

Morpho-Physiological Characters and Soybean Productivity on Alfisol and Vertisol under Intercropping with *Kayu Putih (Melaleuca cajuputi)*

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ABSTRACT

Soybean was intercropped with *kayu putih* because soybean has higher commercial value than other field crops. The survey-based research was conducted during March-May 2014 in Menggoran Forest Resort, Playen Forest Section, Yogyakarta Forest Management District. Stratified random sampling method was used during the research by stratifying the types of soil stratification, rainfall and declivity then was made into 7 land mapping unit (LMU) with map overlay technique. Agronomic characters of soybean were observed at 12 weeks after planting (wap) and the physiological data were observed during the maximum vegetative phase (8 wap). Agronomic and physiological characters of soybean in each LMU were grouped and statistically tested with analysis of variance then continued with orthogonal kontras (alpha 5 %). The results showed that some characters of soybean planted on alfisol had higher value than on vertisol, especially on leaf area, photosynthetic rate, root and canopy weight, 100 grain weight and grain weight per plant. The agronomic and physiological characters of soybean which had significant effects on yield in the intercropping with *kayu putih* system were stomatal density, stomatal conductivity, photosynthetic rate, and leaf area. Soybean intercropped with *kayu putih* produced 1.007 t ha⁻¹ in alfisol and 0.996 t ha⁻¹ in vertisol.

Keywords: intercropping; *kayu putih*; morpho-physiological; productivity; soybean

INTRODUCTION

Intercropping is agroforestry sub-system known as taungya system (Nair, 1993). It is a soil management technique combining tree and

annual plant components in similar space and time. Intercropping is one of the forestry programs to maintain food security of the community around the forest. Forest as the life supporting system has the ability to support food availability.

Forest is a natural supermarket for the poorest one-billion world population. Forest provides nuts, berries, tubers, meat, and fuel for cooking, complementing food crop farming and also providing essential nutrients that may not be available without the forest (Arnold, Powell, Shanley, & Sunderland, 2011). Food from the forest is composed of vegetable protein such as rice, maize, beans, tubers and fruits; as well as the animal protein in the form of forest animals' meat (Kementerian Kehutanan, 2009). Intercropping on *kayu putih* forests in the context of food security is an important part of the forest movement for food.

The forest contribution for food production (forest for food production) is in line with Presidential Decree No. 83 of 2006 on Food Security Council, whereby the Ministry of Forestry is one sector that is partially responsible for food security. The food availability derived from forests is obtained by direct use of germplasm of flora and fauna for the fulfillment of food and housing requirements (Kementerian Kehutanan, 2010). According to the Kementerian Kehutanan (2010), in 2008 the forest areas that have contributed to the national food supply were more than 312,000 ha with a production of 932,000 t of food over food equivalent of the types of rice, corn and soybeans.

Soybean is the leading commodity in Indonesia's food security which is often faced with constraint in its availability. Soybean production in 2013 amounted to 780.16 thousand ts of dry beans or decreased by 62.99 thousand ts (7.47 percent)

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compared to 2012. This decrease occurred in Java which amounted to 81.69 thousand ts (Statistic Indonesia, 2014). By contrast, production increased by 18.70 thousand ts in outside Java. The decline in soybean production occurs due to a decrease in productivity by 0.69 quintal ha⁻¹ (4.65 percent) and reduction in harvested area of 16.83 thousand ha (2.96 percent). Thus, the existence of forests to contribute to the provision of soya is indispensable, one of which is by intercropping of *kayu putih*.

Intercropping on *kayu putih* plantations has special characteristics as compared to intercropping on other tree forest such as teak, pine, mahogany and acacia. This happens because in a *kayu putih* production forest, harvesting is done by pruning the canopy every year. On this basis then, the intercropping in production forests on *kayu putih* is known as perpetual intercropping. This study aimed to determine the morphological, physiological characters and productivity of soybean in the intercropping system on *kayu putih* plantations.

MATERIALS AND METHODS

This research was conducted in Menggoran Forest Resort (RPH Menggoran), Playen Forest Section (BDH Playen), Yogyakarta Forest Management District (KPH Yogyakarta). This research was done in March-May 2014. This research was a survey research and the method used was stratified random sampling. The bases used in site stratification were rainfall map, declivity, and types of soil on a scale of 1:25000. The rainfall map, declivity, and type of soil are then put into a land mapping unit (LMU) with a map overlay technique, so there were 7 LMU's.

The agronomic characters were observed until 12 weeks after planting (wap) and they comprised the leaf area, the weight of 100 grains, the weight of grain per plant and the weight of grain per hectare. The physiological data observed included the stomatal morphology, chlorophyll content, reductase nitrate activity, proline content, CO₂ content of leaf cell and photosynthetic rate. The physiological data was observed during the maximum vegetative phase (8 wap).

The proline content was observed by determining the leaves whose growth was complete and the youngest using Bates method (Arora & Saradhi, 1995). The proline content was determined with the equation:

$$Pc = Pc \text{ (mg.cm}^{-3}\text{)} \times 0.347 \text{ mol.g}^{-1}$$

Remarks:

Pc : Proline content

Proline content was converted into proline content per plant by multi playing proline level with the plant dry weight.

Chlorophyll content was determined according Harborne (1973) and Gross (1991). Chlorophyll level was counted with the following formula:

a chlorophyll : $-0.00269 \times \lambda 645 + 0.00127 \times \lambda 663$

b chlorophyll : $0.0229 \times \lambda 645 - 0.00468 \times \lambda 663$

Total chlorophyll : $0.0202 \times \lambda 645 + 0.00802 \times \lambda 663$

Observation of the nitrate reductase activity was done with Hageman and Hucklesby modified method (Hartiko, 1983). The nitrate reductase activity (NRA) was with the formula:

$$NRA = \frac{SA}{SA} \times \frac{100}{LFW} \times \frac{1}{IP} \times \frac{50}{100}$$

Remarks:

NRA : Nitrate reduction activities

SA : Sample absorbance

LFW : Leaf fresh weight

IP : Incubation period

Observation of CO₂ content of leaf cell and photosynthetic rate was done with photosynthetic Analyzer type LI Cor LI 6400. Analysis of *kayu putih* structure was carried out by calculation the stand basal area (LBDS) in each LMU. The data on the agronomic and physiological characteristics in each LMU were grouped and tested based on orthogonal contrast of 5 %. The influence of the agronomic and physiological characteristics on the result was determined with a multiple regression analysis.

RESULTS AND DISCUSSION

The soybean analysis provides information that there are significant differences in the type of soil to the leaf area at various times of collection, while the grouping based on rainfall and declivity show no real difference. The leaf area in alfisol soil shows the highest value when compared with that in the vertisol soil (Table 1).

The lower leaf area in vertisol soil is caused by this soil having vertic property. The vertic characters of soil are characterized by having to blow up when waterlogged and shrink when dry. This causes a reversal of the soil. When soil with vertic property wet, it will be very sticky and plastic so that the infiltration is low, but when the soil is dry, it will be very hard and massive and form fissures (van Wambeke, 1992). This will result in a disturbance in the growth of plants.

Table 1. The leaf area of soybean in various comparison groups

Comparison groups	Leaf area (cm ²)		
	4 wap	8 wap	10 wap
Type of soils:			
Alfisol	146.11 a	919.51 a	2054.59 a
Vertisol	144.79 b	910.81 b	2035.74 b
Rain fall:			
2000 mm/year	145.71 a	916.70 a	2048.96 a
<1750 mm/year	144.71 a	910.58 a	2034.13 a
Declivity:			
8 – 15 %	145.76 a	916.93 a	2048.95 a
15 – 25 %	145.34 a	914.49 a	2043.72 a
Average	145.32	914.32	2043.31
CV	1.86	1.87	1.84

Remarks: wap: weeks after planting. The number followed by the letter is the same in comparison groups in each column showing insignificant difference in orthogonal contrast of 5 %

The morphological parameters of stomatal (density, width of opening and conductivity of stomata) show no significant difference in all compared groups (Table 2).

Table 2. The stomatal morphology of soybean in various comparison groups

Comparison groups	The stomatal morphology		
	Density (mm ²)	Width of opening (µm)	Conductivity (mol H ₂ O.m ⁻² .s ⁻¹)
Type of soils:			
Alfisol	199.45 a	2.14 a	0.18 a
Vertisol	203.40 a	2.09 a	0.15 a
Rain fall:			
2000 mm/year	204.14 a	2.10 a	0.16 a
<1750 mm/year	194.85 a	2.14 a	0.17 a
Declivity:			
8 – 15 %	214.10 a	2.06 a	0.13 a
15 – 25 %	198.83 a	2.12 a	0.17 a
Average	201.61	2.11	0.16
CV	3.39	5.74	11.66

Remarks: The number followed by the letter is the same in comparison groups in each column showing insignificant difference in orthogonal contrast of 5 %

The stomatal morphology shows the response of plants to the environment. This is presumably due to the environmental factors such as water and light which are still balanced on each LMU so that the response of plant especially the stomatal morphology is relatively similar. This indicates that in the growing space of annual plants between the *kayu putih* structure there are still available resources both under the ground and above the ground.

The chlorophyll content, either the *a*, *b* or total chlorophyll show no significant difference in each comparison group either in soil, rainfall or declivity comparison group (Table 3). The chlorophyll content, either the *a*, *b* or total chlorophyll shows no significant difference because there are nitrogen and magnesium contents in the soil for the chlorophyll formation as the source of energy both under and above the ground in all the relatively homogenous LMUs.

Table 3. The chlorophyll content (*a*, *b* and total) of soybean in various comparison groups

Comparison groups	The chlorophyll content (mg.g leaf ⁻¹)		
	a chlorophyll	b chlorophyll	Total chlorophyll
Type of soils:			
Alfisol	0.45 a	0.54 a	0.99 a
Vertisol	0.43 a	0.51 a	0.94 a
Rain fall:			
2000 mm/year	0.43 a	0.52 a	0.95 a
<1750 mm/year	0.47 a	0.55 a	1.01 a
Declivity:			
8 – 15%	0.43 a	0.52 a	0.95 a
15 – 25%	0.44 a	0.52 a	0.97 a
Average	0.44	0.52	0.96
CV	4.36	4.57	3.98

Remarks: The number followed by the letter is the same in comparison groups in each column showing insignificant difference in orthogonal contrast of 5 %

Soybean grown on vertisol soil has a higher content of proline when compared to the one on Alfisol soil (Table 4). Proline is one of the amino acids which is widely found in higher plants when drought stress. Drought stress conditions are also known decreasing the fresh weight and dry weight of plant. Limiting water also led to a reduction of CO₂ gas exchange at the leaf surface, which is a major component of the process of photosynthesis. It is then not only limit the size of the source, but also the results of plant section (Barunawati, Maghfoer, Kendarini, & Aini, 2016).

The nitrate reductase activity illustrated how many enzymes contained in soybean plants to reduce the nitrate into nitrite (Issukindarsyah, 2013). At the nitrate reductase activity parameter, it shows no significant difference in each group comparison. That is because the nitrogen nutrient in the soil ranges from LMU 1 to LMU 7 which is relatively balanced. The nitrogen in the soil will help the formation of nitrate reductase enzyme.

Table 4. The nitrate reductase activity and proline content in various comparison groups

Comparison groups	The nitrate reductase activity ($\mu\text{mol}/\text{NO}_2^-/\text{jam}$)	The proline content (ppm)
Type of soils:		
Alfisol	3.57 a	1.21 b
Vertisol	3.61 a	1.27 a
Rain fall:		
2000 mm/year	3.59 a	1.22 b
<1750 mm/year	3.60 a	1.30 a
Declivity:		
8 – 15%	3.58 a	1.21 a
15 – 25%	3.59 a	1.24 a
Average	3.59	1.24
CV	6.15	6.12

Remarks: The number followed by the letter is the same in comparison groups in each column showing insignificant difference in orthogonal contrast of 5 %

CO₂ content in the leaf cell shows no significant difference in all comparisons group (Table 5). The CO₂ content in the leaf cell shows no significant difference in all comparison groups, which is related to the environmental factors such as temperature and solar radiation which are more or less the same in all LMUs in RPH Menggoran.

The photosynthetic flow of soybean plants shows significant differences in comparison group of type of soil (Table 5). Photosynthesis is determined by the incoming radiation, leaf area index, and leaf angle. Besides, photosynthesis is influenced by the availability of water, temperature, age of leaf, the translocation of carbohydrates, and the availability of CO₂ (Gardner, Pearce, & Mitchell, 1991; Salisbury &

Ross, 1992). The products of photosynthesis depend on the difference value between photosynthesis and respiration whereby the limitations on the growth of plant are considered as not occurring if the value is not comparable (Gardner, Pearce, & Mitchell, 1991).

Table 5. CO₂ content in leaf cell and photosynthetic rate of soybean in various comparison groups

Comparison groups	CO ₂ content of leaf cell ($\mu\text{mol CO}_2/\text{mol air}^{-1}$)	Photosynthetic rate ($\mu\text{mol CO}_2/\text{m}^2\cdot\text{s}^{-1}$)
Type of soils:		
Alfisol	268.75 a	182.77 a
Vertisol	265.70 a	181.58 b
Rain fall:		
2000 mm/year	267.37 a	182.45 a
<1750 mm/year	266.34 a	181.24 a
Declivity:		
8 – 15%	263.20 a	183.62 a
15 – 25%	267.95 a	181.79 a
Average	267.09	182.12
CV	4.44	2.37

Remarks: The number followed by the letter is the same in comparison groups in each column showing insignificant difference in orthogonal contrast of 5%

The yield from grains in alfisol soil is higher than that in vertisol soil (Table 6). The alfisol soil shows the higher weight value of 100 grains and the grain weight per plant than one on vertisol soil. The weight of 100 grains shows the amount of photosynthesis results is translocated into the soybean plant grain. Vertisols which had hard soil structure so that plant roots were not able to netrate it well (Sudadi & Suryono, 2015).

Table 6. The weight of 100 grains, the grain weight per plant and weight grain per hectare of soybean in various comparison groups

Comparison groups	The soybean grain weight		
	The weight of 100 grains (gram)	The grain weight per plant (gram)	Weight grain per hectare (t)
Type of soils:			
Alfisol	17.75 a	8.63 a	1.007 a
Vertisol	17.58 b	8.54 b	0.996 b
Rain fall:			
2000 mm/year	17.69 a	8.61 a	1.004 a
<1750 mm/year	17.59 a	8.51 a	0.993 a
Declivity:			
8 – 15%	17.69 a	8.55 a	0.997 a
15 – 25%	17.65 a	8.59 a	1.002 a
Average	17.65	8.57	0.999
CV	1.87	1.84	2.36

Remarks: The number followed by the letter is the same in comparison groups in each column showing insignificant difference in orthogonal contrast of 5%

Based on the multiple regression results, the parameters with significant effect on the grain weight are stomatal density, stomatal conductivity, photosynthesis rate and leaf area (Table 7).

Table 7. The affecting factors to the grain weight based on the multiple regression analysis

Variable	Regression coefficient	Note
Intercept	0.43	ns
Stomata density	0.01	**
Width of stomatal openings	0.16	ns
Stomatal conductivity	1.11	*
CO ₂ content of sel	0.0004	ns
Nitrate reductase activity	-0.002	ns
Proline content	-0.37	ns
Chlorophyll content	0.06	ns
Photosynthetic rate	0.58	*
Leaf area	0.03	**
Dry weight	1.55	ns
Weight of 100 grains	0.04	ns

Remarks: (ns) and (*) show no significant and real difference of 5% and (**) shows the significant difference of 1%

The yield from grains in alfisol soil is higher because the agronomic and physiological characters such as the leaf area, plant dry weight and photosynthetic rate are higher than to those in vertisol soil. The higher agronomic and physiological characters will influence the bigger photosynthates which are translocated into the sink. The larger leaf area will cause bigger stomatal density and conductivity resulting in greater CO₂ diffusion. The higher CO₂ content will increase the photosynthetic rate which will subsequently increase soybean yield.

The condition of *kayu putih* structure in RPH Menggoran shows there is abnormality of structure. This can be seen from the structure density which is not up to the required standard of KPH Yogyakarta, that is 2500 ha⁻¹. The highest *kayu putih* structure density level is LMU 3 (2.492 trees/ha). The lowest *kayu putih* structure density level is LMU 6 (317 trees ha⁻¹). Seen from the LBDS value, LMU 3 has the biggest basic area potential compared to other LMUs, that is 29.271 m²/ha. And, the smallest basic area potential value is in LMU 2 reaching 0.771 m² ha⁻¹ (Table 8). The soybean in the intercropping system of *kayu putih* about 1 t ha⁻¹ gives good results if compared to the intercropping in fertile sites such as in East Java teak forests. The soybean yields grown in the shade of teak forest with level of 5-10% at

KPH Padangan, Bojonegoro, Banyuwangi, Jember and Blitar have productivity of around 1.2 ts ha⁻¹. Meanwhile, in Ngawi KPH, the soybean productivity is 0.7 to 1.1 ts ha⁻¹ (Kementerian Pertanian, 2012). The soybean yield is still lower compared to the soy in monocultures system. According to Sudarsono, Melati, & Aziz (2013) soybean yield with cow manure reaches 2.56 to 3.43 t ha⁻¹.

Table 8. The condition of *kayu putih* structure

LMU	The type of structure	Area (ha)	The structure density (N.ha ⁻¹)	LBDS (m ² .ha ⁻¹)
1	<i>Kayu putih</i>	34	923	8.089
2	<i>Kayu putih</i>	40	328	0.771
3	<i>Kayu putih</i>	44	2.492	29.271
4	<i>Kayu putih</i>	99	1.665	12.197
5	<i>Kayu putih</i>	25	1.513	13.254
6	<i>Kayu putih</i>	19	317	3.426
7	<i>Kayu putih</i>	58	751	4.195

Remarks: LMU: Land Mapping Unit, LBDS: the stand basal area

However, the abnormal condition of the number of *kayu putih* per ha will decrease the productivity of *kayu putih* leaves. The shade factor actually has no effect in the intercropping system of *kayu putih* on the annual plant productivity. This is different from the intercropping in the teak forests which along with the age of trees, it will increase the shade influence so it will decrease the productivity of annual plants. The productivity limiting factor of annual plant in the intercropping systems is light resource (Jose & Gillespie, 1995; Gillespie et al., 2000; Miller & Pallardy, 2001). It is also applicable in alley cropping of agroforestry system in which the light is the dominant factor affecting the productivity (Jose, Gillespie, & Pallardy, 2004; Zamora, Jose, Jones, & Cropper Jr, 2009). Light and soil moisture are the key factors affecting the growth of plants affecting the plant productivity in general (Muraoka, Tang, Koizumi, & Washitani, 2002; Sack, 2004; Aranda, Castro, Pardos, Gil, & Pardos, 2005; Quero, Villar, Marañón, & Zamora, 2006; Feng & Li, 2007).

The site condition in *kayu putih* forests in general as well as in Gunungkidul site is less fertile. Meanwhile, the level of ownership of the land area is very small so that the opportunity for cultivation the annual plants in the forest is very high. On this basis, it will require a renewal scheme of *kayu putih* intercropping which is more promising for the production increase of *kayu putih* leaves as

well as the annual plants. Thus, the existence of intercropping in production forests of *kayu putih* gives powers, especially to the forest communities in the availability of local food. The involvement of forest communities in forest management by intercropping system is part of a forestry program to reduce the poverty (Kementerian Kehutanan, 2010).

Soybean development in intercropping system of *kayu putih* can be conducted by using soybean varieties superior effort, distributing of legume inoculants and pruning (branches, shoots or leaves). This consideration is conducted to increase soybean production without increasing damage to forest classes.

CONCLUSION

The soybean yield in *kayu putih* with the intercropping system on alfisol soil shows a higher value compared to the vertisol soil, at the parameters of leaf area, photosynthetic rate, root and leaf weight, weight of 100 grains and weight grain per plant. The agronomic and physiological characters affecting the soybean yield in *kayu putih* with the intercropping system are the stomatal density, stomatal conductivity, photosynthetic rate and leaf area.

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