

Analysis of the Economic Impact and Life Cycle Costs of Precision Agriculture Implementation in Food Crop Cultivation

Adnan Achmad ^{1*}, Hanisah ², Silvia Anzitha ³

^{1*,2,3} Agribusiness Study Program, Faculty of Agriculture, Universitas Samudra, Langsa City, Aceh Province, Indonesia.

Email: adnanachmad@unsam.ac.id ^{1*}, ir.hanisah@unsam.ac.id ², silviaanzithasilviaanzitha@gmail.com ³

Article history:

Received February 10, 2026

Revised February 28, 2026

Accepted March 4, 2026

Abstract

To improve the efficiency of agriculture and food crops, the use of modern technology is necessary. Precision Land Management consists of a suite of high-tech tools including sensors, drones, and Geographic Information Systems (GIS) to monitor land and crop conditions in real time. This allows for optimized utilization of inputs such as water, fertilizer, and pesticides. This paper aims to analyze the economic impact of implementing precision agriculture, focusing on its Life Cycle Cost. This includes not only the initial investment, but also current operations, maintenance, and future savings (although there may be some uncertainty regarding the actual costs). This study used Life Cycle Costing (LCC) and Cost-Benefit Analysis (CBA). The results show that the implementation of precision agriculture reduces resource consumption. For example, sensors have reduced water use in West Java by 30%, and variable fertilizer application based on Sumatra has reduced fertilizer consumption by 40%. However, the main obstacle is the high initial investment costs, which are a burden for smallholder farmers. Therefore, policies that support the adoption of precision agriculture technologies through various means such as fiscal incentives and training are urgently needed, and it is also important to ensure that such tools can be freely used by farmers throughout Indonesia.

Keywords:

Precision agriculture; Life cycle cost; Agricultural technology; Cost-benefit analysis; Food crop cultivation.

1. INTRODUCTION

Precision Agriculture has become a trending approach to improving the efficiency of food crop farming in recent years. To achieve this goal, advanced tools including sensors, drones, and Geographic Information Systems (GIS) are used to monitor fields and crops in real time. Using this technology, water, fertilizer, and pesticide inputs can be adjusted according to the current needs of the crop and soil. In theory, this will increase production yields and reduce resource consumption. One of the recent technological advancements in agriculture benefits not only the farm itself but also, potentially, the entire society. Despite the positive implications of precision agriculture on environmental factors and efficiency, its economic impact is still not fully understood. The life-cycle cost of implementing this technology, including initial investment and operational costs, is a crucial factor that must be studied. Capital expenditures, operational costs, and future hardware and software upgrades and maintenance are all costs that must be analyzed. This study aims to examine the economic impact of implementing precision agriculture in food crop cultivation, focusing on a Life-Cycle Cost comparison. This study fills the knowledge gap by providing a comprehensive overview of the costs and benefits of precision agriculture technology. It is hoped that by doing this, the government can make wise decisions regarding the implementation of precision farming technology and farmers can get good advice from this.

Precision agriculture provides a solution that can transform agriculture: the use of resources to be more efficient (not using too much air, pesticides, or fertilizers). The use of advanced tools such as sensors, drones, and GIS makes it possible to always be aware of the conditions in the field. With this technology, it is easier to match inputs to the needs of specific plants. The benefits obtained are in the form of increased crop yields

and reduced resource waste. However, the economic impact of the application of this technology in general, including the costs and benefits in the long run, needs to be studied more closely. In Indonesia, the agricultural sector is a major component of the economy and food security. Nonetheless, there are many problems, from low productivity to the promise of using natural resources appropriately. Fadli et al. (2025) show that new technologies, to encourage greater efficiency and productivity, are essential if these problems are to be addressed. Precision farming, by optimizing the use of inputs, eliminates these problems. However, this technology also brings with it its own set of problems. For example, you need a lot of capital to spend on the initial purchase of both hardware and software. Ratnasari (2025) in her study on village fund assistance said that public policy support and funding that are able to enable farmers to take advantage of this technology. Precision farming technology has the potential to bring benefits not only in terms of increased production, but also cost efficiency in the long run, which is something that smallholders (who often face high operational costs) need to consider. The Attention Unit (2024) also speaks to the fact that many smallholders face great challenges in using the latest technologies. Therefore, it is crucial to ensure that all farmers, large and small, have access to precision agricultural technology, so that they are not left behind. To do this, it must find a way that allows farmers to use this technology without being too expensive or stuck in technical problems. In addition, climate change is also a factor that should not be ignored. Harahap et al. (2025) show that climate change has an impact on food security and agricultural business strategies in Indonesia. Precision agricultural technology can help manage the use of air and fertilizers more effectively, which can offset the negative impact of climate change on agricultural yields. Therefore, in addition to economic benefits, this technology also has the potential to protect the environment.

Improving crop management efficiency is now a top priority for proponents of precision agriculture. Modern facilities such as sensors, drones, and GIS allow farmers to monitor their crops in real time and adjust the use of resources such as water, fertilizer, and pesticides more accurately than ever before. However, automated control technology also offers something different in agriculture; it offers techniques to increase production. If this is to truly benefit farmers, it is crucial to evaluate the economic impact and associated costs, taking into account practical benefits. Eliyani (2025) in *Crop Management Techniques and Technology Methodology in Agriculture* states that the application of technology has increased crop yields. However, this also requires significant investment, from equipment purchases to operational costs. Therefore, a Life Cycle Costing analysis is essential. This is not only to ensure the technology is effective in increasing agricultural yields, but also to ensure its financial viability for farmers, especially in the long term. Further consideration of the total costs involved in implementing precision agriculture technology is crucial. Anggreni's (2025) research on *Precision Agriculture to Improve Production Efficiency* states that although this technology allows farmers to reduce the use of inefficient inputs such as water and fertilizer, its high initial costs are a serious challenge. Therefore, a real-time assessment is needed. With this data, farmers will better understand whether they can afford to adopt this technology. *How to Optimize Crop Production Using Information Technology*, Research by Swasono and Muthmainah (2023), The authors state that real-time data allows farmers to manage their resources more efficiently. Technology applied to precision agriculture allows for the realization of the specific needs of each crop. Thus, farmers save water, fertilizer, and agricultural chemicals, as easily as before in the pre-digital era. *Precision Agriculture Technology to Improve Rice Production Efficiency in Indonesia* by Tulungen (2024) shows that although this technology reduces operational costs, it still requires a significant initial investment. This paper emphasizes the importance of comparing long-term costs and short-term results. A life-cycle cost evaluation will help farmers, policymakers, and all other stakeholders assess whether precision agriculture technology truly provides sufficient benefits to offset its costs.

The implementation of precision agriculture in Indonesia faces unprecedented opportunities and challenges, especially now that the millennial generation is driving the transformation of this sector. According to Sondakh and Rembang (2020) in their paper "Characteristics, Potential of the Millennial Generation, and Perspectives for Precision Agriculture Development in Indonesia," millennials are very likely to be a major force driving the implementation of precision agriculture techniques. They are more receptive to new technologies than previous generations, and this, more than anything else, could be a key factor facilitating the successful adoption of precision agriculture among young people. Not only is it efficient, environmentally friendly, and energy-efficient, but technology-based ways of life in agriculture will soon be embraced by more people. Long-term food security and sustainable agricultural practices depend on these changes. Furthermore, the fundamental concept of precision agriculture, oriented towards resource conservation, has a profound impact due to its distinctive characteristics. Based on the *Principle of Reducing Agricultural Resource Waste through Precision Agriculture*, Undari and Arista (2024) argue that the great potential of precision agriculture lies in its ability to help reduce waste generated in agriculture. For example, the use of sensor-based irrigation systems and the application of fertilizers according to the needs of individual crops can significantly reduce water and fertilizer consumption. This not only reduces operational costs but also supports environmental conservation efforts, all of which are essential aspects of long-term agriculture. Water management is an integral aspect of sustainable agricultural production, in addition to resource efficiency. In a recent paper, "A Holistic Approach to Sustainable Agricultural Water Resource Management," Pradana et al. (2025) emphasized the need for rational water management to achieve

sustainable agriculture, particularly in countries like Indonesia that experience long periods of drought annually. Precision agriculture technology provides a way to measure actual water use in real time and then adjust irrigation rates according to crop needs, thereby minimizing waste. Such more rational water management not only reduces costs but also has beneficial effects on sustainability and food security in the face of challenges posed by climate change.

Precision agriculture in Indonesia offers significant opportunities in the food crop sector to improve efficiency and sustainability. However, the main challenge remains the personal risks involved in its implementation. Advanced technologies such as sensors and data-driven irrigation systems enable farmers to use resources more efficiently, avoid wasting water and fertilizer, and increase yields. However, a major challenge to overcome is that these technologies are very expensive in the initial stages. We must consider the costs and determine whether they are justified. A life-cycle cost analysis is crucial. We must ensure that the implementation of these technologies will benefit communities for years to come and justify our current expenditures. However, policy support and training for farmers are also needed to ensure widespread access to these technologies. Therefore, this study aims to provide an overview of how precision agriculture technologies can also improve food security and the sustainability of agricultural production methods in Indonesia.

2. RESEARCH METHOD

This research adopts a Life Cycle Costing (LCC) and Cost-Benefit Analysis (CBA) approach to evaluate the economic impact and life cycle costs of implementing precision agriculture technology in food crop cultivation. The process of identifying, selecting literature, and data collection follows the methodology principles used in previous research (Parmawati et al., 2025) while adapting them to focus on the analysis of precision agriculture technology. The selection of data sources in this study involved searching journal articles through several major academic databases, such as the Web of Science Core Collection, Google Scholar, Scopus, and ScienceDirect. Keywords included in the search included "precision agriculture," "life cycle cost," "precision agriculture technology," and "food crop cultivation" as needed. Boolean operators (AND, OR) were used to update the search results and match them to the topic. The search results were limited by certain criteria. First, only articles published between 2015 and 2024 were selected to ensure the most recent developments. Second, peer-reviewed research was used to ensure the information was of good quality and accurate. Third, this study focused on food crops, specifically rice, corn, beans, and soybeans. With these criteria, it was expected that only relevant literature that helped provide accurate information on the implementation of precision agriculture technology and its economic impact would be included.

Inclusion criteria for this study were studies on the application of precision agriculture technology to food crops such as rice, wheat, and soybeans. These studies should also quantify investment costs, operational costs, and economic benefits resulting from their application. Furthermore, the studies should use Life Cycle Costing and Cost-Benefit Analysis to calculate economic impacts. Efficiency statistics should be provided for water, fertilizer, and pesticide use. General values obtained through the application of precision agriculture should also be considered. Studies that did not meet these inclusion criteria were not included in the analysis. Exclusion criteria included studies without information on the application of precision agriculture technology to food crops. They also included reports that focused solely on ornamental and horticultural crops such as flowers, and studies that used precision agriculture technology that had not yet reached a mature level of technological readiness (TRL 7 may not be considered). In addition to excluding studies with incomplete data on investment costs and economic analysis, other types of studies included in this category included studies examining technologies used in controlled environments such as greenhouses or hydroponics that do not represent field farming conditions.

The first step was data collection. Relevant literature was reviewed and data on the lifecycle costs of precision agriculture technologies and their economic impacts were extracted. Included data included publication title, author, year of publication; use of precision agriculture technologies (e.g., variable fertilization irrigation systems or pest control); study location; country or region; type of crop studied, such as rice, corn, and soybeans; and functional units used, e.g., yield per hectare-fed per year. These data on economic impacts and costs were then quantified. Initial costs for equipment and software purchases, staff and employee training were examined. Annual operating costs were determined, including maintenance, new software, and costly items such as electricity or labor. Economic benefits recorded also included savings in fertilizer costs, for example, as well as water and pesticides, along with increased production. Furthermore, cost-benefit analysis data for precision agriculture technologies and high-yield crop protection investments were provided by the China Agricultural Information Institute. The analysis included the costs of high-yield protection construction, production differences, and other investments to be borne by farmers.

To calculate the overall cost of implementing precision agriculture technology, including investment and duration, from start to finish, consider the costs incurred by the company over the years. The first phase includes investment costs: the purchase of consumables (underground tools, sensor tags), training costs, and initial maintenance. The second phase includes replacement and maintenance costs. This includes hardware

and software upgrades, as well as annual system maintenance costs to keep the technology running at optimal levels so it can effectively perform its functions. Annual operational costs are also calculated, such as the money spent from the time the technology reaches break-even on-site. This includes the energy, fuel, and labor used to operate the precision agriculture system over the long term. Ultimately, the evaluation is about how much cost savings can be realized by using fewer inputs such as water, lime, and fertilizer, and how much yield increases are generated.

Analysis of this data using computer programs such as SPSS, or even Excel in some cases where these programs have less statistical power than more robust alternatives, produces economic indicators that include ROI and BCR. The results of the analysis are then presented in tables or graphs to aid understanding of both the economic impact and life-cycle costs of precision agriculture technologies. This data is also used to provide a clearer picture of the economic viability of precision agriculture equipment compared to traditional methods. However, these studies are limited to precision technologies used to grow food crops (rice, corn, soybeans, and so on) on land exposed to wind and sun, rather than in areas with permeable soils and minimal external climate fluctuations. Furthermore, only studies with complete data on investment costs and economic analysis were included for inclusion. Furthermore, the research in this book is limited to studies of TRL 7 or higher because this level assumes the technology has undergone operational testing and is not still in the early stages of development.

Table 1. Inclusion and Exclusion Criteria

Criteria	Inclusion	Exclusion
Publication Year	2015–2024	Before 2015
Technology Type	Precision agriculture technology (e.g., variable fertilization, precision irrigation)	Non-precision agriculture technology, ornamental plants
Research Location	Open-field land (food crops)	Greenhouses, hydroponics, and ornamental plants
Technology Maturity (TRL)	TRL 7 or higher	TRL below 7 (prototype or early-stage)
Research Focus	Economic costs and benefits, life cycle costing analysis	Studies focusing only on technical aspects without economic data
Research Subjects	Food crops (rice, maize, soybeans, etc.)	Horticulture or non-food crops

Table 1 details the inclusion and exclusion criteria for these studies. Studies must have been published between 2015 and 2024 and focus on precision agriculture technologies, such as variable fertilization or precision irrigation, applied to open-field crops. The subset of research using these technologies must have a TRL score of at least 7, with a focus on Initial Equalization and Resilience Constants. Economic cost/benefit analyses and life-cycle cost analyses were not distinguished.

3. RESULTS AND DISCUSSION

3.1. Results

This study focuses on the environmental aspects of crop production in Indonesia, with the aim of analyzing the environmental impacts of conventional agricultural practices and the application of precision agriculture technologies. The study began by searching all existing studies and identified 52 studies that included or partially included them. Duplicates were removed, and then titles and abstracts were screened, leaving 18 studies for further evaluation. A secondary search identified three more studies, resulting in a total of 21 studies used for analysis in this paper. These studies were spread across several provinces in Indonesia, with most focusing on food crops such as rice, corn, and soybeans. In the 21 studies examined, the most frequently cited environmental impact category was climate change/global warming (66%), followed by eutrophication (60%), acidification (57%), human toxicity (33%), ozone depletion (28%), and ecotoxicity (25%). The primary factor cited as causing environmental impacts in Indonesia was the production and use of fertilizers, which contributed to all of the aforementioned categories except for human health and the ozone layer. Energy and pesticide use also have negative environmental impacts, but their contributions are less serious than those of fertilizers. In the freshwater ecotoxicity category, the largest impact comes from pesticide use, accounting for approximately 40% of the total impact. Secondary impacts from fertilizer use and associated emissions from agricultural land are next, at 35%. Operating agricultural machinery involves energy consumption; the greater the energy consumption, the greater the environmental impact. However, these impacts are far smaller than those of fertilizers and pesticides.

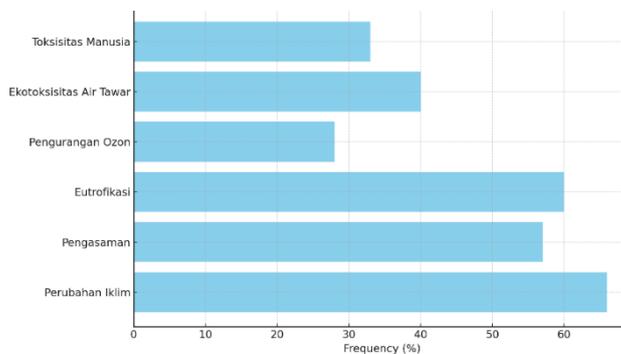


Figure 1. Distribution of Environmental Impact Categories

Figure 1 the environmental impact category distribution shows the most frequently reported Environmental Impact Categories in agricultural studies. This chart shows the frequency of reporting these impacts. Climate Change, with over 60% of studies citing it as a primary concern, clearly tops this list. Eutrophication and Acidification are also frequently mentioned, with around 50% of studies addressing these issues. The situation is slightly better for Ozone Depletion and Freshwater Ecotoxicity, but Human Toxicity is the least frequently mentioned. These results indicate that concerns about global warming, land degradation, and other forms of pollution from agriculture are widespread.

In most of the categories analyzed, fertilizer production and use, as well as emissions from agricultural land, are the primary causes of environmental impacts. Toxic gases produced during energy-dependent fertilizer production, such as methane and nitrous oxide, contribute to global warming and disrupt soil balance. Too much fertilizer also poses a risk of eutrophication, which can poison nearby rivers and lakes, destroying fish and their spawning grounds. Long-term reliance on chemical fertilizers is a problem for soil and water quality in many agricultural areas. In the ecotoxicity category, pesticides are a major contributor to significant environmental impacts. Pesticides are harmful to unintended targets, including non-target organisms such as insects, birds, and soil microorganisms. High levels of pesticide use also increase the risk of water contamination, harming both the environment and humans. In agricultural operations, the use of machinery and heavy equipment also creates significant environmental impacts. Machines for tillage, irrigation, and even small, rotary machines cover cow manure with a layer of dust, all consuming large amounts of fossil fuels, pumping carbon into the air and further exacerbating the problem of global warming.

Table 2. Main Causes of Environmental Impacts by Category

Impact Category	Major Cause	Frequency (%)
Climate Change	Fertilizer production and field emissions	76%
Acidification	Fertilizer production and field emissions	81%
Eutrophication	Fertilizer use	81%
Ozone Depletion	Pesticide use	47%
Freshwater Ecotoxicity	Pesticide use	39.5%
Human Toxicity	Fertilizer production and field emissions	40%

Table 2 shows the main causes of environmental impacts by category. Fertilizer production and agricultural emissions all contribute significantly to Climate Change, Acidification, and Human Toxicity, accounting for over 40%. Fertilizer use accounts for 81% of the Eutrophication category. Meanwhile, pesticide use is the main cause of Ozone Depletion, Freshwater Ecotoxicity, and Human Toxicity, contributing between 39.5% and 47%.

For Focus Question 2, which addressed the spread of precision agriculture in Indonesia, the initial search yielded 39 relevant studies, some of which were from provinces other than the one where the research was conducted (e.g., films). After removing duplicates and filtering titles/abstracts, 12 reports remained for further evaluation. A second search added three more records, bringing the total to 15 studies used in this analysis. Most of these studies were from West Java (5 studies) and Sumatra (4 studies); Bali contributed two studies each, as did several other surrounding regions. The main crops studied were rice, wheat, and soybeans, with only a few vegetables or fruits.

The conclusion drawn from these studies is that precision agriculture can reduce environmental impacts compared to conventional or Business as Usual (BAU) farming practices. The most significant reductions were found in the categories of climate change (12%), energy use (10%), and eutrophication (~14%). For example, the use of a sensor-based irrigation system for rice cultivation in West Java not only reduces the impact of climate change by 20% but also cuts water consumption by 30% due to more efficient water management. Similarly, in oil palm plantations in Sumatra, variable fertilization successfully reduced fertilizer use by 40%. This reduces the impact of eutrophication by reducing water pollution from excessive fertilizer use. However, despite the significant environmental benefits generated by precision agriculture, there are cases in Indonesia where its implementation does not always lead to a reduced level of impact on

the ecosystem compared to BAU practices. For example, in a study in Bali, when a variable drip irrigation system was applied to an orchard, data showed that soil acidification increased by 15%. This is due to fossil fuels, such as diesel, being used to pump groundwater, which increases carbon emissions and causes this unexpected increase in soil acidification (Yassin et al. 2025).

Table 3. Comparison of Environmental Impacts between Precision Agriculture and Conventional Practices

Impact Category	Average Difference (%)	Range (%)	Sample Size
Climate Change	-12%	-20% to -5%	8
Energy Use	-10%	-15% to -5%	6
Eutrophication	-14%	-30% to -5%	7
Acidification	+15%	-5% to 25%	3
Water Use	-30%	-35% to -20%	4
Fertilizer Use	-40%	-50% to -30%	5

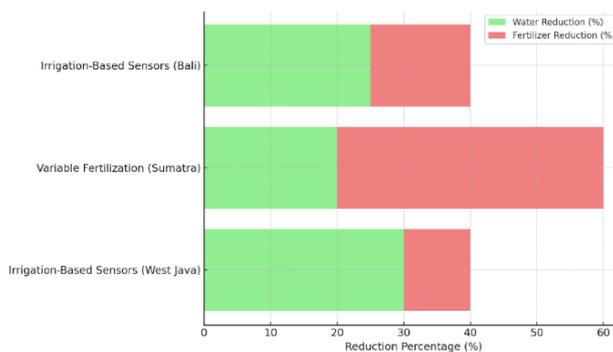


Figure 2. Environmental Impacts of Precision Agriculture vs. Conventional Practices

The following figure shows the differences in environmental impact reduction between the implementation of precision agriculture and conventional farming practices (BAU) in Indonesia. The largest reductions were observed in climate change and water usage, while some categories, such as acidification, showed small increases in certain studies.

Most food crop industries such as rice, maize and soybean are at a turning point in human history where precision agriculture techniques can have uses on a broad scale. Indonesia's West Java region and parts of Bali and Sumatra are already using precision agriculture for various levels of experimentation with good results. Sensing irrigation techniques have been applied in fields growing rice and other cereals. Thanks to this technology, real-time monitoring of soil moisture is now enabling farmers to make gradual adjustments in the flow of water through their crops as conditions change. As a result, water usage has been reduced by as much as 30%, which has brought operational cost savings and relieved some of our water resources of that stress. More timely irrigation giving greater support to crop growth meant that crop yields increased by around 20%. Variable fertilization technology has been applied to fields producing maize in the Sumatra area. This technique provides the soil and crop needs at every single point in the field, using data obtained by soil sensors and images from remote sensing satellites. In fact, fertilizer consumption decreased by 40%, which resulted in cost savings and increased production yields. This behavior also considered an improvement in palmary yields Variable sensor-based irrigation technology is now being used in Bali, a province where many rice producers still use traditional techniques such as flooding the fields. Soil sensors have been nibbed into the ground to directly measure relative humidity levels, thereby providing accurate information every time a decision is made by a farmer. This allows the use of water has been cut down from 25%, helping relieve the limited resources of a regional what with its water resources being pressed as never before. More efficient use of fertilisers also reduced production costs and raised harvest yields.

Tabel 4. Penerapan Teknologi Pertanian Presisi

Precision Agriculture Technology	Regions	Reduced Water Use (%)	Reduced Fertilizer Use (%)	Improved Yield (%)
Sensor-Based Irrigation	West Java (Rice)	30%	10%	20%
Variable Fertilization	Sumatra (corn)	20%	40%	25%
Sensor-Based Irrigation	Bali (Rice)	25%	15%	18%

The application of precision agriculture technology in Indonesia has achieved positive results. For example, savings in resource inputs such as water and fertilizer have been combined with increased agricultural yields. Sensors that automatically adjust irrigation and fertilization in areas requiring more have significantly reduced water and fertilizer use. Another approach involves implementing differential crop growth based on plant growth stage. This has the effect of increasing economic benefits while protecting the environment from pollution. These technologies promise significant improvements in agricultural efficiency in Indonesia, although challenges remain, including initial costs and the necessary farmer training. Precision agriculture engineering systems that combine expertise from various organizations will be a crucial source of support in this regard. Policies such as fiscal incentives should be implemented to accelerate the widespread adoption of precision agriculture technology and ensure the sustainability of agricultural production in Indonesia.

3.2. Discussion

Precision agriculture technology capitalizes on this opportunity with a unique approach. It improves the efficiency of resource use in the agricultural sector, particularly by reducing the environmental impact of conventional farming practices, which are increasingly unsustainable. A report by Getahun et al. (2024) states that sensors and Geographic Information System (GIS) technology enable real-time monitoring of actual land and crop conditions. This allows for more precise, or "safe" adjustments in water, fertilizer, and pesticide use, which in turn reduces waste and increases yields. However, Schimmelpfennig (2018) points out that while the long-term benefits of this technology are substantial, there are significant challenges related to initial investment costs. "It's very difficult for smallholder farmers to implement this kind of technology," Grizzel says. Furthermore, the costs may be far more than the average smallholder farmer can afford unless they are also nearly fully literate in the computer skills required by the program itself. However, from a long-term perspective, this technology can reduce recurring input costs (e.g., chemical fertilizers and water). The biggest beneficiaries are farmers.

According to Brown et al. (2016), the implementation of this technology not only brings significant economic benefits but also makes a positive contribution to the environment. By saving energy and reducing chemical use, it is possible to minimize the carbon footprint of agricultural production, further supporting sustainability goals. The implementation of precision technology is beneficial not only in terms of climate change but also because it reduces emissions from agricultural operations that use fertilizers and energy, which produce greenhouse gases that contribute to global warming. Furthermore, Bahmutsky and Pelletier (2025) emphasize that a careful cost-benefit evaluation is necessary before implementing precision technology. Despite its benefits, one cannot rely on luck alone to achieve complete success in implementing this technology. Farmers must go through a learning process. They need to understand how to use and maximize the results of precision systems for the technology to operate properly.

Precision agriculture technology presents a significant opportunity to increase agricultural production while protecting the environment. However, the most significant challenges are accessibility and initial costs. Policies and incentives are urgently needed to enable more people, from small, medium, and large businesses, to tap into its potential. This, in turn, benefits the entire value chain we depend on. With the right training and support, this technology offers a win-win solution where everyone benefits both economically and ecologically.

4. CONCLUSION

In Indonesia, the application of precision agriculture technology can reduce resource intensity and increase crop yields with a high degree of reliability. Technologies such as sensors, drones, and Geographic Information Systems (GIS) enable farmers to monitor land conditions in real time, allowing water, fertilizer, and pesticide use to be tailored to crop needs to avoid waste. Research shows that precision agriculture technology can save 30% on water use and 40% on fertilizer consumption, potentially reducing negative environmental impacts such as greenhouse gas emissions and eutrophication. However, the biggest barrier to widespread adoption lies in the very high initial investment costs, which are particularly difficult for smallholder farmers to afford. Therefore, from a policy perspective, it is necessary to provide support measures that enable widespread use of precision agriculture, such as fiscal incentives, subsidies, and training programs that help farmers understand and optimally use the technology. With increased yields and long-term cost savings, precision agriculture technology plays a crucial role in improving food security and the sustainability of Indonesia's agricultural sector. However, to ensure these benefits are widely realized, collaboration between the government, the private sector, and educational institutions is essential. Furthermore, we need to ensure that its adoption extends to smallholder farmers, who are a crucial component of the country's food security. The successful implementation of precision agriculture technology depends heavily on the collective efforts of all parties to overcome cost barriers and ensure that farmers receive adequate training.

REFERENCES

- Anggreni, N. V. (2025). Implementasi Pertanian Presisi dalam Meningkatkan Efisiensi Produksi. *Circle Archive*, 1(7).
- Bahmutsky, S., & Pelletier, N. (2025). A systematic review of environmental, technological, and economic evaluation of precision and variable rate technologies. *Precision agriculture'25*, 46-52. https://doi.org/10.1163/9789004725232_004
- Brown, R. M., Dillon, C. R., Schieffer, J., & Shockley, J. M. (2016). The carbon footprint and economic impact of precision agriculture technology on a corn and soybean farm. *Journal of Environmental Economics and Policy*, 5(3), 335-348. <https://doi.org/10.1080/21606544.2015.1090932>
- Eliyani, I. (2025). TEKNIK BUDIDAYA DAN TEKNOLOGI PENGELOLAAN TANAMAN PANGAN. *Teknik Budidaya dan Teknologi Pengelolaan Tanaman Pangan*, 55.
- Fadlan, A., Lubis, R. P., & Tarigan, M. H. (2024). *Ekonomi Pertanian Pelaku Usaha Tani Kecil: Sebuah Perspektif Global*. Serasi Media Teknologi.
- Fadli, Z., Taufikurohman, M. R., Zani, M., Mursidah, M., Tebai, N., Melly, S., & Ika Buni, N. (2025). *Ekonomi dan Manajemen Agribisnis*. Yayasan Tri Edukasi Ilmiah.
- Getahun, S., Kefale, H., & Gelaye, Y. (2024). Application of precision agriculture technologies for sustainable crop production and environmental sustainability: A systematic review. *The Scientific World Journal*, 2024(1), 2126734. <https://doi.org/10.1155/2024>
- Harahap, L. M., Sitanggang, C. B., Tambunan, D. M., Pinem, D. A., & Hasugian, A. B. (2025). Pengaruh Perubahan Iklim Terhadap Strategi Manajemen Agribisnis: Studi Kasus Di Wilayah Pertanian Indonesia (The Effect Of Climate Change On Agribusiness Management Strategies: A Case Study In Indonesian Agriculture). *Jurnal Ilmiah Ekonomi Dan Manajemen*, 3(3), 451-462. <https://doi.org/10.61722/jiem.v3i3.4220>
- Parmawati, R., Hardiansah, R., Yanuwiadi, B., Aziz, A., Gumelar, G. A., Nggauk, S. V., & Suhansa, F. Y. A. (2025). *Circular Economy Di Sektor Pertanian*. Universitas Brawijaya Press.
- Pradana, H. A., Effendi, M., & Mahmudi, K. N. (2025). Pendekatan Holistik dalam Pengelolaan Sumber Daya Air Pertanian Berkelanjutan Menggunakan Analisis Bibliometrik. *Journal of Tropical Agricultural Engineering and Biosystems-Jurnal Keteknik Pertanian Tropis dan Biosistem*, 13(3), 337-349. <https://doi.org/10.24912/jmie.v8i2.31951>
- Ratnasari, Y. D. (2025). *ANALISIS DAMPAK BANTUAN DANA DESA TERHADAP STRUKTUR BIAYA DAN PENDAPATAN USAHATANI PADI DI DESA BICAK, MOJOKERTO* (Doctoral dissertation, Universitas Muhammadiyah Malang).
- Schimmelpfennig, D. (2018). Crop production costs, profits, and ecosystem stewardship with precision agriculture. *Journal of Agricultural and Applied Economics*, 50(1), 81-103. <https://doi.org/10.1017/aae.2017.23>
- Sondakh, J., & Rembang, J. H. (2020). Karakteristik, potensi generasi milenial dan perspektif pengembangan pertanian presisi di Indonesia. In *Forum Penelitian Agro Ekonomi* (Vol. 38, No. 2, pp. 155-166).
- Swasono, M. A. H., & Muthmainah, H. N. (2023). Pemanfaatan teknologi informasi dalam optimalisasi produksi tanaman pangan: Studi bibliometrik skala nasional. *J. Multidisiplin West Sci*, 2(08), 668-683.
- Tulungen, F. R. (2024). TEKNOLOGI PERTANIAN PRESISI UNTUK MENINGKATKAN EFISIENSI PRODUKSI PADI DI INDONESIA. *Jurnal Cahaya Mandalika ISSN 2721-4796 (online)*, 5(2), 720-727. <https://doi.org/10.36312/jem.v5i2.3135>
- Undari, D., & Arista, N. I. D. (2024). Potensi precision farming dalam penerapan prinsip reduce untuk mengurangi limbah sumber daya pertanian. *Waste Handling and Environmental Monitoring*, 1(2), 97-105. <https://doi.org/10.61511/whem.v1i2.2024.1239>

Yassin, H. (2025). Pendekatan Ekologis terhadap Variasi Populasi Hama dan Pengaruhnya terhadap Pertumbuhan Jagung. *Journal of Science and Technology: Alpha*, 1(3), 82–87. <https://doi.org/10.70716/alpha.v1i3.245>