Shade-tree diversification in cacao agroforests: a more sustainable model?

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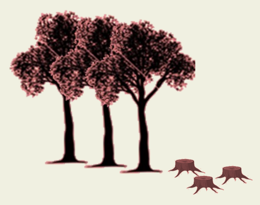
INTRODUCTION

Theobroma cacao: from traditional mixed gardens to monoculture plantations

Cocoa is a primary income source for millions of smallholders. It also thrives in high diversity areas of the lowland tropics.

Agricultural expansion in humid tropics is one of the leading drivers of deforestation and ecosystem degradation.



In Indonesia, cocoa plantations are first established via thinning of rainforest areas.

Farmer efforts to intensify production often include reduction or removal of intercropped shade-trees, leading to biodiversity loss and soil degradation.

Shade trees, cocoa trees, soil fertility and nutrient cycling

Trees are important components of an ecosystem and can alter its physical and chemical soil properties, in turn impacting soil microbial communities and nutrient cycling processes.

An increase in plant biodiversity can lead to improved ecosystem productivity due to, for example, root symbiotic associations and complementarity in resource uptake.

In tropical rainforests, decomposing plant residue contributes to replenish soil nutrient pools, and soil structure is protected from erosion by canopy shade and the litter.

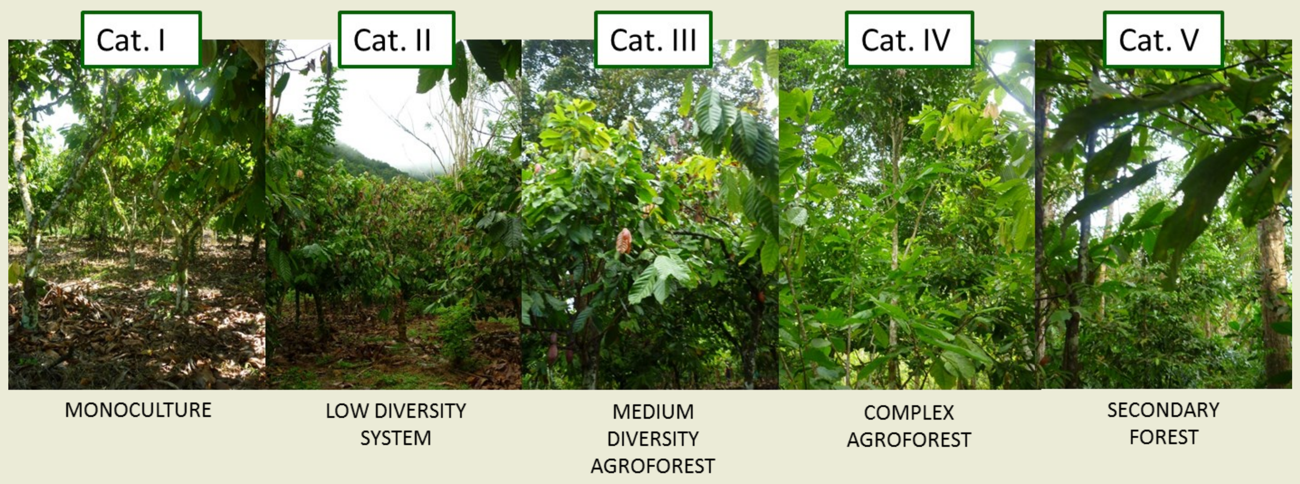
Long-term soil organic matter stabilization within soil aggregate structures is linked to increased soil fertility.

In cocoa agroforests, does shade tree diversification lead to improved soil fertility ?

Cocoa agroforests can support high levels of biological diversity: are they a potential solution to optimize crop production and ecosystem conservation ?

METHODS

Five distinct categories within a shade-tree species diversity gradient were found at the study locations in South-East Sulawesi.



Plot diversity was calculated based on number and density of total trees and shade trees, and standardized using the **Shannon-Weiner** diversity index.

Fertilization rates, yields, and cocoa age are based on **reported values** in farmer interviews at each plot.

To assess the impact of shade tree diversity and fertilization on soil fertility, we measured **pH**, **texture**, **nutrient** contents, **aggregation**, and microbial phospholipid fatty-acid distribution (**PLFA**).

Soil samples were collected in 3 separate communities with three replicates per "biodiversity" category per location. A total of **45 plots** were sampled.

RESULTS

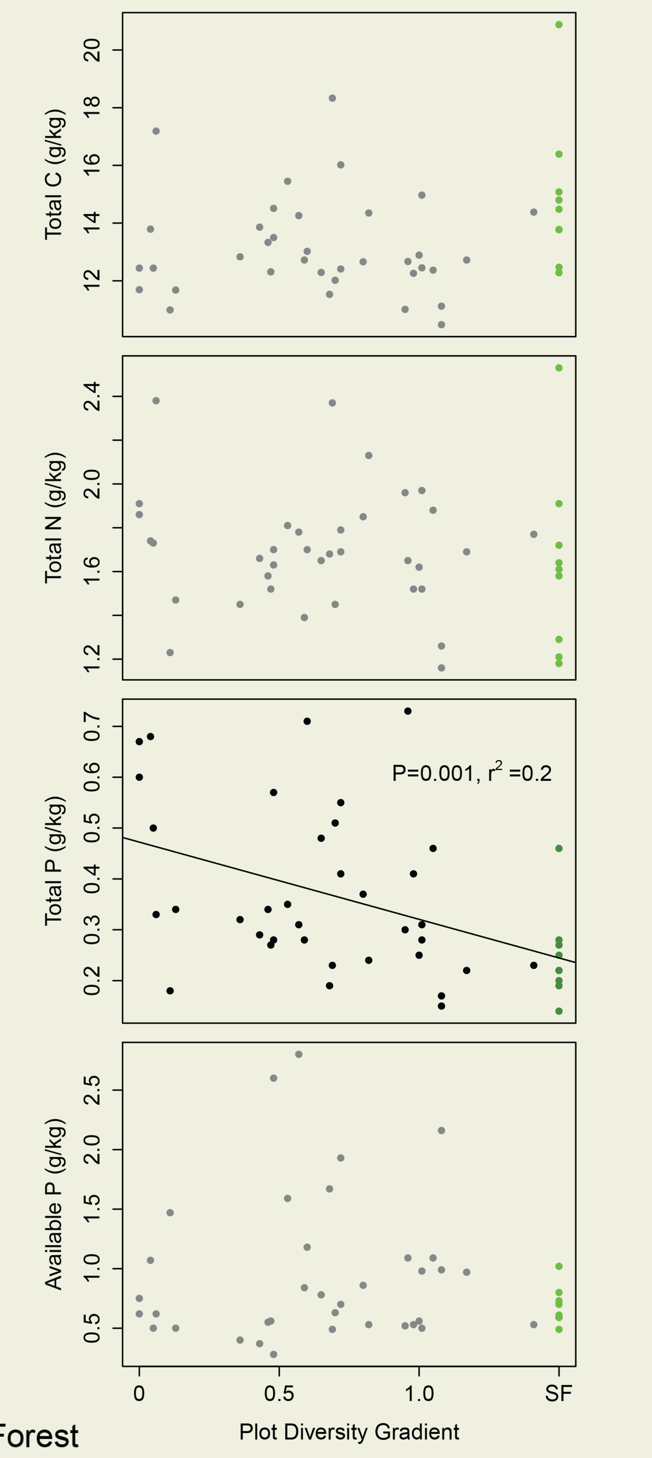
Shade-tree diversity and nutrient levels

Fig. 1: P-values for the effects of fertilizer intensity and shade-tree diversity

	C	N	P	Pi	Yield
Fertilizer Intensity	0.9868	0.2215	0.9791	0.3167	**0.0266**
Shade-tree diversity	0.1516	0.4277	**0.0013**	0.5045	0.4133

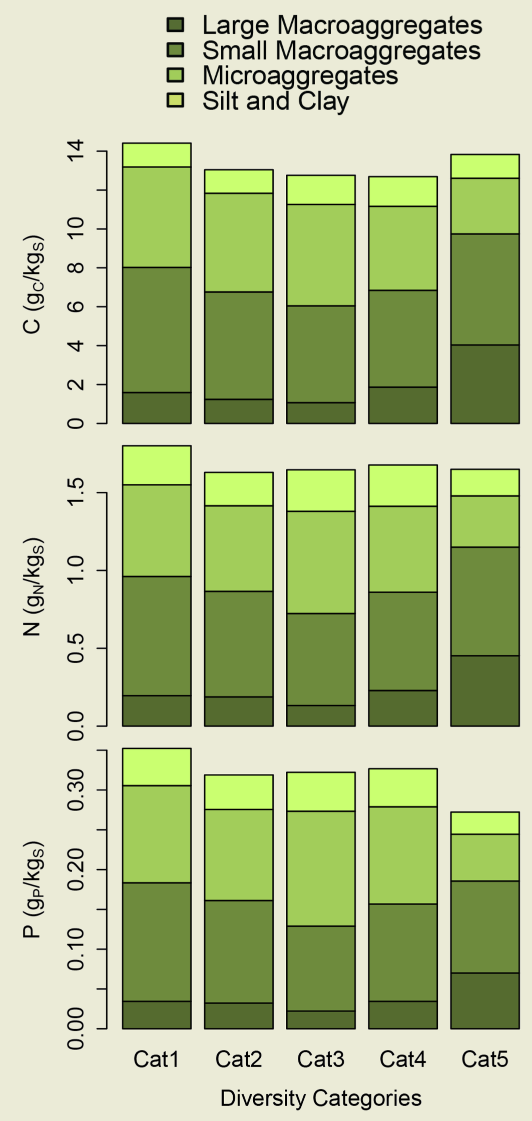
- There are no significant effects of shade-tree species diversity or fertilization levels on soil total C and N and available P pools.
- Total P content showed a significant negative correlation with increasing shade-tree species diversity, perhaps due to increased resource competition in more complex systems.
- Fertilizer input and yields are significantly correlated. There is however no significant effect of fertilizer input on soil nutrient pools at the plot level.

Fig. 2: Soil C, N and P content along a tree species diversity gradient



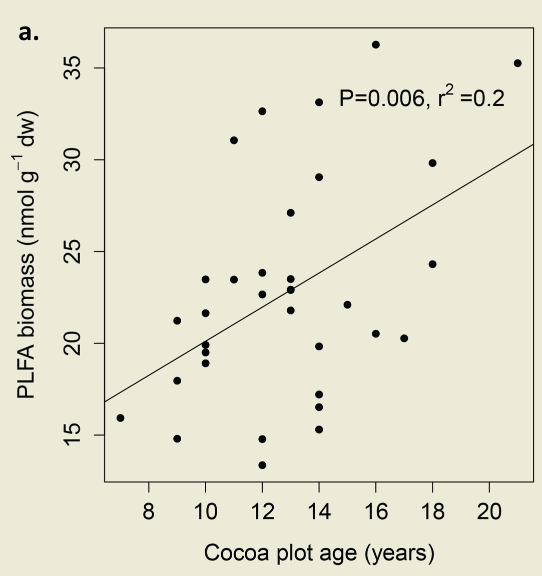
Shade-tree diversity, aggregation and microbial communities

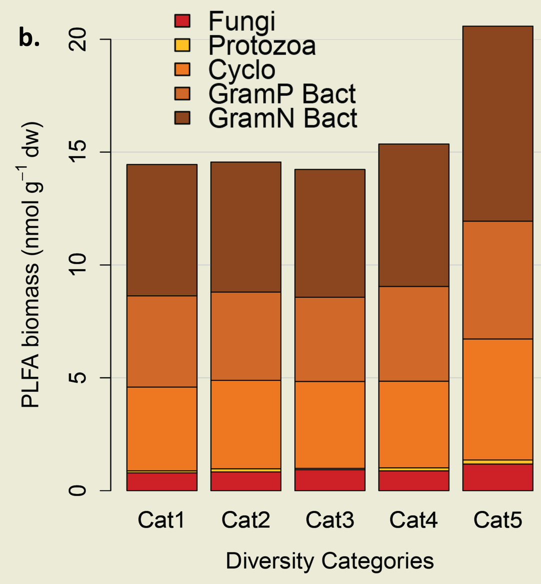
Fig. 3: Average total C, N and P found per soil fraction per kg of soil in each of the diversity categories



- Microbial community size and distribution do not vary significantly between managed cocoa-based systems (categories 1-4) but are higher in secondary forest plots.
- Within the cocoa-based systems there is a significant positive correlation between total PLFA biomass and cocoa plot age.
- Changes in aggregation dynamics are driven by secondary forest plots. Total C, N and P contents do not vary significantly with tree diversity, but nutrient distribution within soil fractions shows distinct differences. C, N and P contents in large macroaggregates are significantly higher in secondary forest than in cocoa-based systems.

Fig. 4: a. Total PLFA biomass as a function of cocoa plot age in years; b. PLFA biomass classes as a function of plot diversity





CONCLUSIONS

1. No positive correlation was found between **farmer management practices** (diversification or fertilization) and **soil fertility indicators**.
2. Other factors such as **long-term land history** and **site-dependent characteristics** might be more important for long-term soil fertility.
3. Tree species diversity **does not appear to be the principal factor determining aggregate formation**. However, tree presence may impact **long-term soil aggregation dynamics and microbial community recovery** following forest clearing events, particularly when plots are left fallow.
4. Shade-trees may be beneficial from an ecosystem perspective through **other mechanisms** such as microclimate control or bio control for certain pests and diseases. Still, results suggest that **despite increased diversity** as compared to monocultures, complex agroforests **remain far from recovering** the complex ecosystem processes found in primary or secondary forests.