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Land use effects on tree species diversity in different ecological zones of Ghana

Miracle Obeng[a], Reginald Tang Guuroh[b], Mathias Becker[a], Shyam Pariyar[a]

[a]*University of Bonn, Inst. Crop Sci. and Res. Conserv. (INRES) - Plant Nutrition, Germany*
[b]*CSIR-Forestry Research Institute of Ghana, Kumasi, Ghana*

Abstract

The understanding of changes in plant species' responses to the interactive effects of land use and climate is not only an important area of research, but could also inform on the effect of such interactions on the composition and structure of future plant biodiversity. We hypothesized that rainfall and land use affect the composition and diversity of tree species and soil fertility attributes. We investigated the effects of land use along an aridity gradient on the population structure and diversity of woody vegetation and on soil fertility attributes in Ghana. The study was performed in: i) the semi deciduous savanna zone, ii) in the moist forest-savanna transition zone and iii) in the evergreen humid forest zone, following a gradient of decreasing aridity. In each zone, we compared protected forest areas with the surrounding non-protected agriculturally used areas. Ten survey plots of 50 m × 20 m (0.1 ha) were randomly selected in each of the six sites (60 observation plots in total). In each plot, composite soil samples from top soil (0–20 cm) were taken for physico-chemical analyses.
Species richness and Shannon-Wiener diversity index were calculated based on species identities and relative abundance in a vegetation layer. Soil fertility attributes were measured for the different land use types in all the ecological zones.
Tukey multiple comparisons of means at 95% confidence level among different land use types showed significant difference in species richness and Shannon Wiener diversity index between land use types (protected forest and croplands) in each ecological zone. We observed tree species diversity increased in a gradient of decreasing aridity (i.e., increasing rainfall regimes). Protected forest areas showed highest levels of tree taxonomic diversity with varying degree among aridity gradients. Soil attributes (pH and C:N ratio) were observed to be significantly different and more homogeneous in dry and moist semi deciduous ecological zones in both land use types compared to Wet evergreen zones. The outcomes of this study depict that the most rapid reduction of tree species diversity occurred in the humid forest zone as a result of agriculture. Hence, the development of agricultural systems where more trees are incorporated on croplands should be focussed on in humid forest environments.

Keywords: Agriculture, climate change, diversification, ecosystem service, forestry, nutrient cycle, system shift

Introduction

Trees composition and diversity play a defining role in ecosystem health and functioning in response to changing environmental conditions (Ruppert et al., 2015). Discerning the mechanisms behind, and the quantification of ecosystem responses to global environmental change is a central theme in recent ecological researches (Reed et al., 2012).

Land use changes and climate are seen as the most important drivers of vegetation composition, ecosystem functioning and thus ecosystem service provision (Zerbo et al., 2016). During the past decades, Africa especially Ghana has been subject to substantial changes in agricultural land use pressure and climate (Knippertz et al., 2015). Appiah-Badu et al., (2022) reported the conversion of forest to more intensive land management (i.e., rubber plantation and croplands) in the high forest zone of Ghana, resulting to a considerable reduction in tree species diversity and a change in their composition. Their study also reported the shift in land use affected soil physicochemical properties strongly, especially at the surface layer (0–10 cm depth).

Despite these findings, there are still gaps in our understanding of how land use and climate (different rainfall regimes) interactively affect vegetation composition and functioning (Guuroh, 2016) as well as soil fertility (nutrients) in south-western ecological zones of Ghana. Therefore, we investigated the effects of land use on the population structure and diversity of woody vegetation and on soil fertility attributes in three different agro-ecological zones of Ghana. The rationale of this study is to contribute to an improved understanding on how shift in land use and different rainfall regime interactively affects tree population structure, diversity of woody vegetation as well the soil fertility or quality (i.e., important soil nutrients) in three ecological zones of Ghana.

Material and Methods.

The study was performed in: i) the semi deciduous savanna zone, ii) in the moist forest-savanna transition zone and iii) in the evergreen humid forest zone, following a gradient of decreasing aridity. We compared protected forest areas with the surrounding non-protected agriculturally used areas along a humidity gradient with aridity indices ranging from 0.9 (dry savanna) to 1.2 (humid forest). Ten survey plots of 50x20 m (0.1 ha) were randomly selected in each of the six sites, using a nested plot design. In each of the 60 observation plots, we assessed tree species richness and Shannon diversity indices, and selected soil fertility attributes (0-20 cm).

Diversity indices equations: Species richness ($\boldsymbol{S} = \sum n$), (where **S** is species richness and **n** is the number of individual species in the community). Shannon-Wiener diversity index ($\boldsymbol{H'} = -\sum_i^s \boldsymbol{pi\ lnpi}$) (where, $\boldsymbol{H'}$ = Shannon Weiner diversity index, $\boldsymbol{pi}$ is the proportion of individuals in the $\boldsymbol{i}$th species i.e. ($\boldsymbol{ni/N}$); $\boldsymbol{s}$ = the number of species, $\sum$ = sum from species 1 to species $\boldsymbol{s}$, $\boldsymbol{ln}$ = log base n. Climate data of the sites were obtained from the WorldClim database online (http://www.worldclim.org/).

One-way analysis of variance with Tukey's post hoc test was performed at the 5% significant level to determine the differences in means of Species richness and Shannon diversity index and physicochemical properties of soil among the two land-use types in the same ecological zone as well as among the ecological zones.

Results and Discussion

Species diversity indices

Vegetation analysis in this study revealed a wider variation in tree species diversity along land use (protected forest and croplands) and a climate gradient (**Figure 1**). Species diversity (species richness and Shannon-Wiener diversity index) was very low in the agriculturally used areas (croplands) compared to the natural vegetations (protected forest) because of excessive anthropogenic activities (farming, logging, mining, non-timber forest products (NTFPs) extraction). Our findings agree with Appiah-Badu et al., (2022), who discovered the conversion of forest to more intensive land management (i.e., rubber plantation and croplands), led to a considerable reduction in tree species diversity and a change in their composition. Our results further showed increase in tree species diversity and composition along a gradient of decreasing aridity. Malik & Bhatt, (2015), confirmed that communities under different environmental conditions differ by the number of species therein.

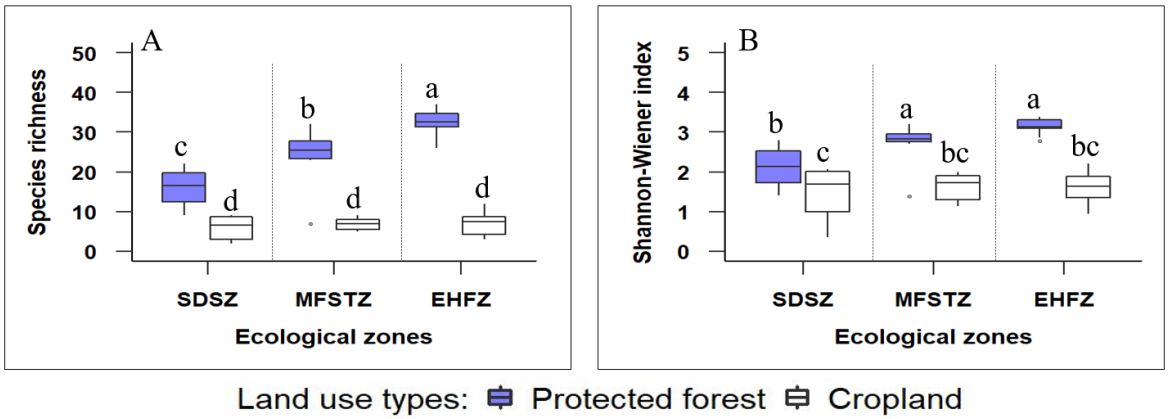

Figure 1: Species richness (**A**) Shannon-Wiener diversity index (**B**) in different ecological zones and under different land uses (Tukey multiple comparisons of means, **n = 10**). SDSZ = the semi deciduous savanna zone, MFSTZ = the moist forest-savanna transition zone and EHFZ = the evergreen humid forest zone.

Soil fertility attributes.

Soil-mineral nutrient content analysis in this study also showed a wider variation in fertility attributes (pH and C:N ratio) along land use (protected forest and croplands) and a climate gradient (**Figure 2**) only in evergreen high forest zone (most humid). No significant differences were observed for land use types in the semi deciduous savanna zone and the moist forest-savanna transition zone. Observed significant differences in the soil attributes (pH and C:N ratio) among land use types in the most humid zones can be attributed to the high amount of rainfall in this region. Also slash-and-burn agriculture predominant in this area. Vincent et al., (2018) mentioned that slash and burn agriculture causes an increase in available nutrient content, particularly phosphorus and basic cations as well the amounts of soil organic matter.

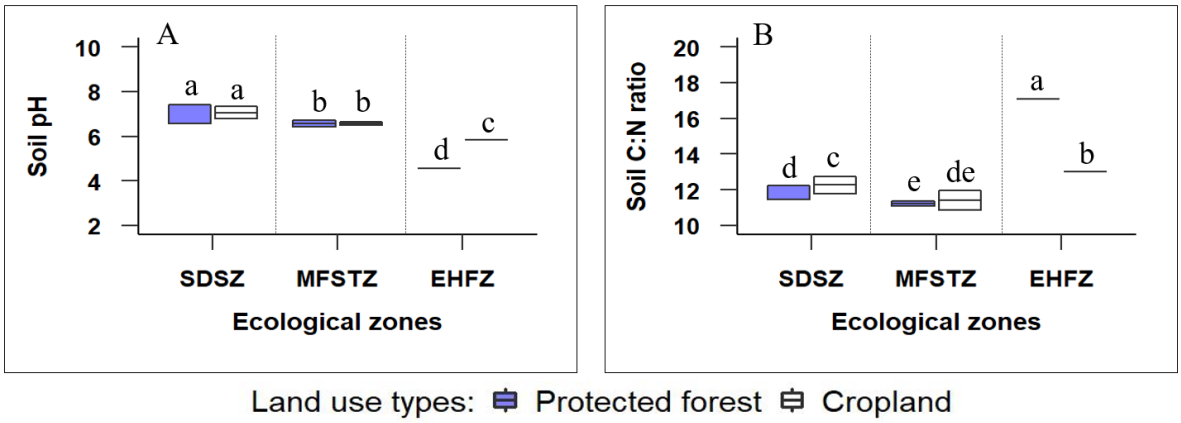

Figure 2: Soil pH values (A) and Soil Carbon:Nitrogen ratio (**B**) (proxi of soil organic matter quality) in different ecological zones and under different land uses (Tukey multiple comparisons of means, **n = 10**). SDSZ = the semi deciduous savanna zone, MFSTZ = the moist forest-savanna transition zone and EHFZ = the evergreen humid forest zone.

Conclusions and Outlook

In general, our study highlighted the vulnerability of tree species diversity and composition to land use pressures as well as climate. This situation threatens tree species diversity conservation and their services. Interestingly, aagricultural land use affected tree biodiversity most in the humid forest zone. Furthermore, land use changes negatively affected soil organic matter quality in savanna and positively in forest environments. Based on these findings, the study suggests the development of agricultural systems where more trees are incorporated on croplands and more focus on agroforestry approaches to the humid forest environment.

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