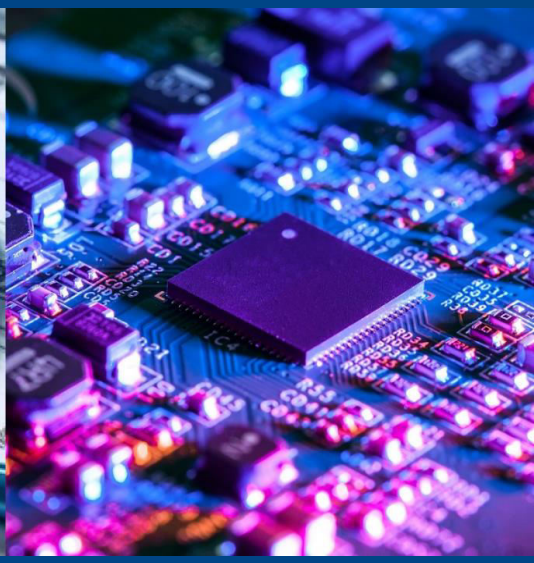
ISSN: 2582-7219





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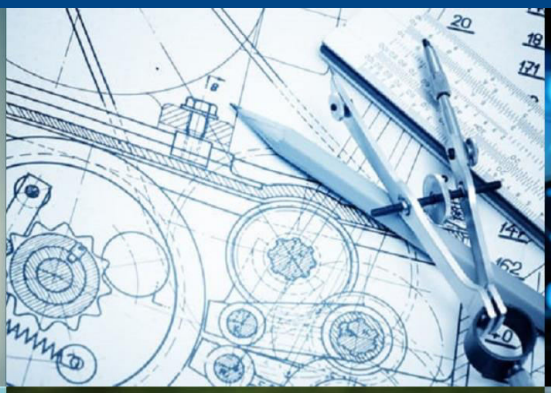

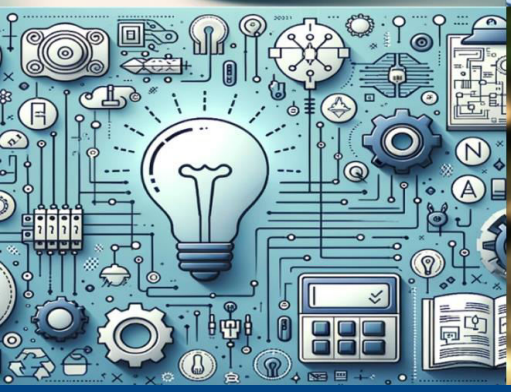

Impact Factor: 8.206 **Volume 8, Issue 4, April 2025**

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ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

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Exploring the Effectiveness of Agri-Tech Solutions for Small Holder Farmers in India's Agricultural Ecosystem: A Perception Study

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ABSTRACT: This paper examines the effectiveness of Agri-tech solutions in addressing the needs of smallholder farmers in India through a perception-based study. Using primary data collected from farmers, the research assesses awareness, accessibility, and impact of digital tools, mobile apps, and precision technologies. The findings indicate moderate awareness but limited adoption, largely due to digital illiteracy, cost constraints, and infrastructure gaps. However, farmers who use Agri-tech report improved access to weather forecasts, market prices, and crop management. The study emphasizes the need for inclusive, user-friendly, and region-specific innovations to enhance Agri-tech accessibility and rural agricultural sustainability.

I. INTRODUCTION

It's a fact that agriculture has been the backbone of the Indian economy and for a long time it included nearly 58% population and contributes nearly 18% to the nation's GDP (Ministry of Agriculture & Farmers Welfare, 2023). While the industry faces quite a few challenges—such as climate change, labor shortages, pest infestations and non-uniform market access—it remains buoyant. Over the last half century, the global population has expanded hugely, and global food security and agricultural sustainability are very challenging problems. In 1960, the population of the world was about 3 billion, and by the time of 1987, the number was about 5 billion. According to a population census which was conducted 2018, the world population is estimated at around 7.6 billion with projections of reaching to 10 billion by the year 2050. Nevertheless, the growth has not been even across various regions. The population of Sub-Saharan Africa has grown fastest, rising nearly 5 fold, from 227 million in 1960 to over 1 billion in 2018. Similar increases were seen in the Northern part of Africa and Middle East as well, where their population grew from 105 million to 449 million and multiplied fourfold. As a result, global food production has never been under such vast pressure from this demographic surge, therefore calling for innovative agricultural solutions that will allow efficient sustainable agricultural practices. In order to tackle these issues, incorporating Artificial Intelligence (AI) in agricultural domains is now proving to be a transformative force that aims at improving the productivity, optimizing the resource allocation, and mitigating farming risks.

The AI in agriculture global marketplace is anticipated to range up to USD 1.7 billion by the end of 2023, and it is expected to raise at a CAGR of 23.1% to range USD 4.7 billion in the year 2028. The quickness to embrace this technology shows that AI can provide real time insights, automate labor intensive tasks, and revolutionise farm management. Thankfully, the smallholder dominated agricultural landscape of India is hugely enthused to this digital revolution through government led initiatives as well as private sector innovations geared towards modernisation of its archaic agriculture sector.

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Objectives of the Study

Methodology

This study employed a mixed-method strategy involving primary and secondary data collection methods to assess the efficiency of AgriTech solutions among smallholder farmers in India.

Primary Data Collection

For the first stage of data collection, a structured online questionnaire was administered to farmers in Karnataka, India, to gain direct insights from the smallholder farmers. The survey included the following topics:

- Demographics of respondents, including age, sex, farm size, region of residence, and farming experience.
- Income and Awareness of Technology: For example, annual income, prior knowledge regarding AI-integrated AgriTech solutions, and current usage of?
- AgriTech Adoptions: Type of solutions used; frequency of use; effectiveness; impact on income.
- Constraints: Barriers to adoption, including affordability, level of digital literacy, and internet connectivity issues.
- Market Restrictions: For example, the factors made available by middlemen, low prices on market days, and poor access to the supply chain.
- Future Willingness for Adoption: For example, interest in integrated AgriTech platforms and willingness to pay for solutions.

Sampling Method:

- Number of Samples: 50 smallholder farmers.
- Sampling Technique: Convenience sampling was used with accessible farmers who voluntarily participated.
- Data Collection Tool: Google Forms-based survey.

Secondary Data Collection

To supplement the primary data, the secondary research was extensive and included reports on:

- Government Reports: Ministry of Agriculture & Farmers Welfare, FAO, World Bank.
- Academic Studies & Market Research Reports: AI in agriculture trends, challenges in AgriTech adoption, and investment patterns.
- Industry Case Studies: Successful Agritech start-ups and policy efforts that encourage technology adoption in farming.

II. LITERATURE REVIEW

1. Farmers' Perceptions of the Utilization of Modern Agricultural Technology in Rural Areas

Hardiyansah B (2024) in his study *Farmers' Perceptions of the Utilization of Modern Agricultural Technology in Rural Areas* examines farmers deliberating about how modern technological tools can be used for agriculture and in its economic perspective. They have collected information from focus groups, discussions, interviews, and observations and collected information from farmers on the method they were using in agriculture, {traditional or modern}. This helps us understand even though many people are using modern technologies like tractors, combines, cultivators, and much more they are priced at the higher end when compared with the traditional tools, and maintenance of these modern technological tools is also quite difficult. And many people are still not aware of modern tools. Modern agricultural technology and tools are mostly used by the new farmers or the young farmers whereas the old generation are still uncertain about these things. There are many groups still spreading awareness of these modern technologies and are playing an important role in adopting these technologies. The recommendations which are given in this paper are to reduce the cost so that everyone can afford it and they are trained on how to make the best use of modern technologies in, agriculture.

2. Agriculture 4.0: Smart Revolution of the Future Farming Sector

Kokale S et al. (2024) in their research paper *Agriculture 4.0: Smart Revolution of the Future Farming Sector* deliberates how several digital technologies IoT, AI, robotics, and precision farming techniques are driving the digital revolution in the farming sector. Even though smart technologies can be used for agriculture practices which will be very effective, efficient, and sustainable people are not embracing this because of the cost that comes along with it, many are not ready to change from their old practices to the new ones because of the low digital literacy. This study also talks about Industry 4.0 which has accomplished many things and people are somewhat accepting this but where agriculture 4.0 is left behind because of shortages of supply chains, deprived policy support, and economic limitations. The authors display the requirement of government encouragement, monetary funding, and agriculturalist training to fill the gap. They endorse

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investing in rural digital infrastructure and sustainability built on guidelines for healthier meticulous agricultural and resource value.

3. Techno-Economics and Environmental Sustainability of Agricultural Biomass-Based Energy Potential

Akter M et al. (2024) in their paper *Techno-Economics and Environmental Sustainability of Agricultural Biomass-Based Energy Potential* catalogues the numerous sources of biomass into arable field crops (AFCs) and horticultural plants (HPs). The assessed electricity generation possible from the existing biomass adding up to 9231.60 MW can encounter approximately 88.0% of the country's total energy demand. Straightforward economic forecasts, circumstance to guarantee the financial feasibility of biomass under these circumstances, with a levelized cost of electricity (LCoE) features on par with a representative to LCoE, as well as a remuneration retro of delivering in the range of 2.93 to 3.75 years. In specific, the plant will lessen CO_2 production by 156 tons/year and create revenue through the carbon credit market. Government choices in favor of policy supporting the mitigation of biomass energy, about keeping enhanced waste management set up intolerable to incentives along the carbon credit trading market.

4. Enhancing Sustainability in Agriculture with Nano fertilizers

Saurabh K et al. (2024) in their study *Enhancing Sustainability in Agriculture with Nano fertilizers* analyse the possibility of the nano fertilizers to transform modern cultivation by cultivating nutrient use effectiveness. The study found an enhancement of nutrient usage efficiency, by up to 30%; a rises in crop harvest by 20%; and a lessening in environmental impression by conventional manures. It found that measured release of the nano fertilizers could promote nutrient absorption and ultimately guarantee good plant growth and soil fertility. In spite of these returns, challenges still exist, including high production costs, the probable existence of toxicities, and supervisory concerns. The study recommended the policy involvement of financial incentives for stakeholders, investments into the making of cost-effective production procedures, and regulation outlines, guaranteeing the safe and responsible use of nano fertilizers in sustainable agriculture.

5. Application of AI Techniques and Robotics in Agriculture:

Wakchaure M et al. (2023) in their study *Application of AI Techniques and Robotics in Agriculture:* an organized evaluation of AI applications contains over 150 research studies since the period of 1960 to 2021. AI applications were divided into three segments: cultivation, monitoring, and harvesting. Automation through AI was detected to support advanced effectiveness in land preparation, seed selection, irrigation, weed identification, and crop health monitoring. Fuzzy logic, ANN, and GA were initiated to be the furthermost extensively used AI techniques, whereas other approaches such as PSO and ABC endured marginally utilized. The authors recommended monetary assistance to endorse AI applications, training programs to build up agriculturalists, and investments in AI-facilitated technologies to accomplish the break between traditional and automated agriculture.

III. DATA ANALYSIS AND FINDING

To know more about the farmers and their background, experience, and their awareness of Agricultural Technology we did a survey and got the answers directly from smallholder farmers in Karnataka. The primary data was collected through a questionnaire, capturing agriculturalists' insights, acceptance levels, benefits, and challenges related to Agricultural Technology. Moreover, secondary data from cross country analysis highlights global investments in Agricultural Technology and their contributions to the cultivated division over the last five years

3.1 SECONDARY DATA

Secondary data analysis is a vital research approach that uses existing datasets to come up with meaningful insights, identify patterns and to confirm hypotheses without having to generate new data. As a robust study, this research study delves in to the viability of use of AgriTech solutions by smallholder farmers in India. Government reports, agricultural surveys, market research and case studies of reliable sources like the Food and Agriculture Organization (FAO), World Bank, Indian Ministry of Agriculture, and several AgriTech companies are used to create it. Secondary data analysis is a key research method that uses already existing datasets to obtain useful insights, detect patterns and verify hypothesis without collecting new data. This study bases on the secondary data and formulates its founding on AgriTech solutions and its effectiveness for the smallholder farmers in India.

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3.1.1 Market Size and Trend

Artificial intelligence for agriculture market worth USD 1.91 billion in the year 2023 expected to grow at a CAGR of 25.5 % during the prediction period 2024 & 2030. Many advantages exist for the different stakeholders in the sector as artificial integration in agriculture has been introduced. The real time monitoring and insights are provided for the benefit of farmers, an improved harvest quality, automated irrigation systems are in practice, the control of outcomes is improved, risks are mitigated from inaccurate treatments, and so on.

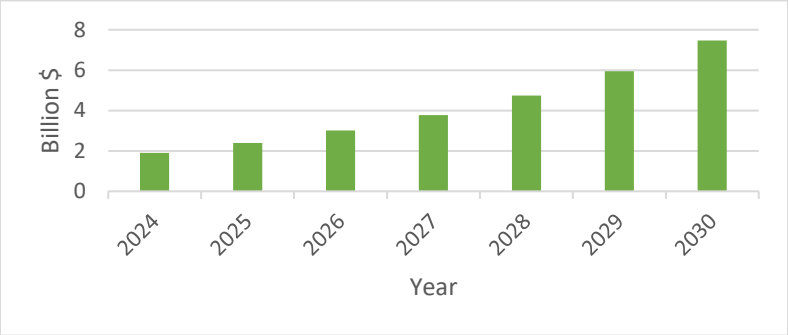

Figure 1: AI in Agriculture Market Size, by Technology, 2023 - 2030 (USD Billion)
Source:https://www.grandviewresearch.com/industry-analysis/artificial-intelligence-in-agriculture-market
Figure 1 depicts the development of AI in the Cultivation Sector valued at $ 1.91 billion in 2023 and is anticipated to raise at a CAGR of 25.5% since 2023-2030.

3.2 PRIMARY DATA

The primary data was collected from smallholder farmers across Karnataka using a structured online questionnaire. The survey focused on demographics, current Agricultural Technology usage, barriers to adoption, willingness to pay for Agricultural Technology solutions, and revenue generation challenges.

3.2 .1 Farmer Demographics

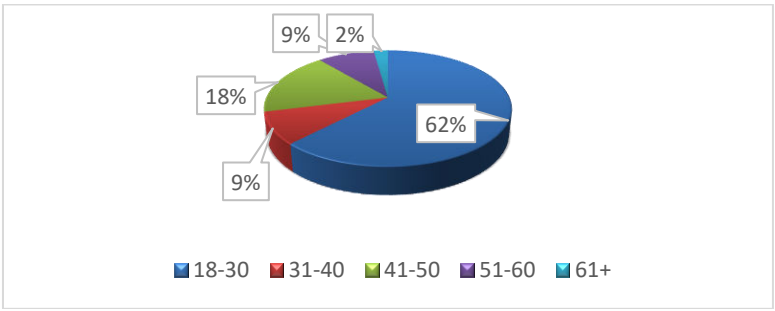

Figure 3: Age of the respondents
Figure 3 depicts the age of the respondents. Most of the respondents, 62%, are 18-30 years old. 18% belongs to 41-50 years followed by 9% from 31-40 and 51-60 years and 2% above 61 years.

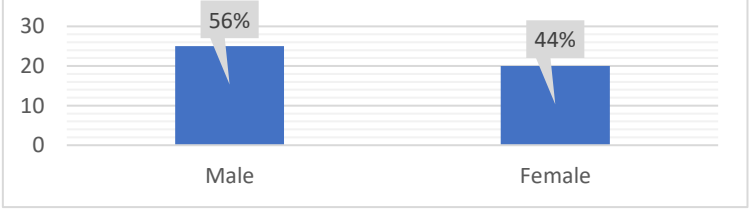

Figure 4: Gender of farmers.
Figure 4 depicts the gender of the farmers, majority of the respondents are male 56% and female 44%.

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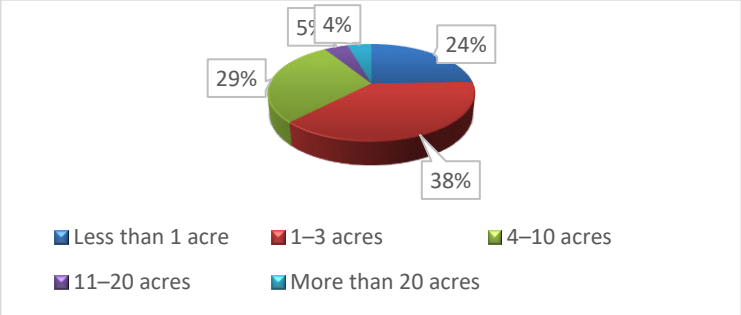

Figure 5: Area of land farmers own.

Figure 5 depicts the area of land farmers own, majority of the respondents have 1-3 acres 38%,29% have 4-10 acres, 24% have less than 1 acre, 5% have 11- 20 acres and 4% have more than 20 acres.

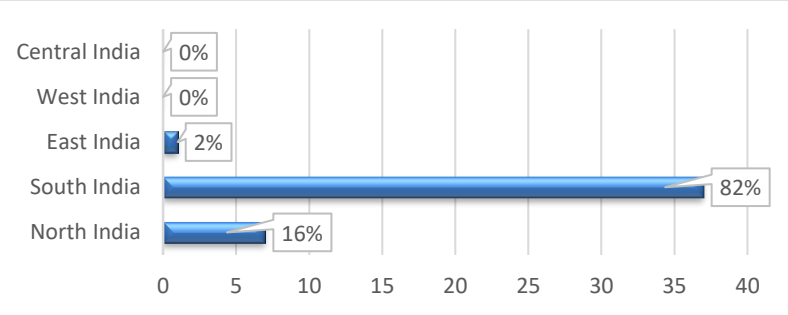

Figure 6: Farmers count based on region.

Figure 6 depicts the farmer's count based on region, the majority of the respondents 82% are from south India, 16% are from north India and 2% are from east India.

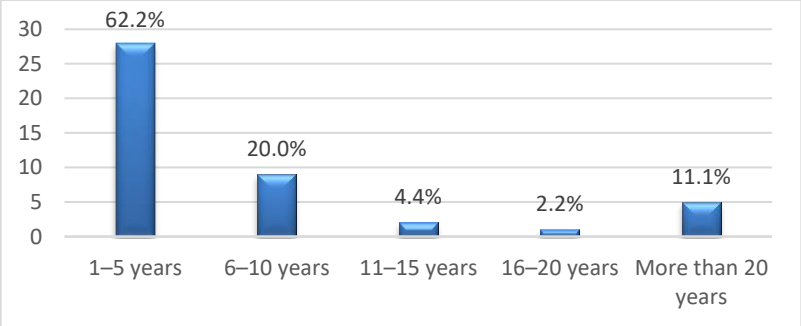

Figure 7: Experience of farmers.

Figure 7 depicts the experience of farmers, majority of the respondents 62.2% have 1-5 years of experience, 20% have 6-7 years of experience, 11.1% have more than 20 years of experience, 4.4% have 11-15 years of experience and 2.2% have 16-20 years of experience.

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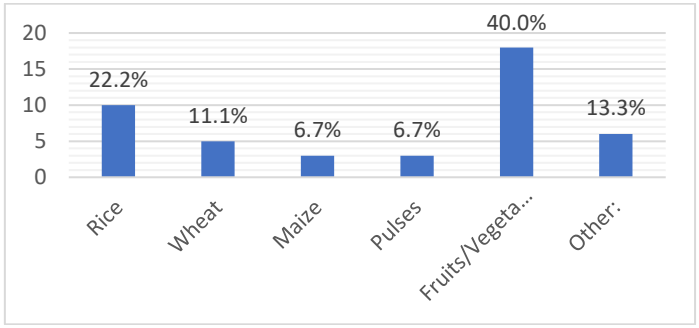

Figure 8: Crops cultivated.

Figure 8 depicts the Crops cultivated by the farmers, most respondents 40% grow fruits/vegetables, 22.2% grow rice, 13.3% grow other, 11.1% grow wheat, 6.7% grow maize, and 6.7% grow pulses.

3.2.2 Income & Awareness

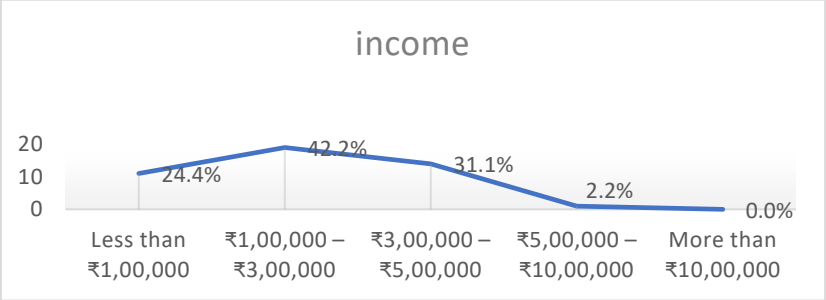

Figure 9: Annual income of farmers.

Figure 9 depicts the annual income of farmers most respondents 42.2% income is Rs 1,00,000-3,00,000, 31.1% of their income is Rs 3,00,000-5,00,000, 24.4% income is less than Rs 1,00,000 and 2.2% income is Rs 5,00,000-10,00,000.

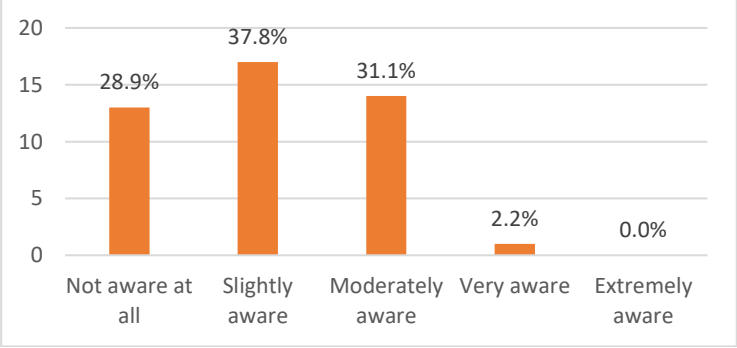

Figure 10: Awareness of agri-tech.

Figure 10 depicts the awareness of agri-tech among most respondents 37.8% are slightly aware, 31.1% are moderately aware, 28.9% are not aware at all, and 2.2 are very aware

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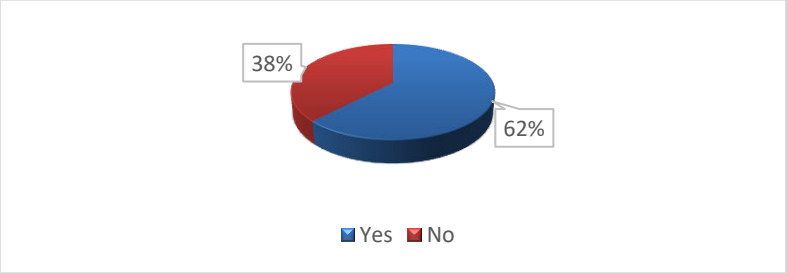

Figure 11: Uses of agricultural tools/technologies.

Figure 11 depicts the uses of agricultural tools/technologies most respondents 62% use agricultural tools and 38% do not use agricultural tools.

3.2.3 AgriTech Challenges

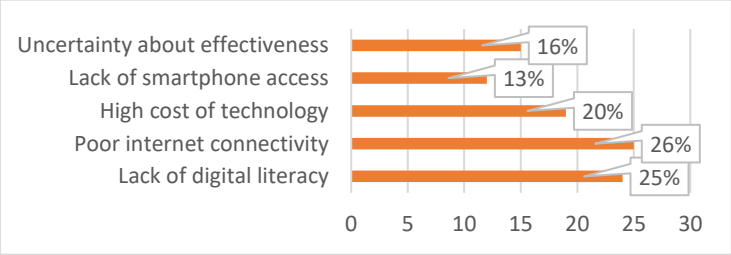

Figure 12: The challenges farmers face in adopting Agri-Tech solutions.

Figure 12 depicts the challenges farmers face in adopting Agri-Tech solutions most respondents 26% have poor internet connectivity, 25% lack digital literacy, 20% have a high cost of technology, 16% are uncertain about its effectiveness, and 13% lack smartphone access.

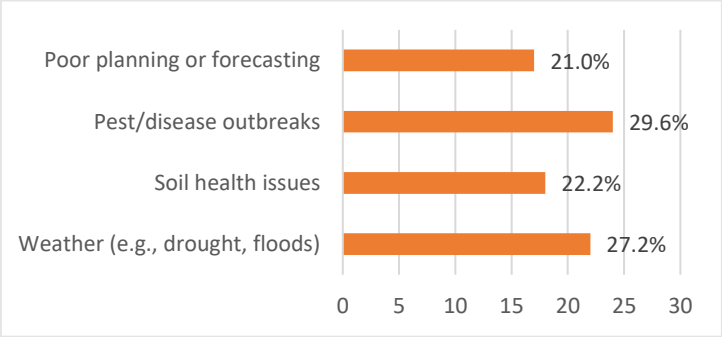

Figure 14: Primary causes of crop failure.

Figure 14 depicts the primary causes of crop failure for most respondents 29.6% pest/disease outbreaks, 27.2% weather, 22.2% soil health issues, and 21% poor planning or forecasting.

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3.2.5 AgriTech Adoption

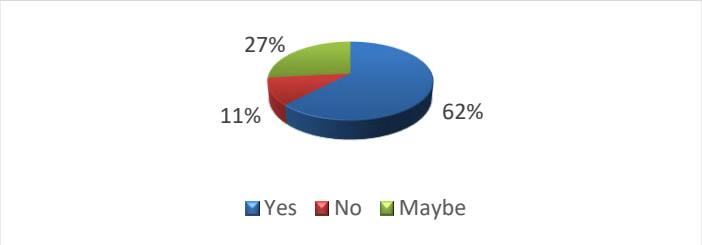

Figure 15: Willingness to adopt integrated agricultural technologies.

Figure 15 depicts the willingness to adopt integrated agricultural technologies, most respondents 62% yes are willing to adopt, 27% are not willing to embrace and 11% may be.

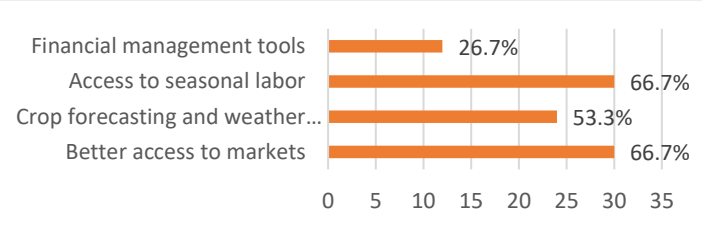

Figure 16: The valuable features that people prefer in the latest agricultural technology.

Figure 16 depicts the valuable features that people prefer in the latest agricultural technology most respondents 66.7% need better access to the market, 66.7% want access to seasonal labor, 53.3% need crop forecasting and weather prediction, and 26.7% need financial management tools.

3.2.6 Willingness to Pay

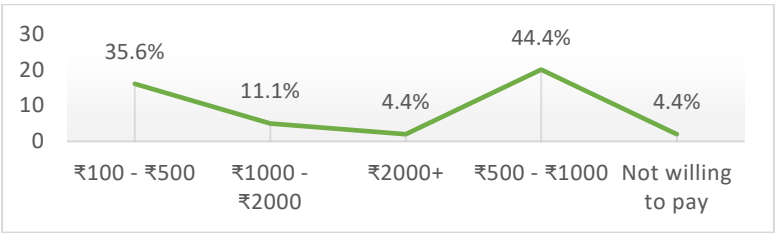

Figure 17: The willingness to Pay (Per Month) of the farmers for the agricultural technology.

Figure 17 depicts the willingness to Pay (Per Month) of the farmers for agricultural technology most respondents 44.4% are willing to pay Rs 500-1000, 35.6% are willing to pay Rs 100-500, 11.1% are willing to pay Rs 1000-2000, 4.4% are willing to pay Rs 2000+ and 4.4% are not willing to pay.

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3.2.7 Revenue Challenges

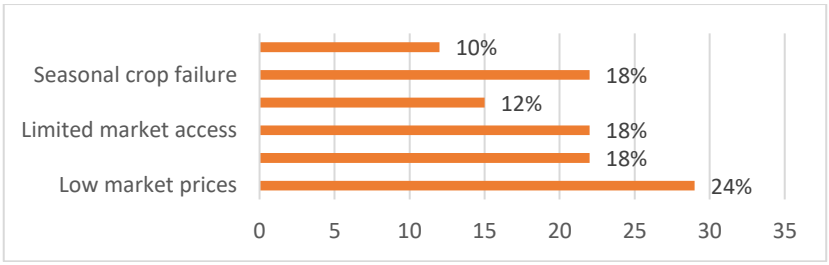

Figure 18: The biggest challenges farmers face in generating revenue from their farms.

Figure 18: depicts the biggest challenges farmers face in generating revenue from their farms most respondents 24% low market prices, 18% dependence on middlemen, 18% limited market access, 18% seasonal crop failure, 12% high input costs, and 10% lack of access to technology.

3.2.8 Tech Solutions

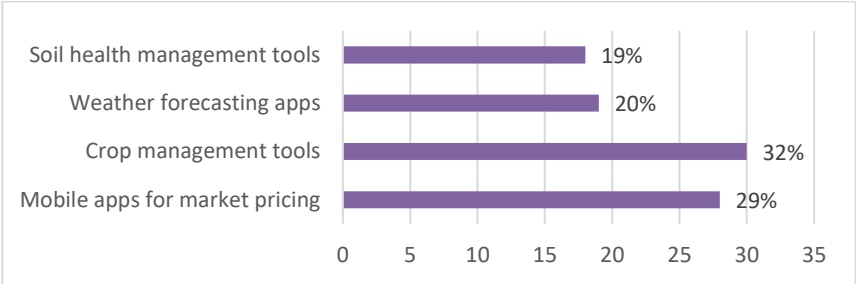

Figure 19: The preferred tech solutions by farmers.

Figure 19: depicts the preferred tech solutions by farmers, most respondents 32% want crop management tools, 29% want mobile apps for marketing pricing, 20% want weather forecasting apps and 19% want soil health management tools.

IV. ISSUES AND CHALLENGES

4.1 High Rate of Technology and Financial Constrictions

One of the most noteworthy blockades to Agri Tech implementation is the high cost of current agricultural equipment. Meticulousness agricultural equipment, AI driven monitoring systems, and clever irrigation resolutions involve considerable investment, which many smallholder agriculturalists may not be able to afford. Moreover, access to credit and financing is inadequate, as economic organizations frequently classify smallholder agriculturalists as high-risk borrowers, making it hard to get mortgages.

4.2 Incomplete Digital Literateness and Practical Information

Several smallholder agriculturalists lack the digital knowledge essential to function Agri Tech solutions successfully. The absence of satisfactory training agendas and user-friendly crossing points additionally confuses acceptance. Agriculturalists are frequently unaware of data-determined agricultural devices, restraining their capacity to influence the assistance of digital agriculture.

4.3 Insufficient Infrastructure and Connectivity

The accomplishment of Agri Tech solutions depends on unchanging internet access, electrical energy, and dependable transportation systems. Nevertheless, many countryside agricultural societies lack the essential set-up to provide digital

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agriculture IoT-based farming solutions and cloud-based management systems experience disruptions due to the low penetration of mobile networks and power outages that are common.

4.4 Resistance to Transformation and Cultural Barriers

Generations have passed the ways of old agriculture through the years until today, and farmers tend to be stubborn regarding new technologies. Many farmers resist AficTech at face value because of fear of financial loss or curtailment of their farming routines. Such an attitude is attributed to a lack of success stories and peer influence.

4.5 Inadequate Customization for Smallholder Farmers

Various AgriTech innovations are formulated for large-scale, commercial farming operations, whereas they are designed to have little or no relevance to smallholder farmers. Massive farmland, sophisticated infrastructure, and substantial data processing capability are human-centric, therefore, making any AgriTech applicable to only larger farms. For example, crop monitoring using drones is mostly too expensive, unwarranted, and useless for smallholder farmers with tiny holdings.

V. SUGGESTION

5.1 Financial Assistance and Subsidization Programs

According to the numerous studies done by (World Bank, 2021), public subsidies, and low-interest loans to smallholders will dismiss them of the monetary burden while obtaining Agri Tech solutions. Ground-breaking joint projects could lead to cost-sharing models which can make the technology reasonably priced (FAO, 2020). New micro-financial institutions must progress in giving products tailor-made for agriculturalists such as innovative systems that encourage the acceptance of modern agricultural tools (IFAD, 2019). Optional facilities separately from financial assistance should also be put in place for counseling farmers on loan suitability, loan settlement structure, and income predictable from investment in Agri Tech. Insurance systems accepted under the government for technology investments will also help reduce the financial risks related to investments.

5.2 Digital Literacy and Capacity Building

The overall training must educate all agriculturalists on how they can use Agri Tech. In suggestion with other stakeholders, government institutions, agricultural universities, and technology businesses should hold digital literacy workshops in rural areas (OECD, 2022). Mobile Apps should be designed in such a way as to ensure easy-to-use interfaces and languages, which help to prepare the way for bridging the gap between technology and field implementation (FAO,2020). Other types of training to consider are peer-to-peer models, where skilled agronomists guide others on Agri Tech applications.

5.3 Infrastructure Development and Connectivity Enhancement

World Economic Forum (2021) claims that investment in countryside infrastructure, such as increased broadband access and better-quality electricity supply, is vital. Government inducements should be provided to telecommunication companies to extend the coverage of their networks into distant agriculture areas.

5.4 Encouraging Farmer Cooperatives and Group-Based Adoption

Farmer cooperatives represent a good opportunity for collective engagement in Agri Tech implementation, bringing diverse resources to pay for costly technological adoption (IFPRI 2018). Farmer organizations promoted by the government may enable group purchases and sharing of digital solutions. This cooperative model has been quite successful in the adoption of technologies in countries such as India and Kenya, where enhanced bargaining power through group purchases has facilitated technology adoption (FAO 2020).

5.5 Customization and Localization of Agri Tech Solutions

Agri Tech firms will be adopting the approaches of developing low-cost, scalable, and locally suitable solutions for smallholder agriculturalists (CGIAR, 2019). These technologies should depend on soil types, climate conditions, and infrastructure. Such associations linking local agricultural research institutions will help choose and design realistic solutions for smallholder needs and foster increased implementation rates (FAO, 2021).

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

VI. CONCUSSION

According to the study, increasing significance is given to AgriTech solutions to tackle farmer-related issues in smallholder farmers of India. While some of the newer technologies, such as AI-based precision farming, soil health monitoring, and crop forecasting, have shown promise in increasing productivity and efficiency, barriers like high costs, digital illiteracy, poor infrastructure, and market access inhibit their adoption.

Findings indicate that while 52% of farmers have started using AgriTech solutions, the overall effect on the income remains moderate to low, with 40% of them stating there was no income change. Digital illiteracy (60%) and poor internet connectivity (52%) are major hindrances in this regard. Despite these shortfalls, 64% of farmers were willing to adopt integrated AgriTech platforms, especially given their potential for market access, seasonal labor availability, and crop forecasting.

Efforts by targeted interventions will be needed to accelerate the adoption of AgriTech with financial subsidies, digital literacy programs, physical infrastructure, and farmers' cooperatives. Custom-built interventions that are cheap and scalable will fill the technology gap and help improve productivity while contributing to sustainable agriculture in the long run.

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