



Agroclimatic characteristics, nutrient uptake, morphological traits, and yield of abaca (*Musa textilis* Nee) under teak-based agroforestry at different stand ages in Ngawi

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Abstract

This research aimed to measure microclimate characteristics, evaluate abaca plants nutrient uptake, morphology and yield, and determine the optimal microclimate characteristics on abaca cultivation land managed using teak-based agroforestry in the middle and advanced phases in Ngawi. The research was arranged in a nested design. The parameters observed include agroclimatic characteristics, nutrient uptake, physiology and morphology, as well as yield of abaca plants. The middle phase of abaca-teak agroforestry shows higher humidity and lower temperatures than the advanced phase with a difference of 3% and 1.57°C, respectively. This is because microclimate in the middle phase is more suitable due to the multistrata canopy structure and greater plant diversity. The absorption all of macro and micro nutrients in the middle phase was better than in the advanced phase, indicating that abaca in the middle phase had more nutrient uptake. The morphological traits of abaca in the middle phase were better and significantly different compared to those in the advanced phase, with the differences in plant height variables of 110.11 cm, apparent stem circumference of 7.99 cm, and number of suckers of 5. Furthermore, in terms of yield characteristics, all variables showed that abaca planted in the middle phase was better than the advanced phase, it can be seen the respective differences in the number of banana fronds is 4 blade, the weight of banana fronds is 2.95 kg/plant, the fresh weight of fiber is 353.66 g/plant, and the weight of dry fiber is 120.67 g/plant.

INTRODUCTION

Abaca banana plant (*Musa textilis* Nee) is included in the male banana category, because it does not produce fruit. The fiber from abaca banana plants is taken before producing fruit (Balittas, 2020). Fiber from the abaca banana plant has advantages compared to fiber from other types of banana plant because its mechanical properties are superior to banana fiber in general. The part of the abaca banana plant harvested is the false stem. Starting from 2014, Bank Indonesia (BI) is more serious about using domestic cotton and abaca fiber raw materials. The country that is the

largest producer of abaca fiber is the Philippines, with a production capacity of 57,000 tons, and the second position is occupied by Ecuador, with a production of 10,000 tons. The Philippines export abaca fiber to Europe, Japan and the USA in pulp form (FAO, 2020). Opportunities for developing abaca plantations in Indonesia are currently increasingly open considering the open international market opportunities, especially the markets of Japan, the United States and European countries. The international market potential is recorded at 600,000 tons of abaca fiber per year.

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The increasing demand for abaca fiber, coupled with the limited availability of land for abaca cultivation, presents a challenge that necessitates innovative solutions. Cultivating abaca under teak stands emerges as a viable alternative, particularly in regions of Indonesia where abaca farming remains relatively uncommon. This approach is expected to contribute positively to the local economy by providing improved economic opportunities for farmers. The cultivation of abaca plants that has been widely implemented in Indonesia is using an agroforestry system with various considerations, especially the limited cultivation area. Abaca plants, which are not primary commodities, only have the opportunity to be cultivated in a mixed plantation model together with other commodities, including forestry stands. Several factors that need to be considered in an agroforestry system are the type of commodity cultivated, root structure, habitat, and plant responses to the environmental factors, such as water, light, nutrients, CO₂, temperature and humidity.

Jose (2012) states that agroforestry is a system of combined planting patterns between forestry plants and agricultural plants, with the aim of preserving economic, ecological and social benefits. Biodiversity is one of the benchmarks for ecological sustainability in an agroforestry system. Abaca banana cultivation is often carried out using an agroforestry system. It is thought that abaca plants, with the C3 photosynthesis pathway, are also quite resistant to shade, so they are in line with development plans, which are more focused on agroforestry. However, information relating to the performance of abaca plants when cultivated using an agroforestry model is currently still not available. Considering this, this research is focused on evaluating the physiological, morphological and yield performance of abaca plants cultivated in the middle and advanced phases of teak-based agroforestry. This research is expected to be able to determine the physiological, morphological and yield performance of abaca plants when cultivated in the middle and advanced phases of teak-based agroforestry.

It is previously stated that the abaca-teak-agroforestry model has not been widely implemented in Indonesia. This research aimed to examine the physiological, morphological and yield performance of abaca plants managed in teak-based agroforestry system. The results of the research can provide information on whether the physiological, morphological and yield performance of abaca can be as expected

when cultivated in the middle and advanced phases of teak-based agroforestry. Differences found in the physiological, morphological and yield performance of abaca between teak-based agroforestry phases can also provide recommendations to determine which teak-based agroforestry phase is more recommended for abaca cultivation.

MATERIALS AND METHODS

Field research was carried out from December 2022 to April 2023 in the Special Purpose Forest Area (KHDTK) Ngawi Regency, East Java Province. Observations of plant physiological traits were carried out at the Plant Production Management Laboratory, Department of Agricultural Cultivation, Faculty of Agriculture, Universitas Gadjah Mada, and laboratory analysis related to plant tissue samples was carried out at the Soil Laboratory, Department of Soil Science, Faculty of Agriculture, Universitas Gadjah Mada. The tools used in this research include raffia rope, wooden stakes, tape measure, price altimeter, centrifuge, telescopic measuring stick, test tube, micropipette, spectrophotometer, photosynthetic analyzer, lux meter, SPAD 502, digital scales, oven, mortar, machine decortication or hammer mill, stationery, and others. The materials used in this research were plant samples from the abaca banana plantation in KHDTK, Ngawi Regency, East Java Province.

The abaca banana seeds were planted with a planting distance of 1.5 m x 1.5 m between shade plants or 3 m x 3 m between abaca plants. Fertilization was applied by spreading manure and urea around the planting holes. In the middle phase of teak-based agroforestry system, abaca plants were intercropped with young teak trees aged four years, along with multipurpose tree species (MPTS), such as fruit trees and leguminous plants. In the advanced phase of teak-based agroforestry system, abaca plants were intercropped with mature teak trees aged 20 years, using the same planting distances. The abaca plants in both systems were of uniform variety and age and managed using standardized cultivation practices. The treatment and maintenance given to the abaca plants in the middle and advanced phases of teak-based agroforestry were the same, in which they were allowed to grow without any input during the growth period. The types of vegetation that

make up the teak-based agroforestry pattern planting, both in the middle and advanced phases, initially have a neat pattern, but due to several reasons, for example, some plants cannot survive, and farmers must harvest several types as needed, resulting in random vegetation.

Samples of abaca banana plants in each middle and advanced phase of teak-based agroforestry were collected to identify their physiological, morphological and yield characteristics. The two study locations were then each divided into three clusters (as replications), resulting in six clusters. Samples of abaca banana plants were collected from all existing clusters, with three stands per cluster. Thus, this research used a total of 18 samples of abaca plants. Each cluster located in the middle and advanced phase of teak-based agroforestry uses a plot of 12.5 m x 12.5 m.

Observational variables observed in this research include microclimate, such as air temperature and humidity measured using a thermo-hygrometer, light intensity measured using a light meter, and rainfall data obtained from the East Java Meteorological Agency (BMKG). Chlorophyll content was analyzed using a spectrophotometer at wavelengths of 663 and 645 nm, and plant nutrient analysis was conducted using destructive and extraction methods. Plant morphological characteristics observed include plant height measured from the base to the tip of the tallest leaf, pseudo-stem circumference measured at chest height using a measuring tape, the number of leaves determined by counting all leaves per plant, and the number of suckers recorded by counting new shoots around the main plant. Yield components, including the number of layers and pseudo-stem fresh weight were measured at harvest by counting the layers and weighing the pseudo-stem, respectively. Fresh fiber weight was measured after sheath destruction, while dry fiber weight was determined after air-drying for 6 hours/day over 7 days, followed by oven-drying at 60–80°C for 6 hours/day over 3 days.

The data on microclimate characteristics, nutrients, physiology, growth and yield of abaca plants obtained were then analyzed for variance (ANOVA) at α 0.05 based on a nested environmental design. Significant differences between treatments were then tested using the HSD-Tukey mean comparison test at α 0.05. To determine variables that have a direct or indirect effect on fiber yields, cross analysis (path analysis) was used. All data analysis was carried out using Microsoft Excel and R-Studio software.

RESULTS AND DISCUSSION

Microclimate data consist of air temperature, air humidity and light intensity, which were measured once a month during the research and recorded 3 times during the day with a time range of 11.00 - 13.00 WIB. The average microclimate data in this study can be seen in Table 1. Data on the average value of microclimate in abaca-teak agroecosystems can be seen in Table 1. According to Moreno and Gapasin (2017), the growing requirements for abaca plants will be optimal when air humidity is in the range of 78-88% and air temperature of 26-30°C. In the middle phase of abaca-teak agroforestry, the average temperature and humidity are closer to the growth requirements than in the advanced phase. Middle phase of abaca-teak agroforestry has constituent components consisting of various vegetation that have a canopy as land cover, and there is no thinning process, thereby resulting in higher air humidity, whereas in advanced phase of abaca-teak agroforestry, there are few vegetation constituent components, and there is a thinning process of teak plants that cause reduced shade, thereby resulting in low air humidity and high air temperature.

Sunlight intensity was measured under teak trees in the four agroecosystems. Based on Table 1, it shows that the highest average value was in the middle phase of agroforestry at 39,972.49 lux,

Table 1. Mean of Microclimate Values

Treatment	Temperature (°C)	Humidity (%)	Light Intensity (Lux)	Light Effect (%)
Abaca Agroforestry Advanced phase	33.46 a	61.47 c	34,081.15 a	64.39 a
Monoculture of 20 Year Old Trees	32.61 a	60.55 c	6,788.40 c	36.86 c
Monoculture of 4 Year Old Trees	32.65 a	68.52 a	26,000.41 b	68.02 a
Abaca Agroforestry Middle phase	31.89 a	64.47 b	39,972.49 a	48.03 b
CV (%)	1.48	1.04	6.71	4.93

Note: the means in column followed by the same letter are not significantly different according to the Tukey α 5% test.

Table 2. Macro Nutrient Uptake of Abaca Plant Tissues in Middle and Advanced Phase Abaca Agroforestry Planting Patterns

Treatment	N (kg/ha)	P (kg/ha)	K (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	S (kg/ha)
Abaca Agroforestry Middle phase	55.57 a	5.67 a	55.88 a	3.67 a	1.97 a	33.96 a
Abaca Agroforestry Advanced Phase	13.29 b	1.07 b	15.91 b	1.77 b	0.54 b	11.36 b
CV (%)	7.84	29.44	17.14	13.70	8.75	13.54

Note: the means in column followed by the same letter are not significantly different according to the Tukey α 5% test.

which showed that the results were not significantly different from the advanced phase of agroforestry at 34,081.15 lux, but showed significantly different results from 4-year-old teak trees monoculture and 20-year-old teak trees monoculture. The lowest light intensity was found in 20-year-old teak trees monoculture. The high and low intensity of light can be influenced by the size of the tree, the size of the plant canopy, the direction the light comes from, and weather conditions. According to Tando (2019), only a portion of the sunlight reaches the earth, and some of it is filtered by atmospheric components, broken or scattered by clouds and layers of dust, so that the movement of clouds also influences the intensity of sunlight.

The highest light permeability was found in 20-year-old teak monoculture at 68.02%, which did not show any significant difference compared to that in the advanced phase of abaca-teak agroforestry at 64.39%, followed by light permeability in the middle phase of abaca-teak agroforestry and 4-year-old teak monoculture at 48.03% and 36.86%, respectively. When compared between agroforestry treatments, light exposure in the advanced phase of abaca-teak agroforestry showed significantly different results from that in the middle phase. Light exposure is the difference between radiation that reaches above the plant canopy and radiation that passes below the plant canopy (Mubarak and June, 2018). The intensity of light reaching the plant canopy will decrease in each leaf layer so that some of the radiation will be blocked. The intensity value varies according to the radiation above the plant canopy. The size of the tall shade tree is accompanied by a fuller canopy condition. As the area of the shade of the shade leaf increases, more light will be intercepted by the shade tree, and the plants under it will be damaged (Jia et al., 2021). Shaded environments with reduced light intensity tend to have lower air and leaf temperatures and higher relative humidity, whereas full-sun conditions with higher light intensity are associated with increased

temperatures and reduced humidity.

Jayebaskaran et al. (2021) state that the leaf tissue can represent nutrient uptake in banana plants from 9 days after planting to 360 days after planting. In this study, the uptake of macro and micro nutrients through the roots, pseudo-stem and leaves generally showed the same results, in which the highest nutrient uptake in banana plants occurred in the budding phase or 270 days after planting. In addition, the leaves serve as the plant's source and sink organs. The roots provide the sink, and the leaves can also serve as the source of photosynthesis results and microelement fertilization. This makes using leaves as a nutrient uptake sample representative for analysis.

Table 2 provides information related to nutrient (N, P, K, Ca, Mg and S) uptake of the plant tissues in the middle and advanced phases of abaca-teak agroforestry. The results of the statistical analysis in the table provide information that all macro nutrient uptake, namely N, P, K, Ca, Mg and S, is significantly influenced by cropping system. Abaca plants in the middle phase of abaca-teak agroforestry shows significantly higher nutrient uptake compared to those in the advanced phase of abaca-teak agroforestry. Plant nutrient uptake is the amount of nutrients absorbed by plants, consisting of macro and micro elements. The factor that influences the level of nutrient uptake in plants is the availability of nutrients in the soil. High nutrient availability in plants can increase plant resistance from plant pest organisms through optimizing nutrient uptake, increasing metabolism in plants, and forming elicitors (Gupta et al., 2017). Research by Bande et al. (2016) reported that the availability of nutrients in abaca cultivation land under plant stands was sufficient for plant growth. The differences in nutrient uptake are related to land management in previous cultivation and different types of agroecosystems. Nutrients uptake in abaca during vegetative growth and flag leaf development is affected by cultivation management, such as shading, irrigation, and NPK fertilization. Improved leaf formation enhances

Table 3. Micro Nutrient Uptake of Abaca Plant Tissues in Middle and Advanced Phase Abaca Agroforestry Planting Patterns

Treatment	Fe (g/ha)	Mn (g/ha)	Cu (g/ha)	Zn (g/ha)	B (g/ha)	Cl (g/ha)
Abaca Agroforestry Middle phase	0.39 a	2.37 a	285.29 a	509.74 a	7007.61 a	13.62 a
Abaca Agroforestry Advanced Phase	0.13 b	0.14 b	100.62 b	141.74 b	1828.16 b	3.25 b
CV (%)	8.51	1.66	29.54	10.06	30.26	22.47

Note: the means in column followed by the same letter are not significantly different according to the Tukey α 5% test.

photosynthetic efficiency, leading to greater assimilate accumulation and nutrient uptake, ultimately resulting in higher yield.

The highest average total N uptake was found in the middle phase of abaca-teak agroforestry at 55.57 kg/ha, which was significantly different from the total N uptake in the advanced phase of abaca-teak agroforestry at 13.29 kg/ha. Apart from the N element, which plays a role in the photosynthesis process, the P element also has a role related to photosynthesis in the formation of important parts of phosphate sugar and other metabolic processes. High total P uptake was found in the middle phase of abaca-teak agroforestry, with an average total P uptake of 5.67 kg/ha, which was significantly higher than that in the advanced phase of abaca-teak agroforestry, with an average value of 1.07 kg/ha. In the plant growth process, P element has an important role in the preparation of ATP, ADP, nucleoproteins, phospholipids and enzyme components (Singh et al., 2021).

K element in abaca plants has an important role related to the formation of fiber quality. The average percentage of high K element uptake was found in the middle phase of abaca-teak agroforestry, namely 55.88 kg/ha, which was significantly higher than that in the advanced phase of abaca-teak agroforestry, namely 15.91 kg/ha. In research by Yang et al. (2016), the lack of K in cotton plants has an influence on the accumulation of cellulose in the fiber. Besides, low potassium can cause irregular fiber development and difficult distribution of carbohydrates. K element also helps the process of photosynthesis and sugar translocation, increases the tolerance level of plants in stressful conditions and helps in cell division and cell development in fruit formation.

Calcium (Ca) uptake was significantly higher in the middle phase of abaca-teak agroforestry, namely 3.67 kg/ha, compared to the that in the advanced phase of abaca-teak agroforestry, which was 1.77 kg/ha. Ca⁺ element is an important element to support the process of plant growth and development. This

element has two main functions, namely as a structural component of cell walls and membranes and as a carrier of external signals that cannot penetrate the cell membrane. Low availability of Ca⁺ elements in plants will weaken cell walls, making plants more susceptible to stress (Bascom et al., 2018). Adequate Ca⁺ in abaca plants can prevent errors in the translation of plant signals so that there is no delay in response between cells and tissues.

The total Mg nutrient uptake in the middle phase of abaca-teak agroforestry (1.97 kg/ha) was significantly higher compared to that in the advanced phase of abaca-teak agroforestry (0.54 kg/ha). Low amount of Mg in banana plants has an impact on the accumulation of dry matter in the roots and shoots, with the implication that Mg in banana plants is an element that does not move to other places and is not allocated to organs (Chen and Fan, 2018). Mg has a contributing role in the photosynthesis process and translocation of the results of photo-assimilates. A lack of Mg in plants can have an impact on the response of anatomical, physiological and biochemical interactions related to the lack of carbon assimilation from the photosynthesis process, thereby causing excessive ROS production in plants causing plants to experience stress (Trankner et al., 2018).

Sulfur is an essential nutrient in plant growth and development. The results of tissue nutrient analysis showed that sulfur (S) uptake in the middle phase of abaca-teak agroforestry was significantly higher (33.96 kg/ha) than that in the advanced phase of abaca-teak agroforestry (11.36 kg/ha). Sulfur nutrient plays a role in the process of forming amino acids as the basic material for forming proteins (Narayan et al., 2022). Besides, sulfur element plays a role in the formation of chlorophyll so that it can help in the process of plant photosynthesis (Mustikawati et al., 2020). Banana plantations that were given 9 g of S fertilizer per banana tree with application twice, namely at planting and 165 days after planting, showed a good response in terms of plant height,

stem circumference and faster harvest time compared to without the addition of S fertilizer (Chaure et al., 2012).

Based on Table 3, the uptake of Fe, Mn, Cu, Zn, B and Cl elements in abaca plants in the middle phase of abaca-teak agroforestry shows high values that are significantly different compared to those in abaca plants in the advanced phase. Mo uptake was not found in either middle phase or advanced phase of abaca-teak agroforestry. The process of absorbing nutrients through roots begins with the availability of nutrients in the form of ions that are dissolved in soil water and available to plants. The mechanism for transferring nutrients from the soil solution to the roots can be through root interception, diffusion or mass flow (Naeem et al., 2017).

The uptake of the Fe nutrient in the middle phase of abaca-teak agroforestry had a high value, namely 0.39kg/ha, which was significantly different from that in the advanced phase of abaca-teak agroforestry, namely 0.13kg/ha. Fe has an important role in determining the level of greenness in plant leaves. According to Li et al. (2021), low amounts of Fe in plants can cause chlorosis in the leaves and reduce chlorophyll levels, whereas when the Fe element is high in plants, the color of the leaves is dark green, which is related to the high chlorophyll content and chloroplast size. This element also has a role as an enzyme cofactor in plants (Ria and Marhento, 2021).

The uptake of the Mn nutrient in the middle phase of abaca-teak agroforestry had a high value of 2.37kg/ha and was significantly different from that in the advanced phase, namely 0.14kg/ha. Manganese (Mn) is needed by plants in small amounts, but has a crucial function in plant growth and development. According to Alejandro et al. (2020), Mn element in plants plays a role in helping photosynthesis, respiration, reducing ROS, the defense system against pathogens and plays a role in hormone signaling in plants.

Cu nutrient uptake of abaca plants in the middle phase of abaca-teak agroforestry was significantly higher (285.29g/ha) than that in the advanced phase (100.62g/ha). Copper (Cu) is a heavy metal that can cause toxic effects on plants if it is available in large quantities, but if it is found in amounts that suit the plant's needs, copper can play a role in helping the growth and development process. Approximately, 50% of the copper in plant cells is located in the chloroplasts, which helps in the process of electron

transport during photosynthesis, so a deficiency of the element Cu can lead to leaf chlorosis and necrosis, and in cases of acute deficiency, it can cause the apical meristem to die and prevent lateral growth (Waters and Ambrust, 2013).

Zn nutrient uptake of abaca plants in the middle phase of abaca-teak agroforestry was significantly higher (509.74g/ha) than that in the advanced phase (141.74g/ha). Zinc (Zn) is needed in small amounts, but has an important role for the plant. Zn has an important role in protein synthesis, activator of enzymes in photosynthesis and chlorophyll biosynthesis (Xi-Wen et al., 2011). Thus, it is necessary to fulfill the needs of Zn element for plants because it can influence plant activities in producing biomass and production in terms of quality and quantity.

B nutrient uptake of abaca plants in the middle phase of abaca-teak agroforestry showed a high value of 7007.61g/ha, which was significantly higher than that in the advanced phase, with a value of 1828.16g/ha. Boron (B) in plants is a nutrient that cannot move within the plant and mostly located in leaf tissue and. B element is very much needed when young plants are growing because it has an important role in helping cell division and cell elongation, so boron needs must be met (Dell, 1997). Boron deficiency can affect the emergence of ROS, which will reduce ascorbic acid and glutathione metabolism in plants (Gupta and Solanki, 2013).

Cl nutrient uptake of abaca plants in the middle phase of abaca-teak agroforestry showed high value of 13.62g/ha, which was significantly higher than that in the advanced phase, with a value of 3.25g/ha. Chlorine (Cl) element in plants will help maintain osmotic pressure, water content and tissue cell turgor in plants, so that plants will be more tolerant of water shortages (Franco-Navarro et al., 2021). Indirectly, as an osmo-regulator in plants, chlorine can maintain production results when there is a water shortage and improve and increase plant production results when conditions are not stressful.

The high uptake of both macro and micro nutrients in plant tissues indicates the presence of nutrients that can support optimal plant growth, and this is found in abaca plants cultivated in the middle phase of abaca-teak agroforestry but not in abaca plants managed in the advanced phase. The teak root systems in the middle phase are still developing, so that root competition between teak and abaca (*Musa textilis*) is relatively low, allowing abaca to absorb more nutrients

Table 4. Morphological Characteristics of Abaca Plants in Middle and Advanced Phases of Agroforestry

Treatment	Height (cm)	Pseudostem Length (cm)	Circumference (cm)	Number of Cubs	Number of Leaves
Abaca Agroforestry Middle phase	243.56 a	145.22 a	20.67 a	7.06 a	4.33 a
Abaca Agroforestry Advanced Phase	133.45 b	83.44 a	12.86 b	2.00 b	4.33 a
CV	10.11	18.92	4.21	30.43	33.31

Note: the means in column followed by the same letter are not significantly different according to the Tukey α 5% test.

from the topsoil. Teak roots in the advanced phase are well-developed, absorbing nutrients from both deeper and surface soil layers. This results in greater nutrient competition with abaca. Optimal plant growth and development produces healthy plants resulting in maximum biomass production. Nutrient uptake in plants is related to the nutrient content in the soil. Some elements show high nutrient uptake even though the soil nutrient content is low. This can happen because these plants have the ability to absorb nutrients more effectively so that their nutrient uptake capacity is high despite its low availability in the soil. Low nutrient content in soil indicates that the soil requires additional fertilization to be able to support and provide nutrient needs to produce maximum plant productivity.

According to Table 4, the abaca plant height in the middle phase of abaca-teak agroforestry was 243.56 cm, which was significantly higher form that in the advanced phase, which was 133.56 cm. The height of abaca plants is influenced by internal factors , such as genetics, and external factors, such as the growing environment. According to Secretaria et al. (2012), the abaca variety of Tangongon was able to reach a pseudo-stem length of 3.3 m.

Furthermore, the results of morphological analysis in the form of abaca pseudo-stem length showed that there were no significant differences in the two agroforestry treatments. The length of the pseudo-stem is related to the height of the plant, the taller the plant, the longer of the pseudo-stem. It can be seen that although the results do not show significant differences, where abaca plants in the middle phase of abaca-teak agroforestry had longer pseudo-stems compared to those in the advanced phase. Factors that support vegetative growth are an appropriate growing environment and proper management to obtain optimal growth. Potassium plays a crucial role in fiber quality formation in abaca. The highest average K uptake was observed in the middle phase abaca-teak agroforestry (55.88 kg/ha), which was

significantly higher than that in the advanced phase (15.91 kg/ha). According to Job et al. (2019), the application of potassium to abaca cultivation land can provide a direct role in increasing the strength of the plant pseudo-stem.

The apparent stem circumference in abaca were the highest in the middle phase of abaca-teak agroforestry, namely 20.67 cm and significantly different from that in the advanced phase, namely 12.86 cm. The size of the plant's circumference is influenced by the available nutrients. According to Uthbah et al. (2017), the circumference of a plant stem increases as the age of a plant increases, and there is sufficient energy supply for plant growth. The energy supply obtained can come from the roots in the form of nutrients and from the leaves in the form of photosynthesis results.

Based on the results of the morphological analysis, the number of suckers was significantly higher in the middle phase of abaca-teak agroforestry, namely 7.06, compared to that in the advanced phase, which was only 2.00. The number of suckers in banana is influenced by internal and external factors. External factors that influence the number of suckers are planting season, planting distance and planting depth (Bendhe and Kurien, 2016). The depth of planting is related to the ability of the roots to grow and elongate, where, it is known that the thickness of the solum in the middle phase of abaca-teak agroforestry is deeper than that in advanced agroforestry, so it is more supportive for the roots to grow and develop, and new suckers on the parent tree will easily form.

There was no significant difference in the number of leaves across all treatments. Growth and development of abaca plants is influenced by genetic factors, so that selecting healthy seeds can be done to optimize plant growth and development, as well as environmental factors, such as the availability of water, light, nutrition for plants and appropriate management.

Table 5. Yield Characteristics of Abaca Plants in Middle and Advanced Phases of Agroforestry

Treatment	Total Foliage	Midrib Weight (g)	Fiber Fresh Weight (g)	Fiber Dry Weight (g)
Abaca Agroforestry Middle phase	9.33 a	3582.56 a	449.22 a	189.33 a
Abaca Agroforestry Advanced Phase	5.00 b	625.67 b	95.56 b	68.66 b
CV	9.04	5.29	12.72	9.85

Note: the means in column followed by the same letter are not significantly different according to the Tukey α 5% test.

Based on the results of morphological observations, it was found that the middle phase of abaca-teak agroforestry treatment had a response that tended to be better than the advanced phase, which can be seen from most of the morphological variables, namely height, circumference and number of suckers. This can be influenced by the growing environment that supports abaca plants. Research by Bande et al. (2013) reported that providing shade-free treatment to abaca plants resulted in the plant height of 299.75 cm, pseudo-stem length of 142.63 cm, circumference of 13.18 cm, number of leaves of 6.38, and number of suckers of 11.81, size This can increase with increasing amount of shade provided (Bande et al., 2013). According to Handriawan et al. (2017), providing shade can affect the height of soybean plants, which are C3 plants. In the growing environment with middle phase of abaca-teak agroforestry, several types of vegetation were found to have dense canopies, so that the shade that comes from the plant canopy can have a positive impact on the morphology of the abaca plants. The abaca with a large plant circumference, large number of suckers, number of banana leaves, pseudo-stem length and tall plant will increase the amount of abaca fiber (from pseudo-stem) compared to banana plants with smaller and shorter circumference.

Plant fiber production is determined by vegetative growth, which is because the part used as fiber is the vegetative part, not the generative part. Based on the results of the analysis in Table 5, the highest number of leaves was found in the middle phase of abaca-teak agroforestry, which was 9.33 per plant, showing significant different results compared to that in the advanced phase, namely 5 per plant. The number of leaves is positively correlated with pseudo-stem fresh weight, fiber fresh weight, and dry fiber yield (Mostafa, 2021). The circumference of the false stem is closely related to the number of leaves. Pseudo-stem consists of a large number of leaves, in which there is a transport flow or mineral

pathway from the root system to the leaves (Armecin & Gabon, 2008). Increasing the circumference and maximum height of the pseudo-stem increases the number of leaves, the fresh weight of the leaves, the fiber fresh weight, and the fiber dry weight. The nutrients available in the soil can also influence the growth of abaca plants and their fiber production.

The fresh weight of abaca leaves in the middle phase of abaca-teak agroforestry was significantly higher, namely 3582.56 g/plant, compared to that in the advanced phase, which was 625.67 g/plant. Significant differences were also found in the fresh and dry weight of abaca fiber. According to research by Secretaria et al. (2012), abaca plants variety of Tangongon planted under agroforestry stands showed a banana stem weight reaching 25.4 kg/plant. Abaca plants are a group of herbaceous plants that have stems in the form of stacked leaf sheaths and contain a lot of water (Ryan and Pigai, 2020). Banana stems contain a lot of water, so their fresh weight is high. Fresh weight is one of the parameters in plant growth studies. Calculating fresh weight is useful for determining plant growth rate. The larger the stem produced, the more fresh fiber produced (Zulkifli et al., 2022). The high fresh weight of fiber also influences the dry weight of fiber. High shading levels reduce the photosynthetic activity of abaca plants, leading to decreased biomass accumulation, which in turn affects both the fresh and dry weight of abaca fiber.

The fresh weight of abaca fiber in the middle phase of abaca-teak agroforestry was significantly higher, namely 449.22 g/plant, compared to that in the advanced phase, which was 95.56 g/plant. The number of leaves is positively correlated with pseudo-stem fresh weight, fiber fresh weight, and fiber dry weight (Mostafa, 2021). Based on this statement, there is a relationship between the fresh weight of abaca fiber and the number of leaves, which are interrelated, so that to produce fresh weight of abaca fiber, it is necessary to apply appropriate

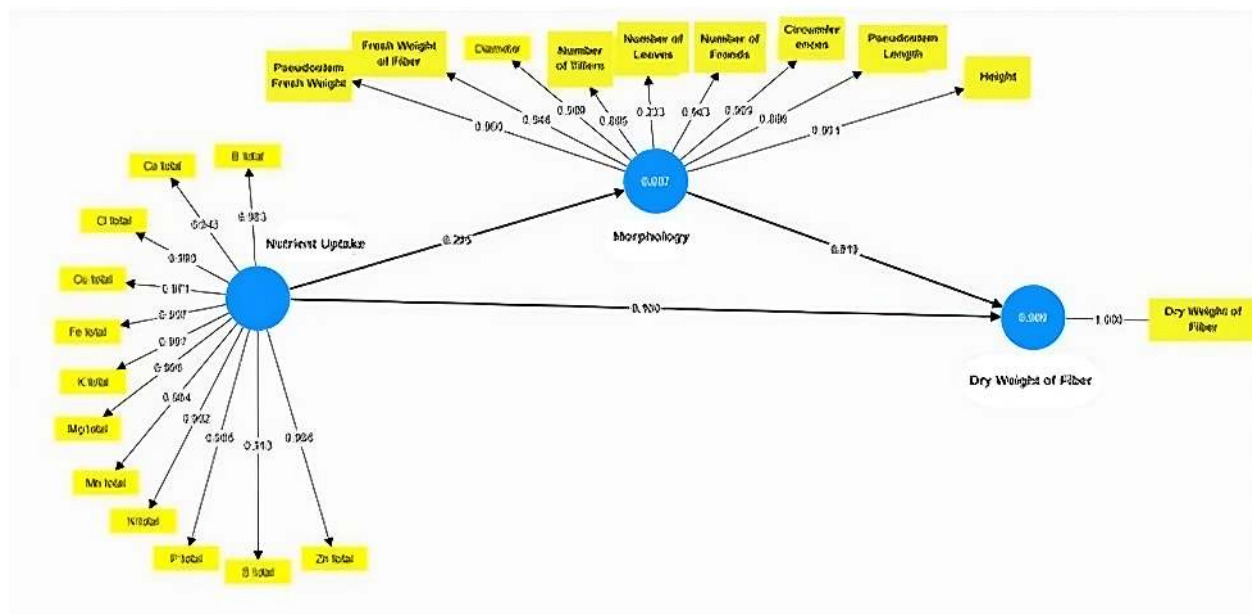


Figure 1. Path Analysis Results

cultivation methods to obtain maximum abaca fiber in terms of quality and quantity. Dry weight is the weight of the plant after harvest in dry condition or in the state of water loss. The dry weight of fiber is obtained from fiber that has been dried with the help of wind and sun for 7 days followed by oven for 3 days each with a duration of 6 hours/day. The dry weight of abaca fiber in the middle phase of abaca-teak agroforestry was significantly higher, namely $189.33 \text{ g.plant}^{-1}$, compared to that in the advanced phase, namely 68.66 g/plant . Bande et al. (2013) reported that the dry weight of abaca plant fiber grown without shade could reach a dry weight of 50 g.plant^{-1} and reached 120 g/plant with 50% shade. Secretaria et al. (2012) showed that abaca plants variety of Tangongon planted under coconut agroforestry stands produced a fiber dry weight of 587 g.plant^{-1} .

Abaca planting carried out in the Lower Odiong region, Javier, Philippines with a planting period of 2 years using an abaca monoculture planting system resulted in plant biomass reaching $33.2 \text{ tons.ha}^{-1}$ and fiber of $1.20 \text{ tons.ha}^{-1}$ (Armecin et al., 2011). The Philippine National Standard (2019) also stated that the potential yield of dry abaca fiber was 1.5 tons.ha^{-1} . Abaca plant biomass obtained in the middle phase of abaca-teak agroforestry in KHDTK Ngawi land with a harvesting period of 2.5 years produced an estimated biomass yield of 24.2

tons.ha^{-1} and potential dry fiber yields of $0.21 \text{ tons.ha}^{-1}$, while that in the advanced phase produced an estimated biomass yield of 6.5 tons.ha^{-1} and potential dry fiber yield of 0.07 tons/ha . It can be said that the results obtained from planting abaca under teak stands in KHDTK Ngawi land, especially in the middle phase, have values that are closer to the results of abaca in monoculture land. The polyculture cropping system, especially teak-based agroforestry with appropriate age and intensity, is expected to prevent competition for nutrients and water between plants so that optimal production results can be obtained from the two commodities being cultivated.

The agroforestry system implemented in forest areas is also expected to be able to support the provision of food for forest area communities through land intensification efforts under forest plant stands with minimal input. Implementation of an agricultural cropping system with trees can produce several benefits obtained from the agroforestry planting system, including providing wood, fuel, food sources, managing biodiversity, restoring soil quality, and having an important role in carbon sequestration (Sarkar et al., 2020).

The results of the path analysis of abaca nutrient absorption, morphology, and fiber dry weight can be seen in Figure 1. In general, nutrient uptake from abaca plant leaves has an indirect effect on the dry weight of the fiber, but has a direct influence on the

morphology of the abaca plant. The morphology of the abaca plant has a direct influence on the dry weight of the fiber, which in this case, the morphology of the plant in the form of plant height, plant stem circumference and the number of leaves will influence the dry weight of the fiber. Plants that are taller and have a larger stem circumference will affect the yield of abaca plant fiber. Nutrients absorbed by plants will be expressed through plant morphology, which can be seen visually as an indicator of plant growth. This is supported by Rahate et al., (2020), mentioning that nutrient management can influence the height of the banana plant, the circumference of the banana plant stem, the number of banana plant leaves, the height of the stem, and the number of banana plant suckers.

CONCLUSIONS

The study demonstrates that abaca cultivation under teak-based agroforestry is feasible in both middle and advanced stand phases at the KHDTK Ngawi site, with the middle phase offering more favorable microclimatic condition characterized by higher humidity and lower temperature due to a multistrata canopy and greater plant diversity. Although soil organic carbon and moisture were higher in the advanced phase, nutrient uptake, physiological performance, and yield components of abaca were significantly better in the middle phase. Morphological traits such as plant height, pseudostem girth, and number of tiller, along with fiber yield parameters, showed notable improvements in the middle phase. Path analysis revealed that leaf nutrient uptake indirectly influenced fiber dry weight through its direct impact on plant morphology, which in turn directly affected fiber yield. Overall, the middle phase of teak-based agroforestry provides a more suitable environment for optimizing abaca growth and productivity.

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