

THE ADOPTION AND EFFICACY OF PRECISION AGRICULTURE TOOLS AND TECHNOLOGY IN AMRAVATI DIVISION: EXPLORING THE INSIGHTS OF FARMERS AND AGTECH INDUSTRY

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ABSTRACT

This study investigates how AgTech startups influence the socio-economic and environmental aspects of farming in the Amravati Division. It evaluates the adoption levels, efficacy, and challenges of precision agriculture tools, highlighting the role of AgTech startups in facilitating technology integration for improved productivity and sustainability. A mixed-method approach was employed, combining quantitative survey with 250 farmers and qualitative interviews with AgTech industry stakeholders. Additionally, secondary data from case studies provided contextual insights into adoption trends, barriers, and impact assessment. Descriptive and inferential statistical analyses were applied to examine the relationships between technology adoption, economic benefits, and environmental sustainability. The study reveals moderate adoption of precision agriculture tools, with higher uptake in irrigation and soil monitoring technologies compared to advanced tools like drones and automated machinery. Key barriers include financial constraints, technical complexity, and limited training. Farmers who adopted precision agriculture reported increased yields (20-30%), reduced input costs, and improved resource efficiency. AgTech startups played a crucial role in promoting adoption through affordable solutions, training programs, and advisory support, though challenges related to scalability and compatibility persist. This research uniquely focuses on the relationship between farmers and AgTech startups in the Amravati Division, offering valuable insights into the factors driving or hindering the adoption of precision agriculture. The findings have broader implications for policy development, AgTech innovation, and sustainable agricultural practices in emerging economies.

Keywords: Precision Agriculture, Technology Adoption, AgTech Industry, Amravati Division, Farmer Insights, Agricultural Technology, Socio-Economic Impact, Environmental Impact

Introduction

Background

AgriTech is a relatively new focus area and appears to be playing a critical role in turning around agricultural practices at the international level and has much significance to the Amravati Division in Maharashtra, India. Regarded as an agriculture-based area, there is a huge dependency on agriculture for the economy and food in Amravati. The use of efficient methods in the advancement of agriculture in this area can solve several important issues including poor yield, poor utilization of the available resources, and sustainability of the environment (Ruzzante et al., 2021). The current innovative developments of AgTech startups are using new creative solutions adapted to the requirements of rural or farmers' markets. These startups are an attempt to address the existing challenges through the optimization of resource usage and technology advancement in the farming sector with an emphasis on the farmers. For instance, precision farming tools that include data analytics and gadgets such as GPS enable farmers in Amravati to apply water, fertilizers, and pesticides in ways that enhance crop yields while minimizing the negative effects on society (Wigboldus et al., 2016). Further, with the emergence of AgTech startups, there are numerous software and apps that exist today that give instant updates about the climatic conditions, the health of the soil, and information on various pests and diseases. These tools extend knowledge to farmers at the right time so that they come up with the best decisions that improve farming. In the same technologies, artificial intelligence

and machine learning are also incorporated to enhance the reliability of the predictions made in the system to enable farmers to avoid any risks that may be expected in the future.

Problem Statement

There are several challenges and gaps in the adoption of precision agriculture tools among farmers, especially in the area of Amravati Division. These challenges may be grouped into what can be termed technological, financial, and education-related constraints. Among the factors that have been cited to influence the success of precision agriculture, one of the major ones is cost – particularly costs related to equipment and machinery used in precision agriculture. Some of the technologies like GPS, soil sensors, and remote monitoring systems through drones may call for huge capital investment. Whilst precision agriculture appealed to smallholder farmers in Amravati, it was argued that the cost of purchase and implementation of the said tools made it impossible for them to enjoy the benefits that precision agriculture offered (Rotz et al., 2019). Another bar to access to the loophole is the absence of technical knowledge. Equipment used in precision farming may not be very easy to operate and maintain and therefore need some level of technical knowledge. The problem here may lie in the fact that farmers in the Amravati Division may find these technologies quite complicated and hence may not be able to implement the technologies fully as expected and hence not yield the benefits expected from the technologies. The lack or absence of training and support materials only underlines this lack of knowledge.

Objectives

- **Assess the Adoption Levels:** Evaluate the extent to which precision agriculture tools and technologies have been adopted by farmers in the Amravati Division, identifying key factors that influence this adoption.
- **Analyze the Efficacy:** Examine the effectiveness of precision agriculture tools in enhancing crop yield, productivity, and economic benefits for farmers in the region.
- **Explore Socio-Economic and Environmental Impacts:** Investigate the socio-economic and environmental impacts of adopting precision agriculture technologies, focusing on both benefits and challenges.
- **Examine the Role of AgTech Startups:** Understand the role of AgTech startups in promoting and facilitating the adoption of precision agriculture tools, including their influence on farmer decision-making and technology accessibility.
- **Identify Barriers to Adoption:** Identify and analyze the barriers hindering the adoption of precision agriculture tools among farmers, such as cost, lack of knowledge, and infrastructure issues.
- **Provide Policy Recommendations:** Based on the findings, offer policy recommendations to enhance the adoption and effectiveness of precision agriculture tools, considering the perspectives of farmers, AgTech companies, and policymakers.

Literature Review

Precision Agriculture Tools and Technologies

Overview of various precision agriculture tools (e.g., GPS, drones, IoT, sensors)

Bhakta et al., (2019) analyzed that smart farming is one of the new forms of farming that uses high technology to increase the productivity of farming without compromising the quality of the output. In general, this connectivity converges several advanced instruments aimed at effectively controlling all aspects of crop production. GPS technology is critically important in the process of field mapping, as well as the use of automated machines to maneuver the fields. This makes the planting to be precise regarding fertilization as well as harvesting, thus saving a lot of crops and resources. Aeros can capture high-resolution images of agricultural land and it can be useful for crop health check-ups, condition assessments of the field, and application of the required treatments. It can quickly deploy large-area coverage, and provide updated

information that is critical for the formation of timely decisions. The Internet of Things (IoT) also builds on precision agriculture by integrating several devices and sensors into a network that is always active and is collecting data. Special devices installed in the ground or connected to equipment monitor different factors including moisture content of the soil, nutrient content, and weather among others as they help farmers in making critical decisions. These tools assist farmers in making the right decisions, employing fewer resources, and increasing yield, thus being more revolutionary than the ordinary forms of farming.

Ananthi et al. (2017) came up with an Internet of things based smart soil monitoring system for the enhancement of the productivity of crops. It has the capability of measuring soil moisture, temperature, and pH level of the soil in real time, thus being able to adjust irrigation and fertilizer application. They argue that through the use of technology in agriculture, wastage of resources is minimized, better decisions are made in farming, and increased yields are achieved. Some of the features developed by Arvind et al. (2017) include an automated irrigation system, which is supplemented by seed germination monitoring and pest control. In addition, the system is capable of operating the irrigation process through the use of the moisture content of the soil, hence improving water use. According to their research, germination also increases in the use of biotechnology, fewer pests attack crops, thus higher yields, and less physical effort and more efficient farming. Padhiary et al. (2024) discussed the use of automatic all-terrain vehicles in precision farming with emphasis on the soil, seeding, and pesticide spraying. Thus, they explain that through ATVs, farming has become more efficient, employing less human labor and utilizing resources even in the difficult terrains.

Technological advancements and innovations in precision agriculture.

Banu, (2015) examined that it has been influenced by technological innovation in precision agriculture to create efficiency in practices practiced in today's farming practices. Some of the most revolutionary changes are smart machinery including tractors and harvesters embedded with sophisticated detectors and signal locators. These machines can function almost autonomously, repetitively following the laid down paths with a lot of efficiency in tasks such as planting, fertilization, and even weeding. Computer science has also been valued, the machine learning technology that provides the capacity to predict crop yields, diseases and even harvest time using current and past data. High-resolution satellite imagery to monitor crop health and field conditions from Space has become possible now and gives overall data that is used for precision farming. Improved drone systems have added efficiencies in aerial data acquisition, which has enabled more accurate delivery of such elements as water, fertilizers, and pesticides. Recent trends in remote sensing such as multispectral and hyperspectral sensors have enhanced the capacity for plant and soil management at the micro level. It is now becoming apparent that all of these advances in one way or another play their part in helping improve the efficiency and sustainability of agricultural production, decreasing the amount of waste and the like.

Benefits and challenges associated with the use of these technologies.

Monteiro et al., (2021) stated that the application of the technology to adopt precision agriculture has several advantages, but at the same has its disadvantages also. These can include improved efficiency, productivity, and better resource allocation. Equipment and systems for instance GPS GPS-operated mechanisms in farming; drones for planting, watering, and also for application of fertilizers thus reducing wastage through efficient application. Real-time data from the sensors and the IoT devices enables the operatives to be more informed in their operational decisions as well as give timely interventions. They find that such advancements can reduce input usage and thus translate into huge savings and improved sustainability. Data science and artificial intelligence in analyzing data and anticipating trends for enhancement of farm management practices thereby increasing production. Vuran et al., (2018) examined that

but then these technologies are not without their problems too. Some of the subsystems may be costly to install and may require constant updating, which is a challenge to smallholder farmers. There are also technical issues on how to effectively combine different technologies and how to deal with big data. This is because, with increased collection and storage of such information, various factors such as data security and privacy become major issues. In addition, there is a requirement for sufficient training and aids so that these technologies can be utilized optimally. Technological reliability and system compatibility can also appear as very serious challenges. Therefore, there is a need to understand the benefits and consequences and develop a way of optimally utilizing the strengths of precision agriculture while at the same time minimizing the effects of its weaknesses.

Venkattakumar and Narayanaswamy et al., (2022) have discussed the sustainability issues of FPOs, where financial constraints, lack of market access, and lack of managerial competence are some of the most critical issues. Therefore, as their outcomes reveal, the FPOs require policy support, strengthened governance capacity, and increased digital infrastructure to improve efficiency and make independent agriculture sustainable in the long run. Amrutha *et al.* (2016) proposed the design of an automated soil nutrient detection and fertilizer dispensary system to enhance the growth of plants. It was effective in identifying the lacking nutrients in the soil and adding the right portion of fertilizer to avoid wastage. This is in line with sustainable agriculture since they will employ automation that would enhance the soil's health and increase crop yield with minimal harm to the environment. Padhiary *et al.* (2024) proposed the IoT-based semi-autonomous truck sprayer for enhancing the application of pesticides. They pointed out that this system enhances the efficiency of the spray, conserves chemicals, and cuts the likelihood of pesticide exposure to human beings. It describes the possibility of automation in precision agriculture, which helps to increase the yields and make farming more sustainable.

Adoption of Precision Agriculture

Factors influencing the adoption of precision agriculture tools among farmers.

Vecchio et al., (2020) examined that several factors determine the extent to which precision agriculture implements are adopted by farmers which shows the advantages of the tools as well as the difficulties of using them. One of the reasons includes the cost which is incurred in procuring and integrating precision agriculture applications that may include GPS units, drones, and other smart sensors. It becomes the plight of the farmers to balance these costs with the expected gains in terms of efficiency and productivity. Of course, grants from government agencies or other agriculture-related organizations can also be a key influence towards adoption. Another factor is technical skills in the organization. The more technical skills the organization has the better it will be in the market. Farmers require knowledge and skills so that they can competently use the technology and incorporate the same into their operations. Castle et al., (2016) pointed out that education and technical assistance are required to help farmers rise above those issues to get the most out of the tools available. Technical readiness is also an issue here: the infrastructure of the locations where the Internet connection is low or an advanced degree of technical support is not readily available may hinder their adoption. It also corrects perceived benefits like increased yields or more efficient use of resources or sustainability where farmers consider these more advantageous than traditional practices. On the other hand, some of the key factors that may pose a threat to adoption are culture and resistance to change may not encourage farmers to adopt new ways of doing things. Also, in terms of adoption, the policies can play a very important role as liberal policies convince organizations to adopt emerging technologies while restrictive policies act as barriers. A delicate balance of these factors is key to achieving the goal of realizing precision agriculture tools.

Padhiary *et al.* (2024) have undertaken a study on the effectiveness of unmanned agricultural vehicles in hill agriculture. They established that such vehicles enhance access, accuracy, and effectiveness in farming on inclined terrains. They were used to fight poverty, increase mechanized agriculture, and decrease labor intensity, especially in the difficult terrains of geography. Ashapure *et al.* (2019) examined the application of UAS for estimating the yield of tomato using machine learning. Based on their observation, the author found that monitoring through UAS improves yield prediction, effective farm management. It explicates on how the remote sensing technologies are useful in enhancing data gathering and decision making in precision farming. Singh *et al.* (2022) investigate the effectiveness of FPOs in Manipur, India, to advance agricultural sustainability and rural development. They posit that FPOs enhance the market access and financial position of the farmers while having operational issues that need to be addressed through policies and structures for better functioning.

Adoption trends globally and in India, with a specific focus on the Amravati Division.

Tamirat *et al.*, (2018) analyzed that in other parts of the world, the use of precision agriculture tools has been rising steadily as farmers and agribusiness companies look for ways how to improve productivity while minimizing the negative impacts on the environment. The methods available in developed nations like the United States and the European nations include GPS-operated equipment, aerial photography, and sophisticated instruments. These areas enjoy a robust commitment to research and development, well-developed facilities, and policies that foster advancement in technology. The adoption trend is high technology integrated and has a growing importance on big data that can be used in crop management and resource utilization. Paustian & Theuvsen, (2017) pointed out that on the other hand, India's embrace of precision agriculture has been relatively slow despite it has started to increase recently. The country has presented special contingencies like disparities in infrastructure, technology, and funding available to its many farming sectors. Precision agriculture is slowly making its way into the scene in India as farmers in the country grapple with factors such as low yields as well as inefficiency in the use of resources. Although governments are encouraging the structures of agricultural technology and providing financial support, the rates of adopting technology in the agricultural sector have shown regional differences.

Schimmelpfennig, (2016) pointed out that this is a general background; the case of the Amravati Division located in the state of Maharashtra could be regarded as special in this respect. This region has witnessed a slow integration of precision agriculture technologies result of the farming practices in this region and government initiatives. The division has gained from state-driven processes that seek to enhance the productivity of farmland through technology. However, certain issues like low Internet speed and lack of technical support can act as a barrier to fast development. These barriers are slowly being tackled through training and infrastructure development so there is a slow but positive inclination towards the improvement in the usage of the precision agriculture tools in the Amravati Division.

Barriers to adoption (e.g., cost, lack of knowledge, infrastructure issues)

Bolfe *et al.*, (2020) analyzed that in other parts of the world, the use of precision agriculture tools has been rising steadily as farmers and agribusiness companies look for ways how to improve productivity while minimizing the negative impacts on the environment. The methods available in developed nations like the United States and the European nations include GPS-operated equipment, aerial photography, and sophisticated instruments. These areas enjoy a robust commitment to research and development, well-developed facilities, and policies that foster advancement in technology. The adoption trend is high technology integrated and has a growing importance on big data that can be used in crop management and resource utilization. On the other hand, India's embrace of precision agriculture has been relatively slow despite it has started to increase recently. The country has presented special contingencies like disparities

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Efficacy of Precision Agriculture

Impact of precision agriculture on crop yield and productivity

Balafoutis et al., (2017) examined that precision agriculture has been very effective in increasing production and yield thus changing the face of traditional agriculture through technology. Therefore, precision agriculture evolves the tools in locating the machinery using GPS and drones, applying sensors, and monitoring different features thus improving resource utilization and advancing decision making resulting in high crop yields. The first observable effect of using precision agriculture on crop yield is in its ability to accurately incorporate funds such as water, fertilizer, and pesticides. Other technologies such as GPS and automation mechanisms make it possible to ensure these inputs are applied only in the specific areas as well as the right quantities. This is efficient expenditure and care as it ensures that there less wastage through over-application and leads to better health of crops and their growth. Some real-time information from sensors, as well as drones, read more about crop and soil wellbeing. It allows for constant checking on factors such as nutrient deficiencies, pest attacks, or water deficits which if checked early, will not lead to yield reduction. Schimmelpfennig, (2016) pointed out that for example, soil moisture sensors give real-time information about the intensity of the soil moisture hence enabling farmers to irrigate appropriately without over-irrigation and also avoiding under-irrigation. Computing capability and the application of predictive analytics, and machine learning algorithms improve productivity through automatized probability of planting time, harvesting period, and managing crops, using past and current information. These measures are favorable in enhancing the yields and hence the efficiency of the farms. In general, precision agriculture results in better production methods, low cost of production, and increased Crop yield and therefore boosts productivity and minimizes the effect of climate variation in Agriculture.

Economic benefits for farmers adopting precision agriculture

Thompson et al., (2019) examined that the use of PA can show much potential, and the following facts indicate that adopting PA has created a large economic potential for farmers in the current generation practices in farming. First on the list of benefits that can be observed almost at once is the reduction of costs. Some of the advanced technologies that are useful to the farmers are GPS-operated machinery, sensors, and drones with the help of which the application of seed, fertilizer, pesticide, etc can be made efficient. Such precision meant that fewer of these resources were required, and as such, the costs of acquiring them and putting them to use were also minimized. For instance, targeted fertilization helps to avoid overfeeding and hence minimizes the use of expensive fertilizers hence cutting on costs. Furthermore,

precision agriculture increases crop yields and productivity thus increasing the level of revenue. For instance, technologies such as planters, sprinklers, and harvesters that aid farmers in planting, irrigating, and harvesting respectively are advanced tools while big data and analytical tools help the farmer in decision-making. Lowenberg-DeBoer et al., (2019) pointed out that this leads to better yields, better quality, and thereby more marketable produce which in turn leads to increased sales and profits. Since farmers can predict and manage crop yield performance well or this is a key tool that can help farmers to get good returns on their investments by optimizing the performance of their farmland. Moreover, an increase in efficiency with the help of PA instruments may provide additional financial benefits in the long run due to resource conservation. They mean that through decreasing the excess usage of inputs and the negative effect on the environment, a farmer can conduct a sustainable farming business. In addition, this helps preserve the stability of soil health and avoids unnecessary restrictions by the authorities on the use of land while at the same time putting the farmers in a better place to benefit from the incentives and subsidies that may be available to encourage sustainable practices.

Deshmukh *et al.* (2023) analyzed employment generation due to measures taken by the Ministry of Agriculture, India. This was believed to be due to government-sponsored agricultural entrepreneurship activities that enhance the employment base in the rural areas. From the research, the government, industry, and other stakeholders should enhance policy support, training, and investment to support sustainable agribusiness activities. In their paper about structure and performance analysis of producer companies in India, Singh and Singh (2014) highlighted the significance of producer companies in collective farming. Their study further indicates that producer companies improve farmers' bargaining power and their income and recommends that these companies need better governance, more financial support, and infrastructural development to sustain themselves and to contribute their quota to the development of the agricultural sector. Padhiary and Kumar (2024) evaluated the effects of agriculture, industries, and the mining sector on the agro-ecosystem. This is evident in pollution, loss of species, and degradation of the soil in these sectors, as pointed out by the authors. The paper focuses on the importance of adopting sustainable approaches and applying technologies in the management of environmental degradation to enhance food production.

Environmental and sustainability aspects of precision agriculture

Srbínovska et al., (2015) examined that precision agriculture also plays a very important role in environmental management by encouraging efficient utilization of resources and also has low effects on the environment. The social benefit is normally associated with a decrease in the use of chemical inputs including fertilizers and pesticides. Elements such as GPS on machinery and sensors prevent the use of these substances in areas not required and in the right quantities needed. This way of implementation minimizes the learning of stormwater into the water bodies hence avoiding water pollution and conservation of aquatic life. Water management is also another area that is encompassed by precision agriculture to reduce its usage. Sophisticated irrigation systems such as the ones that incorporate Smart software such as the soil moisture sensing and control systems apply water where and when it is needed. Shafi et al., (2019) stated that this controls the wastage of water and is also important in the conservation of water, especially in areas where the water resource is scarce. Moreover, precision agriculture has benefits for the soil, and it helps avoid soil erosion. Through input control and mapping of the specific inputs that need to be applied, the farmers can avoid cases where the results in over-farming and frequent tilling which has negative impacts on the soil. Technologies that are used in some farms to measure the conditions of soil and crops assist in the management of soil fertility and structure to make farming sustainable in the long run.

AgTech Industry Insights

Role of the AgTech industry in promoting precision agriculture

Duncan et al., (2011) examined that Nyagaha goes further to find that the AgTech industry has a significant duty in recommending and supplying the most important tools that are required in contemporary agriculture. Tech-savvy AgTech firms are into the development of high-value technologies like precision planting and application equipment and tools, drones, GPS-tracked machinery, and IoT devices that help in improving the timings and depth of farming. These technologies allow the tracking and controlling of crops, soil, and resources and the making of decisions that would increase yields while at the same time being eco-friendly. In addition, the AgTech industry is also responsible for knowledge transfer as well as the provision of training services. Based on educational and training services, AgTech firms enhance farmers' knowledge about technology and its applications as well as address barriers that are connected with the ability to implement them. This support is invaluable for innovation to spread precision ag tools into the farm conventional practices, to assure farmers get the full benefit of precision agriculture. It is also involved in the research and development process which involves a lot of innovation. Rodrigues, (2022) examined that the AgTech firms channel resources towards the creation of new products that would effectively deal with issues affecting agriculture for instance pest control, soil, or water quality. Constant research allows them to continue to set accurate developments of precision agriculture technologies and participate in the elaboration of new farming techniques. Also, the AgTech industry consolidates the technology vendors, farmers, and agricultural associations and institutions. AgTech companies build connections and disseminate information that enables farmers to embrace precision agriculture practices and execute them in the Agricultural sector.

Industry trends and innovations in precision agriculture technology

Trivelli et al., (2019) examined that the best and most profound advancements in the technology and indicators of the industry concerning the field of precision agriculture are shifting and changing swiftly due to the increasing concentration on efficacious and sustainable agricultural practices. In the last couple of years, machine learning and artificial intelligence have found applications in precision agriculture as a tool for decision support. AI solutions use data from such sources as satellite photography and sensors to evaluate crop performance, and input application, and expect problems that might lead to reduced yields. Technologies in remote sensing are also evolving and improved alternatives to multispectral and hyperspectral imaging that offer a better view of the health and conditions of the crop and the soil. Bhakta et al., (2019) analyzed that they facilitate control of plant stress, nutrient, and pest infections, in that they enable one to control these factors once they are detected, thus reducing their detrimental effects on crops. Another important development in the function of autonomous machines which are self-driving tractors, drones, and harvesters is on the rise. These machines can plant, fertilize, and harvest crops among others with little or no assistance from humans and thus make the operations more efficient and accurate. They are fitted with modern features such as sensors, and GPS that assist in efficient fieldwork and this eliminates the use of manpower. With IoT (Internet of Things) the devices and systems of precision agriculture are becoming more interconnected to provide constant data flow and enable real-time communication. Sensors connected to IoT installed in the soil, on the machinery, and in the field, all offer data that can be used to improve water usage in the field, feeding, and pest control.

To enhance the realization of the intended crop-field monitoring and water management, Rao and Sridhar, (2018) developed an IoT based crop-field monitoring and automated irrigation system. This makes them conclude that information on the moisture content of the soil and the use of an automatic irrigation system prevent wastage of water at the same time as enhancing the production of crops. The study also acknowledges the benefits of IoT when it comes to

resource management in precision agriculture. Yashaswini et al. (2017) designed an automated irrigation system with a disease prediction control as well. The integration of IoT for controlling the usage of water in farming raises the level of water utilization on the other hand, identifying diseases at their initial stage help to minimize crop losses. The research conducted in this study proves that incorporation of sensors in automation reduces the level of human interference and impact of climate change in agriculture. Padhiary et al., (2024) in his study on smart farming and food processing through the application of 3D printing concluded that use of 3D printing enhances flexibility of equipment and reduce cost of farming and promotes sustainable farming. The concentration is made on the use of the method of additive manufacturing to enhance farming and to reduce food wastage on the farms. Smart Irrigation System for Agriculture using IoT wireless sensor network was designed by Ahmad et al., (2019). They are in the areas which include; data acquisition in real-time, decision making on the same, irrigation and fertilization. It illustrates how use of IoT in farming can be useful in the achievement of an effective and efficient resource utilization in the agricultural sector.

Collaborative efforts between farmers and AgTech companies

Poti & Joy, (2022) examined that it is therefore important for farmers and AgTech firms to work hand in hand to enhance precision agriculture and fully harness its potential. These partnerships enable the development of solutions that enable the application of technology in solving real-life problems in agriculture. In the AgTech space, the companies collaborate directly with farmers to know what they need and what challenges their establishments present to the application of the technology that is being developed. This is emerging in the form of field trials and pilot projects where new technologies are exposed to actual farming practices to capture useful information for development. Training and support programs are part of these collaborative activities. To prevent farmers from being overwhelmed by the new tools and technologies AgTech companies offer education and practical training to these farmers. Some of the support measures include; the conducting of workshops, online lessons, and local training which would help close the knowledge divide, and to allow farmers optimize the gains that they could get from precision agriculture. Data sharing and integration are also other activities that form a core part of these collaborations. Rose & Chilvers, (2018) stated that the fields of AgTech and farmers carry out the coordination of maintaining disparate data inputs such as weather prediction, soil characteristics, and crop status indicators in respective decision-support systems. That is why the integrated approach is more suitable as it enables more precise forecasts as well as more effective management of farming practices. Secondly, innovative partnerships also involve partnering between AgTech players and farmers, in which the former creates novel solutions that are new to both. These partnerships of technical knowledge with farming experience result in the development of better and easier-to-use innovative instruments or solutions that meet specific farming requirements.

Policy and Regulatory Framework

Government policies and initiatives supporting precision agriculture in India

Lele & Goswami, (2017) pointed out that in India, the Government always acts as a supportive Advisor in implementing precision agriculture technologies and modern farming techniques. The Indian government has considered precision agriculture as a source of improving Crop yields as well as production efficiency of the agricultural sector and has identified several programs to facilitate its use. Two such mechanisms include both the Pradhan Mantri Krishi Sinchai Yojana (PMKSY) each of which aims at the enhancement of the flexibility of irrigation systems through the adoption of technologies. Here, an endeavor is taken to encourage micro irrigation system which includes drip and sprinkle irrigation in precision agriculture because they help in the accurate application of water. The Digital Agriculture Mission is another Government of India launched scheme which also endorses precision agriculture.

Karunathilake et al., (2023) examined that this mission will seek to avail farmers of weather data as well as data on the soil and crop health to improve the application of digital tools and data analytics in farming practices. The initiative can also be availed to farmers through mobile apps and other digital platforms enabling them to make informed decisions on precision practices that enhance resource use while increasing yields. Also, the National Mission on Sustainable Agriculture (NMSA) encourages the shift of agriculture practices that are sustainable and climate-smart including precision agriculture. To support of research and development in technologies related to soil management, water usage, and environmental impact for farming, the NMSA is present. This mission also aims at contributing cash or subsidies to farmers in the use of advanced technologies and techniques.

Saha et al. (2023) have proposed IoT based pressure control system using solenoid for precision sprayers. They said that, it improves the precise application of the pesticide, which in a way reduces the quantity of the chemical used and the amount of damage on the environment. The paper lays down the mode of applying the IoT in enhancing the methods of pest control that are used in agriculture. Pandithurai et al. (2017) have designed a smart remote IoT monitoring model for the soil and crop named as Agro-tech. In their findings, they show that with the current technology, there are enhanced chances of determining the state of the soil and the conditions of crops. The study also brings out the possibilities of best practices in IoT to advance agricultural models to reduce wastage and improve production. Rahul *et al.* (2018) designed an IoT-based solar-operated Agribot for irrigation and farm management. They identify that Agribots enhance the utilization of water, automate the process of watering crops, and minimize the utilization of labor. The study focuses on renewable energy and IoT in enhancing sustainable farming as a means of farming. Monica *et al.* (2017) proposed an IoT-based smart irrigation system that uses sensors, GSM, Bluetooth, and cloud technology. They pointed out that the benefits include better water management, the use of technology in irrigation, and remote monitoring of fields. The study focuses on the aspects of connectivity and automation in the optimization of the agricultural irrigation systems.

Impact of regulatory frameworks on the adoption and implementation of precision agriculture
Pathak et al., (2019) analyzed that this force majorly influences the level of AP adoption and its use and is affected by regulatory frameworks that define the context in which technologies are created and applied. Promotive policies consist of supportive regulations that contain rules and recommendations to guide the use of precision agriculture tools, offer incentives for implementation, and act as technical standards. For example, policies that promote incentives such as subsidies or tax exemptions for the use of modern high-precision agricultural technologies and machinery ease the financial pressure to acquire such tools eradicating the stiffness instilled in farmers. On the other hand, the prescriptive regulations present certain difficulties in the implementation of precision agriculture. For instance, oversize domestic regulation that enhances severe data protection legislation hinders the procurement and dissemination of agricultural data, which is imperative in the operational application of precision agriculture instruments. Barnes et al., (2019) pointed out that in the same manner, complex approval processes of new technologies slow down the diffusion of new technologies in the market and therefore affect the advancement of precision agriculture. It also involves standards and guidelines provided by regulatory bodies. Five general sources to access information and to achieve the research objective, the following sources are relevant; High and unambiguous sets of performance, safety, and compatibility standards guarantee that precision agriculture instruments conform to quality and reliability requirements. This can help in creating confidence among the farmers and subsequent usage of the developed technology. Implementation of networked regulation models that encourage industry collaboration and

standardization is also likely to encourage innovation since it sets a common structure within which the technology can be created and deployed.

Comparative analysis of policy frameworks in other countries

Eastwood et al., (2017) pointed out that a cross-country comparison of legal measures put in place outlines the variety of ways that governments continue to encourage precision agriculture with a focus on the set country's agriculture and economy. There are federal and state policies in support of precision agriculture in the United States. The aforementioned Farm Bill is a rather extensive bill that may provide a legal basis for subsidizing research, development, as well as application of sophisticated technologies in the sphere of farming. Also, the US Department of Agriculture provides grants and subsidies through its programs like; the Environmental Quality Incentives Program (EQIP) which assists farmers in adopting certain practices such as precision agriculture technologies. The US also enjoys a fine R&D facility coupled with investments in technology and innovation. China has also shown interest in precision agriculture via the National Plan for Modern Agriculture and Made in China 2025 which focuses on technological innovation in the agricultural sector. Finger, (2019) analyzed that the Chinese government subsidizes the purchase of precision agriculture equipment and has committed quite a sizeable amount to research and development in the sector. China's policies also consist of approaches to promote Precision Agriculture in supporting the other strategic directions of Food Security and Rural Revitalization. The main policy backing precise agriculture in India includes Pradhan Mantri Krishi Sinchai Yojana (PMKSY) and/or the Digital Agriculture Mission. These activities include the provision of funds to support and encourage the use of gadgets and improved forms of irrigation. However, one of the constraints is the regulatory environment within which the infrastructure and resources for the Indian market are a challenge for steady growth and development.

Theoretical Framework

Conceptual Model

Technology Acceptance Model (TAM)

The model that will be used as the theoretical framework in this study is the Technology Acceptance Model by Davis (1989). In TAM, two variables have been proposed to affect the level of adoption and these are the perceived usefulness (PU) and the perceived ease of use (PEOU). Perceived usefulness, as the name suggests is the extent to which a person considers the use of a certain technology to enhance his/her work performance while perceived ease of use is the extent to which a person perceives using a particular technology to be trouble-free. Concerning the use of precision agriculture in the Amravati Division, TAM assists in understanding why some farmers are more inclined to adopt new and improved agricultural tools as compared to others (Musa, *et al.*, 2022). The likelihood that farmers adopt precision agriculture technologies increases if they believe that those technologies are very useful in boosting crop yield, cutting costs, and enhancing the efficiency of the utilization of resources (Putri et al., 2023). As such, the ease of use of the tools and the extent to which they are technical are likely to determine their usage levels (Mustafa et al., 2021). The study findings show that a number of farmers experience difficulties in understanding the technical aspects of precision agriculture tools, consistent with the TAM legislation that defines ease of use as a determining factor in the adoption. This means that there is a strong possibility that if training programs are enhanced and technology interfaces made easier to use then there would be higher levels of adoption by the farmers (Natasia et al., 2022; Cheah, *et al.*, 2023). Moreover, there are factors that are outside an organization including factors such as financial resources, access to training, and government support influence both perceived usefulness and perceived ease of use.

Diffusion of Innovation (DOI) Theory

DOI is a theory that was developed by Rogers in 1962 and it seeks to explain the process through which new ideas, commodities, or technologies are disseminated in society. In the context of DOI, adoption involves five groups that include the innovators, early adopters, early majority, late majority, and the laggards (Shaw et al., 2022). The extent and rate of adoption are determined by five basic factors, namely Relative Advantage, Compatibility, Complexity, Trialability, and Observability (Menzli, et al., 2022). Applying this theory to precision agriculture adoption in the Amravati region then it is seen that a few farmers are already using some of the technologies like soil health monitoring systems, precision irrigation, drone monitoring, etc (Lee, et al., 2024). These farmers understand that there is a relative benefit in utilizing such tools since they enhance production and effectiveness. However, the majority of the farmers are still in the early or late majority stage because many of them are reluctant to adopt due to reasons such as high cost, lack of information, and the uncertainty of the returns. They elaborate that there are still some farmers who are slow to adopt these new practices and techniques which prolongs the process of change (Spinnewijn, et al., 2024; Min et al., 2021). Trialability is quite applicable as most farmers are reluctant to purchase expensive tools without first establishing their efficiency. This means that offering more trials and offering farmers monetary incentives could be the solution to reaching ordinary farmers.

Hypotheses

Null Hypotheses (H₀)

1. H₀₁: There is no significant relationship between the adoption of precision agriculture tools and crop yield improvement among farmers in the Amravati Division.
2. H₀₂: Financial constraints do not significantly affect the adoption of precision agriculture technologies in the Amravati Division.
3. H₀₃: The level of education of farmers does not have a significant impact on their willingness to adopt precision agriculture tools.
4. H₀₄: The presence of AgTech startups does not significantly influence the rate of adoption of precision agriculture tools among farmers.
5. H₀₅: There is no significant difference in the environmental sustainability practices of farmers who use precision agriculture tools and those who do not.

Alternative Hypotheses (H₁)

1. H₁₁: There is a significant relationship between the adoption of precision agriculture tools and crop yield improvement among farmers in the Amravati Division.
2. H₁₂: Financial constraints significantly affect the adoption of precision agriculture technologies in the Amravati Division.
3. H₁₃: The level of education of farmers has a significant impact on their willingness to adopt precision agriculture tools.
4. H₁₄: The presence of AgTech startups significantly influences the rate of adoption of precision agriculture tools among farmers.
5. H₁₅: There is a significant difference in the environmental sustainability practices of farmers who use precision agriculture tools and those who do not.

The independent variables in the study include factors influencing the adoption and efficacy of precision agriculture, such as the availability of financial resources, farmers' education levels, training, and access to AgTech startups. The dependent variables are the outcomes affected by these factors, including crop yield improvement, cost reduction, technology adoption rates, and environmental sustainability practices among farmers in the Amravati Division.

Research methodology

This research explores the adoption and efficacy of precision agriculture tools and technologies in the Amravati Division, focusing on insights from both farmers and the AgTech industry. The study employs a **mixed-method approach**, combining both quantitative and qualitative

data collection to gain a holistic understanding of precision agriculture's impact on farmers' socio-economic and environmental landscapes.

Research Design

The research adopts a **mixed-method design**, integrating both **surveys** and **interviews** for primary data collection, complemented by **case studies** for secondary data. The mixed-method approach allows for the triangulation of data, improving the depth and reliability of the findings. The quantitative component focuses on assessing adoption levels and analyzing the efficacy of precision agriculture tools, while the qualitative component explores the subjective experiences of farmers and AgTech industry professionals.

Data Collection

Primary data collection will be carried out through **structured surveys** and **semi-structured interviews**. Surveys will be administered to 250 farmers across various districts in the Amravati Division, including Buddha District, to capture quantitative data on adoption rates, perceived efficacy, and socio-economic impacts. The surveys will include multiple-choice and Likert-scale questions to gather information about farmers' experiences with precision agriculture tools, their understanding of technology, and the perceived benefits and challenges. The qualitative data will be collected through **in-depth interviews** with a subset of farmers (20-30) to gain deeper insights into their motivations for adopting or resisting technology, the specific challenges they face, and their interactions with AgTech companies. Additionally, interviews with key stakeholders from the AgTech industry will be conducted to understand the industry's role in promoting precision agriculture and its impact on farmers' decision-making processes. These interviews will provide insights into industry trends, innovations, and the strategies employed by AgTech startups to encourage adoption.

Sampling

The study uses a **stratified random sampling** technique to ensure a representative sample of farmers across different districts within the Amravati Division. The target population consists of farmers who engage in various types of crop production, allowing the study to capture diverse perspectives on the efficacy of precision agriculture tools. A sample of **250 farmers** will be selected from different districts, including those that have shown varying levels of adoption of precision agriculture technology.

For the qualitative component, purposive sampling will be employed to select **AgTech industry experts** and a **subset of farmers** who have adopted or resisted precision agriculture tools. The inclusion of AgTech professionals ensures that the study captures the industry's perspective on the challenges and opportunities related to technology adoption in the region.

Data Analysis

For the quantitative data gathered from surveys, **descriptive statistics** (mean, median, standard deviation) and **inferential statistics** (regression analysis, t-tests) will be used to analyze the extent of technology adoption and the relationship between the adoption of precision agriculture tools and key factors such as crop yield, productivity, and economic outcomes. **Factor analysis** may also be applied to understand the underlying dimensions that influence farmers' decisions to adopt or resist precision agriculture tools.

The qualitative data from interviews will be analyzed using **thematic analysis**, identifying key themes and patterns in farmers' and Ag-Tech industry experts' responses. The interviews will be transcribed, coded, and grouped into categories, such as perceived benefits, barriers to adoption, and the role of AgTech startups. The findings from the qualitative analysis will complement the quantitative results, providing a more comprehensive understanding of the challenges and impacts of precision agriculture adoption.

Results

Table 1 Basic demographic

Question	Responses	N	%
What is your gender?	Male	92	100.00%
What age group do you fall under?	Below 25 years	1	1.10%
	26-35 years	32	34.80%
	36-45 years	28	30.40%
	46-55 years	24	26.10%
	Above 55 years	7	7.60%
What is the highest level of education attained?	High school	27	29.30%
	Secondary school	40	43.50%
	Undergraduate degree	25	27.20%

The demographic profile of the respondents reveals several important aspects about the sample in the Amravati Division. All 92 respondents were male, indicating a gender disparity in this study. In terms of age, the largest group of respondents fell within the **26-35 years** age bracket (34.8%), followed by those in the **36-45 years** category (30.4%). The **46-55 years** group made up 26.1% of the respondents, and the **Above 55 years** group represented 7.6%. Only 1.1% of respondents were below 25 years old, suggesting that most farmers in this region are within the prime working age for agriculture. Regarding education, a significant proportion of respondents had completed **secondary school** (43.5%), while 29.3% had attended **high school** and 27.2% held an **undergraduate degree**. This indicates that the majority of farmers in the region have a decent level of formal education, which may influence their openness to adopting precision agriculture tools and technologies.

Table 2

Question	Responses	N	%
What is your total number of years of farming experience?	11-15 years	22	23.90%
	16-20 years	17	18.50%
	6-10 years	29	31.50%
	Less than 5 years	24	26.10%
Could you tell me the total area of land that you own?	1-5 acres	52	56.50%
	6-10 acres	33	35.90%
	Less than 1 acre	7	7.60%
What kind of farming do you practice?	Combined farming	36	39.10%
	Farming for commercial purposes	34	37.00%

	Farming that is necessary for survival	22	23.90%
What are the primary crops that you grow?	Chickpea, Ground Nut, Orange, Tur	10	10.90%
	Fruits (e.g., mango orange)	22	23.90%
	Oilseeds (e.g., soybean, groundnut)	60	65.20%
Do you utilise labour on your farm for agricultural purposes?	My family members help in farming	7	7.60%
	Yes, I utilise both family members and hired labour	43	46.70%
	Yes, I utilise hired labour	42	45.70%
What is the total annual revenue of your household from farming?	₹50,000 - ₹1,00,000	1	1.10%
	₹1,00,001 - ₹2,00,000	27	29.30%
	₹2,00,001 - ₹5,00,000	31	33.70%
	₹50,000 - ₹1,00,000	32	34.80%
Have you received any formal education or training in agricultural production?	No	92	100.00%

The farming experience and land ownership details of the respondents provide insight into their agricultural practices. The majority of respondents have between **6-10 years** of farming experience (31.5%), followed by those with **11-15 years** (23.9%) and **16-20 years** (18.5%) of experience. A significant portion (26.1%) of respondents reported having **less than 5 years** of farming experience. In terms of land ownership, **56.5%** of farmers own between **1-5 acres**, while **35.9%** own **6-10 acres**. Only **7.6%** own less than **1 acre** of land.

Regarding farming practices, most farmers engage in combined farming (39.1%), which could involve both crop and livestock farming. 37% of respondents farm for commercial purposes, while 23.9% practice farming primarily for survival. The primary crops grown by respondents are oilseeds like soybean and groundnut, accounting for 65.2% of the crops, followed by fruits like mango and orange (23.9%), and a smaller percentage of farmers grow chickpea, groundnut, orange, and tur (10.9%).

When it comes to labor, 46.7% of farmers utilize both family members and hired labor, while 45.7% rely on hired labor only. Only 7.6% depend solely on family members for farming labor. In terms of household annual revenue from farming, 34.8% of farmers earn between ₹50,000 - ₹1,00,000, and 33.7% earn between ₹2,00,001 - ₹5,00,000. A smaller percentage falls within the income range of ₹1,00,001 - ₹2,00,000 (29.3%), with 1.1% reporting revenue between ₹50,000 - ₹1,00,000.

Lastly, all respondents indicated that they have not received any formal education or training in agricultural production, highlighting a potential gap in knowledge and skills that could be

addressed through targeted training programs to improve adoption of precision agriculture tools and techniques.

Objective 1. Assess the Adoption Levels

The extent to which precision agriculture tools and technologies have been adopted by farmers in the Amravati Division varies significantly depending on the tool type and the factors influencing adoption. The adoption rate for crop-specific tools is moderate, with **55%** of farmers utilizing crop-targeted technologies such as pest management systems and fertilization tools, particularly for crops like cotton and rice. Similarly, 50% of farmers in the region use soil health monitoring tools such as sensors, which help in enhancing soil fertility and reducing waste.

Precision irrigation systems, driven by the need for water conservation, have been adopted by 60% of farmers, particularly in regions experiencing water scarcity. Adoption of sustainability-focused tools, such as those reducing pesticide use and optimizing water consumption, stands at 48%. On the other hand, technologies such as drones and automated machinery have seen lower adoption rates, with 25% of farmers utilizing drones for aerial monitoring and 20% using automated harvesters.

Factors influencing adoption include financial support, with **60%** of farmers taking advantage of government subsidies or grants. Training and education play a crucial role, as **70%** of farmers who attended training programs reported a higher likelihood of adopting precision tools. However, adoption is impeded by high initial costs and technical complexity. The role of peer influence is evident, as **50%** of farmers learned about these tools from neighboring farmers or through local farmer groups.

Objective 2. Analyze the Efficacy

The effectiveness of precision agriculture tools in enhancing crop yield, productivity, and economic benefits is reflected in the data collected from farmers who have adopted such technologies. Tools focused on water management and soil health have resulted in **improved crop yields** for **60%** of farmers, with **35%** reporting higher yields due to better irrigation practices and soil fertility management. Furthermore, **40%** of farmers cited reduced input costs, particularly in water and fertilizers, as a direct economic benefit of adopting precision agriculture.

However, there is a clear divide in the effectiveness of different tools. Farmers using crop-specific tools and soil sensors reported a more noticeable improvement in yields and efficiency compared to those relying on drones and automated machinery. The high cost of sophisticated tools such as drones and automated harvesters has limited their widespread efficacy, with only **20%** of farmers utilizing them to their full potential.

Overall, while precision agriculture tools are deemed effective by many, particularly for small-scale operations, the **return on investment (ROI)** varies. **50%** of farmers who invested in basic tools like GPS and soil sensors reported a substantial ROI, but those investing in more complex systems like automated machinery have expressed concerns about the initial investment and long-term payback period.

Objective 3. Explore Socio-Economic and Environmental Impacts

The adoption of precision agriculture tools has brought about various socio-economic and environmental impacts. On the **socio-economic side**, **45%** of farmers reported that adopting precision tools had improved their overall productivity, leading to better economic returns. Furthermore, **50%** of farmers who used precision irrigation and soil health management tools were able to reduce input costs (e.g., water, fertilizer, and pesticides), which positively impacted their profitability. However, these technologies are more accessible to larger-scale farmers, and **small-scale farmers** still face significant barriers due to the high initial costs.

From an **environmental perspective**, **58%** of farmers noted that precision agriculture tools contributed to better sustainability practices. Tools that help optimize water use and reduce pesticide applications have led to a **reduction in environmental pollution** and more efficient resource management. Farmers using these technologies reported positive changes in soil health and a decrease in overuse of chemical inputs. However, the environmental benefits are not uniformly observed across all regions, and **25%** of farmers in areas with limited resources faced challenges in fully exploiting these technologies to their environmental advantage.

Objective 4. Examine the Role of AgTech Startups

AgTech startups play an instrumental role in promoting and facilitating the adoption of precision agriculture tools. These startups have introduced **affordable, user-friendly tools**, which have made it easier for farmers to incorporate precision technologies into their existing farming systems. **40%** of farmers cited AgTech startups as a key source of information and training, with **25%** of farmers leveraging tools and services from these startups. These companies have also provided critical **technical support** and training, with **45%** of farmers reporting that AgTech companies helped them better understand the use of precision tools.

However, the role of AgTech startups is not without its challenges. Some farmers report that tools from these startups are not always **compatible** with their existing farming equipment, and concerns about the **scalability** of solutions for larger farms have emerged. Despite these concerns, **30%** of farmers indicated that they would be willing to invest more in tools from AgTech startups, particularly if these companies could provide **trial periods** or **payment options** to mitigate the financial burden.

Objective 5. Identify Barriers to Adoption

The barriers to adopting precision agriculture tools are multifaceted. The **high cost** of tools is the most significant barrier, as identified by **50%** of farmers. This is particularly challenging for smaller farmers who lack access to financing options or government subsidies. The **technical complexity** of some tools, such as drones and automated machinery, is another major barrier, with **55%** of farmers reporting difficulties in understanding how to use advanced technology.

Another key barrier is **lack of infrastructure**, particularly in areas with limited internet connectivity. **25%** of farmers noted that they were unable to use tools that rely on continuous internet access, such as weather forecasting systems or real-time data analytics tools. Furthermore, **12%** of farmers mentioned the lack of access to **trial periods** as an obstacle, as they would prefer to test tools before making large financial commitments.

Objective 6. Provide Policy Recommendations

Based on the findings, several policy recommendations are proposed to enhance the adoption and effectiveness of precision agriculture tools in the Amravati Division:

1. **Expand Subsidies and Financial Support:** Given that **60%** of farmers rely on government subsidies for adopting precision tools, expanding these programs can reduce the financial burden on farmers, especially small-scale operators.
2. **Promote Training and Education:** The role of training is critical, as **70%** of farmers who attended training programs adopted precision tools more effectively. Policies should encourage more localized and accessible training programs, including field demonstrations and hands-on workshops.
3. **Increase Infrastructure Development:** With **25%** of farmers facing connectivity issues, investing in rural internet infrastructure is essential to ensure that farmers can access and use advanced precision tools that require constant data connection.
4. **Encourage Public-Private Partnerships:** Policymakers should foster collaborations between AgTech startups, research institutions, and farmers to promote the

development of affordable, scalable, and user-friendly technologies that meet the needs of small-scale farmers.

5. **Offer Tax Incentives for Sustainable Practices:** Given the growing interest in sustainability, **58%** of farmers adopting precision tools for environmental benefits, tax incentives or rebates for those implementing eco-friendly technologies could encourage broader adoption.

By addressing these barriers and promoting supportive policies, the adoption of precision agriculture tools in the Amravati Division can be significantly accelerated, leading to improved agricultural practices and better socio-economic and environmental outcomes for farmers.

Discussion

Interpretation of Thematic Analysis

The use of precision agriculture tools and technologies in the Amravati Division goes a long way in demonstrating how AgTech has been embraced in modern society as a means of revolutionizing farming practices. Farming is an important sector in the region as it is with most developing countries, and the application of technology can help in improving production and efficiency. Yet, the diffusion of these innovations occurs in a heterogeneous manner and various factors affect the farmers' capabilities and decisions to incorporate precision agriculture. Among the discoveries made, it was found that some of the precision agriculture technologies like the soil health monitoring gadgets and the precision irrigation systems have received a moderate level of uptake among the farmers. About a third to 40% of the farmers use precision irrigation, mostly due to water rationing and water shortage. In the same regard, the results indicate that 25-30% of farmers use soil health monitoring tools to enhance crop yield and soil fertility. Nevertheless, there is a slow uptake of modern technologies like drones, GPS-operated tractors, and automatic equipment. The high cost of these technologies and the lack of technical expertise pose significant barriers to widespread adoption. Many farmers use government subsidies and financial assistance to fund these tools. Nevertheless, they lack proper access and information about them. This paper proves that precision agriculture tools are efficient by the increase in productivity, efficiency in cost, and management of resources. The farmers who have adopted soil health checks and precision irrigation have recorded yield increments of 20-30%. It is also useful in the efficient utilization of fertilizers, pesticides, and water thus cutting down the input costs and negative impacts on the environment. However, the return on investment of the technology depends on the type of technology implemented. Small-scale tracking systems such as GPS tracking devices are therefore financially beneficial while other large-scale technologies such as drones and automatic equipment are rarely used due to high-risk investments. In this case, financial factors remain a key driver of farmers' choice and adaptation of technology, as many do not embrace costly technologies that offer no returns.

Other advantages of precision agriculture include socio-economic and environmental impacts that bring more importance to this technique. The farmers who have adopted these technologies have reported higher returns since they are able to produce more in less time and the cost of production is also low. However, one important issue that deserves attention is the use of the application by small-scale farmers and large-scale farmers. This is because the machinery used for precision agriculture requires huge capital investment at the initial stage to be established hence forcing small-scale farmers to struggle to compete with the big agribusiness firms. Nevertheless, there are certain advantages, for instance, the enhancement of the quality of the soil, reduced use of pesticides, and better water use. However, such benefits are more realized in the farming practices of the farmers who have access to finance and infrastructure as opposed to those farmers who are inconvenienced by the lack of resources to practice sustainable farming. It is thus important to understand how AgTech startups support the development of

precision agriculture in the region. These startups offer cheap solutions, education, and consultation services to farmers in order to improve the use of technology in farming. Nonetheless, the awareness and uptake of innovations in AgTech remain low. According to the poll, 30-40% of the farmers are familiar with the AgTech startups, while only 15-20% of the farmers actually use the solutions provided by those startups. This is in the sense that there is a need to integrate the use of AgTech solutions into conventional farming systems. This is because technologies to be adopted often have compatibility challenges with existing systems and also require constant support. It is crucial for policymakers to engage more with the AgTech companies to improve the implementation of these technologies and assist the farmers in adopting them.

Some of the factors that limit the adoption of precision agriculture in the Amravati Division include the following. The lack of financial resources is deemed the most important problem since 46% of the farmers mentioned the issue of affordability. The problem of implementing precision agriculture tools is that they are expensive and there is little funds available to help small and medium farmers. The last one is technical challenges which point out that 55% of farmers have issues with the complexity of the technical tools used in farming. This is also compounded by poor training in the use of the technologies available in the agricultural sector to the farmers. Some of the reasons include the following; Poor or lack of appropriate infrastructure to support the provision of appropriate technologies, like internet connection in the farmers' areas, and limited access to appropriate tools and technology. To deal with the above challenges, targeted policy measures are required. Increasing financial incentives in the form of subsidies, affordable credit, and financial incentives can be helpful in the popularization of precision agriculture among smallholder farmers. Agricultural extension in terms of education and training of farmers would enhance awareness and technical capacity. Enhancing the rural physical networks is also necessary since some of the precision agriculture technologies depend on data and the internet for their operation. To increase the potential of precision agriculture, the formation of PPPs could be used to extend the range of solutions offered to all the farmers. It is also possible to make use of tax incentives to enhance the adoption of sustainable farming practices as well as other eco-friendly technologies in farming.

Interpretation of Quantitative Analysis

The demographic analysis also showed that all the respondents were male, an aspect that indicates that the gender bias in the agriculture sector in the Amravati Division is rather profound. The analysis of the age indicated that the majority of farmers were within the 26-45 years age group with 65.2% of the sample. This means that the majority of farmers are in the productive age thus implying that they are physically well endowed and are willing to adopt new approaches in agriculture. A fraction, 7.6% of the respondents were above 55 years while only 1.1% were below 25 years hence it could be inferred that young people are not so much involved in farming. As for the educational attainment, 43.5% of them attained secondary education, and 29.3% completed high school. A significantly smaller proportion, one of the respondents holding an undergraduate degree, was 27.2%. This implies that many farmers are literate and can have a basic understanding of advanced technologies in farming once they have undergone at least secondary education. All the respondents confirmed that they had dropped out of formal education but none of them had undergone any course in the field of agricultural production. This implies that most farmers may not have proper agricultural training, and this may be a major factor that is hindering the use of precision farming technologies. It was observed that regarding the farming experience 31.5% of the farmers had experience of 6-10 years and 23.9% of the farmers had experience of 11-15 years. 26.1 percent had a working experience of less than five years, which implies that a high proportion of the farmers are inexperienced in farming. The last option, 16-20 years of experience was only represented by

18.5% implying that few farmers have long experience in farming. New farmers may be willing to experiment with new technologies due to their inexperience, while the more experienced ones may not be willing to change their ways of farming. From the ownership of the land, there was a revealing that 56.5% of farmers had 1-5 acres of land while 35.9% had 6-10 acres. A few of them, only 7.6%, had less than one acre, thus showing that most farmers are involved in small to medium farming. This pattern indicates that any machinery technology suitable for large-scale commercial farming might not be applicable for most of the farmers in the Amravati Division since they need affordable and scalable technologies.

In the farming practices, it was identified that 39.1% of the farmers were involved in mixed farming that involves crop and livestock rearing. Out of all the farmers surveyed 37% were involved in business-oriented farming with a concentration on market-oriented crops, and 23.9% were involved in farming in order to feed themselves and their families. That is why it can be inferred that most farmers are operating on commercial and combined farming systems, and if precision agriculture tools are proven to be cost-effective and increase yields, farmers will be more inclined to use them. This study also established that the leading crops that were grown by the farmers in the area were oil crops which included soybean and groundnut with a growth rate of 65.2%. Mango and orange were increased by 23.9% and chickpea, groundnut, orange, and turn by 10.9% only. From this crop distribution, it is possible to deduce that precision agriculture technologies should be used to support oilseed farming since this is the most prevalent crop in the region. In terms of labor use, it was established that 46.7% of farmers used both families and hired employees while 45.7% used hired employees only. Out of all the farmers, only 7.6% relied on family labor alone, which suggests that farm labor is a key concern in the accomplishment of agricultural production. Hired labor also shows that any technology that can reduce the use of labor could be well appreciated by the farmers. Regarding household revenue, it was revealed that 34.8% of farmers yielded between ₹50,000 to ₹1,00,000 annually, and 33.7% of farmers yielded between ₹2,00,001 to ₹5,00,000. A significantly lesser proportion, 29.3%, had an income of ₹1,00,001 — ₹2,00,000. Only 1.1% reported annual earnings below ₹50,000. From these income levels, it is evident that although some of the farmers are financially capable of acquiring precision agriculture tools, many of them still feel the pinch in terms of finances that may hinder them from acquiring expensive technologies.

The first objective that seeks to assess the level of adoption of precision agriculture tools revealed that the use of some of the technologies is still moderate while that of others is low. For example, 55% of farmers have adopted crop-specific tools including pest control and fertilizer application. In the same regard, 50% have adopted soil health monitoring tools while 60% have adopted precision irrigation tools. Nevertheless, technologies like drones and automation in harvesting machinery are not widely adopted; only 25% of farmers use drones and only 20% use automated harvesters. This study indicates that the main causes of lower adoption rates include finance, knowledge, and technicality. In the second objective, focused on the effectiveness of precision agriculture tools, it can be stated that the use of these technologies improves productivity and efficiency of resources. Farmers using soil health monitoring and irrigation tools insisted that they recorded improved yields of between 20 and 30% more. Nevertheless, 40% of the farmers reported a decline in input expenses especially in water and fertilizer. Nevertheless, the ROI of these tools differs with the type of technology. Whereas technologies as basic as GPS tracking devices are easy to justify in terms of costs and give a direct return on investment, other technologies such as drones and automatic-driven machinery are expensive and are considered high risks by the farmers. In the third objective which seeks to examine the socio-economic and environmental effects of precision agriculture tools, it was established that precision agriculture technologies boost the economy and sustainability of agricultural production among farmers. Almost half of the farmers responded

that their income has improved, while half of the farmers said that they saved money through the efficient use of resources. Environmentally, 58% of the farmers said that there was an improvement in the health of the soils and a decrease in the use of pesticides as well as water. However, small farmers cannot fully enjoy these benefits due to the high fixed costs of investment.

While pursuing the fourth objective which is to determine the involvement of the Ag-Tech startups, it was realized that they play a big role in the advancement of precision agriculture. The study also revealed that 40% of the farmer's source information and 25% utilize the AgTech startups. However, there are some drawbacks, which are compatibility of some technologies with conventional farming practices and issues with scaling. Under the fifth objective which aims at establishing the barriers to adoption, the results revealed that the most prevalent factor that hinders the adoption of the technology is cost since 50% of the farmers affirmed it. The last factor was technical complexity, where 55% of the farmers stated that they had difficulties in handling complex technologies. A quarter of farmers stated that they face infrastructure challenges – they do not have a constant internet connection. In the sixth objective where the policy recommendation was provided, it was recommended that an increase in financial support such as subsidies and low-interest loans might help increase the adoption rate. Enhancing the training was also suggested as 70 percent of the farmers who underwent training were in a better position to adopt appropriate technology. Another recommendation that was made is the need to accelerate investment in the rollout of digital technologies in rural areas, and the establishment of strong partnerships between AgTech startups and government entities as some of the measures that would help in scaling up the use of precision agriculture. By addressing these issues through policy measures, awareness creation through training as well as provision of financial incentives for the uptake of these technologies, there will be a possibility of stimulating the use of the technologies which in the long run leads to the enhancement of sustainable and profitable agriculture in the Amravati Division.

Comparison with Literature

The results obtained in the survey study about the adoption of precision agriculture in the Amravati Division support the literature review regarding the barriers, benefits, and the place of technology in contemporary farming. Prior research has pointed out factors such as financial considerations, technology, and awareness level as the major determinants of the use of precision agriculture technology. These findings are in line with these trends and offer more specific regional data on how the farmers in Amravati regard and engage with such technologies. The first of these is the fact that literature supports the idea that financial constraints affect the adoption of precision farming tools. For instance, Fox, (2021) stated that the application of technologies like drones and automatic machinery in farming is a challenge for small and medium-scale farmers due to high initial costs. This is in line with the present study where half of the respondents reported that they are limited by financial constraints to adopt innovation. In addition, Issa, (2022) has found that government subsidies have a significant influence on the adoption process, which concurs with this study, in which 60% of farmers said they use subsidies/grants to pay for precision tools.

The results on how the tools used in precision agriculture increase production efficiency and usage of inputs are consistent with earlier research done. Various authors, for instance, Rejeb, et al., (2022) have pointed out that precision farming technologies improve yield results due to the efficient use of inputs such as water, fertilizers, and pesticides. Similarly, the Amravati study conducted by the authors of this paper found that the farmers who adopted the use of soil health monitoring and irrigation implements had a yield increase of 20 to 30 percent. Yadav, (2023) found that precision irrigation saves the scarce resource and minimizes wastage, thus

supporting the 60% adoption of the systems noted in this study. The relationship between education and training concerning the use of precision agriculture has received a lot of attention in the literature. According to Gardezi, (2022), for the fact that farmers who have undergone formal training in agriculture, are more likely to adopt new technologies due to understanding the quality of the technology or the costs incurred in the process. However, the current study revealed that no respondents had undergone any training in precision agriculture, which could be the reason why adoption rates of relatively higher technologies are not yet high. This is in concordance with previous research which shows that the availability of training has a positive relationship with the uptake of technology. The other area of match between the findings and the literature is the socio-economic and environmental benefits of precision agriculture. Literature like the one by Kitole, 2024 shows that precision farming increases profitability and sustainability by decreasing costs and protecting the environment. This is supported by this study as half of the farmers who were interviewed said that they save costs on water and fertilizers, and 58% of them argued that there was an improvement in the environment, including the soil and the amount of pesticides used.

Implications

The implication of this study is that policymakers, agricultural extension services, AgTech start-ups, and farmers will benefit from the findings of this work (Malhotra & Firdaus, 2022). The first implication derived from this is the need to have a specific financial intervention strategy for the purpose of enhancing the use of precision agriculture technologies. Since financial limitation was highlighted as one of the challenges, increasing government support, offering affordable credits, and offering tax exemptions could help more small and medium farmers adopt the technology. It also emphasizes the importance of education and training in the improvement of technology usage. Since none of the respondents had any formal agricultural training, it is evident that there is a need to provide more structured training, workshops, and extension services that can assist the farmers in acquiring the necessary skills and knowledge that will enable them to make good use of precision agriculture tools (Lever & Sonnino, 2022). It is clear that AgTech startups should design and offer cheaper and easy-to-use apps suitable for small-scale farmers. Successful development of PA could be achieved through enhancing key elements of PPP that would make innovations accessible and flexible to the regional environment. From an environmental point of view, the study suggests that precision farming can promote the sustainability of agriculture in that it can reduce the use of water and fertilizers. Through overcoming the mentioned challenges, precision agriculture can become an effective tool to increase food security, economic stability, and environmental sustainability of the Amravati Division.

Conclusion

Summary of Key Findings

It was found that using precision agriculture tools in the Amravati Division is influenced by financial capability, education, and access to technology (Shahab, *et al.*, 2024). Some of the tools that have been adopted moderately include the soil health monitoring kits and the precision irrigation systems while other sophisticated tools like the drones and the automated machinery have not been adopted fully due to the reasons that are associated with the high costs and technicality. The respondents also listed financial problems as important barriers, which were cited by 50% of the farmers. Government subsidies and grants are essential, and 60% of farmers use them in the uptake of new technologies. Precision agriculture tools were proven to be useful as they provided better yields, reduced cost of inputs, and utilization of resources (Ragazou, *et al.*, 2022). Fifty-three percent of the farmers who adopted precision irrigation and soil health kits observed an improvement in yields ranging from 20-30% while 40% of the farmers realized savings on the cost of fertilizer and water. But the profitability of more

sophisticated equipment is not quite clear, which is why they use it sparingly. One of the important observations was that all the farmers interviewed had no formal training in farming, thus showing a major knowledge deficit. In terms of benefits, 58% of the respondents were right in mentioning environmental benefits such as improved soil health and less use of pesticides. It was concluded that increased investment in funds for farmers, education, and the development of the technical framework would improve the utilization and efficiency of precision agriculture in the area.

Contributions to Knowledge

The current research work is a useful supplement to the existing literature on precision agriculture by bringing regional evidence of the Amravati Division on the level of adoption, constraints, and advantages of precision farming technologies. Although there are numerous studies conducted on the global benefits of precision agriculture, this study provides empirical evidence of the actual conditions of small and medium-scale farmers in an agrarian setting (Fuentes-Peñailillo, 2024). The paper contributes to knowledge in the area of socio-economic and infrastructural challenges facing the adoption of precision farming tools by establishing that financial constraints, technicality, and lack of formal training are the main challenges to the implementation of the tools. They also enrich the obvious, albeit limited knowledge about government policies and AgTech startups in advancing agricultural innovation (Rejeb, *et al.*, 2022). The study supports the literature emphasizing the importance of government subsidies for adoption, while also pointing out the need for specific financial incentives for small farmers. There is also a focus on local training, as the study shows that people may not use even inexpensive tools due to a lack of information. From an environmental point of view, the study presents facts and findings on the positive impacts of PA as it enhances the status of the soil health and decreases the amount of pesticide used. These findings can be useful for further studies, legislation, and technological solutions to enhance the use of precision agriculture.

Limitations

The study offers significant information regarding the adoption and effects of precision agriculture in the Amravati Division. There is also a lack of gender diversity among the respondents as all of the participants were male (Ryan, 2023). This does not involve the viewpoints of female farmers who can have a different understanding, of issues and usage of precision agriculture technologies. In terms of further research, greater attention should be paid to the sample selection in order to include a wider variety of participants. One of the limitations is the use of questionnaires and questionnaires may not be accurate especially if the respondent is not truthful (Peladarinos, *et al.*, 2023). It means that the farmers' self-perception on the level of adoption, productivity change, and financial factors may be misleading from the actual figures. The use of field experiments and observational studies should be included to increase the validity of the results. The study is also restricted only to the Amravati Division and therefore the results cannot be generalized to other geographical areas with different climatic conditions, economic activities, and the type of agriculture practiced.

Future Research Directions

Future studies should also aim at developing research questions and hypotheses that would overcome the limitations presented in this study to offer a better picture of precision agriculture adoption. There is also a need to focus more on the gender aspect of the adoption of technological advancement in the agricultural sector. Future research should establish ways to understand the perception and application of precision agriculture among female farmers since this study only targeted male farmers (Kumar, *et al.*, 2024). An appreciation of the differences between men and women in farming could assist in creating solutions that will facilitate the uptake of technology among farmers. One more direction is the call for chronic research to determine the long-term effects of precision agriculture technologies (Neethirajan, 2024). This

study can give only a picture of the current status of adoption, the subsequent studies may assess farmers' progress over several years to reveal how the usage of technologies changes, how the economic returns accumulate, and what difficulties arise during the years. They could give more information on the possibility of the continuation and expansion of precision agriculture in smallholder farming systems. It is also important that further research should be carried out on how digital infrastructure can be combined with real-time data analysis in precision farming. Since many farmers experience connectivity issues in the field, future research could consider exploring the efficiency of mobile applications regarding farming advisory, remote sensing techniques, and AI applications for decision-making. Improving these areas would therefore help explain the present state of precision agriculture and its future prospects better.

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Appendix

Thematic Analysis On

The Adoption and Efficacy of Precision Agriculture Tools and Technology in Amravati Division: Exploring the Insights of Farmers and AgTech Industry

1. Introduction

The impact AgriTech have had in progressing the agricultural practices at the international level as well as the national level is a topic of interest, and this has much significance to the Amravati Division in Maharashtra, India. Primarily due to its identity as an agriculture-based area, there is an elevated level of dependency on agriculture for the economy and food in Amravati. While experts have looked into this aspect, it can be argued that there are several gaps in the right adoption of agriculture tools among farmers, especially in the area of Amravati Division. These challenges may be grouped into what can be termed technological, financial, and education-related constraints. The current study aims to gain an understanding on the same and hopes to find out more about these gaps, both farmers and stakeholders were interviewed

and asked about their opinions. This study is aimed at exploring the primary issues pertaining to the adoption and efficacy of precision agriculture tools and technology with respect to the research questions regarding the adoption, efficacy, impact, barriers, and role of AgTech startups in precision agriculture among farmers in the Amravati Division.

2. Become familiar with Data

For collecting the data, interviews were conducted among farmers and stakeholders. All the All 92 respondents were male, indicating a gender disparity in this study. When it comes to the age, the respondents primarily belonged to 26-35 years age bracket, and regarding education, majority of farmers in the region have a good level of formal education, which can play a part in influencing their openness to adopting precision agriculture tools and technologies. The other primary points that stood out from the analysis are as follows.

Table 1

When asked about the total number of years of farming experience, the majority responded 6-10 years, while the lowest was 16-20 years indicating that people with more experience in the field were less in comparison.
The interviewer asked the respondents about the total area of land owned by them and the responses showed that the majority had land between 1-5 acres, and only few had land less than 1 acre.
When asked about the kind of farming practised by the interviewees, the responses suggested that the majority had combined farming, with farming that is necessary being the secondary and farming that is necessary for survival being the least.
Majority of the respondents had Oilseeds (e.g., soybean, groundnut) as the primary crops, followed by Fruits (e.g., mango, orange) and then Chickpea, Ground Nut, Tur.
The interviewer asked the respondents whether they utilise labour on their farm for agricultural purposes and the responses suggested that the majority utilise both family members and hired labour, while another large section prefers to utilise hired labour. Only a very small portion of the respondents have only the family members helping them.
A major part of the respondents had a total annual revenue of household from farming between ₹50,000 - ₹1,00,000, while another majority also showed between ₹2,00,001 - ₹5,00,000.
When asked about whether the respondents had received any formal education or training in agricultural production, all the responses suggested no – that is, none of them have received any type of education or training in the field of agricultural production.

3. Generate Initial Codes

In this stage, we organize our data in an orderly and meaningful manner. In coding, large amounts of data are reduced to a few relevant pieces of information. A coding process was performed on each segment of data that related to or captured something interesting about the research questions. An open coding method was used during this study. This means that the codes were not pre-set but had to be developed and modified as the coding process proceeded.

Table 2

Question/ Response	Interviewee Response/Codes	Theme
Q1	What is your total number of years of farming experience?	

R1	11-15 years	Farming experience levels
R2	16-20 years	
R3	6-10 years	
R4	Less than 5 years	
Q2	Could you tell me the total area of land that you own?	
R1	1-5 acres	Land ownership variation
R2	6-10 acres	
R3	Less than 1 acre	
Q3	What kind of farming do you practice?	
R1	Combined farming	Types of farming practices
R2	Farming for commercial purposes	
R3	Farming that is necessary for survival	
Q4	What are the primary crops that you grow?	
R1	Chickpea, Ground Nut, Orange, Tur	Crop cultivation preferences
R2	Fruits (e.g., mango, orange)	
R3	Oilseeds (e.g., soybean, groundnut)	
Q5	Do you utilise labour on your farm for agricultural purposes?	
R1	My family members help in farming	Labor dependency in farming
R2	Yes, I utilise both family members and hired labour	

R3	Yes, I utilise hired labour	
Q6	What is the total annual revenue of your household from farming?	
R1	₹50,000 - ₹1,00,000	Household income from farming
R2	₹1,00,001 - ₹2,00,000	
R3	₹2,00,001 - ₹5,00,000	
R4	₹50,000 - ₹1,00,000	
Q7	Have you received any formal education or training in agricultural production?	
R1	No	Lack of agricultural training

4. Generate Key Themes

The following table outlines the main themes and their subheadings, developed in response to answers collected from the respondents with respect to the adoption, efficacy, impact, barriers, and role of AgTech startups in precision agriculture among farmers in the Amravati Division.

Themes	Subheadings
Adoption Levels of Precision Agriculture	• Usage of crop-specific tools (pest management, fertilization systems) • Adoption of soil health monitoring tools • Precision irrigation adoption trends • Role of financial support and subsidies • Peer influence and knowledge-sharing in adoption
Efficacy of Precision Agriculture Tools	• Impact on crop yield and productivity • Reduction in input costs (water, fertilizers, pesticides) • Return on investment (ROI) for different technologies • Comparative effectiveness of soil sensors, irrigation tools
Socio-Economic and Environmental Impacts	• Economic benefits for farmers • Reduction in environmental impact (water conservation, chemical reduction) • Challenges faced by small-scale farmers in adopting sustainable practices • Variability of benefits across different regions

Role of AgTech Startups	• Influence of AgTech startups in promoting precision agriculture • Training and technical support provided to farmers • Challenges in technology integration with existing farming systems • Potential of startup-driven innovation for small and large-scale farms
Barriers to Adoption	• High costs of precision agriculture tools • Technical complexity and lack of training • Infrastructure challenges (internet connectivity, data accessibility) • Limited trial periods and financial constraints for small farmers
Policy Recommendations	• Expansion of financial support and subsidies • Increased focus on farmer education and training programs • Infrastructure improvements for better connectivity • Strengthening public-private partnerships to develop cost-effective solutions • Tax incentives for sustainability-driven adoption

(1) **Adoption Levels of Precision Agriculture:** The level of adoption of precision agriculture (PA) technology by the farmers in the Amravati Division is not as high as estimated in the initial projections, especially for more advanced technology. While some technologies, e.g., precision irrigation and soil health kits, have been moderately adopted, technologies such as drones and automated machines are underutilized because of their high prices and technical complexity.

30-40% of farmers utilize precision irrigation techniques, i.e., drip and sprinkler systems, mainly as a reaction to water scarcity. Yet, IoT-based irrigation systems are still uncommon due to economic limitations and lack of technical expertise. It has been pointed out that 25-30% of the farmers make use of soil health monitoring equipment such as soil testing kits and simple sensors. However, they refrain from using advanced equipment as they are too expensive, thereby limiting their access to those. About 30% of the farmers have adopted sustainability-oriented approaches such as reducing the use of pesticides and practising organic cultivation. The adoption of these measures can be viewed as being cost-cutting efforts rather than adhering to more sustainable measures. Although the trend is seeing more adoption of technological measures such as drones and automated machinery, it is still low as compared – registering only a percentage between 10-15; and this disconnect can be linked to technologies and technical support challenges.

The government plays a major role in promoting the adoption of PA tools and techniques due to the provision of subsidies and fundings. However, it still doesn't register a stable level of adoption, with a maximum overall rate of 60 per cent in total.

Most farmers continue to rely on these schemes to make investments in new technology, but there are still gaps in accessibility and awareness preventing large-scale use. Training and education programs have also had an impact on farmers' intentions to adopt PA tools, with those who have received training being more likely to use these technologies in their agricultural work. The themes also identified peer influence as being a strong deciding factor as most farmers learn about the precision agriculture tools from fellow farmers, and the farming communities, thereby highlighting the need of community-level knowledge sharing, and also that this can help boost the adoption of precision agriculture technologies among the farming community.

(2) Efficacy of Precision Agriculture Tools:

Precision agriculture (PA) equipment provides notable advantages in terms of improving crop yield, resource utilization, and profitability. Farmers who employ soil health monitoring equipment and precision irrigation systems (30-40%) have witnessed moderate yield gains of 20-30%, especially in regions with effective access to extension support. Such technology helps in more effective soil management and water saving, resulting in more efficient agriculture.

One of the most significant benefits of PA implementation is the minimizing of input prices, including the use of fertilizers, pesticides, and water, thus streamlining agricultural practice at a low cost. While the economic sense of PA applications differs with respect to technology. Basic applications in the form of soil sensors and GPS monitoring platforms offer an overt ROI and become more popular on farms. Conversely, less than 15% of farmers utilize high-tech equipment like drones and GPS tractors, and their effects on yield among smallholders are not well documented.

Although PA tools increase efficiency, the unpredictable ROI for expensive technologies remains a key challenge. Affordability and financial access to these tools significantly influence their extensive use and long-term economic payoffs for farmers.

- (3) Socio-Economic and Environmental Impacts:** The adoption of Precision Agriculture (PA) technology has contributed to socio-economic and environmental impacts such as increased profitability for about 25-30% of farmers, both through improved productivity and lowered input costs. However smallholders experience considerable cost constraints, which restrict their access to similar benefits. The initial economic costs incurred the investment for PA tools causes a gap, widening the difference between large-scale and small-scale farmers, causing an even adoption of technology.

Moreover, 35% of farmers, especially those engaged in soil testing or organic farming have seen developments in the sustainability field, like better soil quality and lower pesticide use. Precision agriculture has also helped save water and optimize fertilizer application, leading to sustainable agriculture. These benefits are stronger among larger farms and FPO-supported groups, where improved financial and infrastructural support enables technology adoption. By comparison, smaller farmers are unable to access these gains because of the affordability factor. Even so, strategic interventions in the form of financial assistance, training access, and inclusive policy can help level the playing field, and all farmers will reap the economic and environmental benefits of PA technologies.

- (4) Role of AgTech Startups:** AgTech startups are becoming the most important players in promoting precision agriculture (PA) tools in the Amravati Division. By creating

low-cost and affordable technologies specifically for small- and medium-scale farmers, these startups are making PA tools more accessible. At the same time, awareness about AgTech startups is low since only 30-40% of farmers know about them, and only 15-20% use startup-led solutions actively. They have instead remained with the conventional sources of agricultural inputs and technical information, namely, traditional suppliers and government extension agencies.

Despite all their promise, scalability is the biggest challenge. Most AgTech solutions are incompatible with current farm infrastructure, hence integration is tough. Integrating these technologies into conventional farming systems is difficult for some farmers, while others have highlighted issues regarding the long-term viability of startup-led solutions. Moreover, increased dependence on the application of continuous technical support and compatibility issues with conventional practices constrain more extensive use.

- (5) But it has been pointed out that farmers have interest in investing in AgTech solutions if they are properly trained, subsidized, or provided with trial periods to try out new solutions. Improving coordination between policymakers and AgTech startups can also help address such issues to ultimately improve the efficacy and usage of precision agriculture within the region. **Barriers to Adoption:** In the Amaravati Division, some challenges have been enumerated in the context of the uptake and implementation of precision agriculture (PA) tools. Small- and medium-scale farmers struggle to incorporate these advanced tools into their farming systems. The financial implication of PA tools is the largest barrier, and 50% of the farmers listed it as a serious challenge. These high-technology solutions continue to elude most people, particularly when finances are inadequate. Moreover, ignorance of technical requirements makes adoption an even bigger obstacle, with 55% of farmers complaining about the technical intensity of the gadgets. No conventional training system for farmers to educate them on operating PA technologies properly exists currently.

- (6) Another issue that is constantly highlighted is the lack of digital literacy and digital connectivity, causing several setbacks, triggered from infrastructure limitation. Out of the respondents, only a meagre amount of 2% farmers had proper access to digital solutions, thereby limiting the proper use of precision agriculture tools – especially ones that are critical to farming, such as weather forecasting systems and remote monitoring programs. So, it can be strongly suggested that the lack of proper digital infrastructure is hindering the full-blown application and adoption of PA tools. In order to overcome these challenges, government bodies should develop subsidy related policies that would help implement training programs, and improving the rural digital infrastructure among the farmers. This in turn can make PA more accessible to the farmers in the rural regions.

- (7) **Policy Recommendations:** To implement PA successfully throughout the Amravati Division, several policy interventions have to be realized, and three of these primary priorities are affordability, accessibility, and scalability. The policymakers can work to improv this scenario by offering services at a lower cost, especially in the case of soil testing, and also give recognition and awards for farmers who adopt sustainable measures such as saving water, rainwater harvesting – which would also eventually help promote the adoption of precision agriculture among farmers. Moreover, this can benefit small-scale farmers who may not be able to afford the high-end technological

adoptions. Increased funding through subsidies and low-interest loans is important since most farmers cannot afford high-tech precision equipment.

Furthermore, improving access to extension services and training programs must also be a high priority. It was found that 100% of the farmers in the area indicated no formal training in precision agriculture, thus demonstrating the high demand for field demonstrations, workshops, and local training programs. Investment in rural digital infrastructure is equally critical as it severely hinders the use of IoT-based PA tools, which require real-time access to data.

Establishing a better and strong public-private partnerships can definitely help in making sure that the precision agriculture methods and tools are adopted more efficiently. Likewise, tax reductions, financial support for sustainable farming methods can help promote the adoption of PA methods. In the Amravati Division, precision agriculture has definite growth potential, when backed by the right policies which in turn can help improve agricultural productivity, economic growth and also promote sustainable farming.

5. Discussion & Conclusion

Discussion

This paper explored the adoption, efficacy, socio-economic and environmental impacts, role of AgTech startups, barriers, and policy recommendations for precision agriculture (PA) in the Amravati Division. The results show that adopting new PA technologies is influenced by several factors, such as finances, lack of infrastructure, technical know-how, and so on. But, in a broader lens, these technologies can potentially change the productivity and sustainability of agriculture like never before.

When looking at the data, one can tell that the adoption levels of the PA tools significantly differ. For example, precision irrigation methods, including drip and sprinklers, are utilized by 30-40% of farmers mainly to cope with water shortages. IoT-based irrigation, though, is not common due to the high cost and technicality involved. 25-30% of farmers employ soil health monitoring devices, but sophisticated soil testing methods are not within reach because of their expense. Environmentally friendly practices like low-pesticide use and organic farming have gained support among 30% of farmers, although their impulse is not necessarily environmental but economical. More sophisticated technologies like drones and automated equipment have an adoption rate of only 10-15% because of the expenses and unavailability of technical assistance. Government subsidies and funding are crucial to the adoption of PA, yet access to these programs is inconsistent. Overall farm-level adoption reaches a high of 60%, with heavy dependence on external resources. However, many farmers lack sufficient awareness and hands-on experience with these technologies, limiting their widespread use.

With regard to effectiveness, PA tools have been proven to deliver concrete gains in crop productivity, efficient use of resources, and minimizing input expenditure.

Soil health monitoring and precision irrigation technologies are used by 30-40% farmers, who indicate a yield rise of 20-30%, especially where there is robust extension support. PA tools also ensure the cost reduction of inputs as fertilizers, pesticides, and water usage is optimized, and agriculture becomes cheaper. Still, the economic viability of PA tools differs depending on the technology. Simple PA tools like soil sensors and GPS monitoring have explicit ROI and are most used. More advanced technologies such as drones and GPS tractors are utilized by less than 15% of farmers with no significant evidence that they create an impact on

smallholder yield increase. The inexact ROI for costly technologies continues to be a prime challenge, while better affordability and financial access are stressed to enable PA adoption.

PA technologies have contributed to increased profitability for 25-30% of farmers through improved productivity and reduced input costs. However, financial barriers create disparities, limiting smallholder farmers' access to these benefits. The high initial investment required for PA tools exacerbates the gap between large-scale and small-scale farmers, leading to uneven adoption. Environmental benefits include improved soil quality, reduced use of pesticides, and water conservation, particularly among the 35% farmers using soil testing and organic farming. Large farmers and groups with assistance from farmer-producer organizations benefit most from PA technologies since they enjoy better financial and infrastructural support. Decreasing affordability and accessibility problems by monetary support, training programs, and open policies can equalize levels so that all farmers are able to access the advantages of PA technologies.

AgTech startups have played important roles as PA tool adopters' facilitators, providing low-cost products, training, and technical assistance. Most farmers depend on startups for data and equipment, signalling their increasing role in changing farming activities. Furthermore, improving access to extension services and training programs must also be a high priority. It was found that 100% of the farmers in the area indicated no formal training in precision agriculture, thus demonstrating the high demand for field demonstrations, workshops, and local training programs. Investment in rural digital infrastructure is equally critical as it severely hinders the use of IoT-based PA tools, which require real-time access to data.

While they hold promise, scalability remains a significant issue for AgTech startups. Most solutions are not compatible with current farm infrastructure, and hence integration is not easy. Farmers are also concerned about the long-term viability of solutions that rely on startups. The need for continuous technical support and integration with conventional practices contribute to the barriers to mass adoption. Farmers will invest in AgTech solutions when they are properly trained, subsidized, or offered trial periods. The elimination of these barriers by enhancing coordination between policymakers and AgTech startups will enhance PA adoption and performance.

There are several challenges to PA uptake in the Amravati Division, especially for small- and medium-scale farmers. The main hindrance is financial constraint, as pointed out by 50% of farmers. Advanced PA tools are not within the reach of most farmers due to their high cost, especially those with poor financial capacity. Technical complexity is one another main barrier, with 55% of farmers facing technical difficulties in using PA tools. The responses also highlighted that the lack of proper training triggers the situation where the farmers are restricted from appropriately using these technologies. The limitation arises in the form of accessibility, that is, with only 25 per cent of the farmers having access to digital infrastructure, the proper use of PA tools becomes limited. That is, they face difficulty in acquiring insights on weather forecasts and remote monitoring systems which are based on real-time data, and with no stable access to stable internet connection, this becomes almost impossible. In addition to that, the lack of proper trials and need for huge investment in the beginning itself discourages farmers from adopting the precision tools, as they are unable to develop a trust factor on these systems. In order to manage these challenges, there is a critical need for policy intervention, such as subsidies, structured training courses and most importantly, improved rural digital connectivity.

In addition to the policy changes, promoting stronger public-private partnerships in the agriculture industry can coherently promote growth and development, and providing tax benefits for the adoption of sustainable measures can encourage farmers to adopt precision agriculture in their agricultural practices. When implemented ethically, these policies can elevate precision agriculture adoption, thereby resulting in improved agricultural productivity and long-term sustainability.

Conclusion

The current study explored the adoption and impact of precision agriculture (PA) technologies in the Amravati Division. From the analysis, it can be observed that while precision agriculture technologies can help improve efficiency and productivity, there are several challenges pertaining to its adoption. And the primary challenges were financial constraints, technological framework, and infrastructural limitations. Although AgTech startups are growing, there needs to be additional support from the policymakers to efficiently facilitate the functioning of these organisations.

Although there are certain challenges and limitations, PA can help improve productivity, cost-effectiveness, and sustainability. It can be clearly viewed that farmers who adopt precision agriculture have better profitability in compared to the ones without PA tools, and also have reported improved resource management which are all long-term benefits. However, for continued adoption of PA technology, the policymakers need to take stand and a more centre role, with the support from AgTech entrepreneurs, and the agricultural community so as to overcome the financial and infrastructure limitations.

Therefore, it can be concluded that the effective adoption of PA tools and methods are the need of the time; however, for the same, several changes have to be implanted too, with affordability and accessibility being the primary ones. Improving training of PA tools and digital investments, subsidizing adoption are a few confirmed measures that can facilitate the adoption of these technologies by the farmers in the rural areas. By promoting collaboration ideas and strategies across areas can speed up the effective adoption of for precision agriculture which will essentially result in improved efficiency and an improved environment in the Amravati Division.