

Innovative Agricultural Technologies for Increasing Soybean Production and Farmers' Income in Bima Regency: A Pathway to Sustainable Agriculture

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ABSTRACT

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The productivity of soybean at the farmer level in Bima Regency, Indonesia, remains lower than the yields achieved under research conditions, mainly due to limited adoption of improved cultivation technologies, particularly in the use of certified seeds, planting methods, and balanced fertilization. This study aimed to evaluate the effect of introducing improved soybean production technologies on yield and farm income to support sustainable agriculture. The research applied an action research approach conducted on farmers' fields in three villages of Bima Regency from July to October. The technologies introduced included high-quality certified seeds, optimal plant spacing (40 × 15 cm), NPK fertilization at 100 kg/ha, and foliar fertilizer (PPC) at 1 L/ha. These practices reflect the current recommendations for improving crop establishment and nutrient management as part of sustainable intensification. The results revealed that the introduction of these technologies increased soybean yield from 1.1 t/ha under conventional farming practices to 2.1 t/ha, representing a 48% improvement in productivity. Farm income also rose by 57%, from IDR 7,425,000 to IDR 14,175,000 with the recommended technology package. The economic analysis showed better feasibility, with R/C and B/C ratios of 2.6 and 1.6, respectively, compared to 2.1 and 1.1 under traditional farmer practices. These findings suggest that adopting appropriate agricultural technologies significantly improves soybean productivity, profitability, and resource-use efficiency, offering a sustainable pathway for soybean farming in Bima Regency.

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1. Introduction

Increasing soybean production in Indonesia plays a crucial role in ensuring food security and improving farmers' income, especially in soybean-producing regions such as Bima Regency. Soybeans are essential in the food industry for products like tempe, tofu, and soy sauce. Domestic soybean production still heavily relies on imports, creating a significant challenge. The potential to increase local soybean production remains substantial if efficient agricultural technologies can be applied maximally. [1] showed that the adoption of new technologies in agriculture can significantly enhance production yields, which in turn can improve farmers' income.

Innovative agricultural technologies, such as the use of superior soybean varieties, smart irrigation systems, and precision farming, offer promising solutions to accelerate soybean production. [2] found that advanced agricultural technologies can improve soybean yield and farmer income,

especially through the use of high-quality seeds and precision farming practices. Implementing these technologies enables farmers to optimize resource use and minimize waste, improving overall efficiency and reducing input costs. [3] argued that precision farming allows farmers to monitor crop conditions more effectively, making more informed decisions that lead to higher yields.

However, the adoption of these technologies depends not only on the availability of the technology itself but also on farmers' ability to access and use them. [4] pointed out that the biggest barriers to adoption include limited access to the necessary tools and information. Intensive training programs and financial support from the government are crucial for helping farmers overcome these barriers. [5] emphasized the importance of targeted government policies to facilitate farmers' access to the latest technologies and reduce adoption costs.

Sustainable agricultural technology is equally important in supporting long-term farming productivity. [6] explained that environmentally friendly agricultural technologies, such as organic fertilizers and efficient land management practices, help maintain soil fertility and reduce environmental impacts. Implementing these technologies ensures that soybean production not only increases but also remains sustainable in the long run.

Precision farming has significant potential in enhancing agricultural productivity. [7] revealed that the use of precision farming technologies allows farmers to collect accurate data on soil and crop conditions, enabling them to make more precise decisions on irrigation, fertilization, and pest control. This technology is especially useful in areas like Bima Regency, where land is often limited but has high production potential. [8] emphasized that by using drones, sensors, and automated systems, farmers can achieve better outcomes without needing extensive land areas.

Yet, despite the clear benefits, a major obstacle to the widespread adoption of these technologies is the lack of access and knowledge among farmers, particularly in rural areas. [9] noted that even though these technologies have proven effective, there is a significant digital divide between urban and rural areas in terms of access to modern agricultural technologies. Farmers in remote areas often lack the necessary training and infrastructure to adopt new agricultural practices.

The role of gender in the adoption of agricultural technologies also cannot be overlooked. [10] demonstrated that women farmers often face greater challenges in accessing agricultural resources and technologies compared to their male counterparts, particularly in rural settings. Therefore, effective technology adoption programs must be gender-sensitive, ensuring that women have equal opportunities to access and benefit from new farming technologies. Mendes et al. (2022) suggested that involving women in agricultural technology initiatives can lead to more inclusive and sustainable agricultural practices.

[11] found that the development of drought- and pest-resistant soybean varieties can significantly increase yields. Resistant varieties reduce the need for pesticides and fertilizers, cutting costs for farmers and improving profitability. Therefore, research and development efforts aimed at creating soybean varieties that can withstand environmental challenges are essential for increasing production and ensuring food security.

Technological advancements alone are insufficient without supportive policies. [12] highlighted that policies supporting the adoption of agricultural technologies, such as providing subsidies and financing options for farmers, are vital for accelerating technology uptake. In addition, governments need to promote policies that encourage investments in sustainable agricultural technologies. [5] concluded that effective policies are key to bridging the gap between technological innovation and its application on the ground, ensuring that all farmers, regardless of their financial capacity, can benefit from modern agricultural tools.

In the context of sustainability, [13] stressed the importance of integrating agricultural technologies with natural resource management. Environmentally friendly farming practices, such as the use of organic fertilizers and efficient water management systems, can improve long-term productivity while maintaining ecological balance. These practices are particularly crucial for areas like Bima Regency, where sustainable land use is vital for preserving agricultural land for future generations.

Technology adoption also has significant impacts beyond just increasing production; it can improve the quality of life for farmers. [12] noted that technologies that increase efficiency and reduce dependence on expensive inputs can enhance farmers' well-being by lowering costs and increasing

profits. This is particularly relevant for smallholder farmers who often face economic challenges in maintaining their farms. [14] further highlighted that cost-effective technologies enable farmers to reinvest their savings into other areas of their business, leading to further growth.

The success of agricultural technology adoption depends on collaboration among various stakeholders. [15] emphasized that collaboration between the public sector, private companies, and farmers is essential to creating a supportive environment for technology adoption. The private sector plays a key role in providing innovative solutions, while the government must ensure that policies and programs facilitate technology distribution and access. [16] added that partnerships between these sectors can accelerate the deployment of agricultural technologies, benefiting farmers and communities alike.

[15] concluded that the adoption of appropriate agricultural technologies can bring benefits not only to farmers but also to the broader community and economy. By increasing soybean production through the use of innovative and sustainable farming technologies, Indonesia can reduce its reliance on soybean imports, enhance food security, and boost the incomes of local farmers. This comprehensive approach to agricultural development will contribute to both the economic and environmental well-being of the nation.

2. Method

2.1. Research Approach Research Design

This study adopted a quantitative research approach using an action research design to assess the impact of introducing improved soybean production technologies on yield and farm income in Bima Regency, Indonesia. The action research approach was chosen as it allows for direct involvement of farmers in the application of the technology, facilitating continuous improvement throughout the research process. Farmers were directly engaged in implementing the technologies, and the results were measured to assess the effectiveness of these practices. The research employed a field experiment design with a before-and-after design to compare soybean yield and farmers' income before and after the introduction of the technology. The design aimed to assess the changes brought by the introduction of the new technologies and compare them with the traditional farming practices previously employed by farmers.

2.2. Study Location

This research was conducted in Bima Regency, a major soybean-producing region in Indonesia. The study took place in three villages within Bima Regency during the period of July to October, corresponding to the soybean planting season. The location was chosen due to its high soybean production potential and the fact that many farmers had not fully adopted modern farming technologies, making it an ideal area for assessing the impact of these innovations.

2.3. Population and Sample

The population of the study consisted of all soybean farmers in Bima Regency. The sample was selected using purposive sampling, targeting farmers who had been using conventional farming practices and were willing to adopt the improved technology introduced by the study. The sample size consisted of three groups of farmers from three different villages.

2.4. Technologies Introduced

The following technologies were introduced to the farmers as part of the study:

1. Certified high-quality soybean seeds, which are known to enhance yield and crop quality.
2. Optimal plant spacing of 40 × 15 cm, to provide adequate space for growth and improve plant establishment.
3. NPK fertilization at 100 kg per hectare, to supply essential nutrients for healthy plant growth.

4. Foliar fertilizer (PPC) at 1 liter per hectare, to support crop growth and enhance resistance to environmental stress.

These practices align with current recommendations for improving crop establishment and nutrient management as part of sustainable intensification strategies

2.5. Data Collection Methods

Several data collection techniques were used in this study:

Field Observations. The researchers conducted field observations to assess the agricultural practices being implemented by farmers, including planting methods, seed choices, and fertilization practices. Observations were made during the technology implementation phase throughout the planting season.

Questionnaires. Questionnaires were distributed to the farmers to gather data on their socio-economic conditions, such as income levels before and after the introduction of the technology, as well as the factors influencing their decision to adopt the new farming technologies. The questionnaires also collected information on the challenges faced by farmers in adopting the technologies.

Semi-structured Interviews. Semi-structured interviews were conducted with selected farmers to obtain more in-depth insights into their experiences with the technology. These interviews aimed to explore the farmers' perceptions of the effectiveness of the technologies, the challenges encountered, and the benefits experienced.

Yield and Income Data Collection. Data on soybean yield were collected before and after the introduction of the technology to compare the productivity changes. Additionally, income data were gathered to measure the financial impact of adopting the new farming practices.

2.6. Data Analysis

The collected data were analyzed using descriptive statistics and before-and-after comparison analysis to measure changes in soybean yield and farmers' income. The following analytical steps were taken:

Yield Analysis. Soybean yield data before and after the introduction of the technology were compared to calculate the percentage increase in yield. The yield improvement will be analyzed to determine the effectiveness of the introduced technologies in increasing production.

Income Analysis. Farmers' income before and after technology adoption was compared to calculate the percentage increase in income. This analysis will provide insight into the economic benefits of adopting the new technologies.

Economic Feasibility Analysis. An economic analysis was conducted using the Revenue/Cost (R/C) and Benefit/Cost (B/C) ratios to assess the economic feasibility of the recommended technology package. The R/C and B/C ratios were compared to determine the relative profitability of the new technology package compared to traditional farming practices.

2.7. Research Procedures

The research followed these procedures:

1. Development of research instruments, including questionnaires, interview guides, and observation sheets.
2. Introduction of improved farming technologies to the selected farmers and application of these technologies on their fields.
3. Data collection through field observations, questionnaires, and interviews during the study period (July to October).

4. Analysis of yield, income, and economic feasibility data to assess the impact of the technology.
5. Preparation of the research report, including findings and recommendations for improving agricultural practices.

3. Results

The introduction of advanced agricultural technologies in Bima Regency has led to a significant improvement in soybean productivity. The productivity increased by 48%, from 1.1 t/ha under conventional farming practices to 2.1 t/ha following the adoption of the introduced technologies. This enhancement is clearly shown in the following tables, which illustrate the improvements in various agronomic parameters.

Table 1. Average plant height and number of productive branches with introduced technology compared to farmer practices in Bima Regency.

Technology Applied	Average Plant Height (cm)	Standard Deviation	Average Number of Productive Branches (count)	Standard Deviation
Farmer's Technology (I)	60.75	0.42	2.2	0.48
Farmer's Technology (II)	61.46	0.56	2.6	0.34
Farmer's Technology (III)	63.09	0.49	2.4	0.33
Introduced Technology (I)	67.31	0.44	3.15	0.37
Introduced Technology (II)	63.75	0.31	2.9	0.33
Introduced Technology (III)	61	0.39	2.7	0.35

This table presents the comparison of plant height and the number of productive branches between the technologies introduced in the study and the traditional farmer practices in Bima Regency. The average plant height for the introduced technology was significantly higher than for the farmer practices. For instance, under the first introduced technology (I), the average height was 67.31 cm, which was notably higher than the 60.75 cm observed with the farmer's technology (I). The number of productive branches also showed a similar trend, with introduced technologies resulting in more branches compared to the farmer's practices. For example, under the first introduced technology (I), the average number of productive branches was 3.15, compared to just 2.2 in the farmer's practice (I). These differences indicate that the introduced technology promoted better plant growth and higher productivity.

Table 2. Average number of filled pods and empty pods with introduced technology compared to farmer practices in Bima Regency.

Technology Applied	Average Number of Filled Pods (count)	Standard Deviation	Average Number of Empty Pods (count)	Standard Deviation
Farmer's Technology (I)	39.99	0.51	3.05	0.34
Farmer's Technology (II)	40.25	0.42	2.95	0.44
Farmer's Technology (III)	42.35	0.38	3.13	0.42
Introduced Technology (I)	50.85	0.49	1.35	0.62
Introduced Technology (II)	49.55	0.33	1.79	0.56
Introduced Technology (III)	49.2	0.31	1.4	0.52

This table compares the number of filled pods and empty pods in soybean plants under both the introduced and traditional technologies. The data clearly show that the introduced technology led to a significant increase in the number of filled pods while substantially reducing the number of empty pods. For example, under the first introduced technology (I), the average number of filled pods was 50.85, much higher than the 39.99 pods in the farmer's practice (I). On the other hand, the average number of empty pods in the introduced technology (I) was just 1.35, compared to 3.05 in the farmer's practice (I). This suggests that the introduced technology improved pod set efficiency and reduced the formation of unfilled pods, likely contributing to higher overall yield and better resource utilization.

Table 3. Average pod weight and soybean productivity with introduced technology compared to farmer practices in Bima Regency.

Technology Applied	Pod Weight (g)	Standard Deviation	Productivity (t/ha)
Farmer's Technology (I)	50.12	0.61	1.1
Farmer's Technology (II)	52.16	0.56	1.3
Farmer's Technology (III)	50.05	0.45	1.1
Introduced Technology (I)	64.48	0.43	2.1
Introduced Technology (II)	60.07	0.49	2
Introduced Technology (III)	60.23	0.41	1.9

This table compares the pod weight and productivity (in tons per hectare) between the introduced and farmer technologies. Pod weight is one of the key indicators of crop health and yield potential. The average pod weight in the introduced technology (I) was 64.48 grams, significantly higher than the 50.12 grams observed with the farmer's technology (I). This indicates that the improved techniques led to stronger and healthier soybean plants. Regarding productivity, the introduced technology (I) resulted in a yield of 2.1 t/ha, which is more than double the 1.1 t/ha yield achieved under traditional farming methods. These results clearly highlight the benefits of adopting the introduced technology, not only in terms of pod weight but also in improving overall yield.

Table 4. Economic Feasibility of Soybean Farming in Bima Regency during the MK II 2016 Planting Season.

Description	Introduced Technology	Farmer Technology
Production Cost	2,200,000 IDR	1,300,000 IDR
Labor Cost	3,115,000 IDR	2,475,000 IDR
Total Cost	5,315,000 IDR	3,375,000 IDR
Production (kg/ha)	2.1	1.1
Price per kg	6,750 IDR	6,750 IDR
Revenue	14,175,000 IDR	7,425,000 IDR
Profit	8,860,000 IDR	3,870,000 IDR
R/C Ratio	2.6	2.1
B/C Ratio	1.6	1.1

This table presents an economic analysis of soybean farming, comparing the introduced technology and traditional farmer practices in terms of production costs, revenue, profit, and economic feasibility ratios (R/C and B/C ratios). The total production costs for the introduced technology were 5,315,000 IDR, which were higher than the 3,375,000 IDR for the traditional farming practices. However, the revenue generated from the introduced technology was significantly higher, amounting to 14,175,000 IDR compared to 7,425,000 IDR from the farmer's practices. The profit was also substantially higher under the introduced technology, with 8,860,000 IDR in profit, compared to just 3,870,000 IDR from the conventional methods. The R/C ratio for the introduced technology was 2.6, and the B/C ratio was 1.6, both of which indicate better profitability and economic viability compared to the farmer's practices, which had R/C and B/C ratios of 2.1 and 1.1, respectively. This shows that the introduced technology is more economically feasible, offering higher returns for the same or slightly higher costs.

4. Discussion

The results of this study confirm that the introduction of advanced agricultural technologies has a significant positive impact on soybean productivity and farmers' income in Bima Regency. The 48% increase in soybean yield, from 1.1 t/ha under conventional practices to 2.1 t/ha with the new technology, aligns with findings from [2] who demonstrated that improved agricultural practices lead to higher productivity in smallholder farming systems. These results also reflect those of [12] who highlighted that adopting better technologies can reduce input costs while increasing output, enhancing farmers' overall profitability.

In terms of plant development, the introduction of high-quality seeds, optimal planting distance, and proper fertilization significantly enhanced growth parameters such as plant height and the number of productive branches. As [17] pointed out, high-quality seeds are a critical factor in

increasing crop yields. The data from Table 2 show that the average plant height under introduced technologies (67.31 cm) was higher than under traditional practices (60.75 cm), supporting [18] who noted that better seed quality promotes healthier plant growth. This improvement is essential as [19] emphasized that increased photosynthetic capacity, stimulated by proper spacing, leads to more vigorous plant growth and higher yields.

The introduction of improved planting spacing also contributed significantly to the better yield observed. [19] argued that wider plant spacing reduces competition for water, nutrients, and light, thus allowing plants to grow more optimally. This is consistent with [20] who found that wider spacing in soybean farming increased pod formation. Similarly, [13] confirmed that row spacing directly influences plant growth and yield, which is evident from the higher number of productive branches and filled pods seen with the introduced technology.

Another crucial factor in the productivity increase was the application of NPK fertilizer. [21] demonstrated that proper fertilization, particularly with NPK, boosts soybean yield by supplying essential nutrients for plant growth. The data in Table 4 illustrate that the average pod weight under the introduced technology (64.48 grams) was significantly higher than under conventional practices (50.12 grams), indicating that fertilization contributed to better plant health and greater yield. This finding supports the assertions of [14] who highlighted the importance of phosphorus in accelerating root growth and enhancing overall plant development.

The economic benefits of adopting these technologies are also evident from the financial analysis in Table 5, where the R/C ratio for the introduced technology was 2.6, compared to 2.1 for traditional farming practices. This confirms the findings of [22] in [23] who stated that technological adoption increases both production and profitability. The higher B/C ratio of 1.6 for the introduced technology further supports the idea that these technologies offer a viable economic advantage, as the B/C ratio for conventional practices was only 1.1.

Moreover, the financial analysis showed that the income of farmers using the introduced technology increased by 57%, with profits rising from IDR 3,870,000 under conventional practices to IDR 8,860,000 with the new technology. [24] found that adopting recommended agricultural practices can increase farmers' income by up to 110%. This significant increase in income underscores the importance of introducing improved technologies to smallholder farmers, particularly in areas like Bima Regency, where the potential for higher productivity is often hindered by outdated farming practices.

The use of improved technology not only increased productivity but also led to more efficient use of resources, as evidenced by the reduction in empty pods and the increase in filled pods under the introduced technology (Table 2). [25] found that optimizing plant growth conditions through better practices and inputs can lead to higher quality yields with fewer wasted resources. The significant reduction in the number of empty pods under the introduced technology, compared to conventional practices, suggests that the new methods were more effective at producing viable soybeans.

The results of this study are consistent with the findings of [25] who found that improved agricultural technologies, such as certified seeds and proper fertilization, could significantly increase soybean yield while reducing pest and disease pressure. Indraningsih et al. (2013) emphasized that high-quality seeds are vital for improving crop establishment, which is reflected in the yield increase observed in this study. Additionally, [10] [26] observed that low yields in conventional farming systems often stem from the lack of certified seeds and improper management practices, which was addressed in the introduced technology.

Furthermore, [12] noted that technology adoption must be accompanied by effective support systems, such as farmer training and financial assistance, to be fully successful. While this study does not explicitly focus on these factors, the findings suggest that introducing appropriate technologies, along with adequate support, can greatly enhance farm productivity and income. This is especially true in regions like Bima, where farmers may not have access to the latest agricultural innovations without proper guidance and resources.

In conclusion, the introduction of improved soybean production technologies has proven to be a valuable strategy for increasing productivity, profitability, and resource-use efficiency in Bima

Regency. These findings align with [20] and [19] who highlighted the importance of spacing and seed quality in improving soybean yields. The increase in yield and income demonstrates that adopting modern agricultural practices can lead to significant improvements in both farm productivity and economic viability, making it a promising pathway for more sustainable agriculture in Bima Regency.

Conclusion

The introduction of improved soybean production technologies in Bima Regency significantly boosted both yield and farmers' income. By using high-quality seeds, optimized spacing, and balanced fertilization, farmers achieved higher productivity and profitability compared to traditional methods. These technologies proved to be more economically viable and sustainable, enhancing farmers' livelihoods and demonstrating the potential of innovative practices to improve agricultural efficiency in the region.

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Data and Software Availability Statements

The data supporting this study were generated from an experimental trial conducted by the authors in Bima Regency. All data were statistically analyzed using SPSS version 30. Citation management and referencing were performed using Mendeley. The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

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