Tree and plant interactions in the agroforestry system: does the management of coffee intensification disrupt the soil hydrological system and pine growth?

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Abstract. With increasing population pressure on forests in Perhutani land, coffee industrial plants are integrated in *Pinus merkusii* forests as agroforestry systems in the Community-Based Forest Management program especially in Java. This condition raises the research question (1) whether the growth of pine plants is not affected by the integration of coffee plants with various management?, (2) whether with more intensive management of coffee will be able to improve the growth and production of coffee plants? (3) Does the increasing coffee management will decrease the availability of soil water for coffee plant and pine trees?. This research was conducted with a nested design with one research factor, namely coffee management actions. There are 5 types of coffee management treatment namely (1) no management, (2) coffee with pruning, (3) coffee with laid-down the stems, (4) coffee with pruning and combined with fertilization and (5) reducing a half the pine population, with pruned coffee. The conclusion of this study is that pine growth, which is generally planted as a production forest in Perhutani, will experience a very significant decline if it is converted into a coffee-pine-based agroforestry system. However, as a social function of the forest area, the agroforestry system is still recommended if farmers do coffee treatment with regular pruning and fertilization. Perhutani's recommendation by reducing a half the pine population in the age of 10 years is appropriate to facilitate the interaction of coffee and pine so that water and nutrient competition can be reduced.

Keywords: Coffee-pine agroforestry system, Tree-plant-soil interaction, CBFM, forest production, soil-water.

1. Introduction

Pinus merkusii Jungh. et de Vriese is a type of pine that grows native in the Indonesian region [1]. *Pinus merkusii* can grow at various altitudes, but the best place to grow for this type of pine tree is at an altitude of between 400-2000 above the sea level with an average rainfall of 1,500-3,500 mm per year [2]. Planting of *Pinus merkusii* on forest land was initially used to accelerate reforestation and rehabilitation

of abandoned land in forest areas. This is because *Pinus merkusii* in addition to including the type of fast growing species, this type of pine is a type of pine that does not require special growing conditions so that it is easy to be cultivated. Pine trees have taproots with a root system that is deep and strong enough to grow in deep / thick soil with a light to moderate soil texture and can grow on marginal soil [3]. Especially in Java, with increasing population pressure on forests in Perhutani land, coffee industrial plants are integrated in *Pinus merkusii* forests as agroforestry systems in the Community-Based Forest Management (CBFM) program.

The integration of coffee plants with *Pinus merkusii* in agroforestry systems produces positive or negative interactions between trees and industrial plants. The problem that allegedly occurred in the development of this agroforestry system was the potential competition between coffee plants and pine plants. Land cover and different land management will produce different microclimates on the forest floor. The growth of pine trees is strongly influenced by the combination of balanced and beneficial environmental factors. The environmental factors in question are light, mechanical impedances, nutrients, air, and water. If one environmental factor is not balanced with other factors, these factors can suppress plant growth and there will be competition in the root system between pine trees and coffee plants [4]. Root system of pine trees in general has a deeper penetration into the soil than coffee plants so that coffee plants get access to nutrients that are not optimal [5]. Roots are a means of linking plants to soil, nutrient distribution devices from the absorption site to other organs of the plant, as well as a place for metabolic activities such as respiration, and food storage reserves. The stronger the root in anchoring and gripping the soil, the better the activity at the root. According to [6], assuming that the presence of well-developed roots means that water and nutrient uptake can occur optimally. Root distribution illustrates the distribution of water and nutrient absorption activities. The potential level of water and nutrient absorption will be limited by the number of roots per unit volume of land. With this, root interactions will affect the agroforestry system because there is not only one type of plant root.

The integration of coffee plants with *Pinus merkusii* with a spacing of 3 m x 2 m in its area is inserted with coffee plants in an agroforestry system, with the characteristics of *Pinus merkusii* which is tolerant of marginal soil which is thought not to affect the root system and growth of pine trees, but suppresses the root system and coffee plant growth. For this reason, in an effort to increase coffee production which is expected to increase farmers' income in the CBFM program, the coffee planted is carried out by improving management. Farmers' management in an effort to increase coffee production practiced in UB Forest through (1) medium management with pruning, (2) medium management with laid down the branching of coffee plants, (3) intensive management with pruning and combined with organic and inorganic fertilization. On the other hand, Perhutani's management practice to improve pine growth is carried out with thinning one row of pine after the age of 10 years. The diversity of management in agroforestry systems will lead to different interactions between coffee plants and pine trees. This condition raises the research question (1) whether the growth of pine plants is not affected by the integration of coffee plants with various management?, (2) whether with more intensive management of coffee will be able to improve the growth and production of coffee plants? (3) Does the increasing coffee management will decrease the availability of soil water for coffee plant and pine trees?.

2. Materials and Methods

2.1 Site research

This research was conducted at Andisol, UB Forest land in Sumbersari Village, Karangploso District, Malang Regency. Laboratory work is carried out in the Soil Biology laboratory and Soil Physics laboratory, Faculty of Agriculture, Universitas Brawijaya.

2.2 Research design

This research was conducted with a nested design with one research factor, namely coffee management actions. There are 5 (five) types of coffee management treatment) which are analyzed in this study, namely:

1. 25-year-old pine trees with a tree spacing of 3 m x 2 m + low management : Coffee plants 6 years old are not treated.
2. 25-year-old pine trees with a tree spacing of 3 m x 2 m + medium management : Coffee plants, 6 years old with the treatment of laid down coffee stems.
3. 25-year-old pine trees with a tree spacing of 3 m x 2 m + medium management : Coffee plants 25 years old with the treatment of coffee stems being pruned.
4. 25-year-old pine trees with a plant spacing of 3 m x 2 m + Intensive management : Coffee plants 6 years old with treatment of coffee stems are pruned and fertilized once a year with manure and artificial fertilizers.
5. 40-year-old Pine trees with a tree spacing of 25 years old thinning to 6 m x 2 m + medium management : Coffee plants aged 6 years with the treatment of coffee stems being pruned.

For the pine growth, the pine monoculture at 40 years old was also compared with the growth of 40-year-old Pine trees with a tree spacing of 25 years old thinning to 6 m x 2 m + medium management : Coffee plants aged 6 years with the treatment of coffee stems being pruned.

2.3 Measured Variable

In quantifying the interaction of pine-coffee plantations, the parameters of pine growth, coffee growth, pine and coffee root systems, and soil-water conditions were observed as a reflection of the hydrological conditions of the soil. The variables observed were coffee growth and production. Coffee or pine growth is indicated by plant biomass. The determination of plant biomass was carried out by measuring the diameter of the coffee stem at 120 cm above the soil surface (DBH). Each location, the pine trees and coffee plant is measured by randomly sampling by 11 plants. The DBH value is converted to coffee or pine biomass with the equation for pine [7]:

$$DW = 0.0417 * DBH^{2.6576}$$

And for coffee [8]:

$$DW = 0.281 * DBH^{2.06}$$

Where, DW = biomass dry weight (kg plant^{-1}), DBH = Diameter at Breast Height (cm)

For coffee production, the number of seeds per tree is calculated. From the number of tree seeds assuming that 1 coffee bean is 6 grams of dried seeds, then it can be determined for tree seed production. Soil water content was measured by gravimetric method by taking soil samples at 4 depths at each treatment site.

2.4 Data Analysis

The data obtained in this study were analyzed by variance using the F test at the level of 5%. Furthermore, if the treatment has a significant effect on the measured parameters, then proceed using the Smallest Significant Difference test (BNT) using the Genstat statistical software version 10. Sigma plot 10 software was used to draw the comparison of DBH and biomass of pine, DBH, biomass and production of coffee, and volumetric soil water content at different depth among designed measurement.

3. Results and Discussion

3.1 Pine biomass

The growth of *Pinus merkusii* has been proven to be reduced by the presence of agroforestry practices in production forest areas (Figures 1.a and 1.b). Tree diameter (DBH) for 40 years with an agroforestry system decreased 23% compared to monoculture planted as production forest, while total biomass per tree decreased by 50%. In 25-year-old pine, coffee management by pruning (PS) suppresses pine growth, where DBH decreases 20% compared to without coffee management (NM), and pine biomass decreases 44% compared to without coffee management (Figure 1 c and 1 d). With pruning and supported by improved soil fertility by application of artificial fertilizers and manure (PS + F), it can be proven that it does not affect pine growth (Figure 1 c and 1 d). This indicates that coffee pruning can stimulate the development of a coffee root system which causes water and nutrient competition to *Pinus merkusii*. The development of coffee growth due to pruning can cause limited water and nutrient resources in the soil, can only be improved by adding fertilizer regularly so that the competition can be reduced so that pine growth can be better.

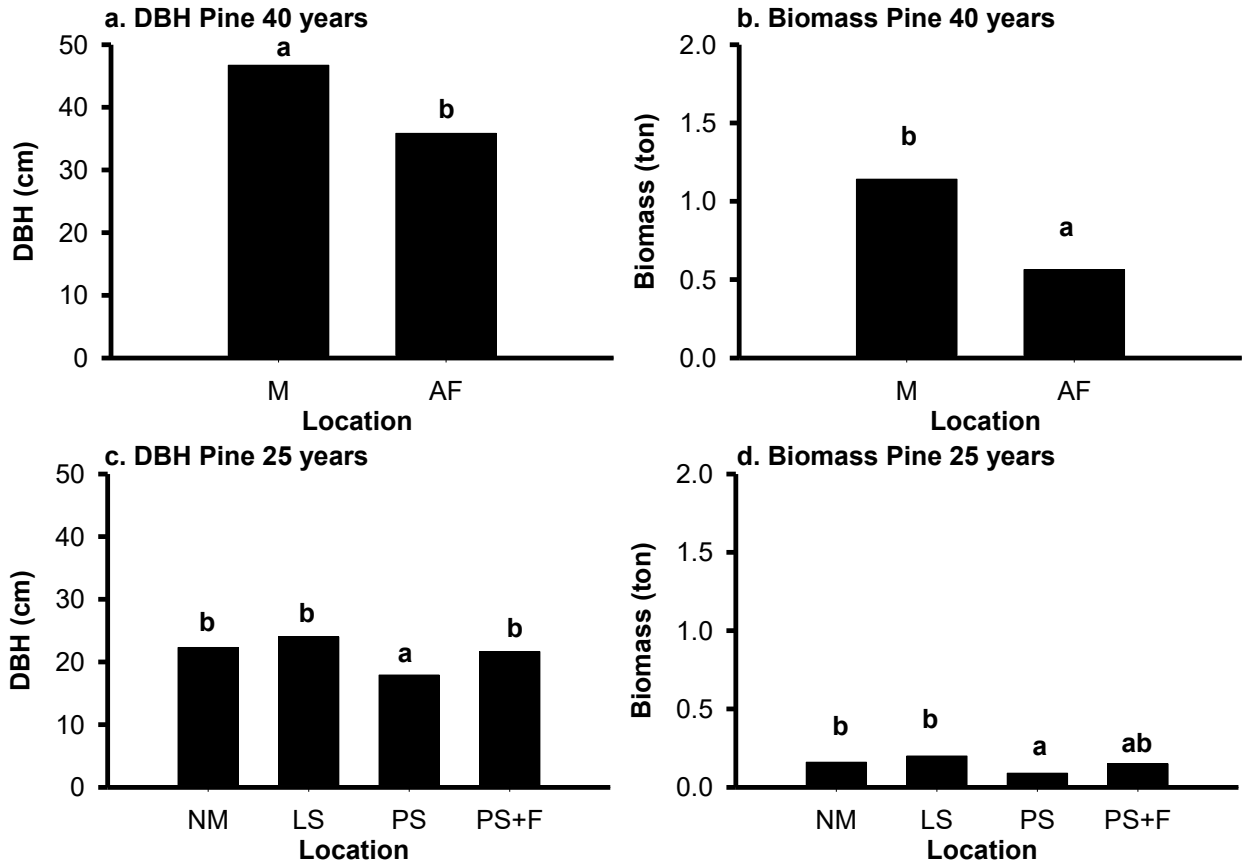

Figure 1. The comparison of (a) DBH of monoculture pine, 40 years old (M) and DBH of pine with tree spacing 6 m x 2 m, 40 years old – coffee 6 years old with pruned stems (AF), (b) Biomass of monoculture pine (M) and biomass of pine with tree spacing 6 m x 2 m, 40 years old – coffee 6 years old with pruned stems (AF), (c) DBH of pine, 25 years old in Coffee-pine agroforestry, with no management (NM), laid down coffee stems (LS), pruned stems (PS), and pruned stems + regular fertilizers (PS+F), (d) biomass of pine, 25 years old in Coffee-pine agroforestry, with no management (NM), laid down coffee stems (LS), pruned stems (PS), and pruned stems + regular fertilizers (PS+F).

3.2 Coffee biomass and yield

Coffee growth cannot be improved with laid down coffee stems (LS), pruned stems (PS) compared to no management (NM) (Figure 2.a, and 2.b). Coffee growth has been proven to be improved by management of pruned stems + regular fertilizers (PS + F), and pine with tree spacing of 6 m x 2 m, 40 years old - coffee 6 years old with pruned stems treatment (S + PS). Additional input from outside of forest land in the form of fertilizer can help reduce nutrient competition between pine trees and coffee plants. Likewise, the recommendation of Perum Perhutani by thinning pine at the age of 10 years from the distance of pine plants 3 m x 2 m to 6 m x 2 m, is able to provide opportunities for coffee to develop properly.

The efforts of farmers to laid down coffee stems (LS), pruned stems (PS) to increase low-cost production have proven to be beneficial to increase coffee yield compared to without coffee management (Figure 2.c.). By increasing investment with artificial fertilizers and manure each year, coffee production can be significantly improved compared to other management treatments (Figure 2.c). The recommendation of Perhutani by thinning pine in the age of 10 years from the distance of pine plants 3 mx 2 m to 6 m x 2 m, is able to provide coffee production better results at low cost, although not as good as management by application of fertilizer from outside forest land.

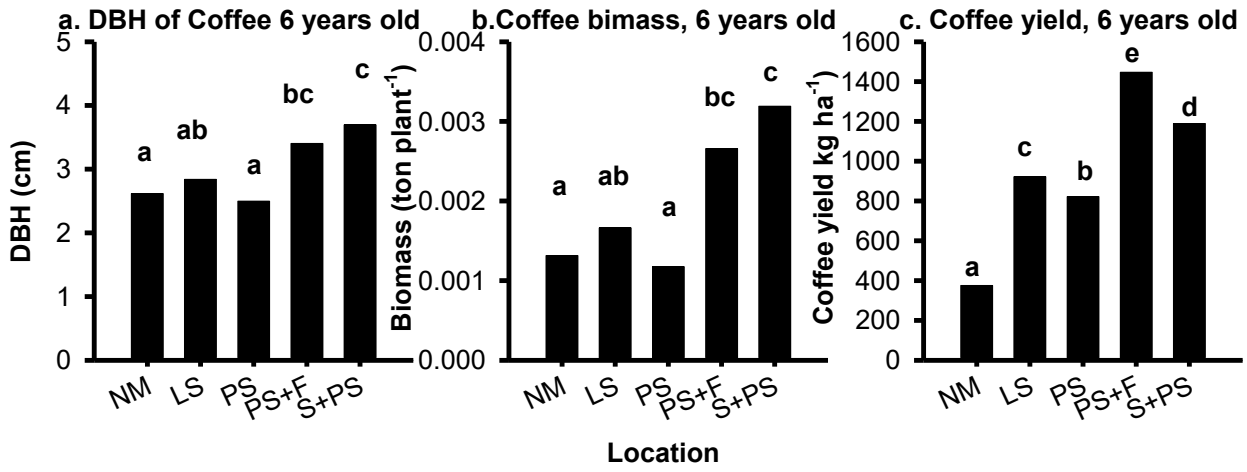

Figure 2. The comparison of (a) DBH, (b) biomass and (c) coffee yield, 6 years old in Coffee-pine (spacing 3 m x 2 m) agroforestry, with no management (NM), laid down coffee stems (LS), pruned stems (PS), pruned stems + regular fertilizers (PS+F), and pine with tree spacing 6 m x 2 m, 40 years old – coffee 6 years old with pruned stems treatment (S+PS).

3.3 Soil water content

Pine which is assumed to consume a lot of water in its growth is proven to cause the soil to be drier (Figure 3) if it is planted tightly (a distance of 3 m x 2 m) with better growth which less pressure by the present of coffee without management (Figure 1.c. and 1.d) during the dry season. With better coffee growth due to fertilization which results in suppressing pine growth the condition of the soil water content at all depth is wetter. In accordance with the management of the production forest management by Perhutani, by reducing the pine population from the distance of pine plants 3 m x 2 m to 6 m x 2 m, soil moisture can be maintained higher than the condition of the dense pine even though still young.

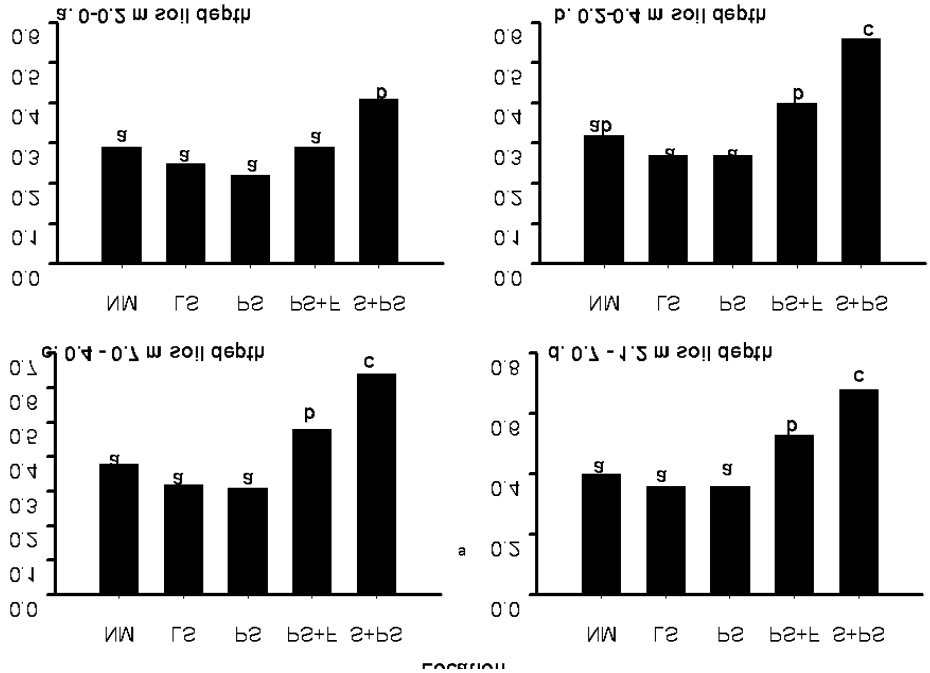

Figure 3. The comparison of volumetric soil water content on (a) 0 – 0.2 m soil depth, (b) 0.2 – 0.4 m soil depth, (c) 0.4 – 0.7 m soil depth, and (d) 0.7 – 1.2 m soil depth,, 6 years old in Coffee-pine (spacing 3 m x 2 m) agroforestry, with no management (NM), laid down coffee stems (LS), pruned stems (PS), pruned stems + regular fertilizers (PS+F), and pine with tree spacing 6 m x 2 m, 40 years old – coffee 6 years old with pruned stems treatment (S+PS) at dry season.

4. Conclusion

The conclusion of this study is that pine growth, which is generally planted as a production forest in Perhutani, will experience a very significant decline if it is converted into a coffee-pine-based agroforestry system. However, as a social function of the forest area, the application of agroforestry is still recommended if farmers do coffee treatment with regular pruning and fertilization so that coffee and pine plants can "work together" in their interactions. Perhutani's recommendation by thinning pine in the age of 10 years from the distance of pine plants 3 mx 2 m to 6 m x 2 m is appropriate to facilitate the interaction of coffee and pine so that water and nutrient competition can be reduced. In this study it can be suggested to do a farming analysis on implementation of coffee and pine-based agroforestry compared to the implementation of pine production forests. The optimization of the pine canopy which does not interfere with pine growth and also provides a 50% canopy cover for coffee growth should also be carried out a more comprehensive study.

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