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The Effect of Organic Fertilizer Plus Micro Fertilizer on Soybean Plant Growth and Yield

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ABSTRACT

Purpose of the study: This study aims to determine the effect of organic fertilizer combined with micro fertilizers on the growth and yield of several soybean varieties cultivated in an agroforestry system under mango trees, as well as to evaluate the potential for developing soybean varieties in these land conditions.

Methodology: The study used a field experiment with a two-factorial Randomized Complete Block Design. Materials included soybean seeds of the Grobogan, Anjasmara, Argomulyo, and Mutiara varieties, manure, and microfertilizers. Tools used included a hand sprayer, light meter, thermohygrometer, oven, analytical balance, and camera. Data were analyzed using ANOVA and further Duncan Multiple Range Test (DMRT) at the 5% level.

Main Findings: All soybean varieties demonstrated adaptability to agroforestry systems under mango stands, although productivity remained low. The Anjasmara variety produced the highest seed weight, while the Mutiara variety had the highest 100-seed weight. Neither organic fertilizer treatment of 5 tons/ha nor a combination of organic fertilizer and microfertilizers significantly affected soybean growth and yield. Varietal factors significantly affected only 100-seed weight.

Novelty/Originality of this study: The novelty of this research lies in the evaluation of the combination of organic fertilizer and microfertilizer on several soybean varieties in an agroforestry system under mango trees. This study provides new information on the response of soybean varieties to shade conditions and the effectiveness of integrated fertilization, thus expanding knowledge on sustainable soybean cultivation strategies in agroforestry areas.

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1. INTRODUCTION

Soybeans are a strategic food commodity that plays a crucial role in meeting the population's need for vegetable protein [1], [2]. This crop is the primary raw material for various food products, such as tempeh, tofu, soy sauce, and soy milk, which are widely consumed daily. Demand for soybeans in Indonesia continues to increase in line with population growth and the development of the soy-based food industry [3], [4]. However, this increasing demand has not been fully matched by optimal domestic production. This situation has resulted in a high dependence on soybean imports, necessitating efforts to sustainably increase soybean productivity [5], [6].

Soybean crop productivity is strongly influenced by environmental factors, varieties, and cultivation techniques [7], [8]. One of the main factors determining the success of soybean cultivation is the availability of nutrients in the soil. Soybean plants require a balanced amount of macro and micronutrients to support vegetative and generative growth [9], [10]. Nutrient imbalances can stunt plant growth and reduce yields [11], [12]. Therefore, proper fertilizer management is a crucial strategy for increasing soybean yields.

While the continuous use of inorganic fertilizers can increase crop yields in the short term, in the long term, it can degrade the physical, chemical, and biological quality of the soil [13], [14]. These conditions can lead to decreased soil fertility and reduced nutrient uptake efficiency by plants. One viable alternative is the use of organic fertilizers as both a nutrient source and soil conditioner [15], [16]. Organic fertilizers can improve soil structure, increase cation exchange capacity, and stimulate soil microorganism activity [17], [18]. Therefore, the use of organic fertilizers is a more environmentally friendly solution to support sustainable agriculture.

In addition to macronutrients, soybean plants also require micronutrients such as zinc (Zn), boron (B), manganese (Mn), iron (Fe), and copper (Cu) in small but essential amounts. Micronutrients play a role in enzyme activity, chlorophyll formation, photosynthesis, and pod and seed development [19], [20]. Micronutrient deficiencies often go unnoticed because symptoms are not always obvious in the early stages of growth [21], [22]. However, micronutrient deficiencies can lead to significant yield reductions [23], [24]. Therefore, the appropriate application of microfertilizers can be an effective way to optimize soybean growth and productivity.

The combination of organic fertilizers with micronutrients has the potential to have a synergistic effect on soybean growth [25], [26]. Organic fertilizers can increase the soil's ability to retain micronutrients, thus stabilizing their availability to plants [27], [28]. On the other hand, microfertilizers can supplement nutrient needs not met by organic fertilizers. The interaction between the two is expected to increase the efficiency of nutrient absorption by plant roots [29], [30]. With integrated fertilization, plant growth and soybean yields have the potential to increase optimally.

Several previous studies have separately examined the effects of organic fertilizers and microfertilizers on soybean growth and yield [31], [32]. The results indicate that organic fertilizers can improve soil physical properties and plant vegetative growth, while microfertilizers contribute to flower formation, pod formation, and seed quality. However, studies specifically evaluating the combination of organic fertilizers and microfertilizers on soybean plants are relatively limited [33], [34]. A gap analysis indicates that information on effective combination dosages and plant responses to these treatments has not been widely reported. The novelty of this research lies in examining the interaction between organic fertilizers and microfertilizers in improving soybean growth and yield under specific cultivation conditions.

The urgency of this research is based on the need to find efficient, environmentally friendly fertilizer technologies that can sustainably increase soybean productivity. Efforts to increase soybean yields need to be implemented through cultivation innovations that focus not only on yield quantity but also on maintaining soil quality and fertility. The combination of organic fertilizer and microfertilizers is a potential alternative to address these challenges. Scientific information on the effectiveness of this combination of fertilizers is essential as a basis for technical recommendations for farmers. Therefore, the primary objective of this study was to determine the effect of organic fertilizer plus microfertilizers on soybean growth and yield.

2. RESEARCH METHOD

2.1. Time and Place of Research

This research was conducted for three months, from March to May, in Gunung Gajah Village, Cawas District, Klaten Regency. Geographically, the research location is at coordinates 7°46’7.5” South Latitude and 110°39’37” East Longitude with an altitude of approximately 211 meters above sea level. The land used has Inceptisols soil type which supports the research implementation. The research area is located under a mango tree stand so it has unique environmental conditions. Meanwhile, laboratory analysis was conducted at the Ecology and Crop Production Management Laboratory, Faculty of Agriculture, Sebelas Maret University Surakarta.

2.2. Research Materials and Tools

The tools used in this study included a hand sprayer for fertilizer application, a light meter for measuring light intensity, a thermohygrometer for monitoring ambient temperature and humidity, and a scale for measuring plant weight [35]. Additionally, an oven was used to dry samples prior to measurement, and a camera was used for documentation during the study. All of these materials and tools were used to facilitate observation and data collection.

The materials used in this study included soybean seeds from several varieties: Grobogan, Anjasmara, Argomulyo, and Mutiara. Additionally, manure served as a source of organic matter and microfertilizers to support plant nutrient requirements during growth. The use of various soybean varieties aimed to determine plant responses to the treatments.

2.3. Research Design and Data Analysis

This study used a completely randomized block design with two treatment factors: soybean variety and fertilizer type. The first factor was soybean variety, with four levels: Grobogan (V1), Anjasmara (V2), Argomulyo (V3), and Mutiara (V4). The second factor was organic fertilizer treatment, with two levels: organic fertilizer application at a dose of 5 tons/ha (P1) and organic fertilizer application at a dose of 5 tons/ha combined with microfertilizer (P2). The combination of these two factors resulted in eight treatments, each replicated three times, so that all treatments were randomly assigned within each research group [36], [37].

The research data were analyzed using analysis of variance (ANOVA) using the F test at the 5% significance level to determine the effect of the treatments. If the analysis showed significant differences between treatments, the analysis was continued with a Duncan Multiple Range Test (DMRT) at the 5% significance level. This further test was conducted to determine the differences in the effects between each treatment combination in more detail. The results of the data analysis were then used as a basis for drawing conclusions regarding the effect of organic fertilizer combined with micro fertilizers on the growth and yield of soybean plants in various varieties tested.

2.4. Research Implementation

The research began with measuring and preparing the research plots. The land was divided into three blocks arranged perpendicular to the soil fertility level. Each block had a different elevation because the research was conducted on a terraced agroforestry system. Eight experimental plots measuring 1.8 m x 1.8 m were created in each block, with a spacing of 30 cm between each plot. This resulted in a total of 24 research plots.

The next stage was soil cultivation and fertilization. Soil cultivation was carried out by hoeing until the soil was loose, then leveling and clearing it of weeds and other plant debris. Organic fertilizer was applied simultaneously with the soil cultivation process to ensure it was evenly mixed into the planting medium. Microfertilizers were then applied at planting time according to the prescribed treatment. Subsequent microfertilizer applications were carried out weekly by spraying the plants with a hand sprayer.

Planting was carried out simultaneously after digging the planting holes in each research plot, with a spacing of 20 cm x 20 cm. Each planting hole was filled with two soybean seeds, each of the treatment varieties: Grobogan, Anjasmara, Argomulyo, and Mutiara. After planting, maintenance activities were carried out to support optimal plant growth. Maintenance included weeding every two weeks or occasionally if weed growth became excessive. This step aimed to reduce competition between soybean plants and weeds for nutrients, water, and light.

Harvesting was carried out when the soybean plants reached physiological maturity, according to the harvest age of each variety. Signs that the plants were ready for harvest were marked by the leaves changing color to yellow-brown, numerous leaves beginning to fall, and fully filled, yellow-brown pods. The harvesting process involved uprooting the entire plant, from the roots to the crown. The pods were then separated from the plants and dried in the sun. Once the pods were dry, the soybean seeds were removed from the pods and weighed to determine seed weight, one of the research parameters.

2.5. Observation of Variables

Observations in this study were conducted on three sample plants in each treatment combination, with observations taking place every two weeks, three times. Observations were divided into two types: destructive and non-destructive [38]. Destructive observations involved directly taking plant samples for further analysis, while non-destructive observations were conducted without damaging the sample plants. Both methods were used to obtain comprehensive data on soybean growth and yield. Observed parameters included morphology, physiology, and yield components.

Destructive observations included plant biomass, number of branches, light interception, root nodule effectiveness, pod weight, number of pods, and 100-seed weight. Plant biomass was measured by taking plant samples at 18, 32, and 46 days after planting (DAP). They were then oven-dried at 60°C for 24 hours until they reached a constant weight before being weighed. The number of branches was observed by directly counting sample plants of the same age. Light interception was measured using a light meter by comparing the light intensity above and below the plant canopy, then calculated as a percentage. Meanwhile, root nodule effectiveness was observed by counting the number of active and inactive nodules based on the red pigment color inside the root nodules after they were split.

Yield components in destructive observations included pod weight, pod number, and 100-seed weight. Pod weight was measured by weighing soybean seeds that had been separated from the pods and dried beforehand. The number of pods was counted at harvest time, distinguishing between full and empty pods. This observation aimed to determine the actual productivity of each treatment. The 100-seed weight was obtained by manually counting 100 soybean seeds, then weighing them to determine the physical quality of the harvest. The 100-seed weight was used as an indicator of the quality and size of the beans produced.

Non-destructive observations included measurements of the leaf area index (ILI), specific leaf area (SLE), leaf unit price (LSP), absolute growth rate (AGR), and harvest index. The leaf area index was calculated based on the ratio of total leaf area to the area occupied by the plant. This parameter reflects the plant's ability to capture light for photosynthesis. Specific leaf area (SLE) is calculated by comparing leaf area to leaf weight, reflecting leaf thickness and photosynthetic capacity. Specific leaf area (SLE) and specific leaf area (LDS) measurements were conducted at 18, 32, and 46 days after planting (DAP).

The unit leaf weight (SLE) is used to determine leaf efficiency in supporting plant biomass accumulation. The value is obtained by comparing the change in plant weight with the change in leaf area at two different observation times. Furthermore, the absolute growth rate (AFR) is calculated to determine the increase in plant biomass per unit time. This parameter provides an overview of the plant's ability to produce dry matter during the growth period. Specific leaf area (SLE) and specific leaf area (LPA) measurements are based on dry weight and leaf area data at each observation interval.

The final parameter observed is the harvest index, which is the ratio of economic yield, in the form of soybean seed weight, to total plant biomass. Measurements are conducted after harvest by weighing the dried seeds from the sun and the oven-dried plant biomass. The harvest index is used to determine the plant's efficiency in allocating photosynthetic output to the generative organs. The higher the harvest index, the greater the proportion of biomass converted to seed yield. This parameter is an important indicator in evaluating the success of treatments on soybean productivity.

3. RESULTS AND DISCUSSION

According to the description of each variety, the Grobogan soybean variety is harvested at 77 days after planting, while the Anjasmara, Argomulya, and Mutiara varieties are harvested at 82 days after planting. Signs that the soybeans are ready for harvest include brownish or black pods and yellowing or drying leaves. The overall production of the four soybean varieties is shown in Table 1.

Table 1. Production Components of Four Soybean Varieties

Variety	Number of pods (Fruit)	Filled Pod (fruit)	Hollow Pod (fruit)	Seed Weight (kg/ha)	Harvest Index
Grobogan	8.04	5.50	2.54	203.23	0.42
Anjasmara	8.88	6.50	2.38	236.15	0.51
Argomulya	5.54	4.46	1.08	128.85	0.44
Mutiara	7.29	4.67	2.63	168.96	0.30

3.1. Number of Production Pods

During the generative phase, photosynthesis is translocated to the reproductive organs, particularly in pod and seed formation. Filled pods are pods that produce seeds, while empty pods are pods that do not produce seeds or are non-productive. Light intensity and shade duration influence soybean growth and yield. If 60% sunlight intensity is provided from the beginning of pod filling, the number of pods and seeds will be lower than soybeans grown without shade.

Analysis of variance results showed that soybean variety and fertilizer type had no significant effect on pod filling, and there was no interaction between treatments. Further analysis showed that the number of filled pods between varieties was not significantly different and was nearly uniform, with an average range of 4.46-6.50 pods per plant. The Anjasmara variety had the highest number of filled pods, at 6.50 (Table 1). Pod filling is related to nutrient content and light interception; the greater the nutrient content and light interception, the more pods. Observations showed that fertilizer treatment had no effect on pod filling.

The results of the analysis of variance showed that soybean varieties and fertilizer types had no significant effect on empty pods, and there was no interaction between treatments. Further analysis showed that the number of empty pods between varieties was nearly uniform, with an average range of 1.08–2.63 (Table 1). Although not significantly different, there was a tendency for the Mutiara variety to have the highest number of empty pods. The percentage of empty pods compared to filled pods was 41%. According to the variety description, the Mutiara variety adapts best to rice fields, where the land receives full sunlight. In shaded agroforestry areas, where light is reduced, seed filling is less than optimal, resulting in many empty pods.

3.2. Seed Weight

Seed weight is an important component in the observation because it is related to the results of the cultivation that has been carried out. The results of the analysis of variance showed that soybean varieties and types of fertilizers did not significantly affect seed weight and there was no interaction between treatments. Seed weight between varieties, respectively Anjasmara 236.15 kg/ha, Grobogan 203.23 kg/ha, Mutiara 168.96 kg/ha, and Argomulyo 128.86 kg/ha (Table 1). Although not significantly different, there is a tendency for the Anjasmara variety to be heavier than other varieties, this is because during the vegetative period, the Anjasmara variety has more biomass and number of branches than other varieties. When compared to the variety description, the seed weight produced in this study was low. Low productivity is related to the lower light intensity under the tree stand compared to in open areas in addition to the competition for nutrients and water between trees and intercrops. Because the light that reaches the plant is only 48%, growth and yield are less than optimal. Shading of 50% during growth resulted in a 37-74% reduction in soybean yield. The use of organic and microfertilizers, or organic fertilizer alone, had no effect on seed weight.

3.3. Harvest Index

The results of the analysis of variance showed that soybean varieties and fertilizer types did not significantly affect the harvest index and there was no interaction between treatments. The results of further analysis, the harvest index between varieties were Anjasmara 0.51, Argomulyo 0.44, Grobogan 0.42, and Mutiara 0.30, respectively (Table 1). The harvest index of the Anjasmara variety has a higher value than other varieties. The harvest index is determined more by plant genetic factors than by environmental factors. A high harvest index indicates that the division of photosynthates into usable parts is going well. Judging from its growth, the Anjasmara variety is better than other varieties, this affects the components of the harvest yield, including the harvest index value.

3.4. Weight of 100 Seeds

The results of the analysis of variance showed that soybean varieties had a very significant effect on pod filling and there was no interaction between treatments. The results of further analysis, the weight of 100 seeds of the Mutiara variety, (14.70 grams), was significantly different from the Anjasmara variety (13.49 grams) and Grobogan (13.29 grams), and also significantly different from the Argomulyo variety (11.71 grams) (Figure 1). The weight of 100 seeds is closely related to the genotype of each variety. In Figure 8, it can be seen that the Mutiara variety has the highest weight of 100 seeds because the Mutiara variety has large seeds, while Argomulyo has the lowest because the Argomulyo variety has small seeds. Compared with the description of soybean varieties, the weight of 100 seeds of the Mutiara, Argomulya, and Grobogan varieties can be said to be less than optimal. For the Mutiara variety, for example, from the description it is known that the weight of 100 seeds is ± 23.2 grams, while in the study it was only 14.7 grams. This means that soybean pod filling is still not optimal. For the Anjasmara variety, pod filling was optimal, as it matched the variety's description. The fertilizer treatment used did not affect the weight of 100 soybean seeds.

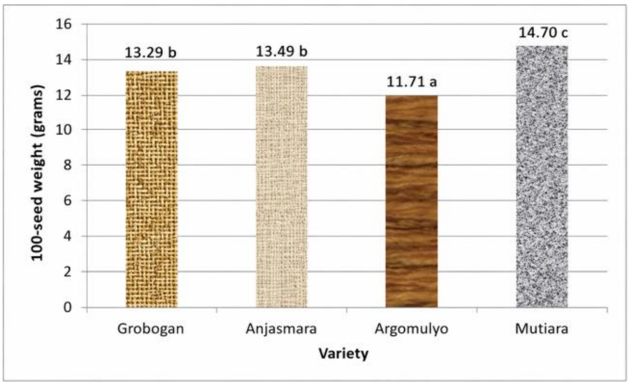

Figure 1. Weight of 100 Seeds of Four Varieties of Soybeans

This study showed that all soybean varieties tested were adaptable to agroforestry systems under mango stands, although the shaded conditions resulted in suboptimal plant productivity. The adaptation of soybean plants to shaded environments indicates a certain degree of tolerance to limited light. However, low light intensity remains a major limiting factor in photosynthesis, resulting in suboptimal biomass formation, pod filling, and seed development. This demonstrates that the success of soybean cultivation in agroforestry systems is not solely determined by the variety's genetics but is also significantly influenced by environmental conditions.

The insignificant effect of organic fertilizer application and the combination of organic fertilizer and microfertilizers on soybean growth and yield indicates that plant nutrient requirements are likely not the primary limiting factor under these research conditions. Low light intensity under mango stands is thought to have a more dominant influence on plant physiological processes than fertilizer treatment. Under shaded conditions, plant photosynthesis is limited, thus reducing the plant's ability to utilize nutrients. Consequently, additional nutrients from organic fertilizers or microfertilizers have not been able to provide optimal growth and yield responses.

Furthermore, the effectiveness of organic fertilizer is significantly influenced by the decomposition process of organic matter and the activity of soil microorganisms. In agroforestry systems, competition between soybeans and perennial crops such as mangoes for water and nutrients can reduce the efficiency of fertilizer utilization by soybeans [39], [40]. This condition prevents the plants from fully absorbing available nutrients to support pod and seed formation. This explains why the combination of organic fertilizer and microfertilizers did not significantly increase yields in this study.

The differences in response between varieties indicate that genetic factors play a significant role in determining plant adaptability to agroforestry environments. The Anjasmara variety showed a tendency for better grain yield and harvest index compared to other varieties, indicating a more efficient distribution of photosynthates to the generative organs. Meanwhile, the Mutiara variety had the highest 100-seed weight, indicating a genetic characteristic of larger seed size. These findings indicate that selecting appropriate varieties is an important strategy for soybean development in agroforestry areas.

This study also demonstrates that agroforestry systems have the potential to be an alternative for soybean cultivation in areas with limited open agricultural land. Integrating annual crops with perennial crops can support more efficient and sustainable land use [41], [42]. Furthermore, the use of organic fertilizers supports environmentally friendly farming efforts because it helps maintain soil quality and reduces dependence on synthetic chemical fertilizers. Therefore, this research contributes to the development of sustainable agricultural systems that integrate productivity and environmental conservation.

In terms of impact, the results of this study can serve as a reference for farmers and agricultural practitioners in selecting more adaptable soybean varieties in agroforestry systems. This research also provides information that shade management and environmental conditions require more serious attention than simply focusing on fertilizer additions. For the development of agricultural science, this research can serve as a basis for designing more effective soybean cultivation strategies on marginal land or land with certain levels of shade.

However, this study still has several limitations. The study was conducted only during one growing season and at one research location, so the results obtained do not fully reflect the wider diversity of agroforestry conditions. Furthermore, this study did not examine soil nutrient availability in detail or the physiological effects of plants on shade stress. Another limitation is the limited fertilizer dosage used, so the potential plant response to other dosage combinations cannot yet be optimally understood. Therefore, further research needs to be conducted with varying levels of shade, more diverse fertilizer doses, and physiological observations of plants in order to obtain a more effective and productive agroforestry soybean cultivation strategy.

4. CONCLUSION

Based on the research results, all soybean varieties tested showed potential for development in agroforestry systems under mango trees. This indicates that soybean plants are still able to adapt and grow in environmental conditions with a certain level of shade. However, the productivity generated in this system is still relatively low, so efforts are needed to improve cultivation techniques to optimally increase crop yields. Application of organic fertilizer at a dose of 5 tons/ha, either applied alone or in combination with microfertilizers, has not had a significant effect on increasing soybean growth or yield. This condition indicates that the fertilizer treatment provided is not able to optimally meet plant nutrient needs in agroforestry conditions. Therefore, further research is needed regarding more effective combinations of doses, types of fertilizers, and application techniques to support increased soybean productivity in this cultivation system. Further research is recommended to test various doses and combinations of organic and microfertilizers under varying levels of shade to develop more effective fertilization strategies in agroforestry systems. Furthermore, further research should examine plant physiological aspects, such as photosynthetic rate and nutrient uptake efficiency, to understand the adaptation mechanisms of soybean varieties to shaded conditions.

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AUTHOR CONTRIBUTIONS

Conceptualization, A.P. and A.A.; Methodology, A.P.; Software, A.A.; Validation, A.P., A.A. and Z.A.; Formal Analysis, A.P.; Investigation, A.P.; Resources, Z.A.; Data Curation, A.A.; Writing – Original Draft Preparation, A.P.; Writing – Review & Editing, A.A. and Z.A.; Visualization, A.A.; Supervision, Z.A.; Project Administration, A.P.; Funding Acquisition, Z.A.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

Not applicable.

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