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The Role of Organic Fertilizer and Tree Pruning on the Growth and Nitrogen, Phosphate and Potassium Uptake of Red Ginger in Sengon Agroforestry System

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ABSTRACT

Red ginger is one of the C3 plants that has the potential as an herbal medicine. This causes red ginger to be sensitive to high temperatures and light intensity. One effort that can be done is to implement an agroforestry system. The study aims to examine the effect of fertilization and tree pruning on the growth and nutrient uptake of red ginger. The study used a randomized block design with a nesting pattern. The first factor, pruning trees, had two levels: without pruning (1730-12270 lux) and with pruning of sengon stands (2430-24900 lux). The second factor, nested within the first, was fertilization with four levels: chemical fertilizer, corn cob compost, *Indigofera tinctoria* compost, and goat manure compost. The highest plant height in the treatment without pruning was 107.83 cm. *Indigofera tinctoria* compost nested in pruning treatment showed the highest number of leaves and nitrogen absorption, which were 99 leaves and 0.125 g.plant^{-1}. Corn cob compost nested in pruning treatment produced the highest phosphate absorption, which was 0.360 g.plant^{-1}. Nitrogen absorption was positively correlated with phosphate and potassium absorption. Compost and pruning application can increase the growth and nutrient absorption of red ginger in agroforestry.

1. INTRODUCTION

Free radicals have become an increasing concern in recent years. This is supported by studies showing increased oxidative stress markers across the population. Increased oxidative stress in the body has been linked to a decline in overall human health [1]. Increased oxidative stress in humans contributes to higher rates of cardiovascular disease, cancer, diabetes, psychiatric disease, neurological disorders, kidney disease, and lung disease [2]. The human body has so far developed and possesses natural antioxidant defenses. Although the human body already has natural defense capabilities, supplementation with exogenous antioxidants is still necessary to reduce the worsening impact of free radicals [3]. Research on antioxidants has shown promising results in combating excessive free radicals. Some plants that can be consumed to improve the body's ability to deal with free radicals are blueberries [4], spinach [5], almonds [6], green tea [7], and dark chocolate [8]. In addition, red ginger (*Zingiber officinale* var. rubrum) is also known as a source of bioactive compounds that can counteract free radicals in the body [9]. A comprehensive review in Molecules highlighted that red ginger contains more than 40 antioxidant compounds, with 6-gingerol, 6-shogaol, and zingerone being the most active [10]. Such compounds have demonstrated the ability to neutralize various free radicals, such as superoxide, hydroxyl, and peroxynitrite radicals.

Red ginger's antioxidant, anti-inflammatory, and immunomodulatory properties have been shown to neutralize free radicals, which has increased interest in developing sustainable cultivation methods to meet consumer demand [11]. However, optimal growth of red ginger requires specific environmental conditions. Red ginger can grow optimally at temperatures of 25-35 degrees Celsius, soil pH of 6.8-7.4, and annual rainfall between 2500-4000mm [12, 13]. Red ginger is a C3 plant that is sensitive to high temperature and light intensity. Red ginger can also thrive under shade because temperature and humidity are better maintained. The shade of 25% increases ginger yields by 11% to 29% compared to ginger plants grown in open fields [14]. Agroforestry systems, a farming method that integrates trees and crops, can be a promising solution by providing natural shade for red ginger. In addition, agroforestry systems also provide many benefits that can optimize red ginger cultivation. A meta-analysis published in Soil Use Management found that agroforestry practices increased soil organic carbon by an average of 19% compared to conventional agriculture [15]. Another meta-analysis by study [16] found that transitioning from agriculture to agroforestry increased soil organic carbon stocks at 0-15 cm depth by 26%, 0-30 cm by 40%, and 0-100 cm by 34%. Agroforestry systems significantly increased biodiversity compared to monoculture systems. Agroforestry systems provide up to 45% more benefits to biodiversity and 65% more benefits to ecosystem services than conventional agricultural systems [17]. This can support the long-term sustainability of agriculture.

Several studies have demonstrated the successful integration of ginger species in agroforestry systems. Research published in Agronomy System reported that agroforestry with bamboo species was observed to increase ginger yield and oleoresin content by 10.5-15.6 and 14.45-28.61 percent, respectively, compared to monocropping [18]. A study [19] on ginger agroforestry systems with Gmelina arborea also yielded similar results. In the first year of the study, they produced 3.97 tons of ginger per hectare in the agroforestry system, while the monoculture system only reached 3.25 tons per hectare. In the second year, it produced 6.37 tons of ginger per hectare in the agroforestry system, while the monoculture system only reached 4.77 tons per hectare. However, several studies have reported suboptimal ginger growth in agroforestry systems with too much shade. When shade reached 75%, dry rhizome weight decreased by 25% compared to 50% or 25%. In addition, the content of gingerol compounds also decreased by 33% in 75% shade compared to 50% shade [20]. The solution that can be done to overcome conditions that are too densely shaded is the strategic pruning of agroforestry trees. Therefore, pruning, which involves selectively removing branches or parts of trees to control the amount of shade, positively impacts crop yields [21]. Research on the specific effects of red ginger cultivation with session-based agroforestry systems, a type of agroforestry that involves rotating crops and trees in the same field over different seasons, is still limited, so further research needs to be done.

Soil fertility is essential besides light management in red ginger agroforestry systems. Soil fertility in red ginger cultivation can be improved through fertilizer application [22]. Inorganic fertilizers can provide instant and high yields, but organic fertilizers can offer a sustainable approach to improving soil quality and crop yields in agroforestry systems [23]. A meta-analysis in MDPI Agronomy found that organic fertilizer application can significantly increase soil organic matter by 12.73%, soil carbon sequestration by 13.19%, nitrogen sequestration by 7.91%, and potassium sequestration by 7.37% [24]. Organic fertilizers indirectly affect crop yields by increasing soil nutrients, soil organic carbon storage, and pH [25]. Agroforestry systems have the potential to provide an ideal environment for sustainable red ginger cultivation. Proper shade management through pruning combined with organic fertilization can optimize environmental conditions to suit the needs of red ginger. Such an integrated approach not only supports optimal growth and yield but also contributes to soil health and ecosystem resilience in the long term. Previous studies such as those conducted by study [26] on the role of pruning and fertilization with cow dung compost and chemical fertilizers on the growth and yield of red ginger. The research by Sharma et al. [18] discussed the combination of mulch types with fertilization with cow dung fertilizer on the growth and yield of red ginger in a bamboo-based agroforestry system. There are few discussions in the literature on using local fertilizers such as Indigofera tinctoria compost, corn cob compost, and goat dung compost combined with pruning for red ginger cultivation in agroforestry systems. Therefore, the effect of several types of organic fertilizers and pruning on the growth and absorption of nitrogen, phosphate and potassium of red ginger needs to be investigated further. The study aims to examine the effect of fertilization and pruning of sengon tree stands on the growth and nutrient uptake of red ginger.

2. MATERIALS AND METHODS

The study was conducted at a location in the lowlands at an altitude of 158 meters above sea level, namely in the sengon plantation in Sukosari Village, Jumantono District, Karanganyar Regency, Central Java, Indonesia, with coordinates 07° 38' 228" East Longitude and 110° 56' 886" South Latitude. The study used a completely randomized block design with a nested pattern. The first factor as a nest was pruning sengon trees with two levels, namely without pruning (light intensity at noon was 1730-12270 lux) and pruning sengon stands (light intensity at noon was 2430-24900 lux). The second factor as a factor nested in the nest was fertilization with four levels, namely chemical fertilizer with nitrogen phosphate potassium (NPP) compound fertilizer (40-60-45) 300 $kg.ha^{-1}$, corn cob compost, *Indigofera tinctor*ia compost, and goat manure compost (20 $tons.ha^{-1}$). Repetition was carried out three times. Randomization was performed by randomly assigning factors nested within nests within each group. Sengon trees used for the agroforestry system in this study were 5-10 years old, with an average tree height of 15.3-19.25 meters. Pruning of sengon stands was carried out by pruning 25%; namely, 2-3 branches were pruned [27]. Pruning times were carried out one week before planting, eight, and sixteen weeks after planting. The land used in the study had a soil type with a low acidity level of 5.5 and an acidic category. The study used red ginger rhizome of Jahira I variety.

The materials used in this study were chemical fertilizer nitrogen phosphate potassium (NPP) compound fertilizer (40-60-45), organic fertilizer corn cob compost (pH 7.34; organic C 62.21%; organic ingredients 85.71%; total nitrogen 1.44%; total phosphate 1.43%; total potassium 2.17%; nitrogen available 2.10%; phosphate available 0.98%; and potassium available 1.75% [28]), *Indigofera tinctoria* compost (organic C 52.48%; organic ingredients 90.48%; total nitrogen 2.84%; total phosphate 1.54%; total potassium 2.44%; available nitrogen 1.30%; available phosphate 0.92%; available potassium 1.52% [29]), and goat manure compost (pH 7.3; organic C 42.3%; organic ingredients 88.5%; nitrogen 22.3 $mg.kg^{-1}$; phosphorous 38.4 $mg.kg^{-1}$; magnesium 11.8 $mg.kg^{-1}$ [30]) and laboratory analysis materials for nitrogen, phosphate, and potassium absorption analysis. The tools used in the study were a lux meter, digital scales, thermohygrometer, measuring instruments, documentation tools, and cultivation tools. The laboratory analysis tools used were spectrophotometer, atomic absorption spectrophotometer (AAS), distillator, titrator, oven, and analytical balance. Nitrogen, phosphate and potassium of plant tissues were analyzed at the Soil Chemistry Laboratory, Faculty of Agriculture, Sebelas Maret University, Indonesia. Nitrogen, phosphate, and potassium tissue were analyzed for the maximum vegetative phase, which was eight weeks after planting (WAP). Nitrogen analysis was carried out using the Kjeldahl method [31]. Kjeldahl is a method that involves the conversion of organic nitrogen to ammonium by boiling with sulfuric acid and distilling with alkali to liberate ammonia for determination by titration. The Kjeldahl method, with certain modifications, has been widely used for plant analysis to date [32]. Phosphate analysis was carried out using a spectrophotometer.

Preparing plant destruction samples was carried out with a modification of the procedure by Friel and Ngyuen [33] with wet ashing using HNO_3 and $HClO_4$. The ready solution was analyzed using a spectrophotometer with a wavelength of 400-470 nm [34-37]. Potassium analysis was carried out using an atomic absorption spectrophotometer (AAS); this method was chosen because it meets the ISO/IEC 17025 standard and is the easiest, simplest, most precise, and most accurate method [35, 36]. The nitrogen uptake variable was generated by multiplying the plant biomass by the nitrogen value of the plant tissue. The phosphate uptake variable was generated by multiplying the plant biomass by the phosphate value of the plant tissue. The potassium uptake variable was generated by multiplying the plant biomass by the potassium value of the plant tissue. The data obtained were analyzed using analysis of variance (ANOVA) at a level of 5%. If it had a significant effect, it was continued with Duncan's Multiple Range Test (DMRT) at a level of 5%. The data were also analyzed using Pearson Correlation to measure the strength and direction of the relationship between several variables.

3. RESULTS AND DISCUSSION

3.1 Plant height

The results showed that pruning treatment significantly affected plant height (Table 1). The average plant height in the treatment without pruning was 96.55 cm, and the pruning treatment was only 80.83 cm. This is because the light intensity in the treatment without pruning was lower than with pruning treatment. Low light intensity triggers auxin synthesis mediated by PIF and YUCCA [38]. Light strongly influences various aspects of the auxin system, controlling auxin levels, transport, and responsiveness [39, 40]. Auxin can promote plant height elongation because auxin movement from cell to cell in response to external cues is the primary mechanism for producing asymmetric auxin distribution and differential cell elongation [41, 42].

Table 1. Height of red ginger plants at the age of 22 WAP in an agroforestry system (cm)

Treatment	Without Pruning	Pruning
Chemical fertilizer	86.72 a	71.12 a
Corn cob compost	92.79 ab	81.37 a
Indigofera tinctoria compost	107.83 b	89.78 ab
Goat manure compost	98.88 ab	81.05 a
Average	96.55 b	80.83 a

Note: Numbers followed by the same letter in a row and column are not significantly different according to the 5% DMRT.

Fertilization treatments nested in pruning treatments affected the height of red ginger plants (Table 1). Fertilization with *Indigofera tinctoria* compost nested in the treatment without pruning showed the highest plant height of 107.83 cm. This is supported by the *Indigofera tinctoria* compost material, one of the legume families. Apart from that, *Indigofera tinctoria* compost contains organic C 52.48%, organic ingredients 90.48%, total nitrogen 2.84%, total phosphate 1.54%, total potassium 2.44%, available nitrogen 1.30%, available phosphate 0.92%, available potassium 1.52% [29]. Compost from legumes contains high nitrogen and phosphate and can form a symbiosis with soil microorganisms such as rhizobium and mycorrhiza [29, 43]. This symbiotic relationship can encourage auxin production, causing root elongation [44, 45]. More than 80% of bacteria associated with the rhizosphere can synthesize auxin. Root elongation indicates the depth of the root system and is correlated with plant height [46-48]. A deeper root system is caused by increased water and nutrient absorption capacity [49].

3.2 Number of leaves

The results showed that pruning stands could increase the number of red ginger leaves in the agroforestry system (Table 2). This is because higher light intensity can increase the number and area of stomata opening, increasing the rate of photosynthesis [50]. High photosynthesis rates increase the amount of photosynthate stored in the leaves so that the number and specific weight of the leaves increase [51]. The results showed that the treatment without pruning showed a low number of leaves, which was only 75.65 leaves. This is because low light intensity can reduce electron transfer and the net photosynthesis rate so that carbohydrates are reduced [52]. Carbohydrates as a result of photosynthate and function as carbon reserves stored in plant organs [53]. The amount of carbohydrates encourages and supports the increase in the number of organs, such as leaves, so low light intensity causes a low rise in the number of leaves. Treatment with *Indigofera tinctoria* compost nested in the pruning treatment showed the highest number of leaves. *Indigofera tinctoria* compost contains high nitrogen [29, 54]. The number of leaves in the goat manure fertilizer treatment nested in the pruning treatment was not significantly different from the *Indigofera fertilizer* treatment. This is supported by the nitrogen content in goat manure fertilizer, which is also high at 3.26%. Nitrogen is needed in large quantities as an element that makes up amino acids, proteins, cell walls, and cell membranes. Nitrogen deficiency can reduce the rate of photosynthesis and leaf area so that it can inhibit plant growth and development) [55]. Nitrogen is also a chlorophyll component, so nitrogen content is positively correlated with chlorophyll content. Many studies have shown that nitrogen fertilization increases photosynthesis along with increasing chlorophyll content [56]. C3 plants like red ginger need more nitrogen for light absorption and transport. This indicates that nitrogen is essential in supporting the growth of red ginger in agroforestry systems.

Table 2. Number of red ginger leaves at 22 MST in an agroforestry system

Treatment	Without Pruning	Pruning
Chemical fertilizer	68.83 a	71.50 a
Corn cob compost	76.83 a	77.17 a
Indigofera tinctoria compost	74.83 a	99.00 b
Goat manure compost	82.17 ab	94.50 b
Average	75.65 a	84.54 b

Note: Numbers followed by the same letter in a row and column are not significantly different according to the 5% DMRT.

3.3 Nitrogen uptake

The results of our study, which showed that pruning treatment significantly influenced the nitrogen uptake of red ginger in the agroforestry system (Table 3), are in line with the findings of study [57]. Their research also demonstrated that nitrogen uptake and plant dry weight were highest at high light intensity. This alignment with previous research not only validates our findings but also underscores the crucial role of light intensity in regulating the absorption, translocation, and assimilation of nitrogen into organic compounds [58]. Previous studies have shown that nitrate uptake in C3 plants peaks during periods of higher light in agroforestry systems. Increased nitrate uptake stimulates photosynthesis, increasing sucrose transport under light conditions [59]. Nutrient uptake requires systemic signal molecules that transmit light signals to the roots. Increased nitrogen uptake at higher light intensity can be associated with higher plant dry weight at that light intensity. There is a relationship between plant nutrient accumulation and biomass production [60].

In addition, light intensity affects NO_3 absorption [61]. The level of nutrient absorption is related to the growth rate. Increased biomass production also increases the total amount and intensity of nutrient absorption. The results showed the highest nitrogen absorption in the fertilization with Indigofera tinctoria fertilizer nested in the pruning treatment. This is due to the high nitrogen content in *Indigofera tinctoria* compost which can support the process of photosynthesis and nitrogen accumulation in tissues [62]. In addition, compost from the legume family contains rhizobium and can associate with soil microorganisms to increase the availability of nutrients, one of which is nitrogen. Soil with low nitrogen content makes it difficult for plants to absorb nitrogen. Fertilization with high nitrogen content can increase nitrogen availability for plants, increasing the nitrogen absorption value [63]. Nitrogen is a macro component in protein molecules, enzymes, and chlorophyll needed for photosynthesis. In addition, nitrogen is also involved in the formation of nucleic acids (DNA and RNA) and various other compounds required for the synthesis of essential substances in plants. Nitrogen absorption is positively correlated with potassium and phosphate absorption. Higher nitrogen absorption means higher red ginger growth [12]. An increase will follow increased nitrogen absorption in the number of leaves that can support the photosynthesis process. Optimal photosynthesis will support the formation of red ginger rhizomes [64]. Nitrogen absorption also supports potassium absorption; the amount of potassium absorbed by plants will follow the amount of nitrogen absorbed. Red ginger requires potassium for metabolic regulation; the higher the photosynthesis process, the higher the potassium absorption by red ginger [65].

Table 3. Nitrogen uptake of red ginger in agroforestry systems ($g.plant^{-1}$)

Treatment	Without Pruning	Pruning
Chemical fertilizer	0.071 a	0.074 a
Corn cob compost	0.068 a	0.079 ab
Indigofera tinctoria compost	0.084 ab	0.125 b
Goat manure compost	0.081 ab	0.110 b
Average	0.076 a	0.097 b

Note: Numbers followed by the same letter in a row and column are not significantly different according to the 5% DMRT.

3.4 Phosphate uptake

Pruning treatment did not affect the phosphate uptake of red ginger in the agroforestry system (Table 4). However, the fertilization treatment nested in the pruning treatment affected the phosphate uptake. Fertilization with corn cob compost nested in the pruning treatment showed the highest phosphate uptake of 0.360 $g.plant^{-1}$. Corncob compost contains 62.21% organic carbon; organic ingredients 85.71%, total nitrogen 1.44%, total phosphate 1.43%, total potassium 2.17%, nitrogen available 2.10%, phosphate available 0.98%, and potassium available 1.75%. The high phosphate content in corn cob compost supports this. Compost can convert insoluble phosphorus into soluble phosphorus due to ion exchange with anions and remineralization into more soluble phosphorus. Phosphorus, as a macronutrient, plays a role in plant metabolism. Increasing leaf light interception increases the response of plant roots to fertilization. Increasing light capture decreases leaf phosphate concentration, which is caused by increased photosynthesis and shoot growth rates that exceed the ability of root phosphorus to supply leaves [66].

However, too low light intensity can inhibit the phosphate absorption process [67]. C3 plants such as red ginger show high photosynthesis rates and sucrose concentrations in agroforestry systems because the light intensity is low. Too high light intensity can cause growth-induced phosphate deficiency in shoots, producing systemic signals to induce root growth. Root growth is positively correlated with nutrient absorption. This is because the longer the root, the wider the absorption area to capture more nutrients in the soil [68]. The more absorption by the roots, the higher the phosphate levels in the tissue. Increased phosphate levels in the tissue can support the plant photosynthesis more effectively [69]. The results of this study indicate that phosphate absorption is correlated with the number of red ginger leaves in the agroforestry system. This is supported by the role of phosphate in plant metabolism, such as photosynthesis. The increasing number of leaves will support the photosynthesis process and the effectiveness of light absorption. The increased photosynthesis process will increase the amount of photosynthesis. The abundant photosynthate will be distributed throughout the plant tissue for growth.

Table 4. Phosphate uptake of red ginger in agroforestry systems ($g.plant^{-1}$)

Treatment	Without Pruning	Pruning
Chemical fertilizer	0.191 a	0.167 a
Corn cob compost	0.155 a	0.360 b
Indigofera tinctoria compost	0.182 a	0.234 ab
Goat manure compost	0.226 ab	0.221 ab
Average	0.189	0.245

Note: Numbers followed by the same letter in a row and column are not significantly different according to the 5% DMRT.

3.5 Potassium uptake

Pruning treatment affected the potassium uptake of red ginger in agroforestry systems (Table 5). This is because plants at higher light intensities require higher potassium for physiological processes [70]. Efficient photosynthate transport to the absorbing organs and utilization of absorbed light energy in photosynthetic CO_2 fixation require high potassium levels [71]. Under high light intensity, in photosystem II, excited electrons released during water splitting increase, putting extra pressure on photosynthetic CO_2 fixation, primary metabolism, and phloem loading [70]. K^+ is more involved in several physiological activities related to osmoregulation, cell expansion, stomatal regulation, stimulation of enzyme activity, protein biosynthesis, photosynthesis, and phloem loading and transport [71]. Fertilization treatment did not affect potassium uptake of red ginger in agroforestry systems (Table 5). This may be because the soil used in this study was acidic, with an acidity level of 5.6. Soil with low pH tends to have lower potassium availability. Potassium uptake is correlated with phosphate and nitrogen uptake (Table 6).

Table 5. Potassium uptake of red ginger in agroforestry systems (g.plant^{-1})

Treatment	Without Pruning	Pruning
Chemical fertilizer	0.093	0.094
Corn cob compost	0.094	0.107
Indigofera tinctoria compost	0.079	0.153
Goat manure compost	0.102	0.104
Average	0.092 a	0.114 b

Note: Numbers followed by the same letter in a row and column are not significantly different according to the 5% DMRT.

Table 6. Correlation of nitrogen, phosphate and potassium uptake

Observation Variables	Nitrogen Uptake	Phosphate Uptake	Potassium Uptake
Nitrogen uptake	1	0.884**	0.893**
Phosphate uptake	0.884**	1	0.918**
Potassium uptake	0.893**	0.918**	1

Note: ** Correlation is significant at the 0.01 level (2-tailed)

4. CONCLUSION

Pruning affects plant height, number of leaves, nitrogen and potassium absorption of red ginger in agroforestry systems. The highest plant height in the treatment without pruning was 107.83 cm. *Indigofera tinctoria* compost nested in pruning treatment showed the highest number of leaves and nitrogen absorption, which were 99 leaves and 0.125 g.plant^{-1}. Corn cob compost nested in pruning treatment produced the highest phosphate absorption, which was 0.360 g.plant^{-1}. Nitrogen absorption was positively correlated with phosphate and potassium absorption. Compost and pruning application can increase the growth and nutrient absorption of red ginger in agroforestry. Pruning level of 25% on sengon trees by pruning 2-3 branches to support the growth and nutrient absorption of ginger in agroforestry systems in Indonesia.

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