

Scattered trees in smallholder farms improve soil properties and litter decomposition in humid-agroecosystems in Ethiopia

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Abstract

Low agricultural productivity associated with poor soil fertility management characterizes the sub-Saharan African agriculture. Trees in farmlands are believed to improve soil properties and agricultural productivity, yet smallholders are limited in their choice of agroforestry tree species. Here, we assessed the effect of *Cordia africana* and *Croton macrostachyus* trees on soil properties and leaf litter decomposition in parkland agroforestry in Bullen District, Benshangul Gumuz, northwestern Ethiopia. We used a randomized complete block design with a distance from a tree trunk setup to draw soil samples and conduct a litter burial experiment across five farmlands. In each farmland, three mature trees per species were identified, separately, and under each tree, three transects containing three concentric radial distances measured from a tree trunk were established. Using this setup, a total of 45 composite soil samples per the study species were drawn and analyzed for soil pH, total nitrogen, available phosphorus, organic carbon, and cation exchange capacity. Additionally, leaf litter mass losses of the study species were quantified for three consecutive months. The results revealed that all the measured soil variables and litter decomposition were significantly different between distances for both *C. africana* and *C. macrostachyus*. A significantly higher nutrient contents and litter decomposition were observed under the tree canopies than outside, and for *C. macrostachyus* than *C. africana*. We conclude that trees in farmlands might improve soil properties through litter addition and decomposition. Future studies should disentangle the role of litter addition and microclimate effects of trees in farmlands on soil properties.

1. Introduction

Low agricultural productivity associated with soil degradation due to overexploitation and poor soil fertility management practices characterize the sub-Saharan African agriculture sector (Zingore et al. 2015; FAO 2017; Bjornlund et al. 2020). Besides, a peculiarly rapid population growth further undermines the ability of countries in this region to meet their soaring domestic food demands, resulting in ca. 30% of the population being food insecure (Pfister et al. 2011; Van Ittersum et al. 2016). In the last few decades, for example, the African population increased from 228.7 million in 1950 to 1.341 billion in 2020, the increase being higher in sub-Saharan Africa, making food provisioning intractable (Bremner 2012; Van Ittersum et al. 2016; Kaba 2020). Increasing food production is often associated with committing more land to agriculture through clearing forests and converting other natural ecosystems, such as woodlands and grasslands (Bowers et al. 2017; Franks et al. 2017). Yet, this, in turn, exacerbates land degradation and reduction in agricultural productivity, resulting in a rather declining overall food production compared to other developing regions (Bjornlund et al. 2020). In recent days, some efforts have been made to improve soil fertility through the increased use of chemical fertilizers (van Beek et al. 2016; Van Ittersum et al. 2016; Magnone et al. 2022). Unfortunately, nonetheless, extensive use of chemical inputs to increase crop yield has been proven to impose adverse consequences on the environment and human wellbeing (Utaile & Cross 2016; Shanka 2020; Demi & Sicchia 2021), suggesting the need for an alternative approach that benefits agriculture, environment, and society combined (Gowing & Palmer 2008; Bybee-Finley & Ryan 2018; Shanka 2020). Land management approaches, such as climate-smart

agriculture, watershed management, and agroforestry have been thought to have positive impacts on soil fertility and agricultural productivity while improving the environment and biodiversity (Wawire et al. 2021; Mekuria et al. 2022).

Agroforestry, a deliberate integration of woody plants with crops or animals, is widely practiced by small landholders in the tropics, and the sub-Saharan Africa, in particular, to simultaneously address food production and environmental sustainability (Reubens et al. 2011; Wilson & Lovell 2016; Waldron et al. 2017; Kuyah et al. 2019). Agroforestry is believed to increase agricultural productivity due to the advantageous effects of woody plants on soil properties (Fahad et al. 2022; Gupta et al. 2023). Trees in agroforestry systems recapture and pump back leached nutrients via deep roots and replenish soil organic matter and nutrient contents through litter addition and decomposition (Pardon et al. 2017; Negash & Starr 2021; Dori et al. 2022; Fahad et al. 2022; Kassa et al. 2022). For example, majority of nutrients taken up by plants return to the soil through litter decomposition (Hossain et al. 2011; Liu et al. 2022). Indeed, nutrients in plants return to soil in several ways such as through abiotic leaching while decomposition, soil-microbes mediated process, constitutes a major mechanism by which complex organic matters mineralize into smaller molecules that are readily absorbed by plants (Park & Cho 2003; Hossain et al. 2011; Song et al. 2023). Among plant litter types such as fallen leaves, twigs, seeds, and other debris, leaf litter accounts for more than 70% of the litter and contains comparatively higher concentrations of nutrients (Hossain et al. 2011; Song et al. 2023). The amount of nutrients delivered by litterfall to the soil through decomposition is therefore an important factor for sustainable agriculture, yet the magnitude of nutrients return to soil varies from species to species (Hasanuzzaman & Hossain 2014; Kassa et al. 2022).

In Ethiopia, agroforestry is a longstanding land use practice traditionally embedded into the farming systems (Derero et al. 2021; Lelamo 2021). Yet, currently, there is a declining trend in trees on farmland due to a combination of factors, such as a policy pressure toward promoting intensive monospecific farming and farmers' need for more land for food crops (Amare et al. 2019; Tega & Bojago 2023). Besides, the knowledge-base for different woody plant species for improving soil properties is not yet well-established, further jeopardizing the ability of farmers to make important decisions on their land management (Gebrewahid et al. 2019; Zerssa et al. 2021; Tega & Bojago 2023). Such a problem is conspicuous in the northwestern part of Ethiopia, including the study area, where farmers tend to remove trees from their smallholdings for fear they should overcompete for resources and reduce crop yields. Previous studies elsewhere in Ethiopia, however, showed promising effects of trees on soil properties and crop yield (Getahun et al. 2014; Manjur et al. 2014; Musema et al. 2019; Abdella et al. 2020). Despite these promising effects of trees to smallholder agriculture, the mechanisms how trees contribute to improving soil properties remains severely underemphasized in scientific research (but see Mahari 2014; Negash & Starr 2021), creating huge knowledge gaps for establishing evidence-base to sustain trees on farmlands. Consequently, appropriate tree species selection based on nutrient release via litter decomposition can be an important criterion in agroforestry. The information on nutrient status underneath trees compared to treeless open areas will draw peoples' interest to incorporate tree species in their farmlands.

In this study, we focused on assessing the effects of two widely grown tree species, namely *Cordia africana* and *Croton macrostachyus*, by smallholder farmers in northwestern Ethiopia, on soil nutrient status and leaf litter decomposition along a gradient of distance from tree trunks beneath trees across farmlands. Previous studies elsewhere in Ethiopia revealed that both *C. africana* and *C. macrostachyus* are known to positively affect soil properties (Gindaba et al. 2005b; Mamo 2017; Mohammed et al. 2018; Gota 2022). Yet, to our knowledge, no study has been conducted to understand tree species' effect on agricultural soils in the study area. Furthermore, it appears hard to generalize that tree species in agroforestry systems can have the same effects on soil properties due to variations in tree management and agroecology. Here, based on the literature review, we hypothesized that nutrient status and leaf litter decomposition rates were inversely related to radial distances from the trunks of the study species.

2. Methods

2.1 Study area

The study was conducted in Bullen District, Metekel Zone, Benshangul Gumuz, northwestern Ethiopia (Online Resource 1). The region has a moist to humid subtropical climate with an annual mean rainfall and temperature of 900mm and 28.5°C, respectively. The majority of people in the district are agrarian and depend largely on producing a variety of cereal crops such as Maize (*Zea mays*), teff (*Eragrostis teff*), sorghum (*Sorghum bicolor*), and finger-millet (*Eleusine coracana*). Farmers traditionally integrate woody plants with these crops, and the most commonly occurring plants include *Acacia abyssinica*, *Erythrina abyssinica*, *C. macrostachyus*, *C. africana*, and *Ficus sure* (Lelamo 2021; Manaye et al. 2021). The soils of the study are mainly vertisols and humic nitisols (Anbessa 2022; Wakwoya et al. 2023).

2.2 Study species

In this study, we used the two most commonly grown agroforestry tree species, namely *C. macrostachyus* and *C. africana*, as proxies for tree effect on soil properties and litter decomposition. Whereas *C. macrostachyus* belongs to the Euphorbiaceae, *C. africana* belongs to the Boraginaceae family. Both *C. macrostachyus* and *C. africana* are native to Africa and the Arabian Peninsula and occur in a wide range of agroecosystems and are suited for inter-cropping (Bekele et al. 1993), thus traditionally grown in croplands across Ethiopia (Lelamo 2021). Furthermore, these trees are deciduous and exhibit a more or less comparable growth and biomass production (Bekele et al. 1993; Gindaba et al. 2005a; Tadesse 2007). Yet, their effect on agricultural soil properties, and litter decomposition, in particular, is understudied (but see Mahari 2014).

2.3 Study design

We investigated soil nutrient status and leaf litter decomposition under *C. macrostachyus* and *C. africana* in smallholder farmers' land using a complete randomized block design with five blocks (farmland/s, hereafter). We focused on the leaf litter of the study species as it constitutes the main and fastest source of organic matter and nutrients to the soil than other litter types (Hossain et al. 2011). In each farmland,

we identified three mature trees, and established sampling points along three orthogonal transects crossing through the origin at $1/3 \times$ crown radius, $2/3 \times$ crown radius, and $3 \times$ crown radius (m), relative to a tree trunk (Tanga et al. 2014; Fig. 1). We investigated soil nutrient status and leaf litter decomposition under *C. macrostachyus* and *C. africana* in smallholder farmers' land using a complete randomized block design with five blocks (farmland/s, hereafter). We focused on the leaf litter of the study species as it constitutes the main and fastest source of organic matter and nutrients to the soil than other litter types (Hossain et al. 2011). In each farmland, we identified three mature trees, and established sampling points along three orthogonal transects crossing through the origin at $1/3 \times$ crown radius, $2/3 \times$ crown radius, and $3 \times$ crown radius (m), relative to a tree trunk (Tanga et al. 2014; Fig. 1). Then, under each tree, soil samples from the upper 20 cm were collected at each sampling points using soil augur, thoroughly homogenized by radial distance, and transferred to a sterile polyethylene bag, resulting in a total of 45 composite soil samples per species across the five farmlands. Here, it is worth noting that we used different farmlands for *C. macrostachyus* and *C. africana*, and also data were collected under solitary trees with at least 10 m away from the nearest woody plants to control for systematic error in the soil data.

We further used the same design for assessing the decomposition of oven-dried (48 hrs. at 60°C) pooled leaves of *C. macrostachyus* and *C. africana*, separately, using a litterbag method (Karberg et al. 2008; Keuskamp et al. 2013; Xie 2020). We filled empty litterbags with 2.00 mg of litter and enclosed them with a stainless-steel mesh to protect them from termites (Smith et al. 2019; Utaile et al. 2020). Two litterbags were buried 8 cm deep at each radial distance, separately, for each tree species, at the end of February 2023. Litterbags were retrieved monthly for three consecutive months and oven-dried (48 hrs. at 60°C) to assess the percentage of litter mass loss after cleaning debris from the litterbags. We then averaged the percentage mass loss for each corresponding radial distance under each tree species.

2.4 Soil chemical analysis

Soil properties were determined following standard procedures (Pansu & Gautheyrou 2006). Soil pH was determined with a glass electrode using 1 g of soil in 5 ml of water. Plant-available phosphorus was determined using the Olsen-P method (Olsen, 1954). Soil nitrate and ammonium were quantified with a 1 M KCl-extraction and a subsequent colorimetric analysis using a segmented auto-flow analyzer (Skalar, Breda, The Netherlands). Soil organic carbon was calculated using the loss-on-ignition method (Hoogsteen et al. 2015).

2.5 Data and statistical analysis

All statistical analyses were conducted in R (R version 4.3.0; R Core Team, R Foundation for Statistical Computing, Vienna, Austria). We assessed variations in soil nutrient status under *C. africana* and *C. macrostachyus* using linear mixed models (LMMs) with distance from the tree trunk and species identity as fixed factors and farmlands (i.e., BlockID) and individual trees nested in farmlands (i.e., TreeID) as random factors, to account for variations due to clustered study design (Zuur et al. 2009). Similar models were also run to determine the effects of *C. africana* and *C. macrostachyus* on leaf litter decomposition

by including the incubation period (time) as a fixed covariate. Pairwise differences in the mean values of soil properties and leaf litter mass loss were assessed with Tukey's posthoc test using 'glht' function in the 'multcomp' R package (Hothorn et al. 2023). All model assumptions were assessed, resulting in log-transformation of pH, AP, and leaf litter mass loss in both *C. africana* and *C. macrostachyus*. All fixed covariates were assessed for interaction, and checked for potential multicollinearity using the variance inflation factor (threshold of $VIF \leq 5$) before LMM analyses. Final models were selected based on Akaike's information criteria (AIC) using the *get.models* function on the object returned by the 'dredge' function in the 'MuMIn' R package (Barton 2019). Marginal and conditional R^2 coefficients were calculated for each final model (Nakagawa & Schielzeth 2013). Linear mixed effect models were performed using the 'lmer' function in the 'lme4' R package (Bates et al. 2023).

3. Results

3.1 Soil properties under *Cordia africana* and *Croton macrostachyus*

We showed that soil properties significantly varied among distances relative to trunks of *C. macrostachyus* and *C. africana* trees (Table 1). All variables showed decreasing trends in mean values with increasing distance from tree trunks (Fig. 2). Other than pH and CEC, there were significant variations in soil properties between the tree species (Fig. 2; Online Resource 2). The higher mean values of soil properties were recorded under *C. macrostachyus* than under *C. africana* (Fig. 3; Table 1).

3.2 Litter decomposition under *Cordia africana* and *Croton macrostachyus*

Leaf litter decomposition rates varied strongly between radial distances ($F = 1325.6$, $P < 0.0001$), tree species ($F = 415.9$, $P < 0.0001$), and litter incubation periods ($F = 2564.6$, $P < 0.0001$). Mass loss strongly decreased with distance but increased over time (Fig. 4; Online Resource 3). The higher average mass loss was observed under *C. macrostachyus* (49.59%) than under *C. africana* (41.12%) (Fig. 3; Table 1).

Table 1 Summary of the mean ($\pm$ SD) values of soil variables and percentage leaf litter mass loss along distance gradient under *Cordia africana* and *Croton macrostachyus* trees in Bullen District, Benshangul Gumuz, northwestern Ethiopia. N= 45 per species. $P < 0.05$. (*) $0.10 \geq P\text{-value} > 0.05$; * $0.05 \geq P\text{-value} > 0.01$; ** $0.01 \geq P\text{-value} > 0.001$; *** $0.001 \geq P\text{-value}$. Distance: 1/3*crown radius, 2/3*crown radius, and 3*crown radius in meters (m).

Variables	1/3 * crown radius (m)	2/3 * crown radius (m)	3* crown radius (m)	overall mean
<i>C. africana</i>				
pH-H ₂ O	5,95±0,27 ^a	5,69±0,15 ^b	5,29±0,10 ^c	5,64±0,33
TN (%)	0,17±0,03 ^a	0,16±0,02 ^b	0,11±0,02 ^c	0,21±0,06
AP (mg/Kg)	3,57±1,35 ^a	2,66±0,89 ^b	1,46±0,60 ^c	3,43±2,56
OC (%)	2,16±0,40 ^a	1,76±0,22 ^b	1,30±0,22 ^c	2,45±0,81
CEC (meq/100g)	29,81±5,51 ^a	23,69±3,10 ^b	18,39±2,39 ^c	23,40±6,27
Mass loss (%)	28,75±6,56 ^a	37,26±9,03 ^b	57,34±9,97 ^c	41,12±14,87
<i>C. macrostachyus</i>				
pH-H ₂ O	6,01±0,21 ^a	5,77±0,10 ^b	5,30±0,12 ^c	5,69±0,33
TN (%)	0,25±0,05 ^a	0,21±0,04 ^b	0,16±0,05 ^c	0,21±0,06
AP (mg/Kg)	5,54±3,24 ^a	3,25±0,90 ^b	1,51±0,47 ^c	3,43±2,56
OC (%)	2,96±0,57 ^a	2,71±0,68 ^a	1,68±0,51 ^b	2,45±0,81
CEC (meq/100g)	28,75±4,35 ^a	23,83±3,56 ^b	17,63±4,96 ^c	23,40±6,27
Mass loss (%)	35,09±7,46 ^a	46,21±10,14 ^b	67,48±9,00 ^c	49,59±16,14

Table 2 Parameter estimates of the linear mixed models for soil properties and litter decomposition (N= 45 per species). F value/ beta-coefficients are given for each predictor. Marginal (R²m) and Conditional (R²c) given for each final model. Estimates for distance: D₁= 1/3 * crown radius (m), D₂= 2/3 * crown radius (m), D₃= 3 * crown radius (m). Time: t₁= 30 days, t₂= 60 days, t₃= 90 days. Tree species: CA= *Cordia africana*, CM= *Croton macrostachyus*. (*) 0.10 ≥ P-value > 0.05; * 0.05 ≥ P-value > 0.01; **0.01 ≥ P-value > 0.001; ***0.001 ≥ P-value.

Variables	Distance	Tree species	Time	R ² m/R ² c
pH-H ₂ O	448.0*/ D ₁ : 5.9 D ₂ : 5.7 D ₃ : 5.3	1.6/ CA: 5.9 CM: 6.0	-	73.7/78.1
TN (%)	162.7***/ D ₁ : 0.18 D ₂ : 0.15 D ₃ : 0.11	17.1**/ CA: 0.18 CM: 0.24	-	57.4/76.3
AP (mg/Kg)	102.7***/ D ₁ : 4.0 D ₂ : 2.4 D ₃ : 1.0	5.1*/ CA: 4.0 CM: 5.0	-	41.6/52.5
SOC (%)	193.1***/ D ₁ : 2.2 D ₂ : 1.9 D ₃ : 1.1	17.3**/ CA: 2.2 CM: 2.9	-	60.0/75.0
CEC (meq/100g)	216.7***/ D ₁ : 29.5 D ₂ : 24.0 D ₃ : 18.2	0.17/ CA: 29.5 CM: 29.0	-	56.0/65.3
Litter decomposition	1325.6***/ D ₁ : 3.5 D ₂ : 3.4 D ₃ : 3.1	415.9***/ CA: 3.5 CM: 3.7	2564.4***/ t ₁ = 3.5 t ₂ = 3.8 t ₃ = 4.2	0.96.8/96.9

4. Discussion

4.1 Effect of tree species on litter decomposition

It is widely believed that inherent litter quality exerts strong effects on initial stage litter decomposition (Djukic et al. 2018; Petraglia et al. 2019). Our results revealed that *C. macrostachyus* leaf litters decomposed faster than *C. africana* at all-time points across distance gradient from the tree trunks (Fig. 4, Table 1 & Online Resource 3). This difference in decomposition rate between the tree species could be associated with the intrinsic variations in their litter quality (Bakker et al. 2011; Gao et al. 2016; Maynard et al. 2022; Zhao et al. 2022). Overall, for example, tree species with high leaf nutrient content (e.g., nitrogen) and low carbon-nitrogen ratio tend to decompose faster than those with low nutrient and high carbon-nitrogen ratio (Cornwell et al. 2008; Zhao et al. 2017; Wallwork et al. 2023). In this connection, consistent with our results, other studies showed that *C. macrostachyus* had higher leaf nutrient contents and rate of decomposition than *C. africana* (Gindaba et al. 2005b; Mahari 2014; Negash & Starr 2021).

In addition to their direct effects through litter quality, agroforestry trees can influence litter decomposition through their impacts on microclimate conditions (Gosme et al. 2020; de Carvalho et al. 2021) or inducing changes in decomposer community composition (Lagerlöf et al. 2014; Beule et al. 2022). We found a strongly higher rate of litter decomposition under the tree canopies than the open fields (Fig. 2, Table 2 & Online Resource 3), indicating tree species effect on litter decomposition possibly due to their effects on microclimate or decomposer communities or both. For example, Mohammed et al. (2018) showed a significantly lower soil temperature and a higher moisture content under canopies of *C. macrostachyus* and *C. africana* trees, which, in turn, were found to favor increased rates of litter decomposition under their canopies (Mahari 2014; Negash & Starr 2021). Interestingly, these microclimatic effects were revealed under canopies of other agroforestry tree species (Belsky et al. 1993; Akpo et al. 2005; Lott et al. 2009; Tanga et al. 2014), with consequences to litter decomposition (Akpalu et al. 2020; Negash & Starr 2021). We further argue that the observed difference in litter mass loss between the tree species could be associated with soil microclimate driven changes in decomposer community composition (Kurzatkowski et al. 2004; Beule et al. 2022; Ortiz et al. 2023). For example, Ortiz et al. (2023) compared the abundance and composition of soil fauna under agroforestry and non-agroforestry systems, and found a higher values of beneficial soil organisms under agroforestry systems, which are proven to play an important role in litter decomposition (Kurzatkowski et al. 2004; Beule et al. 2022).

4.2 Effect of tree species on soil properties

Integrating trees with crops in farmlands is encouraged due to the growing evidence that trees enhance soil nutrient status (Pinho et al. 2012; Pardon et al. 2017). We found that the mean soil pH, SOC, TN, AP, and CEC were all significantly higher under both *C. macrostachyus* and *C. africana* trees at the nearest distance from the tree trunks (Fig. 2, Table 1 & Online Resource 2). The variations could be attributed to higher organic matter contents arising from the accumulation of more litter under the tree canopies than otherwise, releasing more nutrients through litter decomposition (Gindaba et al. 2005b; Mahari 2014; Mamo 2017; Mohammed et al. 2018; Dori et al. 2022; Gota 2022; Mesfin & Haileselassie 2022).

Mohammed et al. (2018) and Mahari (2014), for example, showed a significantly higher soil TN, AP, SOC, and CEC under canopies of *C. macrostachyus* and *C. africana* elsewhere in Ethiopia, reaffirming the overriding effect of agroforestry trees on soil nutrient status (Pinho et al. 2012; Bedada & Goshu 2021; Mahmud et al. 2021; Tsufac et al. 2021; Fahad et al. 2022). However, evidence is well-established that trees differentially influence soil properties in agroforestry systems due to intrinsic variations in their relative resource use strategies (Rhoades 1996; Isaac & Borden 2019; Maynard et al. 2022). Tree species with acquisitive strategies tend to shade readily decomposing leaves faster than those with conservative use strategies (Wright et al. 2004; Zhao et al. 2017; Gorné et al. 2022; Wallwork et al. 2023). We found that *C. macrostachyus* had significantly higher mean values for all measured soil variables under its canopies than *C. africana* (Fig. 3, Table 1 & 2), which is also corroborated by numerous previous studies (Gindaba et al. 2005b; Mahari 2014; Getachew et al. 2015; Mohammed et al. 2018). Gindaba et al. (2005) and Mahari (2014), for example, showed that *C. macrostachyus* had higher leaf nutrient and lower carbon and lignin contents compared to *C. africana*, suggesting the latter being relatively a more resource conservative species (Wright et al. 2004; Gorné et al. 2022).

4.3 Implications for use in farmlands

Tropical soils, and the sub-Sahara African soils, in particular, are among the most degraded soils with severe consequences to food production (Tully et al. 2015; Zingore et al. 2015). Agroforestry practices seem to bring sustainable solutions to replenishing soil quality while also positively contributing to human and environmental health (Brown et al. 2018; Pantera et al. 2021). Yet, implementing agroforestry comes with many challenges and tradeoffs that demand a strong knowledge-base of multipurpose tree species for successful utilization. In this respect, understanding tree-soil interactions in agroforestry systems is a key step to whether or not to recommend the use of a specific tree species for integration with annual crops on farmlands. Our study clearly demonstrated that *C. africana* and *C. macrostachyus* enhance soil nutrient status and litter decomposition, providing important evidence for raising public awareness and positively influencing policymakers. Future studies should nonetheless explore if the improvements in soil properties are strongly associated with crop yields and determine tree densities to optimize tradeoffs.

Conclusions

Our results showed that scattered *C. africana* and *C. macrostachyus* trees in farmlands seem to significantly improve soil properties. This could happen either directly through nutrient addition, or indirectly through ameliorating microclimate for litter decomposition. Our results suggest that both mechanisms might occur with trees on farmlands. First, soils under canopies of *C. africana* and *C. macrostachyus* had higher nutrient contents than soils outside their canopies, and second, litter decomposition rates were higher under tree canopies than outside, suggesting both litter addition and microclimate-driven effects of trees on soil properties. Future studies should disentangle the role of litter addition and microclimate mediated effects of trees on soil properties in farmlands.

Declarations

Author Contribution

Y.U.U. conceived the research idea and design; G.N.A. collected data; Y.U.U. and G.N.A. performed statistical analyses; Y.U.U. wrote the manuscript and G.N.A. commented on the manuscript.

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Figures

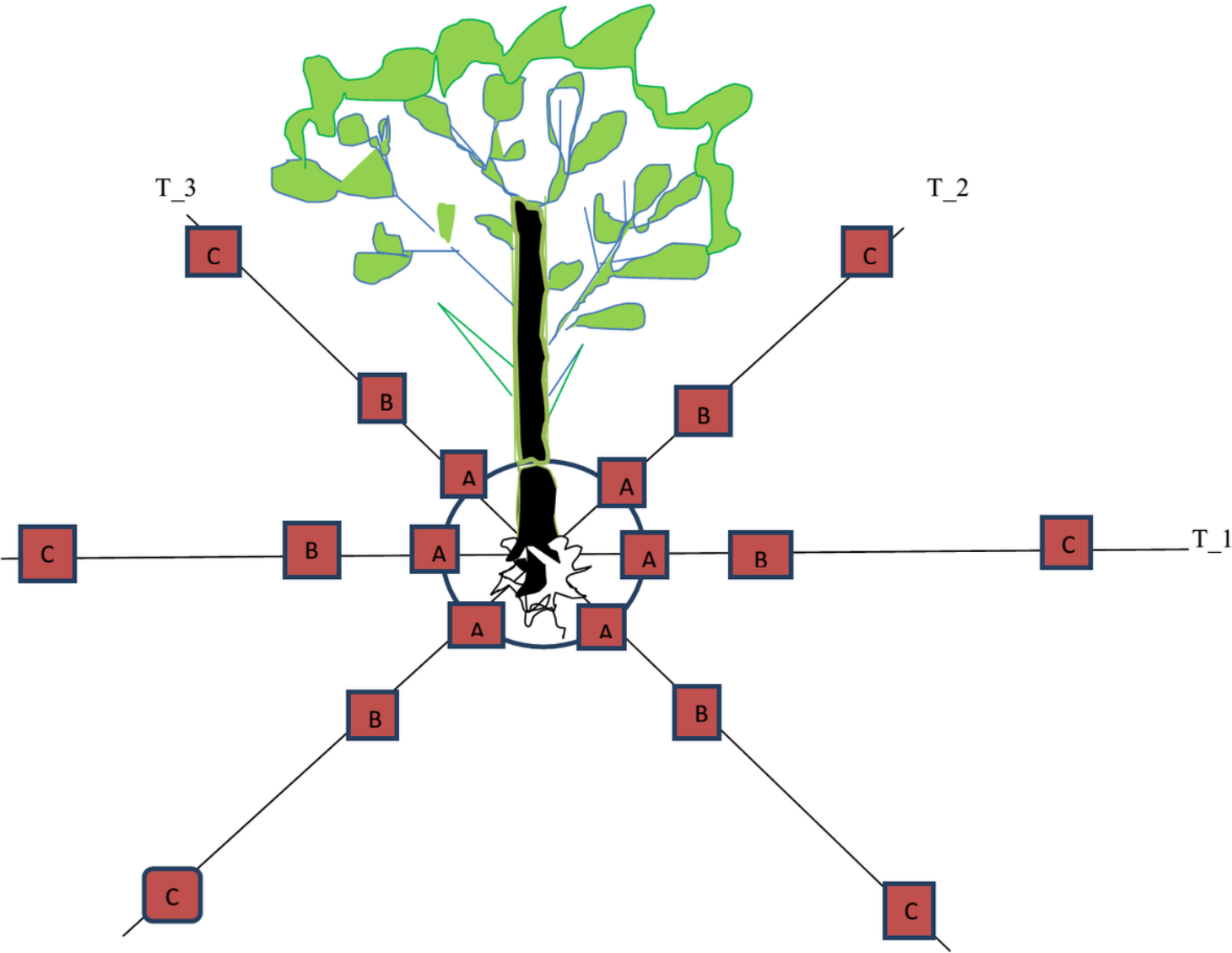


Figure 1

Schematic representation of a diagram showing soil sampling and litter burial points along distance gradient from tree trunks under *C. macrostachyus* and *C. africana* trees. T_1 = Transect 1; T_2 = Transect 2; T_3 = Transect 3. Distance: A= $1/3 \times$ crown radius (m); B= $2/3 \times$ crown radius (m); C= $3 \times$ crown radius (m)

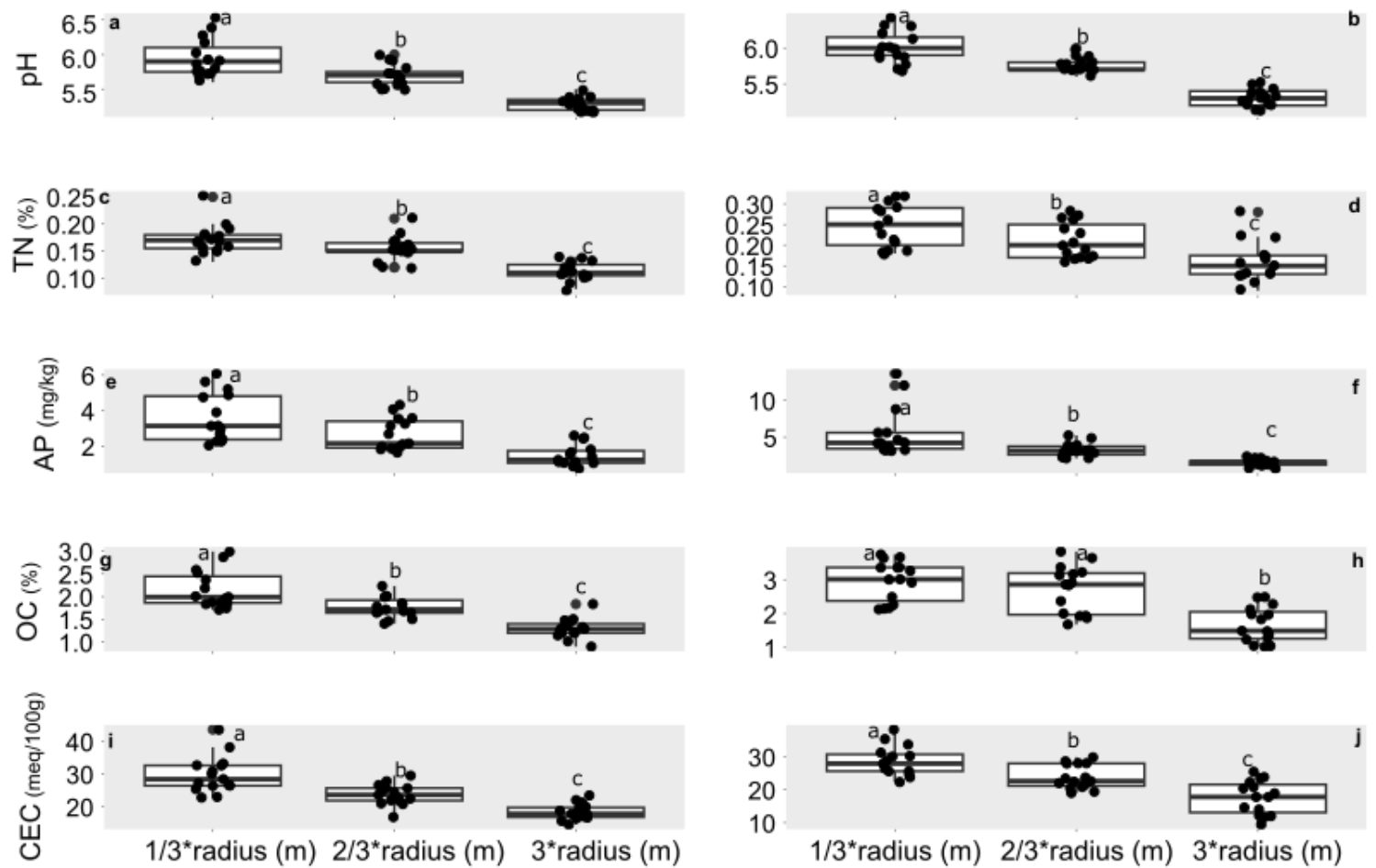


Figure 2

Boxplots for trends in soil properties along distance gradient from tree trunk under *C. africana* (a, c, e, g, i) and *C. macrostachyus* (b, d, f, h, j) trees in Bullen District, Benshangul Gumuz, northwestern Ethiopia (P < 0.05)

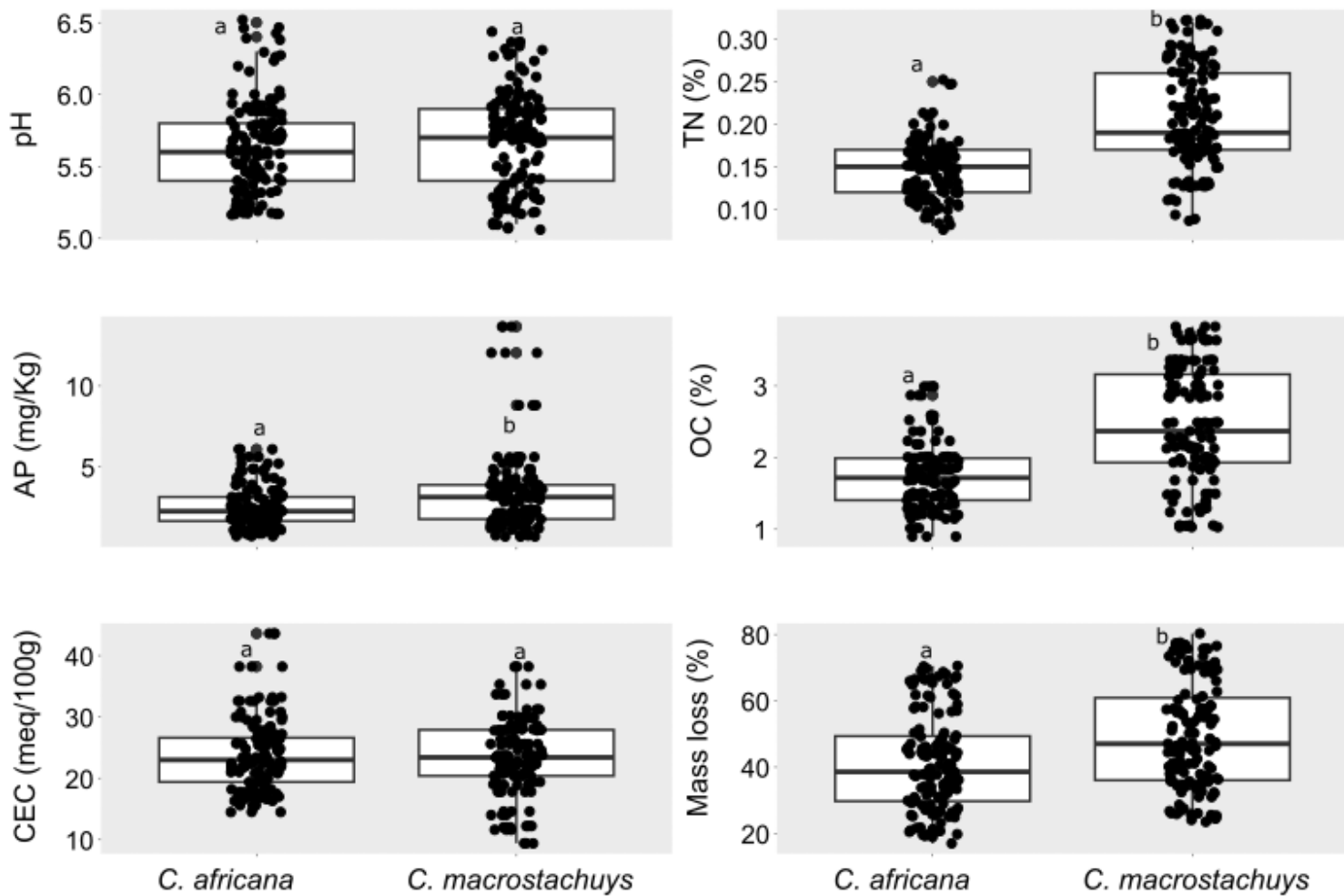


Figure 3

Boxplots comparing trends between soil properties under *C. africana* and *C. macrostachyus* trees in Bullen District, Benshangul Gumuz, northwestern Ethiopia (P < 0.05)

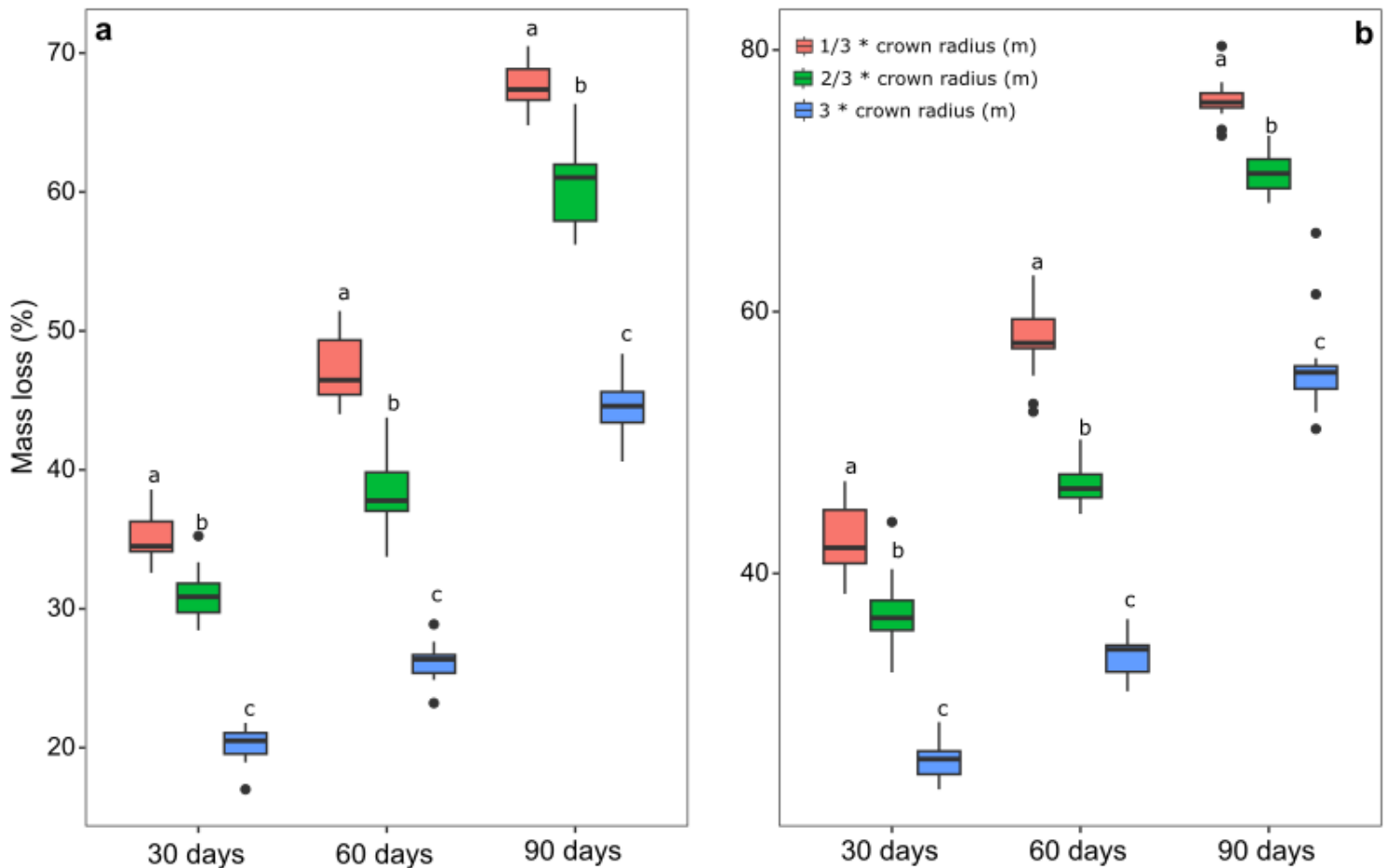


Figure 4

Boxplot showing trends in percentage litter mass loss along distance gradient from tree trunk (1/3 * crown radius (m), 2/3 * crown radius (m), 3 * crown radius (m)) under *C. africana* (a) and *C. macrostachyus* (b) over 90 days leaf litter incubation period in Bullen District, Benshangul Gumuz, northwestern Ethiopia (P < 0.05)

Supplementary Files

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