	0.170	4.18	1.02	$p < 0.05$
Risk perception	Medium – Large	+0.30	0.180	1.67	0.43	n.s.
Social influence	Small – Medium	–0.39	0.165	2.36	0.49	n.s.
Social influence	Small – Large	–0.62	0.194	3.19	0.78	n.s.
Social influence	Medium – Large	–0.23	0.206	1.12	0.29	n.s.
Self-efficacy	Small – Medium	–0.44	0.154	2.85	0.59	n.s.
Self-efficacy	Small – Large	–0.79	0.182	4.34	1.06	$p < 0.01$
Self-efficacy	Medium – Large	–0.35	0.192	1.82	0.47	n.s.

Note: Tukey–Kramer SE = $\sqrt{[(MSW/2)(1/n_i + 1/n_j)]}$. Critical q (k = 3, df = 57) ≈ 3.41 at α = 0.05 and ≈ 4.29 at α = 0.01. Cohen's d uses the pooled SD (√MSW).

Table 9: Adoption Rates with 95% Confidence Intervals and Pairwise Odds Ratios by Farm Size

Panel A: Adoption rates (Wilson 95% CI)

Farm size	n	Adopters	Adoption rate (%)	95% CI (%)	Odds of adoption
Small	28	5	17.9	7.9 – 35.6	0.217
Medium	20	8	40.0	21.9 – 61.3	0.667
Large	12	8	66.7	39.1 – 86.2	2.000
Overall	60	21	35.0	24.2 – 47.6	0.538

Panel B: Pairwise odds ratios (Wald test)

Note: Significance level α = 0.05.

Table 10: Testing of Hypotheses

Comparison	Odds ratio	95% CI	z	p-value
Medium vs. Small	3.07	0.82 – 11.45	1.67	0.096
Large vs. Small	9.20	1.97 – 42.99	2.82	0.005
Large vs. Medium	3.00	0.67 – 13.40	1.44	0.150

Hypothesis (H_0)	Test applied	Test statistic (df)	p-value	Decision
H1	Chi-square test of independence	$\chi^2 = 9.126$ (df = 2); Cramér's V = 0.390	0.010	H_0 rejected; H1a accepted
H2	Chi-square test (Fisher's exact for awareness)	Awareness: $\chi^2 = 6.462$ (df = 1) Information source: $\chi^2 = 14.681$ (df = 3) FPO membership: $\chi^2 = 11.774$ (df = 1)	0.011 0.002 0.001	H_0 rejected; H2a accepted
H3	One-way ANOVA	Usefulness: F = 4.12 Ease of use: F = 3.45 Risk perception: F = 4.89 Social influence: F = 2.98 Self-efficacy: F = 5.21 (df = 2, 57 for all)	0.021 0.039 0.011 0.058 0.008	H_0 rejected; H3a accepted (at least one group differs)

DISCUSSION

The findings are in line with general data, indicating that adoption is not only driven by technological factors but also by farm size, institutional support and perception. Adoption rates are a variable that varies both within and across regions, crops and farm sizes, with high start-up costs and lack of technical knowledge and infrastructure challenges identified as the constraints for diffusion in India [11]. Greater adoption by large farms and among members of an FPO could support the claim that FPOs aggregate land under one roof (without changing the ownership structure), allowing economies of scale and that the cooperative nature of the models makes adoption of precision technologies economically more feasible and a more effective knowledge transfer mechanism. This is also aligned with the argument that the small farmers are not yet ready to adopt precision farming techniques even because of a lack of understanding of the precision farming concept, the crippling cost of precision technology, etc. [13]. This means that knowledge alone is not enough; practical training is important, as poor infrastructure, restricted funding and lack of understanding and access to technology continue to be key challenges [14]. Farmers should not be viewed as a single entity; policy should be adjusted for the small and medium-sized farmers, as the involvement and range of PA differ among countries due to many factors, including socioeconomic conditions, technicians, land size, etc. [15].

CONCLUSION

Of course the size of the farm is important, but that isn't all. The bigger the holding size, the higher the adoption, but the reasons for this trend are as much institutional and social as economic in nature. Information flows better through trusted networks than through official channels alone, evidenced by farmers being much more willing to try the technology if they learn of it from fellow farmers or their phones. In addition, small farmers may perceive that the technology is more risky and that it is harder to use and awareness raising is not enough to alter their opinion. Practical demonstration, sharing equipment and guided technical assistance / hand-holding support are likely to be more effective on the village level. Thus, instead of calling upon individual small farmers to invest alone, the extension agencies and farmer associations should create facilitating mechanisms for collective buying and collective use. One size doesn't fit all farms and the ones that most need the help will continue to be overlooked in policy formulation.

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