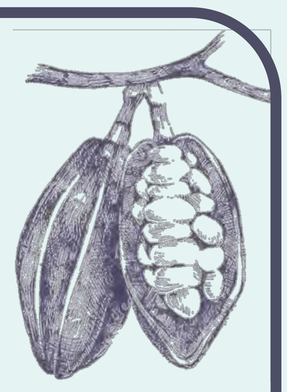
The effects of tree species diversity on soil fertility in cocoa-plantations of southeast Sulawesi



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Cocoa agroforests can support high levels of biological diversity: are they a potential solution to optimize both productivity and soil conservation ?

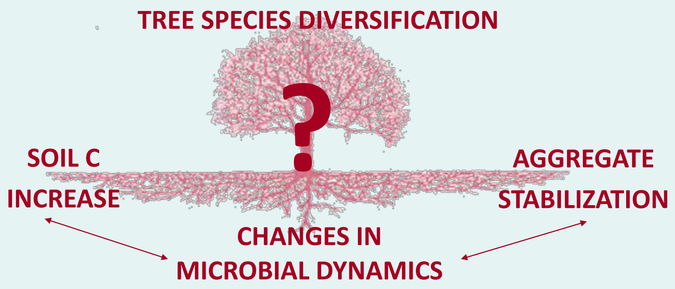
CONTEXT

Globally, **cocoa** is a primary income source for millions of smallholders in developing countries who depend on the crop for their livelihoods. However, cocoa production is **threatened** by declining yields, and **contributes** to deforestation and ecosystem degradation.

Agroforests have been promoted as a potential solution to bridge ecological conservation and needs for increased agricultural productivity, particularly in tropical countries. The **benefits of tree diversification** in cocoa plantations are thought to range from microclimate regulation to alternative income sources for farmers.

Tree species diversity is also thought to maintain **soil fertility** through:

- Biomass increase & root + litter input diversification
- Improved substrate availability for soil microbiota
- Improved soil organic matter stabilization
- Resource uptake stratification



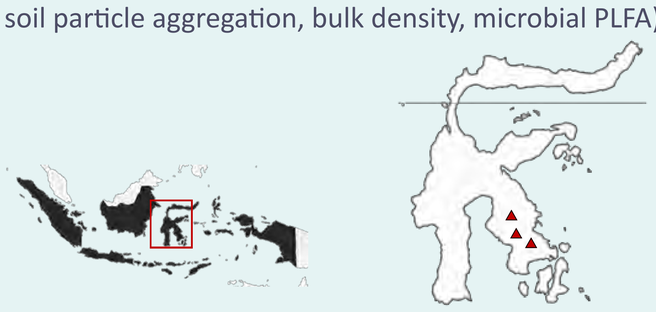
We tested whether in cocoa agroforests, tree species diversification was linked to improved soil fertility.

METHODOLOGY

We selected a range of cocoa plots representing the variation in tree diversity commonly observed in southeast Sulawesi. Our plots ranged along a continuous diversity gradient from **cocoa monocultures** (no diversity) to **complex agroforests** (high diversity). Cocoa plots were then compared with **secondary** (SF) and **primary forests** (PF) as a baseline.

Plot diversity was calculated based on abundance and richness of different tree species and standardized using the Shannon-Wiener diversity index.

We then assessed the **effect of tree species diversity on physical, chemical and microbial soil fertility indicators**
(total C, N and P, available P, pH, CEC, base saturation, soil particle aggregation, bulk density, microbial PLFA).

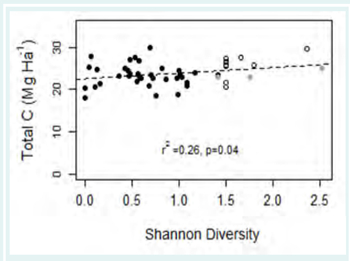


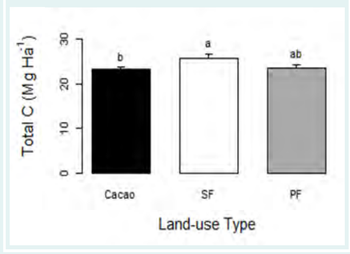
Sampling locations in southeast Sulawesi, Indonesia

RESULTS

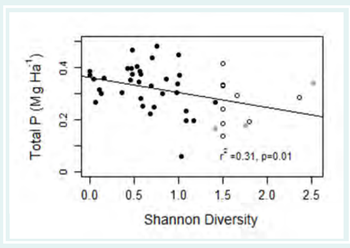
SOIL NUTRIENTS

- Soil total C increased with tree diversity, but this effect was driven by SF and PF plots.





- Soil total P decreased with tree diversity.

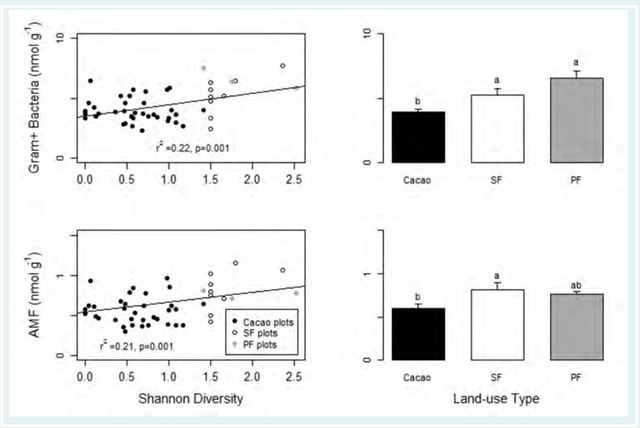


- Soil N and available P were not correlated with tree diversity.

This suggests that nutrient content in cocoa agroforests is not directly linked to tree species diversification.

SOIL MICROBES

- Gram+ bacteria and arbuscular mycorrhizal (AM) fungi abundance increased with tree diversity. This effect was driven by SF and PF plots.



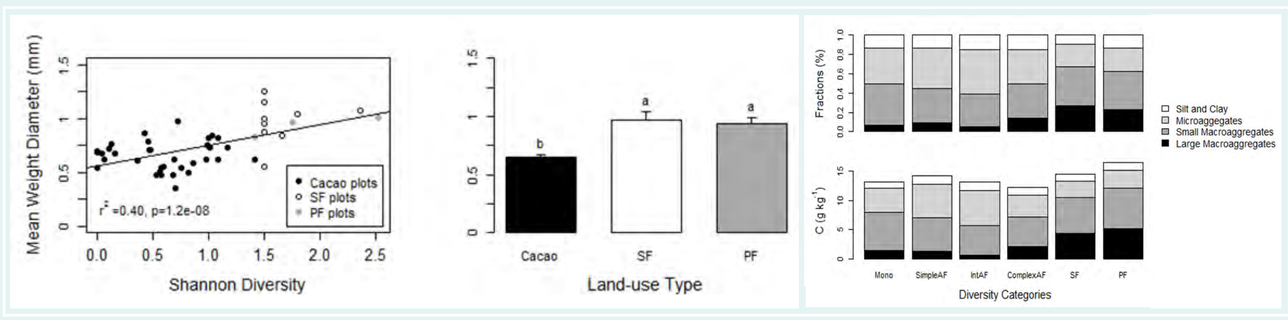
- Total PLFA and Gram– bacteria abundance was highest in secondary forests

- Soil C was positively correlated with bacteria-associated PLFA (R^2=0.33, p<0.001); soil aggregation was positively correlated with AM fungi-associated PLFA (R^2=0.11, p=0.05).

We find no indication of a direct effect of tree diversity on soil microbes in cocoa agroforests; our data does suggest recovery in secondary forests, likely through an increase in bacteria and AM fungi which promote aggregation and soil C stabilization.

SOIL AGGREGATES

- **Soil aggregate stability**, indicated by mean weight diameter (MWD), increased with tree diversity, but this effect was driven by SF and PF plots. Similarly, the proportion of **large-macroaggregates** (>2000 µm) and of **C bound within large-macro-aggregates** also increased with tree diversity, but again this effect was driven by SF and PF plots.



This indicates that other factors could be more important for the formation and stabilization of aggregates.

YIELDS & FERTILIZER INPUTS

- We found no significant relationship between tree diversity and other soil properties (pH, available P, micronutrients)
- Cocoa yield and fertilizer input were not correlated with tree species diversity or soil fertility

CONCLUSIONS

1. Soil C, aggregate stability, and soil microbial abundance were highest in primary and secondary forest.
2. We found no significant effects of tree diversity on any measured soil properties within cocoa plantations.
3. Forest plots differ from cocoa plantations not only through higher tree diversity levels, but also through increased above-ground biomass. They are also much older than cocoa plots.
4. These factors could thus be important for soil fertility, although more research is needed to quantify this further.
5. Our findings do suggest that secondary forests might be more beneficial than agroforests for soil function restoration after deforestation for microbial communities, soil C pools and aggregate stabilization.