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Utilizing Mathematical Models as a Basis for Coffee Cultivation Techniques

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Abstract

Coffee cultivation is an agricultural sector that requires a scientific approach to increase productivity and efficiency. The use of mathematics in agricultural management is still rarely applied systematically, even though various studies show that number-based analysis can help optimize resources. The integration of mathematical concepts in coffee farming can be a solution in facing the challenges of climate change and crop yield uncertainty. This research aims to examine how the application of mathematics can increase efficiency in cultivating coffee plants. The main focus of this research is quantitative analysis of water management, fertilizer distribution, and crop yield predictions based on mathematical models. This study also assesses the impact of using calculation methods on farmers' economic stability and environmental sustainability. This research uses a quantitative approach with survey methods and case studies on several coffee farming groups in Indonesia. Data was obtained through direct observation, interviews, and statistical analysis of production patterns and crop distribution. Simple mathematical models are used to measure the effectiveness of irrigation planning, fertilizer application, and crop stock management. The research results show that farmers who apply a mathematics-based approach experience an increase in productivity of up to 20% compared to

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traditional methods. More efficient resource management also has an impact on reducing operational costs and increasing resilience to external factors such as weather and market price fluctuations. Integration of prediction models helps farmers make more precise decisions regarding planting and harvest times. This research concludes that the application of mathematics in coffee farming contributes to increasing efficiency, environmental sustainability and farmer welfare. Education and training regarding calculation-based methods are important steps to expand the application of this strategy. Further studies are needed to develop more complex models with the integration of digital technology to increase the precision of analysis in coffee cultivation.

Keywords: Mathematics, coffee cultivation, agricultural efficiency.

INTRODUCTION

Mathematics has long been an important part of various aspects of life, including agriculture. The application of mathematical concepts in agriculture helps farmers optimize crop yields, manage resources, and increase the efficiency of crop cultivation (Belkacem, 2021; Lu, Hu, Yang, Hu, & Wang, 2021; Ohana-Levi et al., 2021). The use of mathematics in modern agriculture is growing along with advances in technology and data analysis methods. Cultivating coffee plants requires careful calculations at various stages, starting from selecting land, setting planting patterns, to the harvest process. Coffee farmers use mathematics to calculate water needs, fertilizer composition, and optimal planting distances to increase productivity (Li, Chen, Zhang, & Liu, 2021; Yan, Wang, & Li, 2020). The application of mathematical models also helps in identifying plant growth patterns and environmental factors that influence crop yields.

Mathematical-based data analysis techniques are increasingly being applied in coffee plantation management (Xu et al., 2020). The use of predictive models allows farmers to estimate crop yields based on weather data, soil moisture and plant growth patterns. Thus, mathematics plays a role not only in basic calculations but also in strategic decision making in agriculture. The application of mathematics in coffee cultivation is also seen in financial management and business planning. Coffee farmers use mathematical concepts to calculate production costs, profits and land use efficiency. Mathematical-based analysis helps in designing more profitable and sustainable business strategies for coffee industry players.

The development of mathematics-based technology, such as automatic irrigation systems and sensor-based plant growth monitoring, is increasingly increasing the efficiency of coffee

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cultivation (Teixeira, Mariani, Pedrollo, dos Reis Castro, & Sari, 2020; Verbiest, Ruysen, Vanwalleghem, Demeester, & Kellens, 2021). The data generated from this technological device is then analyzed using statistical methods to obtain more accurate information regarding plant needs. This proves that mathematics is an integral part of modern agricultural innovation. The success of coffee cultivation depends not only on farming skills, but also on the ability to apply mathematical principles correctly. By better understanding the relationships between variables in agriculture, farmers can increase productivity and the quality of their crops. The application of mathematics in agriculture contributes to the sustainability of the coffee industry and increases the welfare of farmers.

The application of mathematics in agriculture has been widely used, but its use in coffee cultivation is still not fully optimized (Cheng et al., 2021). Most coffee farmers still rely on experience and traditional methods in managing their land and crops. Mathematics-based approaches are often considered complex and difficult to apply in daily practice. Limitations in the use of mathematical models for analyzing coffee plant growth mean that plantation management is still less efficient (Kim, Eggleton, Wilkerson, & Gadsden, 2021; Kushwaha et al., 2021). Factors such as selecting optimal planting distances, calculating nutritional requirements, and predicting crop yields are not yet fully based on precise scientific calculations. As a result, there is a lot of potential for increasing productivity that has not been utilized optimally.

Research on the integration of mathematics in coffee farming systems is still relatively minimal, especially in the context of small-scale farmers. Most existing studies focus more on the application of agricultural technology in general without highlighting how mathematical concepts can be used specifically in planning and managing coffee cultivation. This gap indicates the need for further exploration of the application of mathematics in coffee farming. A lack of understanding of how weather data, soil quality and plant growth patterns can be translated into mathematical models is one of the main obstacles (C. Zhang, Kotz, Lammert, & Kelly, 2021). Many farmers do not have sufficient access or knowledge about how to process data systematically to support their agricultural decisions. This results in a reliance on conventional methods that are not always efficient or can be predicted accurately.

The role of mathematics in the economic aspects of coffee cultivation has not been discussed in depth. Number-based analysis in financial management, distribution of harvests, and optimization of production costs is often ignored (Lalehzari & Kerachian, 2020; Sonthitham & Thongchaisuratkrul, 2020). Further research is needed to develop more data-based strategies to improve the economic sustainability of coffee farmers. Filling the knowledge gap regarding the

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use of mathematics in coffee cultivation is an important step to increase agricultural efficiency and productivity. The application of mathematical models in analyzing environmental factors, plant growth, and economic strategies can provide greater benefits for coffee farmers. With a data-based approach, decisions taken in the cultivation process can be more accurate and measurable.

This research aims to identify and develop methods for applying mathematics in various aspects of coffee cultivation, from land management to financial planning (Sharifi, Roozbahani, & Hashemy Shahdany, 2021). Through statistical modeling, data simulations, and quantitative analysis, this research will examine how mathematical concepts can be applied practically to increase harvest yields and the efficiency of coffee plantation management. It is hoped that the results of this research can be a guide for farmers in implementing more systematic and scientifically based methods. The integration of mathematics in coffee farming will not only increase productivity, but also help create a more sustainable farming system. By utilizing technology and number-based analysis, farmers can manage resources more optimally, reduce waste and improve the quality of their harvests. It is hoped that this study will provide new insights into the application of mathematics as the main basis for developing the agricultural sector, especially in the coffee industry.

RESEARCH METHODS

This research uses a quantitative research design with a descriptive and experimental approach (Lalehzari & Kerachian, 2020; Sharifi dkk., 2021; Sonthitham & Thongchaisuratkrul, 2020). Descriptive methods are used to analyze data related to coffee plant growth patterns based on environmental factors and land management. An experimental approach was applied to test the effectiveness of applying mathematical models in managing coffee cultivation. Data collection was carried out through surveys, field observations, and direct experiments on coffee plantations. The population in this study consisted of coffee farmers in several major coffee producing areas in Indonesia (Zamani, Ali, & Roozbahani, 2020). The sample was selected using a purposive sampling technique by considering variations in geographical conditions, cultivation methods used, and the level of technology adoption in agriculture. Respondents involved included small farmers, medium-scale plantation managers, as well as agricultural experts who have experience in managing coffee plants.

Research instruments include questionnaires, observation sheets, and sensor-based agricultural technology devices. Questionnaires were used to collect data regarding cultivation

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practices implemented by farmers as well as their understanding of the use of mathematical concepts in agriculture. Observation sheets are used to record plant growth conditions, land use efficiency, and crop yields (C. Wang, Shang, & Khayatnezhad, 2021; Zamani et al., 2020). Sensor devices are used to measure environmental variables such as temperature, soil moisture and light intensity which influence the growth of coffee plants. The research procedure begins with the primary data collection stage through interviews and direct observation in the field. The data obtained was then analyzed using statistical methods to identify plant growth patterns and factors that influence coffee productivity (Hadas, Kölle, Karpina, & Borkowski, 2020; Hung, Ivanovna, & Mengesha, 2021). A mathematical model was developed based on the results of data analysis and applied in a coffee plantation management simulation. The evaluation was carried out to assess the effectiveness of the model in increasing cultivation efficiency and optimizing crop yields.

RESULTS AND DISCUSSION

The data collected came from a survey of 100 coffee farmers in three main coffee producing regions in Indonesia, namely Aceh, West Java and South Sulawesi. Statistical analysis shows that 70% of farmers still rely on traditional methods in determining planting patterns and fertilizer requirements without systematic mathematical calculations. The remaining 30% have begun to apply mathematical principles to land management and resource distribution.

The research results also show that farmers who use a mathematics-based approach experience an average increase in productivity of 20% compared to conventional methods (Loretts O., Ojha N., Vinogradov S., Ruchkin A., & Kukhar V., 2020; H. Zhang et al., 2021). Production data per hectare shows significant variations between farmers who apply mathematical calculations and those who do not. The following table presents the average coffee harvest in one year based on the method used:

Cultivation Method	Average Production (Kg/Hectare/Year)
Conventional Method	900
Mathematics Based Method	1.080

This increase in crop yields is closely related to more accurate calculations regarding the need for fertilizer, water and plant density. Planting patterns regulated using a mathematical approach have also proven to be more efficient in reducing the risk of crop failure due to unstable environmental factors.

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Further analysis shows that the application of mathematics in coffee cultivation is most widely applied in the management of planting patterns and irrigation systems. Farmers who use mathematical models to determine planting distances and the number of seeds per hectare tend to have higher and more uniform yields. Another factor that influences productivity is the use of weather data in determining optimal fertilizing and watering times. The use of calculation techniques to determine fertilizer doses and nutritional composition shows a positive impact on the growth of coffee plants. Farmers who calculate fertilizer needs based on soil analysis experience increased yields compared to farmers who use fertilizer randomly (Kang, Chen, & Zhao, 2020; Q. Wang, Mao, & Li, 2020). This proves that a number-based approach is more effective in optimizing plant growth and reducing unnecessary production costs.

The effectiveness of mathematical methods is also seen in more efficient water systems. Farmers who use predictive models based on rainfall patterns can reduce water consumption by up to 25% compared to conventional watering methods. This not only increases resource efficiency but also helps in dealing with the increasingly uncertain impacts of climate change. The differences in planting patterns between farmers who use conventional and mathematics-based methods can be seen in plant density and harvest success rates. Farmers who arrange planting distances based on land area calculations and sunlight requirements have more uniform plant growth compared to those who plant randomly. The harvest from this group also has more uniform coffee bean sizes and high quality.

From an economic perspective, farmers who use mathematical calculations in determining operational costs show a more stable level of profit. Number-based financial management helps them allocate funds for garden maintenance, fertilizer purchases, and long-term investments. Reducing costs due to more efficient use of fertilizer and water also contributes to increasing the profitability of coffee businesses. Regression analysis shows that there is a positive correlation between the level of adoption of mathematical methods and land productivity. The higher farmers' understanding of the application of calculations in cultivation, the greater their chances of increasing crop yields and resource efficiency. This factor is an important indicator in determining the sustainability of mathematics-based methods in the coffee industry.

Farmers who do not use number-based methods tend to face problems in maintaining consistent crop yields from year to year. The uncertainty factor in determining the timing of fertilization, watering and harvesting often causes fluctuations in production results. This proves that an experience-based approach alone cannot always produce stable results in the long term. The use of calculations in harvest strategies is also an important factor in improving the quality of

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production results. Farmers who use weather data and coffee fruit maturity level to determine harvest time have more optimal results compared to farmers who only rely on visual estimates. This technique ensures that the harvested coffee beans are at an optimal level of maturity, thereby increasing quality and selling price.

Evaluation of crop distribution systems shows that farmers who apply mathematical analysis models are better able to manage their supplies efficiently. Accurate calculations of harvest yields allow them to determine more profitable sales strategies, including determining the right time to sell coffee based on market price fluctuations. The relationship between the application of mathematics and increased productivity is not only visible in crop yields but also in operational cost efficiency. Farmers who apply mathematical methods in land management can reduce waste of resources without reducing production yields. Data-driven calculation models help them in identifying factors that can be optimized to increase profits.

Correlation analysis shows that there is a close relationship between farmers' education level and their ability to apply mathematical concepts in agriculture. Farmers with a better understanding of calculation methods have higher yields and are able to adopt agricultural technology more quickly. This shows the importance of education and training in supporting the application of mathematics in the agricultural sector. Technological developments that integrate automation systems based on mathematical calculations further strengthen the relationship between mathematics and agricultural efficiency. Data-based prediction models can be used to increase accuracy in cultivation planning and reduce the risk of losses due to external factors. This innovation opens up opportunities for farmers to rely more on scientific analysis in making agricultural decisions. A case study was conducted on a group of coffee farmers in the West Java area who implemented a cultivation system based on mathematical calculations. In one year, this group was able to increase harvest yields by 22% compared to the previous year. This success is attributed to the use of a calculation system in determining more effective planting patterns and fertilizer distribution.

From an economic perspective, this group of farmers experienced an increase in income of 18% due to operational cost efficiency. The use of calculations in marketing strategies also helps them in selling their crops at the most profitable times. This success shows that the integration of mathematics in agriculture can have a real impact on farmer welfare. The application of mathematical methods in this case study also contributes to environmental sustainability. Reducing excessive fertilizer use and more water-efficient irrigation systems show that a numbers-based approach not only increases productivity but also maintains ecosystem balance. This

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research shows that the use of mathematics in cultivating coffee plants contributes significantly to increasing productivity and resource efficiency. Farmers who apply calculation methods in land management, fertilizer distribution and irrigation systems experience an average increase in crop yields of 20% compared to conventional methods. Data-based prediction models help farmers optimize water and fertilizer use, thereby reducing waste and operational costs.

Correlation analysis shows that farmers who have a better understanding of mathematical principles are better able to adopt agricultural technology innovations. The success in the case study conducted in West Java strengthens the finding that implementing a number-based approach can increase farmers' economic stability and environmental sustainability. The use of predictive models in watering and fertilization systems also reduces the negative impact of climate change on crop yields. The application of mathematical calculations in determining harvest times and marketing strategies allows farmers to maximize selling prices and profits. The stock calculation model and market price fluctuations applied in this research have been proven to help farmers manage production and distribution more strategically. The results of this research indicate that mathematics is not only a technical tool in coffee cultivation, but also a determining factor in the sustainability of agricultural economics.

The results of this research are in line with previous research which states that the application of data-based technology can increase agricultural productivity. Studies in other countries such as Brazil show that the use of weather prediction models and fertilizer dose calculations can reduce uncertainty in coffee farming. These findings strengthen the argument that the integration of mathematics in the agricultural sector is not just theory, but a practical solution to increase production results. The main difference with previous research lies in the implementation aspect at the small and medium farmer level. Many previous studies have focused more on the application of artificial intelligence-based technology in large-scale plantations, whereas this research highlights how simple calculation methods can be implemented by traditional farmers at low cost. This contribution shows that advanced technology is not needed to optimize coffee production, but rather a basic understanding of mathematical concepts.

The results of this research also provide a new perspective on data-based agricultural management in Indonesia. Previous studies emphasized increasing production through the use of fertilizers and pesticides, while this research shows that resource efficiency can be achieved through a mathematical approach. The use of calculations in determining planting patterns and land management is a more sustainable alternative compared to chemical-based intensification approaches. The findings of this research are an indicator that the use of mathematics in

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agriculture is still not optimal among small and medium farmers. Most farmers still rely on intuition and experience in managing coffee cultivation, so their productivity and efficiency are not optimal. The gap in understanding of number-based methods indicates the need for more intensive education and training programs for farmers.

These results also show that technological adaptation in agriculture can be done gradually without having to rely on sophisticated tools or devices. The application of basic mathematical principles such as weather data analysis, fertilizer requirement calculations, and resource distribution can be applied with a simple approach. Awareness of the importance of calculations in agricultural management is a sign that the agricultural sector is experiencing a shift towards a system that is more data-based and scientific analysis. This study is proof that the integration of science into agricultural practices has a direct impact on farmer welfare. The increase in crop yields and cost efficiency found in this research shows that mathematics is not only an aid in planning, but also a strategy for increasing profits and resilience of agricultural businesses. Changing farmers' mindsets in applying scientific concepts in agriculture can be the first step towards modernizing a more sustainable agricultural system.

The application of mathematics in coffee cultivation can be a solution to the productivity and efficiency problems that farmers have been facing. By adopting a more systematic calculation method, farmers can optimize the use of land, water and fertilizer without significantly increasing operational costs. The use of data in agricultural decision making is an important step in increasing the competitiveness of farmers in the global market. Another implication of the results of this research is the importance of educating farmers about the benefits of mathematics in agricultural management. If a numbers-based approach can be understood and implemented by more farmers, there will be broader productivity increases in the coffee plantation sector. The government and related institutions can use these findings as a basis for designing training and mentoring programs for farmers.

These findings also show that a scientific approach to agriculture can be an alternative to less efficient and environmentally unfriendly practices. Reducing excessive use of fertilizer and optimizing water resources can contribute to the sustainability of the agricultural ecosystem. Implementation of a data-based system in coffee cultivation can be a model for other agricultural sectors to adopt calculation-based strategies to increase crop yields. The increase in crop yields found in this research was caused by optimizing resources through more accurate calculations. Farmers who apply calculations in determining planting patterns, fertilizer doses, and irrigation systems can avoid waste and increase production efficiency. This approach allows them to adapt

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cultivation strategies to environmental conditions more systematically compared to traditional methods.

The application of number-based methods also helps farmers reduce the uncertainty that often occurs due to weather factors and environmental changes. Data collected on various variables such as rainfall, temperature, and humidity allows them to take more informed decisions in managing the farm. Accuracy in planning is a major factor in increasing productivity and stability of crop yields. Success in applying mathematics in coffee cultivation is also supported by increasingly widespread access to information and technology. Although most farmers still use conventional methods, the availability of weather data, agricultural calculators and simple mathematics-based tools helps them in adopting more effective strategies. This change is a major factor in increasing agricultural productivity and efficiency.

The next step of this research is to increase the adoption of mathematical methods among coffee farmers through education and training programs. Developing hands-on practice-based training modules can help farmers understand the benefits of calculations in increasing crop yields. Collaboration with educational institutions and the government is key in expanding the implementation of this method. The application of more sophisticated calculation models such as big data analysis and artificial intelligence in coffee farming could be a future research direction. The integration of this technology can help farmers manage production more accurately and estimate crop yields based on more complex data trends. Further studies are needed to assess the effectiveness of this approach on a broader scale. Long-term evaluation of the impact of applying mathematics in coffee cultivation is also needed to measure the sustainability of this method. Further research can be conducted to see how these changes in agricultural practices contribute to farmer welfare and economic stability in the agricultural sector.

CONCLUSION

This research found that the application of mathematical concepts in coffee cultivation significantly increases the efficiency of resource use and crop productivity. The use of calculations in irrigation systems, fertilizer distribution, and analysis of planting patterns provides more optimal results compared to conventional methods. The application of data-based predictive models has also been proven to be able to reduce the impact of uncertainty due to climate change on coffee production.

The main contribution of this research lies in the development of a mathematics-based method that can be applied by small and medium scale farmers with a simple but effective

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approach. The calculation model used in this research can be adapted without the need for high-tech equipment, making it easier to implement in various agricultural conditions. These findings expand understanding of the role of exact sciences in the agricultural sector and open opportunities for the integration of mathematics in sustainable agricultural strategies.

The limitations of this research lie in the scope of the study which is still limited to certain areas and has not considered economic and social variables in more depth. Further studies are needed to test the effectiveness of this method in different geographic conditions and agricultural systems. The development of more comprehensive models with the integration of digital technology and artificial intelligence is a future research direction to improve prediction accuracy and agricultural management efficiency.

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