Forest conversion into cacao agroforestry and cacao plantation change the diversity of arbuscular mycorrhizal fungi

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Abstract. Arbuscular mycorrhizal fungi (AMF), a plant root-fungus association, has been studied widely across different ecosystems. However, little information provided in tropical land use systems. Here, we studied the diversity of AMF in the forest, cacao agroforestry, and cacao plantation. A preliminary survey was done to estimate the AMF richness and diversity. This study reveals an interesting fundamental finding where AMF richness and diversity were significantly higher in the plantation compared to the natural ecosystem. AMF communities were significantly affected mixed vegetation in the forest and became a generalist in an agroecosystem of the cocoa plantation. Presented results indicate that AMF diversity and community structure are influenced by vegetation and ecological conditions.

1. Introduction

There since arbuscular mycorrhizal fungi beneficially contribute as an ecosystem services provider [1] to the growth of many perennial crops [2] and sustainability in agroecology as well as natural ecosystems [3], it is interesting to cover the diversity of AMF along a tropical land-use gradient.

In a mutualistic symbiosis of plant root-AMF [4,2], the plant receives phosphorous (P), nitrogen (N) and carbon (C) from soil by the fungus, while the plant translocate carbon to the fungus [5–7]. The unique fungal extraradical mycelia of AMF can build a network on plant roots to available nutrients that not possible reached by normal roots [8–11]. AMF-plant symbiosis involved the difficult essential nutrient acquisition, for example, P [12], which is one of the difficult nutrients to uptake by roots without associated with AMF. Some studies also reported the role of AMF in plant-pathogen protection in the rhizosphere [13–15].

Plant-AMF association can be found in varying natural [3,16–18] and managed[19–22] ecosystems. However, little information covers tropical regions. The diversity of mycorrhiza affected by field conditions. It is because each type of plant can give a different response to different mycorrhiza [23,24]. Moreover, AMF species is also related to soil properties [25,26], farming management [27–30] and environmental factors [31].

The land conversion has been reported to decrease soil ability to support plant growth. For example, damage the soil structure which begins with a decrease in soil aggregate stability [32,33], decreased soil
organic matter and plant root activity [34–36] and influence on soil microorganisms [35], and decline
the plant root vitality in supporting ecosystem functionality [37].

Forest conversion into managed plantations and agroforestry cacao in Central Sulawesi established
in the last four decades [38,39]. The increasing world demands on cocoa and its derivate products have
become a driver for the forest conversion into cacao plantations and agroforestry cacao. In this study,
we addressed the hypothesis that forest conversion into the managed plantation of cacao and agroforestry

cacao reduce AMF richness and diversity.

2. Material and Method

2.1. Study Site and Sampling
The study was located in three different land uses forest, agroforestry cacao, and cacao plantation in
Palolo regency, Central Sulawesi, Indonesia. In each land use, five plots were installed (40 × 40 m). A
preliminary study was conducted to find the maximum number of tree fine roots in different land uses.
Soil cores were collected in four distances from the tree (0.5, 1, 1.5, and 2 m) and replicated 5 times.
Here we found that 1 m distance from the tree was the highest number of fine roots. Therefore, all soil
core then collected as suggested by the preliminary study. In each plot, 5 soil cores were collected from
random 5 trees. Thus we had 375 samples (3 different land uses x 5 plots x 5 trees x 5 soil cores). The
soil core dimension was 0.05 m diameter and 0.20 m depth. The soil cores were stored at 4°C before
used.

2.2. Isolation and Identification of Mycorrhiza
Soil cores collected, then separated from their roots. AMF identification was based on spore following
by wet pour-filter continued by centrifugation [40]. A total of 10 grams soil diluted in 100 ml water and
stirred, then sieved with 200, 125, 63, and 20 μm sieving respectively. Each sieved material centrifuged
(3,500 rpm) then re-sieved using filter paper to isolate the spore. Spore characteristics identified and
counted with a microscope. Taxonomical AMF was done in a genus level followed by methodology
introduced by Schüßle et al, and Redecker et al. [41,42].

2.3. Data Analysis
Colour The number of spores was counted based on the genus. In order to calculate our sampling effort,
the rarefaction curve was developed [43]. Species richness of AMF was measured per land use systems,
continued by Shannon, Simpson, Dominance indices [44] as equations:

- Shannon index ($H'$) (equation 1)

$$ H' = -\sum p_i \ln p_i $$

- Simpson index ($D$) (equation 2)

$$ D = \frac{\sum n_i(n_i - 1)}{N(N - 1)} $$

- Dominance index (equation 3)

$$ C = \sum P_i^2 = \sum \left( \frac{n_i}{N} \right)^2 $$

Where $n_i$ is the number of individuals of taxon $i$, $p_i$ is the proportion of the $i$-th species, $N$ is the total
number of species, $H'$ is Shannon’s. Simpson and Dominance indices range from 0 (all taxa are equally
present) to 1 (one taxon completely dominates the community). In the Shannon index, $H'$ varies from 0
for communities with a single taxon to high values for communities with many taxa. The diversity indices were calculated using PAST statistics version 2.17 [45]. To compare the difference of diversity among the land uses, one way ANOVA was calculated by R statistics version R 3.4.3 (R core team, 2014) continued by Tukey’s honestly significant difference test.

AMF community was estimated by non-metric multi-dimensional scaling (NMDS). The NMDS plot was created using PAST 2.17c [45]. One way multivariate analysis of variance PERMANOVA, Anderson et al. [45] was used to distinguish the AMF community related to the land use systems. Bray-Curtis similarity index was used to measure the distance.

3. Results and discussion

3.1. AMF spore abundance in different land use systems

A total of 9,209 AMF spores were collected. Rarefaction curve (Figure 1) showed the number of samples analyzed was sufficient to estimate the AMF spore diversity in each land use. Rarefaction curves that show an increase indicate most of the species still have to be found. In this study, the curve shows a line, implies that sampling is more likely to produce only a few additional species [47]. The most abundant AMF was founded in cacao plantation, followed by cacao agroforestry, and forest respectively (Figure 2).

Since intensive farming practices decline the AMF abundance and effectiveness [48–50], we expected that frequent fertilizer and fungicide applications would decrease the species richness and abundance of AMF. It is, however, interesting to find that the species richness of AMF higher in managed plantation compared to forest ecosystems. According to González-Cortés et al (2012), the number of vegetation in old plantation might be the reason for the AMF host. Trees also had higher preferences for AMF host compared uncanopied plants [51,52]. In Central Sulawesi, cacao plantations are mostly owning by local farmers. Traditional farming systems are common where we can find other lower plants in the plantations. Having a higher abundance of AMF in cacao plantations might be supported by those mixed vegetations and host preferences of AMF.

![Figure 1. AMF richness accumulation in forest (n=125), agroforestry (n=125), and cacao plantation (n=125).](image-url)
3.2. AMF diversity

The AMF richness was higher in the managed plantation of cacao and cacao agroforestry compared to forest system (Table 1). We detected Glomus, Gigaspora, Scutellospora, Acaulospora, and number of unidentified AMF. Glomus was the most abundant genera of AMF detected among land uses. The diversity indices of land uses were compared. Shannon, Dominance and Simpson diversity indices showed that forest site had slightly lower diversity than cacao plantation and cacao agroforestry (Table 2).

**Table 1. The AMF richness in different land use systems**

| Genera     | Forest | Cacao Agroforestry | Cacao Plantation |
|------------|--------|--------------------|------------------|
| Glomus     | 1128   | 2385               | 3180             |
| Gigaspora  | 97     | 180                | 219              |
| Scutellospora | 30     | 82                 | 72               |
| Acaulospora | 108    | 194                | 573              |
| Undetermined | 136    | 352                | 473              |

**Table 2. The diversity of AMF along different land use systems. Data shows means (n= 125 ± SD). Different letters in the same column indicate significant differences between land use systems with P<0.05.**

| Land Use          | Shannon | Dominance | Simpson |
|-------------------|---------|-----------|---------|
| Forest            | 3.02    | 0.06      | 0.94    |
| Agroforestry cacao| 3.22    | 0.05      | 0.95    |
| Cacao plantation  | 3.35    | 0.05      | 0.95    |
Figure 3. The NMDS plot of AMF diversity in different land uses (forest in green, cacao agroforestry in blue, and cacao plantation in brown; n=5).

AMF fungal communities were significantly different only in the forest ($P = 0.01$) and cacao agroforestry ($P = 0.008$) after PERMANOVA and NMDS ordination (Figure 3). Cacao plantation did not show a significant effect on AMF communities. AMF communities in the forest mostly separated from cacao plantations and cacao agroforestry communities. The distribution of AMF indicates that mixed trees in forest and agroforestry were greater than the plantation. Among all AMF we found, Glomus was the most distributed in all land uses. It is not surprising since many reports dedicate Glomus as generalist AMF [53–55].

We noted that AMF richness and diversity were lower in natural ecosystems compared to cacao plantation and cacao agroforestry. Similar finding with the previous studies see, for example, [56,57] Possible mechanisms imply this finding that different soil chemical properties lead the diversity of AMF in different ecosystems [58,59]. The rhizosphere environmental conditions, driven by abiotic and biotic variables are possible to be the reason for AMF community distribution [60–62]. Moreover, several environmental factors affect AMF communities along a tropical land-use gradient. Soil moisture, temperature, rainfall, and plant communities are factors affected the AMF dispersal [63–65].

As a fundamental survey, this study has pronounced the diversity of AMF in different land use systems are influenced by various conditions. Thus, another study has to be developed to investigate environmental factors related to the network distribution of AMF communities in different tropical land uses. Sharpening the identity of AMF is another case to be answered. Since we found numbers of undetermined AMF, it is interesting to find more deeply the novel specificity of AMF in tropical regions.

4. Conclusion
This study highlights the AMF diversity affected by land use system associated with plant diversity and environmental factors. Higher species richness and diversity of AMF spore in monospecific plantation suggest increasing of functional diversity of AMF induce by agricultural input in farming systems.

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