



Farmer readiness for Ag-IoT adoption in India: A survey study

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ABSTRACT

Internet of Things based Agriculture (Ag-IoT) is widely adopted by farmers and agriculturists worldwide. Ag-IoT involves technologies such as the internet, sensors, and communication technologies that help automate agricultural labour and improve monitoring, efficiency, and cost. The survey was conducted during 2021 to 2024 with the objective to find out the farmers' readiness for adopting Ag-IoT ecosystems in India using qualitative research methodology, and data were collected through a questionnaire and one-to-one interviews with 100 farmers from six states of India. The findings indicated that 86% of respondents expressed willingness to adopt Ag-IoT technologies. 61% of respondents have no concern of security and privacy in Ag-IoT. However, only 24% of farmers were aware of Ag-IoT, indicating a significant awareness gap about Ag-IoT solutions, security and privacy. Also, the outcome score of 46.19 from the correlation analysis indicated the positive influence of study parameters on the conclusions drawn from our study. The outcomes of this survey can be used by policymakers, researchers, and technology developers to design strategies to promote the secure and effective adoption of Ag-IoT solutions in agricultural communities. Specifically, security researchers need to develop suitable digital forensics and incident response management solutions for Ag-IoT to support its growth and adoption.

Keywords: Ag-IoT security challenges, Digital transformation, Rural agriculture digitisation, Smart agriculture

The Food and Agriculture Organisation (FAO) of the United Nations (UN) reported that 60% of the world's population relies on agriculture for their livelihood, and there will be a need for a 70% increase in food production by 2050 (Mekouar 2018). Various factors, such as population growth, and shrinking farmland necessitate the exponential growth in agricultural production. To meet the substantial food grain requirement of 480 mt by 2050, developing countries like India require a rapid adoption of agricultural modernisation strategies (Ahmad *et al.* 2024). Industrial agriculture 4.0 has significantly improved agriculture efficiency and production in the last 50 years by optimising the use of land, seeds, and other resources (Goedde *et al.* 2020).

India has achieved a mechanisation level of 40–45%, while the United States are at 95%, Australia at 90%, Japan at 99%, South Korea at 97%, Brazil at 75%, and China at 91% (Trendov *et al.* 2019). Internet of Things based Agriculture (Ag-IoT) employs communication technologies, embedded systems, microcontrollers, and sensors to automate the functionality of agricultural activities (Rudrakar and Rughani 2023). By implementing Ag-IoT, various costs such as labour

wages, fertiliser and pesticide consumption rates can be significantly reduced, making Ag-IoT a cost-effective and eco-friendly approach to food production (ADB 2018). A study conducted in India and Kenya exposed the challenges faced by smallholder agriculture in implementing Ag-IoT, such as issues related to measurement devices, limited access to components, device design, sensor calibration, and associated expenditure (Antony *et al.* 2020).

Hence, the novel contributions of our study aimed to survey 100 farmers from six different states which represents a relatively broader area; a conceptual framework to define farmer readiness based on certain parameters and a thorough statistical analysis of the responses received from the farmers to draw useful conclusions for informed decisions and policy designs from the appropriate stakeholders.

MATERIALS AND METHODS

Survey study design: The cross-sectional qualitative survey was conducted during 2021 to 2024 to evaluate the preparedness of farmers in India to adopt Ag-IoT, which enables the collection of multidimensional parameter's data. The study consisted of two types of survey i.e. primary data collection through a survey and secondary data analysis from literature.

Primary data collection was carried out through a survey of 100 farmers from six states in India, namely

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Gujarat, Madhya Pradesh, Rajasthan, Punjab, Maharashtra, and Andhra Pradesh, ensuring geographical diversity. The responses were collected through one-to-one interviews and telephone calls, with each interview lasting approximately 15 min. Our study employed a purposive sampling approach to survey 100 farmers. Most of the respondents were from rural farming communities, as the study focused on agricultural practices. A small number of peri-urban farmers engaged in commercial farming were also included. Respondents were recruited through farmer associations, local contacts, and agricultural extension networks, and those willing to participate voluntarily completed the survey. To ensure farmers’ understanding of technical terms related to Ag-IoT, the survey introduced various terminologies, including smart

farming, Ag- IoT, automatic systems, smart irrigation, smart pesticides/fertiliser sprinklers, and smart livestock farming. All these technical terms were explained to farmers before conducting the interviews.

Questionnaire: To collect farmers' perspectives on readiness to adopt Ag-IoT, a structured, multi-section questionnaire was developed with 10 questions (Table 1). The initial questions were evaluated by experts, including academic researchers in Ag-IoT and domain practitioners. Later, a pilot study was conducted among selected farmers from Maharashtra to evaluate the clarity and relevance of the questions. Feedback from the pilot study was used to further refine the questionnaire. To ensure simplicity and ease of participation for farmers, the questionnaire was

Table 1 Interview questionnaire

S.no.	Interview question	Purpose of the question	Parameter
1	Education (Uneducated/(5 th) or Below 5 th Middle school (8 th)/High School (10 th) Higher Secondary School (12 th)/Bachelor's degree/ Master's degree Above master's degree)	To know about the literacy rate of farmers and their understanding of English language proficiency.	P1
2	Are you able to operate or use a smartphone from your farm?	To estimate farmers' digital literacy level.	P1
3	How much agricultural land (in acres) does a farmer own, less than 3 acres, Less than 7 acres, or Above 7 acres?	The land area is classified into three parts which will help us with better data analysis. This question helps to get the answer to their level of difficulty in managing their farm and if they are looking for any smart facility to deal with this difficulty.	P2, P8
4	What kind of facilities/applications/equipment do you have for efficient agriculture? (Thresher/Plougher/Tractor IoT based device for agriculture others/No Facilities of Machines)	This question solicits farmers' awareness about emerging agricultural amenities and the economic flexibility to adopt them.	P3, P8
5a	Which farming would you like to prefer? Manual farming, Mechanical farming or smart farming?	Before seeking a response, farmers were clarified with the meaning of manual farming, mechanical farming, and smart farming. Manual farming means farming only with human labour and typical agricultural tools. Mechanical farming includes mechanisation, and smart farming includes the automation of agricultural labour using technology.	P4
5b	Would you like to shift existing agriculture to Ag-IoT?	This question helps to understand farmers' perception of adopting a new type of agriculture.	P4
6a	Why would you like to shift existing agriculture to Ag-IoT?	To understand the motivation and purpose behind their move to adopt Ag-IoT.	P5
6b	In what factors IoT based smart agriculture is beneficial?	To get the answer about what benefits they are calculating while adopting Ag-IoT.	P5
7	Do you think that language can be an issue or challenge for using IoT based tools in Ag-IoT?	This will provide suggestions for designing multilingual Ag-IoT solutions for better acceptance and adaptability.	P5
8a	Do you have relevant information about the service center for repairing smart appliances?	Awareness on availability of Service center city to get quick repairing of Ag-IoT devices	P6
8b	How far is the service center from your location (If you would like to repair the Ag-IoT based devices)?		P6
9	What are the challenges/issues/obstacles that you may have to face while using Ag-IoT?	To know what limitations are there which prevent its adoption.	P7
10	Do you think there can be any type of security/data privacy issues with smart agriculture?	This question helps to know the understanding level of cyber-attacks and security and get the knowledge about their concern about digital privacy.	P9, P10

designed to be straightforward and time-efficient, requiring minimal assistance to answer.

Conceptual framework for farmer readiness: In this section, we present a conceptual framework for a structured approach to interpreting the data as given in Fig. 1. Each question was mapped with a parameter that defines a specific aspect of readiness from farmers.

RESULTS AND DISCUSSION

Demographic data compilation: In this study, majority of the farmers participated were accounted as male at 96%, and female about 4%. The respondents' educational levels varied considerably with 22% graduated, 17% higher secondary, and a small group completed their primary or middle school education, whereas 5% never schooled (Table 2).

Farmers' digital literacy rate (P1): This survey observed that 43% of farmers reported finding it easy to follow operational instructions for Ag-IoT solutions given in English whereas 48% of farmers perceived it as challenging because of language barriers. Manufacturers designing working manuals and mobile application controls in local languages could potentially address this issue (Table 3).

Agricultural Land (P2): In terms of landholding, 52% farmers owned small landholdings of less than 3 acres, followed by 28% with medium-sized landholdings (3–7 acres) and 20% with large landholdings (7+ acres). For evaluation, we consider the smaller land size owned by the majority (52%) of farmers (Table 2).

Agricultural amenities (P3): This survey observed that 31% farmers have basic agricultural amenities (water-pump). 25% of farmers own heavy machinery (sprayers, power-tillers, threshers, plows, and tractors). 31% of farmers

possess semi-automated machines, 2% Ag-IoT, while 45% have no amenities due to poor economy. For evaluation, we considered all the farmers who have at least one amenity were 55%.

Preference between traditional farming and smart farming (P4): According to our survey, 86% of the farmers expressed interest in adopting Ag-IoT. The positive response from farmers indicated a willingness to embrace new technologies (Table 3).

Influencing factors towards Ag-IoT (P5): The farmers highlighted several benefits of Ag-IoT, such as better monitoring capabilities (89%), time saving (88%), and low labour costs, better automation and monitoring (86%), and greater yields (83%). This highlights the farmers' expectation that Ag-IoT offers potential cost savings. For evaluation, we considered the average response of 86% of people believing Ag-IoT as beneficial.

Availability and distance of service centers (P6): The study found that a service center for Ag-IoT is located away from their homes approximately 25 km for 27% of the respondents, 50 km for 25% of farmers while 100 km for 41% farmers. Moreover, 7% of farmers reported that they have to travel more than 100 km in search of a service center. For evaluation, we considered an average distance of 50 km to include the service center as proximate. Total 49 farmers reported the distance up to 50 km.

Cellular network-based internet accessibility (P7): To connect to the Internet, Ag-IoT relies on cellular network connectivity. The range of the cell network directly impacts data transfer speed and the reliability of the connection (Virk *et al.* 2020). The survey reported that only 48% of farmers have access to the internet, while 43% of farmers do not receive cellular network coverage, and 9% of farmers lack information about the coverage area network. Furthermore, approximately 22% of farmers cannot access cell phone networks on their farms. These issues pose significant obstacles to the successful implementation of Ag-IoT. For evaluation, we considered the unavailability of network coverage reported by 22% farmers.

Economic status of farmers (P8): Our survey observed that 64% of farmers can't afford Ag-IoT solutions due to their poor economic status, and 61% of farmers were unaware of Ag-IoT terminology. The status can be improved by providing subsidies, grants, or financial assistance programmes specifically targeted towards the adoption of Ag-IoT making it more accessible to farmers.

Ag-IoT security/threat awareness among farmers (P9): The implementation of various embedded devices in Ag-IoT introduces potential security and cyber threat risks, as they are vulnerable to hacking and unauthorised manipulation (Rudrakar and Rughani 2023, Rudrakar *et al.* 2023). From the farmers' responses, it was analysed that 61% of the farmers believe that there would be no security or privacy breaches while using Ag-IoT devices. About 31% of farmers expressed concerns about the possibility of data privacy breaches. Remarkably, 8% of the farmers were unaware of the security threats associated with Ag-IoT. For evaluation,

Table 2 Demographic data of responders

Variable	Category	Frequency	Percentage
		(n)	(%)
Gender	Male	96	96
	Female	4	4
Education level	Uneducated (Never attended school)	5	5
	Primary school (till 5 th)	12	12
	Middle school (6 th to 8 th)	16	16
	High school (9 th and 10 th)	19	19
	Higher secondary (11 th and 12 th)	17	17
	Graduate (Bachelor's degree)	22	22
	Master's degree	6	6
Landholding size	Small (<3 acres)	52	52
	Medium (3–7 acres)	28	28
	Large (>7 acres)	20	20

Table 3 Farmers' response to different parameters

Farmers behaviour/Thought	Yes	No	May be
Farmers would like to shift existing agriculture into Ag-IoT	86%	8%	6%
Farmers can operate or use a smartphone from their farm	77%	21%	2%
Language as a challenge for using IoT based devices in Ag-IoT	48%	52%	NA
Did Farmers have relevant information about IoT-based devices in Ag-IoT?	24%	76%	NA
Farmers believe that the use of Ag-IoT reduces labour costs or beneficial.	86%	9%	5%
Farmers feel security/data privacy/ breaches issues in Ag-IoT?	31%	61%	8%

we considered 8% as unaware and 92% as aware of the farmers (Table 3).

Despite India being the second-largest internet user, only 42% users are aware of cybersecurity and privacy issues while the China and the USA have awareness rates of 36% and 83%, respectively (Lin *et al.* 2022). This lack of awareness may make farmers easy targets for attackers to disrupt the Ag-IoT systems in India.

Cyber attacks on Ag-IoT(P10): The integration of the internet and communication technology into agriculture enables remote access for farmers to obtain real-time data about their farms and livestock (Rudrakar *et al.* 2024). However, this convenience also exposes Ag-IoT to potential attacks targeting vulnerabilities in IoT devices and communication protocols. According to Union Ministry of Home Affairs (MHA), there has been an increase of over 400% in cybercrime incidents in India over the last four years (Ranjan 2025). Hence, it is crucial to anticipate security incidents and proactively implement security measures for Ag-IoT ecosystems. Furthermore, there is a pressing need for the digital forensics community to develop forensic-ready solutions that enable effective investigation outcomes in case of security breaches. These measures safeguard Ag-IoT ecosystem against threats and ensure its long-term sustainability in India. For evaluation, we consider the responses of parameter 9.

Correlation analysis based on survey results: The survey responses are statistically analysed and evaluated against the proposed conceptual framework to draw certain conclusions as given in Fig. 1 and Table 4. The conclusions (C1–C5) are divided into two levels, where Level 1 represents C1–C4 and Level 2 represents C5. From Fig. 1,

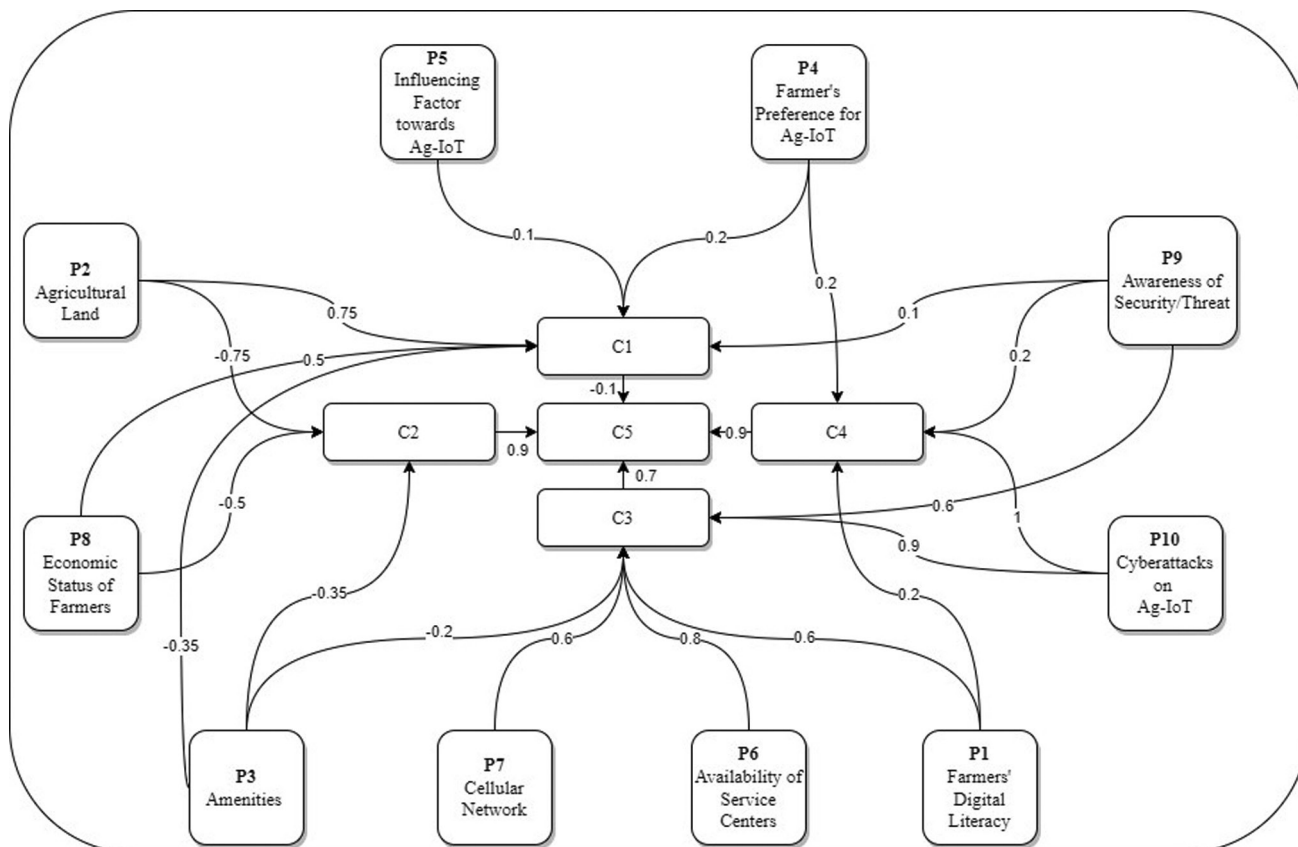


Fig. 1 The conceptual framework for farmer readiness for Ag-IoT adoption in India: Correlation with Parameters and Conclusions^{C1-C5}. C1, Increase in agricultural production/profit/economy, Contribution to farmers' income, GDP of the country and ability to meet growing food demand; C2, Barrier to agricultural production/ Profit/ Economy, lacking farmers' income, GDP for the country, and inability to meet growing food demand; C3, Risk of failure of Ag-IoT System, impact on crop production, Extra cost for labour and service, Reduced cost efficiency; C4, Increase in the rate of cyberattacks on Ag-IoT Systems; C5, Decline in the adoption rate of Ag-IoT, Need for awareness about Ag-IoT, Potential need to develop solutions for digital forensics and incident response management in Ag-IoT.

Table 4 Correlation analysis of proposed framework based on survey results

Parameter (P)	P weight	P score	Conclusion level-1	CL1 weight	CL1 score	Conclusion level-2 (C5)
P2	0.75	52	C1	-0.1	55.62	46.19
P3	0.35	55				
P4	0.2	86				
P5	0.1	86				
P8	0.5	36				
P9	0.1	92				
P2	-0.75	52	C2	0.9	56.40	
P3	-0.35	55				
P8	-0.5	64				
P1	0.6	83	C3	0.7	37.54	
P3	-0.2	55				
P6	0.8	49				
P7	0.6	22				
P9	0.6	8				
P10	0.9	31				
P1	0.2	17	C4	0.9	43.75	
P4	0.2	86				
P9	0.2	92				
P10	1	31				

we observed that level-2 depends on level-1, and level-1 depends on all parameters P1–P10. In our evaluation, we substituted the scores for each parameter to calculate the scores for level-1 and finally, these scores were used to obtain the level-2 score. From the results, we understood that there is a moderate positive influence of 10 chosen parameters on the conclusions of level-1. Similarly, C1–C4 also have a moderate positive influence on the conclusion C5. The adoption of Ag-IoT has shown promising results in developed countries and holds significant potential for similar growth in developing nations like India. To ensure the widespread adoption of Ag-IoT in India, it is important to address few primary challenges, such as awareness of technology, affordability, security concerns among farmers through government initiatives, research and development.

Limitation: While the respondents of this survey represent diverse educational and experiential backgrounds, the sample size of 100 is relatively small compared to the total farming population of the country. The results reflect the perceptions of the sampled farmers across six states and may not represent all farmers in India.

Overall, this study explored the readiness of farmers for adopting Ag-IoT through a survey of 100 farmers from six Indian states. The findings of this study indicated that majority (86%) of farmers expressed interest in shifting toward Ag-IoT. However, the correlation analysis highlighted a significant influence of study parameters on Ag-IoT adoption, such as varying levels of digital literacy, limited awareness of IoT-based agricultural devices, and cybersecurity concerns. By addressing these challenges,

policymakers, researchers, and technology providers can support the responsible growth of Ag-IoT. Although the survey represents a small sample of farmers from selected regions, we believe it provided useful insights for developing strategies to promote the growth of Ag-IoT in India.

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