Plant productivity enhancement in a simulated Amazonian Dark Earth (Terra Preta Nova)

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Abstract

Amazonian Dark Earths (ADEs) are highly fertile human-made soils, commonly found in Amazonia. These soils have a unique soil biota and a high content of charcoal, organic C, available P and Ca as a result of repeated burning and additions of bone and organic matter (OM) over centuries of Amerindian occupation. "*Terra Preta Nova*" techniques aim to replicate these soils by adding ADE components, but little is known of their single and synergistic impacts on plant productivity. We replicated an ADE by adding five distinct components and studying their single and interactive effects on maize production in the greenhouse. Earthworms (*Pontoscolex corethrurus*), OM (horse manure), biochar (from Brazil nut), ground fish bones and pottery sherds were added to a nutrient poor soil, and after 60 days plant height, above and below-ground (root) biomass, root length, and soil fertility levels were assessed. The main components affecting plant productivity were earthworms, OM and fish bone meal, with significant synergistic effects, while biochar and pottery, although significant, were not as important for plant growth and soil fertility.

Keywords: soil fertility, agricultural sustainability, Amazonia, soil biology, soil amelioration

Introduction

Over centuries of occupation, Amazonian Amerindian populations generated highly fertile Amazonian Dark Earths (ADEs, also known as *Terra Preta de Índio* in Portuguese), by the addition of fresh and burned organic materials (human excrements, animal remains such as fish bones, plant organic matter) and pottery sherds. These soils are highly sought out by present day farmers in the region due to the high plant production potential. They tend to have high soil C, available Ca and P contents, as well as a unique soil biota, including important earthworm populations (Cunha *et al.,* 2016). It is well known that organic materials such as animal manures (Bayu, Rethman and Hammes, 2008) and fish bone meal (Blatt, 1991), biochar (Ding *et al.,* 2016) and earthworms (Brown, Edwards and Brussaard, 2004) can positively affect plant production. However, the impact of pottery sherds on plant production is not well known, though they may contain important nutrient stocks (Rodrigues, 2014). Very few studies have reported results of ADE recreation (*Terra Preta Nova*), on plant production in nutrient poor soils, and none of them evaluated interactions between the different components of ADEs. Hence, the present study was undertaken to evaluate the impact of organic manure, biochar, fish bone meal, earthworms and ceramics on plant production in a nutrient poor Latosol.

Methodology

A clayey yellow Latosol was obtained from Paraopeba-MG, in Central Brazil, and a fractional factorial experiment was installed using 160 pots with 4 kg soil (dry wt equivalent) each. In each pot, each of the five components of ADEs were added or not, generating 32 treatments, each of with was replicated five times (Figure 1, Table 1). A hybrid maize variety was grown in the greenhouse, and 55 days after germination, plant production parameters (height, fresh biomass above and below-ground, root length), soil fertility (exchangeable nutrients, pH), and earthworm survival were recorded. When added to the treatments, earthworms (*Pontoscolex corethrurus*) were 5 individuals, biochar from Brazil nut shells at 10 percent (w/w), ceramic pieces (pottery shards) at 10 g Kg^{-1} soil, partially composted organic matter (horse manure) at the rate needed to reach 2.6 percent C in the soil, and fish bone meal at fertilizer rate of 500 mg dm^{-3} P in the soil. Earthworm abundance, soil C and pottery mass were within values that can be found in ADEs under field conditions. The pots were randomly placed in the greenhouse and a single maize plant per plot kept after germination. Statistical analyses (individual treatment effects and interactions) were evaluated using General Linear Models (GLM) with R (RStudio Team, 2016).

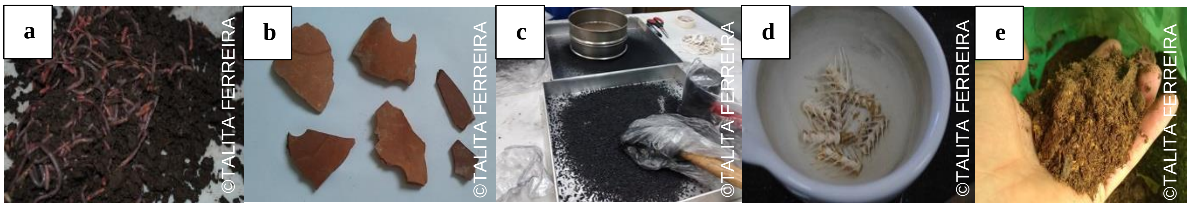

Figure 1: Components of the ADEs used in the Terra Preta Nova experiment in the greenhouse evaluating maize production after 60 days

a) Earthworms Pontoscolex corethrurus; b) Pottery shards; c) Biochar from Brazil nut shells; d) Fish bones before grinding (to produce fish bone meal); e) partially composted horse manure

Results

All of the ADE components used to create the *Terra Preta Nova* had significant impacts on maize production (Table 1). Surprisingly, biochar had a slightly negative impact and ceramics had a major positive impact on shoot mass, while highest positive impacts overall on plant parameters (up to 26 percent increase in shoot mass) were observed with addition of organic matter and fish bone meal, in particular (Table 2). Earthworms positively impacted both shoot and root mass (Tables 1, 2). Several important two-way as well as three-way interactions were detected (Table 1). Four-way interactions were only significant in the absence of OM, with all the remaining components (W x B x P x F). Soil fertility impacts were observed mainly with addition of fish bone meal, but also with OM, with significant increases in available P levels.

Table 1: Results of the GLM tests of significance of main-effects of the different ADE components (factors) and their combined treatments (interactive effects) on maize shoot and root biomass and length after 55 days germination under greenhouse conditions

Treatment	Shoot mass	Root mass	Root length	Treatment	Shoot mass	Root mass	Root length
W	***	***	ns	W x B x P	ns	ns	ns
OM	***	***	***	W x B x OM	ns	ns	ns
P	***	ns	ns	W x P x OM	ns	ns	ns
F	***	***	***	**W x B x F**	**	**	ns
B	*	ns	ns	W x P x F	ns	ns	ns
W x OM	**	***	***	**W x OM x F**	ns	*	***
W x P	ns	ns	ns	**B x P x OM**	***	***	ns
W x F	***	***	**	**B x P x F**	**	ns	ns
W x B	***	*	ns	**B x OM x F**	*	ns	ns
OM x P	ns	ns	***	**P x OM x F**	*	ns	ns
OM x F	***	***	***	W x B x P x OM	ns	ns	ns
OM x B	*	**	***	**W x B x P x F**	***	***	ns
P x F	ns	**	**	W x B x OM x F	ns	ns	ns
P x B	**	***	ns	W x P x OM x F	ns	ns	ns
F x B	ns	ns	*	B x P x OM x F	ns	ns	ns

W=earthworm; OM=organic matter (horse manure); P=pottery sherds; F=fish bone meal; B=biochar. Treatments with significant main effects or interactions are highlighted in bold.

Table 2: Mean values of plant height, shoot and root biomass and root length (and correspondent increase) of maize plants for each component of the ADE used in the *Terra Preta Nova* greenhouse experiment

Treatment	Plant height (cm)	Shoot biomass (g)	Root biomass (g)	Root length (cm)
Earthworm				
Presence	**95.7 (+2%)**	**12.2 (+20%)**	**2.78 (+11%)**	12784
Absence	**93.4**	**10.2**	**2.50**	12674
Biochar				
Presence	94.9	**11.8 (-3%)**	2.70	12516
Absence	95.7	**12.2**	2.78	12784
Ceramics				
Presence	98.5	**13.0 (+24%)**	2.94	13488
Absence	94.3	**11.3**	2.60	12266
OM				
Presence	**99.9 (+6%)**	**13.4 (+26%)**	**3.03 (+17%)**	**13889 (+13%)**
Absence	**94.3**	**10.6**	**2.60**	**12266**
Fish bone meal				
Presence	**100.0 (+10%)**	**13.4 (+26%)**	**3.02 (+24%)**	**13789 (+19%)**
Absence	**91.0**	**10.6**	**2.44**	**11546**

Treatments with significant presence effects are highlighted in bold typeface.

Discussion

A spiked interest in "*Terra Preta Nova*" began around 10 years ago, due to the supposed high potential soil fertility and C sequestration effects of biochar (Lehmann, 2009). In fact, the use of biochar and organic matter together had significant interactive effects on plant production parameters. Although biochar use in agriculture has considerably increased, there are still some concerns regarding its possible impacts to soil quality in the long term (Verheijen *et al.*, 2010). Furthermore, in the present experiment, use of biochar resulted in a slight negative impact on maize shoot mass, but root mass and length were not affected. However, several interactions with biochar were significant, showing that it has potential to impact plant parameters depending on what is used together with it. Physical parameters were not measured, and biochar is known to have impacts on soil porosity and water movement (Blanco-Canqui, 2017).

Earthworms are well known plant growth promoters, and *P. corethrurus* is distributed throughout the tropical world, particularly in disturbed regions and agroecosystems, where it can have important effects on soil properties (Taheri, Pelosi and Dupont, 2018). Furthermore, earthworms can ingest biochar (Ponge *et al.,* 2006), and impact organic matter mineralization and nutrient availability, and these may be important reasons why they had positive impacts on maize production in the present experiment (Brown, Edwards and Brussaard, 2004).

Pottery sherds may be important in long-term nutrient release (Rodrigues, 2014), but also in modifying soil physical properties such as porosity and water availability, and in the present case, their addition was important for promoting shoot growth. Little is known of the use of potsherds in agriculture, and they may play a role in *Terra Preta Nova*, particularly in clayey soils with physical restrictions to plant growth.

Organic manures are important for sustainable agriculture in small farms (Bayu, Rethman and Hammes, 2008), particularly where inorganic fertilizers are less available and/or unaffordable. They have important fertilizer value contributing with K, Ca, Mg, N, P, S and B to plant nutrient needs. Fish bone meal and OM were the two most important plant growth promoters in this *Terra Preta Nova* experiment. Fish bone meal also has significant amounts of Ca, P, Mg, S, Fe, Zn, Mn and Cd (Buddhachat *et al.,* 2016), all of which are important for plant growth. The use of high-P and N-containing organic residues is an important strategy for increasing soil fertility and plant production in nutrient-poor soils of the tropics. In acid soils, additional benefits of bone meal use may be long-term impacts on pH and associated nutrient availabilities.

Conclusions

These preliminary results show the potential for wider use of household and farm refuses, such as bones, manures and broken pottery in soil improvement, and the importance of interactive effects in affecting plant growth, factors that need further attention in future soil fertility and management schemes such as Terra Preta Nova technologies, based on the Amazonian Dark Earth concept. However, longer-term and field experiments are needed using these concepts in order to verify these phenomena.

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