Unraveling the Drivers and Barriers of Wireless Sensor Networks (WSNs) Uptake Amongst Grape Growers in Maharashtra

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Abstract: Globally, 70 per cent of water is used for irrigation, and there is a huge gap in fresh water and irrigation requirements to feed the growing world population owing to resource constraints. In India, 80 per cent of water is used for irrigation purposes owing to the irregulated consumption posed by drought situations. The method of irrigation in the current scenario does not account for weather forecasts, soil moisture in the root zone, evapotranspiration, plant growth stage, and crop coefficient. Irregulated irrigation can lead to plant water stress, which, in turn, leads to slow growth and low productivity. Therefore, sustainable water use is necessary in India. Precision farming is a solution to most agricultural problems faced by India, although the adoption of this technology is nascent in India. Understanding the benefits and adoption behavior of precision technology, such as WSNs, requires much attention for broader adoption. Most existing literature has focused on developed nations, which may not be suitable for developing nations. This study investigates the factors responsible for WSN uptake and the level of adoption among grape farmers in Maharashtra State, India. Cross-sectional data were collected via a survey using a multistage sampling framework. Water saving and crop dynamics also emerged as significant factors for the level of adoption. However, high costs, fragmented land holdings, institutional issues, and gender inclusivity are barriers to adoption. The findings emphasize support from the government and design technologies with reasonable cost and durability to lower service charges. Overall cost, service charge, farm size, and institutional support are necessary for the diffusion of technology in developing nations, providing relevant insights for policymakers, service providers, and developers.

1 INTRODUCTION

Globally, 70 per cent of water is used for irrigation, and there is a huge gap in fresh water and irrigation requirements to feed the growing world population owing to resource constraints. The agriculture sector alone sustains the livelihood of around 55 per cent of India's population and contributes nearly 18.6 per cent to the gross domestic product. India is characteristically a country of small agricultural farms, where approximately 80 per cent of the total land holdings are less than 2 ha with 30 per cent irrigated land only. India has made tremendous progress in food production over time due to various technological interventions and achieved a production level of 319.57 million tonnes during 2019-20. However, Indian farmers still face significant challenges in terms of optimizing resource use, minimizing crop losses, and increasing overall productivity. These challenges include limited access to water resources, unpredictable weather patterns, inadequate irrigation systems, and pests and diseases that affect crop health. Furthermore, the increasing population and changing dietary patterns in India pose additional pressure on the agricultural sector to produce more food.

Agriculture has seen many revolutions, including the domestication of animals and plants a few thousand years ago, the systematic use of crop rotations, and other improvements in farming practices a few hundred years ago, or the "green revolution" with systematic breeding and the widespread use of man-made fertilizers and pesticides several decades ago (Walter et al., 2017; Vashishth et al., 2021). Agriculture is currently undergoing a fourth revolution triggered by the exponentially increasing use of information and communication technologies (ICT) (Vashishth et al., 2021). Over the years, agricultural methods have not improved much, and farmers still use conventional

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strategies based on expectations of the crop's nutritional needs. Delivering the same nutrient input across the entire farm is no longer the best choice, as it leads to heavy fertilizer and pesticide usage, unnecessary water consumption, environmental degradation, and high crop production costs. There is an urgent need to adopt more farmer-friendly location-specific production management strategies in a concerted manner to achieve vertical growth in production with ensured quality of produce and judicious use of natural resources for better returns per unit area. In this context, precision farming has the potential to efficiently utilize resources per unit of time and area to achieve sustainable agricultural practices and increase productivity.

A broad definition of precision agriculture based on that provided by the National Research Council (NRC, 1997) is as follows "Precision agriculture is a management strategy that uses information technologies to provide and process data with high spatial and temporal resolution for decision-making concerning crop production". In India, the definition of precision agriculture varies due to small land holdings, even with the large and progressive farmers. suitable definition in India is " Precise application of agricultural inputs based on soil, weather and crop requirement to maximize sustainable productivity, quality, and profitability i.e. minimum input-maximum output approach." Precision agriculture in India is gaining importance owing to various factors. One of the main factors is the increasing population and changing dietary patterns in India, which are putting additional pressure on the agricultural sector to produce more food. Another factor is the need for sustainable and environment-friendly agricultural practices. In recent years, research has been conducted to evaluate the effectiveness of Wireless Sensor Networks (WSNs) in agricultural research plots. Several agricultural start-ups have entered the Indian market to introduce WSNs to farming fields. The Indian government also plans to provide farmers with sensors, due to the advantages of this technology. WSNs are wireless networks that are composed of base stations and numerous nodes (wireless sensors). These networks are utilized for monitoring environmental or physical conditions, including temperature, pressure, and sound, and for transmitting data collaboratively through the network to a central location. A WSN is comprised of a series of small, low-cost, low-energy, and easily deployable sensors (Pazand & Datta, 2008). These sensors are utilized in agriculture (Casto et al., 2021). Wireless sensor networks are required for precision agriculture for several reasons. Wireless sensor networks monitor various parameters such as temperature, humidity, soil moisture levels, and crop growth, firstly, provide timely and informed decisions regarding irrigation, fertilization, and pest control, leading to more efficient use of resources and improved crop yields (Musa et al., 2022; Naresh et al., 2020; Liu, 2022). These data allow farmers to implement targeted irrigation practices, minimize water waste, and ensure optimal water use. Second, wireless sensor networks eliminate the need for physical wiring and manual data collection, reduce labor-intensive tasks, and allow farmers to focus on other aspects of farming. In addition, wireless sensor networks enable data transmission over long distances, making it easier for farmers to monitor and manage large agricultural areas. Third, wireless sensor networks can provide early warning systems for weather conditions, crop diseases, and pest infestations (Thakur et al., 2019; Li et al., 2020). This helps farmers take preventive measures and minimize potential losses (Thakur et al., 2019; Wang et al., 2006; Li et al., 2020; Kumar & Paramasivam, 2017). Furthermore, sensor networks are cost-effective and scalable, making them suitable for implementation in diverse agricultural landscapes in India. These advantages make wireless sensor networks an essential tool for precision agriculture in India, helping farmers optimize their farming practices, reduce costs, and increase productivity.

Sensor networks allow them to make data-driven decisions and apply resources, such as water, fertilizers, and pesticides, more efficiently (Thakur et al., 2019). Precision agriculture using wireless sensor networks is gaining traction in India (Shah et al., 2009). Farmers increasingly realize the benefits of adopting precision agriculture techniques supported by wireless sensor networks. These techniques not only improve overall crop yields but also reduce production costs and minimize environmental impacts.

The adoption of precision farming technology has been studied extensively, with research focusing on factors such as farm size, education levels, and perceptions of net benefits. Attitudes and perceptions of farmers towards precision farming are crucial in determining their willingness to adopt. Cost, complexity, and reliability concerns can hinder adoption, while access to information and training programs, demonstration plots, and extension services can play a vital role. The opinions and experiences of peers, family members, and community members may also influence adoption. Government policies, support measures, and incentives can promote adoption. While previous studies have evaluated socio-economic factors affecting precision agriculture adoption using a single precision technology mostly from developed country contexts, valuable references for policy-making have been provided by previous studies, but further research is necessary to fully understand the factors affecting precision farming technology adoption in developing countries. The adoption of WSNs in developing countries, particularly India, has been understudied in the literature. This paper evaluates the perceptions of WSN technology, attitudes toward adoption, barriers to uptake, and final adoption decisions. In this study, the study advances the literature related to adoption by focusing on characteristics corresponding with the number of WSNs adopted in India. The paper aims to fill these gaps by examining various factors, including socioeconomic, agro-economic, financial, and institutional characteristics, that may influence the intention to adopt and barriers in WSNs widespread uptake.

2 METHODOLOGY

2.1 Field Survey

Data for this study were obtained from a survey of grape producers from Nashik District (Dindori, Niphad, Sinar, and Chandwada blocks) of Maharashtra. The primary data were collected through a questionnaire survey to obtain information about producer drivers and barriers to WSN. A multi-stage random sampling method was used to select households. District, Taluks, villages, and WSN-adopted householders were similarly selected in 12 villages with the help of agriculture start-ups (Fyllo, Fasal, Sensartics pvt ltd, Jio Agri, Yuktix,) working in this area. 50 (n=50) farmers were selected based on the current adoption of WSNs and those who have at least used technology for a minimum of 3 years. This study purposely concentrates on Nashik. Firstly, Nashik's geographical location and climate are conducive to grape cultivation. Additionally, Nashik has a long history and tradition of grape cultivation, with established infrastructure and expertise in grape farming practices due to the highest area under this crop farmers tends to use new technology to be efficient in the production. Grape crop selection is mainly due to more number of adopters available compared to other crops. WSNs uptake in India mainly for commercial crops and horticulture crops due to their high profits such as sugarcane, pomegranate, chili, banana, apple, guards and orange (Fig.1). Grape soil-water status constitutes one of the main driving factors that affect plant vegetative growth, yield, and wine quality. using a wireless sensor network in grape cultivation can provide continuous measurement of soil and crop parameters to characterize the variability of soil water status, which can help grape growers maximize crop yield and minimize susceptibility to various pests and diseases. Additionally, the technology can facilitate the creation of a real-time networked database that can be used to design the planting layout, irrigation, and fertilization system layout. Sula Vineyards in Nashik, India provided field support during the deployment of the wireless sensor network at their farms (Shah et al., 2009). In the Nashik Grape industry, many Agri start-ups introduced wireless sensor network technology in the fields of farmers for irrigation and microclimate monitoring purposes.

2.2 Empirical Approach

Perceptions and barriers were collected from the adopted farmers using a survey method. The obtained results were analyzed using descriptive statistics. Follow-up open questions were asked to respondents who could volunteer further reasons for their responses around intended adoption and barriers while hindering the uptake of WSN (Barnes et al., 2019; Maheswari et al., 2008).

3 FINDINGS

3.1 Socio-Economic Characteristics

Table 1 provides descriptive statistics summarizing the distribution of key continuous variables in the survey data for the 50 farmers. Regarding precision agriculture technology adoption, respondents use 2.78 technologies on average, though utilization ranges from 1 to 10 technologies demonstrating substantial variation. The mean education level is approximately senior secondary at 13.22 years, with a fair degree of dispersion between 10 and 17 years. Meanwhile, the average farm size consists of 14.59 acres but the spread spans very small 5 acres to quite large 53 acre holdings. Looking at wireless sensor network specifics, the mean coverage area is 7.41 acres, though deployment reaches up to 30 acres in maximum cases. Correspondingly, the average annual cost of WSN amounts to a substantial Rs. 107,000, but with extreme variation from Rs. 20,000 to nearly Rs. 500,000 for sophisticated systems - Showing major differences in technology sophistication. The associated annual average service charge lies around Rs. 7,500 with similar variability. For farmers themselves, mean year of experience stands at 29 years highlighting highly seasoned cultivators. Farming households typically engage 2 workers, largely family members, but labour provision extends up to 8 members revealing wide-ranging labour resourcing. Reasonable mean distances to agriculture extension agents suggest moderate geographical access at 5.91 km. Lastly, annual revenue from grape cultivation averages Rs. 434,000 across sampled farmers, capturing largely commercially-focused profitable growers, but ranges from Rs. 200,000 to Rs. 650,000 in exceptional cases. Thus, while averages indicate overall representative central tendencies, substantial deviations highlight the diversity across grape farms in the study region.

Table 1. Descriptive statistics of continuous variable

Factors	Mean	Min	Max	SD
Num_of_ technology	2.78	1	10	2.45
Education	13.22	10	17	2.18
Farm_ Size	14.59	5	53	10.16
Total_Area_ WSN	7.41	2	30	5.83
Farming experience (Years)	29	5	60	13.65
No_person_ farming	2.25	1	8	1.22
Num_YR_ Insta	3.66	2	5	0.83
Distance_ agent	5.91	0	15	3.19
Cost_ WSN	107000	20000	490000	107265.25
Service_ charge/ Yr	7523.44	2000	15000	4467.79
Farm_income (000)	434000	200000	652000	100439.78

Table 2 provides a descriptive summary of the key socioeconomic characteristics of the 50 farmers that have adopted wireless sensor network (WSN) technologies. The sample has relatively high levels of education, with most possessing 10-15 years of schooling and only 15.6 per cent having very advanced qualifications. In terms of farm size, distribution is balanced between medium (4-10 acre) and large-scale (>10 acre) holdings, allowing reasonable comparison. Regarding age, most fall into the active 31-50 years (68.8%), followed by the 51-60 years' group. Only 6.2 per cent represent younger generation farmers under 30 years old.

Furthermore, the most common level of farming experience is 11-30 years (43.8%), pointing to the prevalence of highly seasoned agriculturalists, potentially more amenable towards technology integration. Social category membership leans more towards the general category (62.5%) rather than other backward classes. In addition, while sole proprietor-cultivators constitute 12.5 per cent, the majority rely on family-based collective farming groups of 2 members (68.8%) revealing moderate household sizes on grape farms. Income levels show polarization towards mid-tier groups making Rs. 310,000–500,000 annually (71.9%), still representing largely profitable commercial activities supporting technology purchases.

Moreover, strong social capital exists through widespread agricultural organizational membership (81.2%) that can enable WSN technology diffusion through peer networking. The branch of farmers without access to credit is also limited at 21.9 per cent, though it would be critical to evaluate if this prohibited adoption in other cases. Peer influence in adoption decisions is also prevalent at 71.9 per cent, highlighting the need for visible pilot trials and testimonials to motivate adoption. In summary, the profile of these WSN adopters consists largely of commercially focused, small-scale grape producers with extensive cultivation expertise balanced with a mid-career orientation amenable towards innovation.

Table 2. Socio-economic characteristics distribution of WSNs adopted farmers

Parameter	Adopted farmers (%)
Num_of_technology	
Low intensity (1-3)	37.50
Medium intensity (4-8)	53.13
High intensity (9-11)	9.38
Farm size (Acre)	
Medium farmers (4-10)	53.1
Large farmers (>10)	46.9
Age (Yrs)	
Less than 30	6.2
31-50	68.8
51-60	12.5
More than 61	12.5
Education (Yrs)	
10 to 15	84.4
15 to 17	15.6
Farming experience (Years)	
Less than 10	12.5
11 to 30	43.8
31 to 50	37.5

More than 51	6.2
Social category	
GM	62.5
OBC	37.5
No of persons engaged in farming	
1 member	12.5
2 members	68.8
3 members	12.5
4 members	3.1
8 members	3.1
Farm income (Rs) from grape	
<300000	3.1
310000-400000	37.5
410000-500000	34.5
>510000	25
Organization membership	
Yes	81.2
No	18.8
Access to financial support	
Yes	78.1
No	21.9
Social influence in adoption	
Yes	71.9
No	28.1

Table 3 presents detailed statistics on the specific WSN technologies implemented by the surveyed farmers. It covers 5 categories including moisture sensors, scalar sensors, tracer units, master nodes, and full weather stations. For each variant, it provides a breakdown of the average area under coverage (4.6 to 9.5 acres), the average number of nodes adopted (1.6 to 2.08), the mean cost per installation (INR 27,800 to 95,428), and the mean annual service charges paid (INR 2,700 to 6,428). The table also shows the substantial deviations around these technology investment levels with maximum costs ranging from INR 120,000 per scalar unit to INR 364,000 for a weather station. Overall, farmers tend to install sensors over reasonably small land sizes of 2 to 5 acres, with 1-2 sensor nodes on average linked to a base station. Moisture sensors and scalar units constitute the cheapest options with weather stations and master nodes being far more capital and service intensive. The data highlights how farmers tend to implement fairly basic sensor network configurations for critical applications like soil moisture monitoring, rather than high cost and complex deployments. It provides insights into current investment ranges across distinct types of WSN technologies farmers are adopting, also revealing significant price variability across units and operators even for the same underlying technology and acreage coverage. The large deviations point to the lack of standards and need for regulations around WSN charges and specifications. The insights on variants can help prioritize current recommendations and policies for supporting WSN-based precision irrigation among smallholders.

Table 3. Technology characteristics of adopted farmers

WSN technology variant	Mean	Min	Max	SD
Only Moisture				
Area	4.6	2	7	1.82
Number	1.6	1	2	0.55
Cost	27800	12000	42000	13535.14
Service Charge (Yr)	2700	2000	4000	836.66
Scalar				
Area	5	2	15	3.74
Number	2.08	1	8	2.02
Cost	40692.31	20000	160000	40468.89
Service Charge (Yr)	2096.15	750	3000	554.7
Tracer				
Area	5	2	10	3.16
Number	1.6	1	3	0.89
Cost	47000	20000	90000	28195.74
Service Charge (Yr)	4200	2000	7000	2167.95
Master				
Area	3.92	2	9	2.65
Number	1.67	1	5	1.63
Cost	84500	47000	250000	81138.77
Service Charge (Yr)	7333.33	5000	9000	1505.55
Weather Station				
Area	4.79	2	17.5	3.6
Number	1.71	1	7	1.45
Cost	95428.57	50000	364000	78678.82
Service Charge (Yr)	6428.57	3000	9000	1247.86

3.2 Perception of Adoption

The top reasons for adopting WSNs were: crop dynamics (11%), good quality produce (14%), technology being scale neutral (14%), and reduction in water use (13%). Increased yields (10-20%) and real-time pest/disease detection (10%) were other notable reasons (Table 4).

Table 4. Perception for the adoption of WSNs

Reasons	Response (%)	Rank
Good quality of produce & increase in shelf life of berries	14	I
Technology Scale neutral	14	I
Optimize water (30- 40 %) compared to drip irrigation	13	II
Reduction in overall cost	12	III
Crop dynamics	11	IV
Real-time detection of pest and insect	10	V
Crop-specific nutrient recommendation	9	VI
Increase in 20 % yield	8	VII
Increase in 10% yield	5	VIII
Low investment	4	IX

3.2 Barriers for adoption

Results highlighted that the top barriers were high service charges (11%), lack of government support (10%), accreditation issues (10%), and problems with produce marketing (11%). Other barriers like land fragmentation, lack of information, network issues, and financing constraints were also reported by fewer respondents (Table 5). Reasons like water savings, crop dynamics, produce quality and scale neutrality encouraged adoption, while service costs and institutional issues posed barriers.

Table 5. Barriers for adoptions of WSNs

Barriers	Response (%)	Rank
Need to depend on petiole analysis of the soil	11	I
High service charges	11	I
Accreditation problem of technology by the Government	10	II
Farmland is too scattered	9	III
No regularization of cost and service charge	9	III
No Government support	7	IV
Lack of finance and credit facility	5	V
User-friendly app and voice alerts	5	V
Electric power supply issue	5	V
The automation unit needs to be purchased separately	5	V
Trust issue on accuracy	4	VI
Lack of information	3	VII
Replacement of technology needs additional charges	3	VII
Network incompatibility	2	VIII

4 CONCLUSIONS

This study analyzed factors influencing wireless sensor network (WSN) technology adoption among 50 grape farmers in Maharashtra. Annual service charges and high technology costs deter the intensity of WSN adoption, highlighting affordability barriers. Offering financing support and initial discounted charges could enhance adoption. Farm income exhibits the most substantial positive influence, indicating that revenue-based ability to absorb costs is critical. Policies to bolster farmer incomes would enable WSN investments. As technology installation time increases, usage intensity declines potentially due to shifting needs. This suggests innovations and upgrades are required over time. Farm size shows a small positive effect on adopted intensity. Scale-appropriate policies should promote WSNs among both small and large holdings.

5 POLICY SUGGESTIONS

Provide subsidies and financing support to lower service charges and upfront costs, enhancing WSN affordability. Develop cost-sharing or lease-based models. Implement minimum price standards, crop insurance, and income stabilization programs to raise and stabilize grape farmer earnings. This would facilitate WSN investments. Fund R&D initiatives to continuously upgrade WSN solutions to align with evolving farmer requirements over time after initial adoption. Undertake comparative trials showcasing WSN effectiveness across varied farm sizes. Enable scale-neutral policies for promotion based on potential water and cost savings. The findings highlight that strengthening farmer economics and purchasing power is vital for precision solutions like wireless sensor networks to transform smallholding agriculture alongside technology advancement effectively. Hybrid policy approaches are required spanning technology, institutions, and farm economics.

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REFERENCES

Adesina, A. A. (1995). Farmers' perceptions and adoption of new agricultural technology: Evidence from analysis in Burkina Faso and Guinea, West Africa. *Agricultural Economics*.

Agussabti, Rahmaddiansyah, Deli, A., Arida, A., & Mahda, F A. (2022). Factors affecting the decision of potato farmers in adopting superior seeds in Bener Meriah District. https://scite.ai/reports/10.1088/1755-1315/951/1/012016

Ahmad, L., Jafar Shanono, N., & Mustapha Nasidi, N. (2022). Toward adoption of drip irrigation and soil-moisture sensors by small-scale farmers. *Fudma journal of sciences*, *6*(3), 259–270. https://doi.org/10.33003/fjs-2022-0603-961

Amin, Z., Andry, A., & Humaidi, E. (2022). Analysis of the Adoption Rate of BATAN Mutant Rice Varieties in the Musi Rawas Area. https://scite.ai/reports/10.25181/jppt.v22i2.2405

Bai, A., Kovách, I., Czibere, I., Megyesi, B., & Balogh, P. (2022). Examining the Adoption of Drones and Categorisation of Precision Elements among Hungarian Precision Farmers Using a Trans-Theoretical Model. https://doi.org/10.3390/drones6080200

Balogh, P., Bujdos, Á., Czibere, I., Fodor, L., Gabnai, Z., Kovách, I., Nagy, J., & Bai, A. (2020). Main Motivational Factors of Farmers Adopting Precision Farming in Hungary. https://doi.org/10.3390/agronomy10040610

Barnes, A. P., Soto, I., Eory, V., Beck, B., Balafoutis, A. T., Sanchez, B., Vangeyte, J., Fountas, S., Van Der Wal, T., & Gómez-Barbero, M. (2019). Influencing incentives for precision agricultural technologies within European arable farming systems. *Environmental Science & Policy*, *93*, 66–74. https://doi.org/10.1016/j.envsci.2018.12.014

Biggs, S. D. (1990). A multiple source of innovation model of agricultural research and technology promotion. *World Development, 18(11), 1481-1499.* doi:10.1016/0305-750x (90)90038-y

Blasch, J., Vuolo, F., Essl, L., & Kroon, B V D. (2021). Drivers and Barriers Influencing the Willingness to Adopt Technologies for Variable Rate Application of Fertiliser in Lower Austria. https://scite.ai/reports/10.3390/agronomy11101965

Bucci, G., Bentivoglio, D., Belletti, M., & Finco, A. (2020). Measuring a farm's profitability after adopting precision agriculture technologies: A case study from Italy. https://scite.ai/reports/10.21014/acta_imeko.v9i3.799

Cameron, A., and Trivedi, P. (2009). *Microeconometrics Using Stata*. College Station, TX: Stata Press.

Castle, M H., Lubben, B., & Luck, J D. (2016). Factors Influencing the Adoption of Precision Agriculture Technologies by Nebraska Producers. https://digitalcommons.unl.edu/ageconworkpap/49/

Chatfield, C., Ehrenberg, A. S. C., & Goodhardt, G. J. (1966). Progress on a simplified model of stationary purchasing behaviour. *The Journal of the Royal Statistical Society*, 129(3), 317-367. doi:10.2307/2343502

Cincera, M. (1997). "Patents, R&D, and Technological Spillovers at the Firm Level: Some Evidence from Econometric Count for Panel Data Models." *Journal of Applied Econometrics*, 12(3), 265-280.

Ehrenberg, A. S. C (1959). The pattern of consumer purchases. *Applied Statistics*, 8(1), 26-24.

Gabriel, S A. (2014, June 30). Comparative analysis on precision farming technologies in selected crops of North Eastern Karnataka. https://ageconsearch.umn.edu/record/196802/files/Shitu%20full%20Thesis%20NewJune%202014.pdf

Gardezi, M., & Bronson, K. (2019). Examining the social and biophysical determinants of U.S. Midwestern corn farmers' adoption of precision agriculture. https://doi.org/10.1007/s11119-019-09681-7

Giua, C., Materia, V. C., & Camanzi, L. (2022). Smart farming technologies adoption: Which factors play a role in the digital transition? *Technology in Society*, *68*, 101869. https://doi.org/10.1016/j.techsoc.2022.101869

Gould, B. W., Saupe, W. E., & Klemme, R. M. (1989). Conservation Tillage: The Role of Farm and Operator Characteristics and the Perception of Soil Erosion. *Land Economics, 65(2), 167.* doi:10.2307/3146791

Hadush, M. (2019). Analyzing the effect of production risk and time preference on the use and choice of improved livestock feeding practice in Ethiopia.

https://scite.ai/reports/10.21776/ub.agrise.2019.019.2.4

Hausman, J. B., Hall, H. and Griliches, Z. (1984). “Econometric Models for Count Data with an Application to the Patents- R&D Relationship.” *Econometrica,* 52(4), 909-938.

Isgin, T., Bilgic, A., Forster, D. L., & Batte, M. T. (2008). Using count data models to determine the factors affecting farmers’ quantity decisions of precision farming technology adoption. *Computers and Electronics in Agriculture*, *62*(2), 231–242. https://doi.org/10.1016/j.compag.2008.01.004

Khan, A M. (2013). Precision farming technique for water resource management. https://shodhganga.inflibnet.ac.in/handle/10603/63675

Kendall, H., Clark, B., Li, W., Jin, S., Jones, G., Chen, J., Taylor, J A., Li, Z., & Frewer, L J. (2021). Precision agriculture technology adoption: a qualitative study of small-scale commercial “family farms” located in the North China Plain. https://doi.org/10.1007/s11119-021-09839-2

Liu, Y., Shi, K., Liu, Z., Qiu, L., Wang, Y., Liu, H., & Fu, X. (2022). The Effect of Technical Training Provided by Agricultural Cooperatives on Farmers’ Adoption of Organic Fertilizers in China: Based on the Mediation Role of Ability and Perception. https://scite.ai/reports/10.3390/ijerph192114277

Maheswari, R., Ashok, K. R., & Prahadeeswaran, M. (2008). *Precision Farming Technology, Adoption Decisions and Productivity of Vegetables in Resource-Poor Environments*. *21*, 11.

Mulla, D J., & Khosla, R. (2015). Historical Evolution and Recent Advances in Precision Farming. https://doi.org/10.1201/b18759-2

Negatu, W. and Parikh, A. (1999). The impact of perception and other factors on the adoption of agricultural technology in the Moret and Jiru Woreda (district) of Ethiopia. *Agricultural Economics, 21(2), 205-216.* doi:10.1016/s0169-5150(99)00020-1

Pathak, H. S., Brown, P., & Best, T. (2019). A systematic literature review of the factors affecting the precision agriculture adoption process. *Precision Agriculture*, *20*(6), 1292–1316. https://doi.org/10.1007/s11119-019-09653-x

Paxton, K. W., Mishra, A. K., Chintawar, S., Roberts, R. K., Larson, J. A., English, B. C., Lambert, D. M., Marra, M. C., Larkin, S. L., Reeves, J. M., & Martin, S. W. (2011). Intensity of Precision Agriculture Technology Adoption by Cotton Producers. *Agricultural and Resource Economics Review*, *40*(1), 133–144. https://doi.org/10.1017/S1068280500004561

Pierpaoli, E., Carli, G., Pignatti, E., & Canavari, M. (2013). Drivers of Precision Agriculture Technologies Adoption: A Literature Review. *Procedia Technology*, *8*, 61–69. https://doi.org/10.1016/j.protcy.2013.11.010 *13*(6), 713–730. https://doi.org/10.1007/s11119-012-9273-6

Ravikumar, R., & Azhagesan, J G. (2016). An Analysis of the Factors Influencing the Decision to Adopt Precision Farming in Krishnagar District of Tamil Nadu. https://www.researchgate.net/publication/355034581

Scoones, I., Thomson, J. (1994). Knowledge, power and agriculture- towards a theoretical understanding: In Scoones, I. and Thomson, J. (Eds.), Beyond Farmer First. Rural Peoples' Knowledge and Extension Practice. London: Intermediate Technology Publications, pp. 16-32.

Shruthi, K., Hiremath, G M., & Joshi, A T. (2018). An overview of use of precision farming technologies by the farmers- A case study of North Eastern Karnataka. https://doi.org/10.18805/ijare.a-4889

Subedi, S., & Kattel, R R. (2021). Farmers’ perception and determinants of dairy cattle insurance in Nepal. https://scite.ai/reports/10.1080/23311932.2021.1911422

Taheri, F., D'Haese, M., Fiems, D., & Azadi, H. (2022). Facts and fears that limit digital transformation in farming: Exploring barriers to the outreach of wireless sensor networks in Southwest Iran. https://scite.ai/reports/10.1371/journal.pone.0279009

Thompson, N M., Bir, C., Widmar, D A., & Mintert, J. R. (2018). Farmer perceptions of precision agriculture technology benefits. https://doi.org/10.1017/aae.2018.27

Tey, Y. S., & Brindal, M. (2012). Factors influencing the adoption of precision agricultural technologies: A review for policy implications. *Precision Agriculture*,

Wang, N., Gao, Y., Wang, Y., & Li, X. (2016). Adoption of eco-friendly soil-management practices by smallholder farmers in Shandong Province of China. *Soil Science and Plant Nutrition*, *62*(2), 185–193. https://doi.org/10.1080/00380768.2016.1149779

Yarashynskaya, A., & Prus, P. (2022). Precision Agriculture Implementation Factors and Adoption Potential: The Case Study of Polish Agriculture. *Agronomy*, *12*(9), 2226. https://doi.org/10.3390/agronomy12092226

Yatribi, T. (2020). Factors Affecting Precision Agriculture Adoption: A Systematic Literature Review. https://doi.org/10.2478/eoik-2020-0013