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Role of Organic Fertilizer Types on Nutrient Absorption and Soybean Yield in Teak-based Agroforestry Systems

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ABSTRACT

Background: Indonesia's soybean production is insufficient to meet the demand for domestic soybean consumption as 86.4% demand is met from imports. Climatic conditions strongly influence soybean production and its quality in Indonesia, so the agroforestry system are used to to boost soybean production. However, the weakness of the agroforestry system is the low light intensity resulting in lower production. This study examines the effect of various organic fertilizers on nutrient uptake and soybean yields in teak-based agroforestry systems.

Methods: The study used a complete randomized block design with one factor, namely the type of fertilizer with seven levels, namely inorganic fertilizer (Urea 50 kg/ha, SP36 100 kg/ha and KCl 100 kg/ha), *Indigofera tinctoria* compost, corncob compost, peanut green manure, chicken manure, goat manure and cow manure (dose of 5 tons/ha) and repeated three times.

Result: The type of fertilizer affects nitrogen and potassium uptake, root length and biomass, number of leaves, plant biomass and 1 ha soybean yield in a teak-based agroforestry system. *Indigofera tinctoria* compost produced the highest nitrogen and potassium uptake, 13.83g and 2.77 g. Nitrogen uptake is positively correlated with root length and plant biomass. The highest soybean yield in the peanut green manure treatment was 1.6 tons. Organic fertilizers increased nutrient uptake and soybean yields under teak stands compared to inorganic fertilizers.

Key words: Corncob compost, Green manure, *Indigofera tinctoria* compost, Plant biomass.

INTRODUCTION

Soybean is Indonesia's primary source of vegetable protein, so soybean consumption per capita is relatively high *i.e.* 12.22 kg per year (Ramulo *et al.,* 2021). Based on the Indonesian Central Bsureau of Statistics, the demand for soybeans in Indonesia in 2022 will reach 2.9 tons (BPS, 2022). However, 86.4% of domestic demand for soybean is met from imports. The level of soybean imports in Indonesia in 2022 very high *i.e.* 2,475,286.7 tons (BPS, 2022). This high level of imports is because soybean production in Indonesia as low as 632.3 thousand tons (BPS, 2023). The imbalance between soybean consumption and production requires efforts to support increased soybean production by intensification or extensification. However, intensification and extensification of soybeans are relatively low due to the high conversion of agricultural land into residential or industrial areas and climate anomalies (Cui, 2020). Climatic conditions affect the production and chemical composition of soybean seeds (Sobko *et al.,* 2020). Increases in global average temperatures and the frequency of extreme climate phenomena, high temperatures and rainfall directly affect yield stability and soybean production.

Efforts to anticipate environmental changes due to climate anomalies are by selecting plants and cultivation technology (Lee *et al.,* 2020). Agroforestry is an option of culturing crops with relatively low energy inputs and focusing on environmental productivity (Budiastuti *et al.,* 2022). The agroforestry system is a system of intercropping cultivation by utilizing relatively abundant forest areas in Indonesia (Smethurst *et al.,* 2017). This is supported by the ability of trees to create a microclimate that reduces temperature and heat stress, maintains soil moisture and produces nitrogen. Currently, teak is widely planted with agroforestry systems in tropical countries. The system allows farmers to diversify production, reduce agricultural risks, contribute to food security and generate much-needed income. Indonesian farmers cultivate teak as a component in an integrated multi-species agroforestry system (Achmad *et al.,* 2022). Based on Roshetko *et al.* (2013) that as many as 82% of farmers in Gunung Kidul, Indonesia, cultivate teak trees with an agroforestry system with intercrops of cassava (26.6% of agroforestry), peanuts (23.8%), upland rice (18.0%), soybeans

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(8.1%) and long beans (2.9%). Based on Stewart *et al.* (2021) teak-based agroforestry provides benefits with teak in a 20-year rotation. But the problem in agroforestry systems is that the light under the trees is relatively low for the plants. Low light intensity will cause the photosynthesis process not to be optimal, so plant yields are low.

Efforts are to support crop yields in agroforestry systems by selecting plants that can adapt to low light and fertilization applications. Food crops that can adapt under optimal light are C3 plants such as soybeans (Yadav and Mishra, 2019). Therefore, soybean has the potential as an intercrop in agroforestry systems (Aziez *et al.,* 2022). According to Affandi *et al.,* (2019), soybean production in a 1.5-year-old sengon-based agroforestry system is 3.3 tons.ha^{-1}. Based on the research results by Mantino *et al.*, (2020), soybean yields decreased by 35% in complex agroforestry systems due to lack of light. Efforts to support crop yields in agroforestry systems are fertilization. However, in agroforestry systems, it is not recommended to use chemicals such as chemical fertilizers. Using chemical fertilizers can cause environmental pollution, decrease soil fertility and depletion of soil organic carbon (Triatmoko *et al.*, 2020). Organic fertilizers are nutritional support in agroforestry systems because organic fertilizers are more effective at absorbing soil carbon to improve soil quality and crop yields (Bhangu and Virk, 2019). The application of compost can increase soybean production in agroforestry systems by 102.60% compared to no fertilization (Suryanto *et al.,* 2020). This is because compost can improve soil quality by increasing the symbiosis between soybean roots and microorganisms in the soil. This research examines the effect of various types of organic fertilizers on nutrient uptake and soybean yields in teak-based agroforestry systems.

MATERIALS AND METHODS

The research was conducted in Bakaran, Sukosari, Jumantono District, Karanganyar Regency, Central Java, Indonesia, with coordinates 07°38′ 228″ East Longitude and 110°56′ 886″ South Latitude with a height of 158 meters above sea level and a slope of 3% from March to December 2022. Soybean planting was carried out in the second week of May 2022. Soybean plants were harvested when the plants were 84 days after planting. The research was carried out under teak stands with light intensity received by soybean plants was 24300 lux. In contrast, the intensity of sunlight in the open is 78400 lux. The soil in the study area had a pH of 5.8, total nitrogen 1.2% (deficient category), total phosphate 0.4% (very low category) and total potassium 0.011 (very low category). The research was carried out using a Complete randomized block design with one factor, namely the type of fertilizer. Fertilizer types consist of seven levels, namely inorganic fertilizers, *Indigofeta tinctoria* compost, corncob compost, green peanut manure, chicken manure, goat manure and cow manure with each dose of 5 tonnes/ha. The experiment was replicated thrice. Teak trees in the research area are 10-15 years old. Characteristics of teak trees in the study area were tree height of 15 m, trunk height of 6.5 m, canopy height of 8.5 m, canopy area of 4.2 m^2, tree circumference of 64 m and umbrella canopy shape. Teak trees have been planted at a distance of 2.5 × 2 meters. The plot size in each treatment was 3.5 ×1.5 meters. The materials used in this study were soybean seeds of the Dena 1 variety, inorganic fertilizers (urea 50 kg.ha^{-1}, SP36 100 kg.ha^{-1} and KCL 100 kg.ha^{-1}), *Indigofera tinctoria* compost, corncob compost, chicken manure, goat manure, cow manure and laboratory analysis materials. The tools used in this study were cultivation tools such as hoes, pickles, lux meters (Shanghai, China), ovens (Binder ED 56, Indonesia) and laboratory tools for plant tissue analysis.

The observed variables were number of leaves, plant biomass, root length, root biomass, nitrogen uptake, potassium uptake, phosphate uptake, soybean yield/ hectare and weight of 100 seeds. Plant and root biomass was carried out by drying plant samples using an oven at 60°C for 96 hours (Sitompul and Zulfati, 2019). Nutrient nitrogen, phosphate and potassium uptake were produced by multiplying the tissue value by plant biomass. Plant tissue's nitrogen, phosphate and potassium were analyzed at the maximum vegetative phase of 12 week after planting. Nitrogen analysis was carried out using the Kjeldahl method (Roy *et al.,* 2013). Phosphate analysis was carried out using the UV-vis spectrophotometer method. Phosphate analysis was carried out using the UV-vis spectrophotometer method by modifying the Friel procedure with wet ashing using HNO_3 and $HClO_4$ (Friel and Ngyuen, 1986) and the solution was analyzed using a spectrophotometer with a wavelength of 400-470 nm (Kibria *et al.,* 2019). Potassium analysis was carried out using the Atomic Absorption Spectrophotometry method. This method was chosen because it complies with ISO/IEC 17025 standards and is the easiest, simplest, most precise and most accurate method. The research data were analyzed using analysis of variance based on the F test with an α test of 5% (95% confidence level). If it has a significant effect, further analysis was carried out using Duncan's multiple range test at a 5% level. The relationship between variables was analyzed using a correlation test with Pearson's correlation.

RESULTS AND DISCUSSION

Nutrient uptake

The fertilizer type influenced plants' nitrogen and potassium uptake (Table 1). Fertilization with *Indigofera tinctoria* compost showed the highest nitrogen and potassium uptake, 13.83% and 2.77% respectively. Nitrogen and potassium absorption in *Indigofera tinctoria* fertilizer treatment was not significantly different from peanut green manure and cow manure (Table 1). However, nitrogen uptake in the inorganic fertilizer treatment, corncob compost, chicken fertilizer and goat fertilizer significantly differed from the *Indigofera tinctoria* compost treatment. Nitrogen uptake in the inorganic fertilizer treatment was 54.6% lower compared to *Indigofera*

tinctoria compost. This high nitrogen content soybean grown on soil fertilised with soil fertilized with *Indigofera tinctoria* and pea nut manure was probably due to high nitrogen content of these manure *i.e*. 2.8% and 2.06% respectively. High nitrogen content of these manures was because these Leguminous crops. Legumes contain a lot of nitrogen because they have root nodules that can supply nitrogen (Sharma *et al.,* 2019). Legume plant roots can form symbiosis with nitrogen-fixing bacteria and form root nodules. This bacterium forms a mutualism symbiosis with soybeans and can fix atmospheric nitrogen into a form of nitrogen that soybeans can use. In addition, legume fertilizer can improve soil chemical and physical properties, such as soil structure, so plant roots can easily penetrate the soil (Etesami, 2022). This is consistent with the results of this study that nitrogen and potassium uptake are positively correlated with root length (Table 3). Longer roots can increase nutrient absorption. This capability is supported by the high organic matter content of *Indigo tinctoria* fertilizer, which is 52.48% (Budiastuti *et al*., 2021). Organic materials have an essential role in efforts to increase the efficiency of fertilizer use. Adding *Indigofera tinctoria* compost can reduce soil cohesiveness and affect soil water-holding capacity and microbial and root growth.

The fertilizer type does not affect phosphate uptake in soybean plants (Table 1). This is because the available phosphate content in the soil is very low. However, the lowest potassium absorption was in the treatment of inorganic fertilizers, 0.35%. This is probably because plants can only take up 30-50% of the chemical fertilizers, so many of the components used are lost in the soil and contaminate groundwater (Saini *et al.,* 2021). The efficiency of using chemical fertilizers decreases due to fertilizer saturation. Treatment with various organic fertilizers tends to increase phosphate uptake (Table 1). This is because organic fertilizers are mineral sources with high amounts of essential plant nutrients. Organic fertilizers gradually release nutrients into the soil solution and maintain a balance of nutrients for healthy plant growth. Nutrient uptake in this study was high because the agroforestry system could maintain soil temperature and moisture.

Root growth

The type of fertilizer affected root length and root biomass (Table 1). *Indigofera tinctoria* compost treatment showed the longest root of 18.67 cm and the highest root biomass of 4.54 g. The root length and biomass of *Indigofera tinctoria* fertilizer treatment were not significantly different from other organic fertilizer treatments. The length and biomass of the roots in the *Indigofera tinctoria* compost treatment were significantly different from those in the organic fertilizer treatment. Root length indicates the area of the absorption of nutreints and water so the longer the root, the more optimal the absorption of water and nutrients by soybeans (Xiong *et al.,* 2021). Organic fertilizers can improve soil structure, so plant roots can penetrate the roots. In addition, this organic fertilizer contains high organic matter to increase the activity of microorganisms (Nardi *et al.,* 2021). The results of this study indicate that plant biomass is correlated with potassium uptake (Table 3). Root growth exhibits a high degree of plasticity in response to nutrient availability, affecting plant roots' development and spread. The lowest root length and biomass were in inorganic fertilizers (Gagné *et al.,* 2022). Root growth will slow down when experiencing water and nutrient stress. The results of this study indicate that the nutrients contained in inorganic fertilizers are not available in the soil and cannot be absorbed by plants. This is because application of chemical fertilizers for a long time can cause a decrease in pH, increase soil acidification and decrease available nitrogen (Zhang *et al.,* 2019). In addition, chemical fertilizers cause a reduction in soil organic matter content so that they can harden the soil, reducing soil productivity (Itelima *et al.,* 2018). Hardened soil causes plant roots to be unable to penetrate the soil, causing limitations in absorbing water and nutrients. The roots will adjust their morphology to absorb water more optimally, such as extending the roots to find water sources or increasing the lateral root branches to expand the absorption area.

Attributes and yield

The type of fertilizer resulted in significant effect on the number of soybean leaves (Table 2). The highest number of leaves (25.67) was in the *Indigofera tinctoria* fertilizer

Table 1: Effect of fertilizer types on nutrient uptake and root growth in Soybean.

Fertilizer type	Nitrogen uptake (%)	Phosphate uptake (%)	Potassium uptake (%)	Root length (cm)	Root biomass (g)
Inorganic fertilizer	6.27a	0.35	0.75a	10.67a	2.05a
Indigofera tinctoria compost	13.83c	0.52	2.77b	18.67b	4.54b
Compost corn cobs	6.90ab	0.47	1.19a	15.00ab	4.16b
Peanut green manure	12.13bc	0.61	1.49ab	15.67ab	4.18b
Chicken manure	7.94ab	0.39	1.26a	17.00b	3.37ab
Goat manure	7.67ab	0.37	1.62ab	14.33ab	4.01ab
Cow manure	11.58abc	0.45	1.99ab	18.67b	3.36ab

Note: Numbers followed by the same letter in the same column are not significantly different based on duncan's multiple range test (α= 0.05).

Table 2: Effect of fertilizer types on soybean growth and yield in a teak-based agroforestry system.

Fertilizer type	Number of leaves	Plant biomass (g)	Weight of 100 seeds (g)	Soybean yield/ha (tonnes)
Inorganic fertilizer	15.00a	1.39a	17.83	0.880ab
Indigofera tinctoria compost	25.67b	3.33b	26.26	1.010abc
Compost corn cobs	23.33b	2.05a	24.47	1.411abc
Peanut green manure	25.33b	2.37ab	16.96	1.633c
Chicken manure	19.67ab	2.05a	17.72	1.517bc
Goat manure	25.00b	2.29ab	16.97	1.278abc
Cow manure	26.33b	3.22b	19.72	0.828a

Note: Numbers followed by the same letter in the same column are not significantly different based on duncan's multiple range test (α= 0.05).

Table 3: Correlation between nutrient uptake and root growth and soybean yield.

	Nitrogen uptake	Phosphate uptake	Potassium uptake	Root length	Root biomass	Plant biomass	Soybean yield in 1 ha (tonnes)
Nitrogen uptake	1	0.083	0.327	0.472*	0.070	0.770**	-0.165
Phosphate uptake	0.083	1	0.269	0.206	0.432	0.192	0.025
Potassium uptake	0.327	0.269	1	0.525*	0.445*	0.628**	-0.147
root length	0.472*	0.206	0.525*	1	0.354	0.723**	0.206
Root biomass	0.070	0.432	0.445*	0.354	1	0.371	0.145
Plant biomass	0.770**	0.192	0.628**	0.723**	0.371	1	-0.144
Soybean yield 1 ha	-0.165	0.025	-0.147	0.206	0.145	-0.144	1

Note: *Significant at 0.05 level, **Significant at 0.01 level.

treatment and was not significantly different from the treatment of other types of organic fertilizers (Table 2). The number of leaves in the *Indigofera tinctoria* compost treatment was significantly different from the inorganic fertilizer treatment. The increase in the number of soybean leaves in the agroforestry system in the organic fertilizer treatment was supported by better root growth and high nutrient uptake in *Indigofera tinctoria* fertilizer treatment, This is because organic fertilizers have a variety of nutrients needed by soybean growth, including the formation of leaves (Thapa *et al.,* 2021). The number of soybeans leaves positively correlated with fresh weight, biomass, root length and nitrogen uptake (Table 3). Leaves have a significant role in light capture and photosynthesis. More leaves will support the process of photosynthesis and the effectiveness of light absorption. The increased process of photosynthesis will increase the number of leaves.

Many photosynthates will be distributed throughout plant tissues for growth. In line with El-Desouky *et al.,* (2021)., the more the number of leaves, the more photosynthates which can support the increase in fresh weight, dry weight and root length. The results of this study indicate that the type of fertilizer affects plant biomass and soybean yield/ha (Table 1). *Indigofera tinctoria* fertilizer showed the highest plant biomass (3.33 g). The high nitrogen content in *Indigofera tinctoria* fertilizer supports this. Nitrogen, as an essential macronutrient, plays a role in chlorophyll production, thereby increasing the growth of soybean leaves (Eddy and Yang, 2022). A higher number of leaves will encourage the production of plant biomass. In addition, organic fertilizers with a high nitrogen content can increase the availability of soil nitrogen and the diversity of soil microorganisms. This greatly affects plant biomass (Zhang *et al.,* 2019). The results showed that the type of fertilizer affected soybean yield (Table 3). Soybean yield in the treatment of peanut green manure showed the highest soybean yield, namely 1.6 tons. The high yield was supported by the high content of potassium and phosphate in the peanut green manure, namely 1.43% and 2.17% respectively (Budiastuti *et al.,* 2021). The nutrient content in these fertilizers can increase phosphate solubilizing bacteria which can convert bound inorganic or organic phosphates into hydrogen-phosphate ions (H_2PO_{4-}) available to plants, thereby increasing plant growth and yield. Soil phosphate content positively correlates with soybean seeds' yield and protein and carbohydrate content due to an increase in high acid phosphatase resulting in seed yields. However, soybean production in this agroforestry system is still deficient compared to that in a monoculture system. Soybean production in a monoculture system reaches 2-4 tonnes/ha (Gaweda *et al.,* 2020). Low production in agroforestry systems is caused by lower light intensity, namely only 24300 lux, which soybean plants can receive (Tsaniya *et al.,* 2022). The low light intensity causes the photosynthesis process not to be optimal and the photosynthate is focused on the canopy area. Plants allocate more energy to the crown than to the roots in conditions of low light intensity.

CONCLUSION

The type of fertilizer affects nitrogen and potassium uptake, root length and biomass, number of leaves, plant biomass and soybean yield/ha in a teak-based agroforestry system. *Indigofera tinctoria* fertilizer produced the highest nitrogen and potassium uptake, 13.83 g and 2.77 g. Nitrogen uptake is positively correlated with root length and plant biomass. The highest soybean yield was obtained from peanut green manure, namely 1.6 tonnes. tons. Organic fertilizers increased nutrient uptake and soybean yields under teak stands compared to inorganic fertilizers.

Conflict of interest

All authors declare that they have no conflict of interest.

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