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EFEITOS DO CARVÃO DE COCO BABAÇU E ADUBAÇÃO ORGANO-MINERAL NA FERTILIDADE DE UM ARGISSOLO CULTIVADO COM MILHO NA PERIFERIA LESTE DA AMAZÔNIA

São Luis – Maranhão
Setembro – 2011

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Engenheira Agrônoma

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Orientador: Dr. Christoph Gehring

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Não se precipite em querer vencer. Há sempre um encanto a ser absorvido nos períodos dos preparos...
Antes da vitória a luta!!!!

Pe. Fábio de Melo

DEDICO *aos meus pais Gerard e Isabel, por todo amor, educação e dedicação.*

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Capítulo I

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*A Introdução Geral segue as normas da ABNT

RESUMO

O carvão vegetal quando aplicado ao solo pode proporcionar benefícios nos atributos químicos e físicos aumentando a produção das culturas. O trabalho teve como objetivo avaliar o efeito do carvão de babaçu associado a diferentes fontes de adubação sobre o desenvolvimento do milho e na fertilidade de um Argissolo da periferia leste da Amazônia. O delineamento experimental foi em esquema fatorial 3x3 (3 doses de carvão x 3 formas de adubação). O carvão aumentou o pH, diminuiu a acidez potencial do solo, fixou e tornou mais disponível para a planta o P e o K, com ausência de cinza. Os efeitos gerados pelo carvão ocorreram com apenas 45 dias, descordando com a maioria da literatura, que diz ser necessário longos períodos para o carvão fazer efeito no solo. Também afetou positivamente o desenvolvimento da planta, sendo observado maior acúmulo de matéria seca na parte aérea e maior densidade radicular. O carvão quando associado à fonte de adubação orgânica promove condições favoráveis ao bom desenvolvimento da planta. A aplicação do carvão como prática agrícola pode ser viável uma vez que traz benefícios ao solo e ao desenvolvimento da planta podendo ser uma alternativa sustentável às regiões dos trópicos.

PALAVRA CHAVE:

Fertilidade do solo, Adubação orgânica, Potássio, Fósforo

1 INTRODUÇÃO GERAL

1.1 SOLOS DA REGIÃO AMAZÔNICA E PRÁTICAS AGRÍCOLAS

Os Latossolos e os Argissolos são as classes de solo predominantes na região Amazônica, cobrindo aproximadamente 75% de sua bacia. Os Latossolos nessa região são profundos, extremamente intemperizados e geralmente de baixa fertilidade natural (Bernoux et al., 2002). Os Argissolos possuem, em geral, argila de baixa atividade e reduzida capacidade de troca de cátions (Moraes et al., 1996).

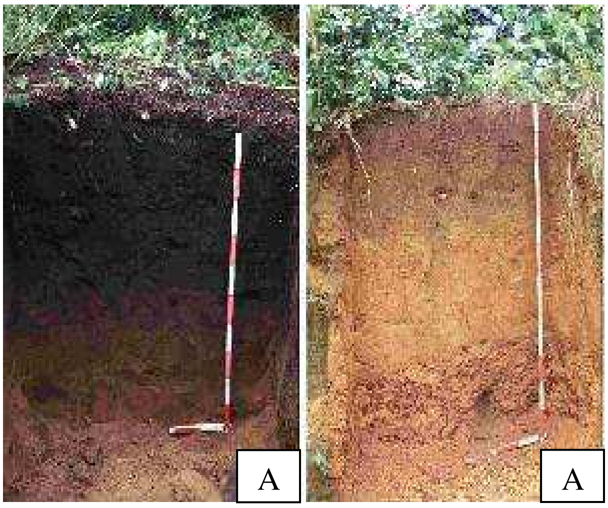
A baixa fertilidade química dos solos Amazônicos está muito associada com o seu material de origem e a atuação do intemperismo sofrido devido às condições climáticas presente nessa região. As fortes chuvas causam problemas sérios de lixiviação de nutrientes (Hölscher et al., 1997) e com a constante umidade e elevada temperatura as taxas de decomposição da matéria orgânica ocorrem de forma acelerada.

O Maranhão possui uma parte do seu território dentro da chamada Amazônia Legal (região leste) que possui em seus solos algumas das características citadas acima. Associado a esses solos de baixa fertilidade natural o Maranhão ainda possui a agricultura de derruba e queima ou itinerante como prática agrícola familiar, que associada ao curto tempo de pousio fez com que essa prática entrasse em uma crise ambiental e socioeconômica (Gehring, 2006).

A busca por alternativas à agricultura itinerante é incessante com a implantação de diversas práticas, que podem ser classificadas nas seguintes categorias: (i) revolução verde, (ii) sistemas agroflorestais e (iii) roça melhorada (Gehring, 2006). Atualmente o que vem sendo estudado por pesquisadores é a aplicação de carvão vegetal no solo com a finalidade de melhorar a agricultura em ambientes tropicais e recuperar solos degradados. A aplicação do carvão no solo surgiu com as Terras Pretas de Índio, onde se tenta, em parte, reproduzir suas características tornando os solos mais férteis e sustentáveis (Lehmann e Joseph 2009)

1.2 TERRA PRETA DE ÍNDIO

As Terras Pretas de Índio (TPIs) são solos encontrados na Bacia Amazônica que apresentam horizonte A antrópico (Au) (Kern et al., 1999) com elevada fertilidade, alto teor de matéria orgânica (MO) e nutrientes, como nitrogênio, fósforo, potássio e cálcio (Cunha et al., 2009) (Figura 1).



Fonte: WOOD & GLASIER, (2004).

Figura 1 – Comparação entre um perfil de Terra Preta de Índio (A) e um solo adjacente (B).

O processo de formação das TPIs está relacionado com o depósito de resíduos de origem vegetal (folhas e talos de palmeiras diversas, cascas de mandioca e sementes) e de origem animal (ossos, sangue, gordura, fezes, carapaças de quelônios e conchas), além de uma grande quantidade de cinzas e resíduos de fogueiras (carvão vegetal) realizadas por homens pré-históricos. Esse grande aporte de material orgânico, provavelmente, tenha contribuído para a formação destes solos altamente férteis (Kern e Kämpf, 1989; Kern, 1996).

Os solos com Terra Preta de Índio estão localizados em sítios arqueológicos distribuídos praticamente em toda a região amazônica, a grande maioria apresenta de 2 a 5 ha, porém existem áreas com até 100 ha de extensão.

1.3 APLICAÇÃO DO CARVÃO VEGETAL NO SOLO

Fragmentos de carvão vegetal podem ser encontrados em diversos solos na forma de carbono pirogênico ou black carbon ou biochar, que podem ter sido resultado de queimadas naturais ou da ação humana.

O carvão ou biochar é rico em carbono e produzido a partir da carbonização de matérias de fonte orgânica (ex.: madeira). A produção do carvão é realizada por meio da decomposição térmica do material orgânico com pouca ou na ausência de oxigênio em temperaturas relativamente baixas (<700ºC) (Lehmann e Joseph 2009)

O carvão vegetal é produzido pelo processo de carbonização ou pirólise, ou seja, a partir do aquecimento com temperaturas superiores a 300 °C, em atmosfera pobre ou na ausência de oxigênio, concentrando o teor de carbono pelo efeito do aquecimento. Dependendo da temperatura final de carbonização, pode apresentar diferentes composições (Trompowsky et al., 2005), em sua maior parte, de estruturas aromáticas caracterizadas por ligações em forma de anel benzênico e átomos de C com oxigênio (O) ou hidrogênio (H) (Lehman e Joseph, 2009). Essas legações entre o C-O e C-H, mantêm as estruturas aromáticas estáveis do carvão, que servem para medir o grau de aromaticidade dos compostos (Hammes et al., 2006).

Estruturalmente o carvão é poroso, uma vez que a água e os compostos voláteis (CO, CO_2 e CH_4) contidos na madeira foram eliminados durante o processo de carbonização, deixando espaços vazios. Cerca de 70 a 80% do volume do carvão vegetal é formado por poros. Logo, o carvão apresenta baixa densidade, variando de 0,3 a 0,4kg dm^3 (Cunha, 2005).

Devido à sua composição e estrutura molecular o carvão pode contribuir para a fertilidade do solo e sua sustentabilidade (Cunha, 2005). As unidades aromáticas presentes na estrutura periférica do carbono pirogênico contêm constituintes ácidos, principalmente carboxílicos (Glaser et al., 2002), que explicariam os altos valores da CTC dos solos das TPI's. Os componentes húmicos derivados do carbono pirogênico também apresentam altas aromaticidade e densidade de cargas (Cunha, 2005).

A aplicação de carvão no solo pode proporcionar o aumento do nível de matéria orgânica do solo e da capacidade de retenção de nutrientes, reduzindo perdas por lixiviação e aumentando a disponibilidade de nutrientes às plantas (Glasser et al., 2001; Lehmann et al., 2003); aumento da quantidade e estabilidade da matéria orgânica, o que contribui para o sequestro de carbono (Batjes e Sombroek, 1997); aumento da germinação e da biomassa vegetal (Chidumayo, 1994) e aumento da produção das culturas (Lehmann et al., 2003; Ogundute et al., 2004).

1.5 CARVÃO DE BABAÇU

O Brasil é um dos maiores produtores de carvão vegetal, respondendo por cerca de 1/3 da produção mundial segundo a Sociedade Brasileira de Silvicultura (2006) .O setor industrial caracteriza-se como o principal consumidor de carvão vegetal, sendo responsável pelo consumo de 89% das 10,5 milhões de toneladas de carvão vegetal produzidos no ano de 2007 (BEN, 2008).

No Maranhão uma das matérias primas promissoras para a produção de carvão é o coco babaçu, que também está presente na rotina dos pequenos produtores, que vivem do extrativismo do coco. A palmeira do babaçu domina as paisagens perturbadas pelo homem, transformadas como resultado da agricultura itinerante (Muniz, 2006).

Como na maioria das regiões do Brasil, a produção do carvão de coco babaçu no Maranhão também é praticada sem muita tecnologia (Brito, 1990). Como não é necessária a derrubada das palmeiras e o carvão é produzido a partir dos frutos que já caíram no chão e que são utilizados para extração da amêndoa, o carvão de coco babaçu é considerado ecológico e renovável (Santos et al., 2011)

A utilização do endocarpo do coco para a produção de carvão comparando com os outros componentes do fruto apresenta uma queima mais lenta, produzindo pequena quantidade de cinzas. Estas características reforçam sua qualidade de bom material para fabricação de carvão (Teixeira, 2002).

Sendo assim a produção de carvão pode ser associada com seu uso na agricultura, uma vez que há sobras de carvão, que não são vendidos por não possuírem o tamanho adequado para a comercialização. Não apenas do babaçu, mas como de outras fontes de produção o carvão pode vir a ser uma alternativa no uso agrícola sustentável nos trópicos.

2 REFERÊNCIA

BATJES, N.; SOMBROEK, W. Possibilities for carbono sequestration in tropical and subtropical soil. **Global Change Biology**, v. 3, p. 161-173.1997.

BEN. **Balanço Energético Nacional** 2008 – Base 2007. Brasília, 2008.

BERANOUX, M.; CARVALHO, M.C.S.; VOLKOFF,B.; CERRI, C.C.; Brazil's soil carbono stocks. **Soil Science Society of America Journal**, Madison, v.66,p.888-896.2002.

BRITO, J. O. Princípios de produção e utilização de carvão vegetal de madeira. **Documentos florestais**, v. 9. p. 1-19. 1990.

CHIDUMAYO, E. Effects wood carbonization on soil and initial developmnt of seedlings in miombo woodland, BZâmbia. **Forest Ecology Manage**, v.70, p. 353-357. 1994.

CUNHA, T. J. F. **Ácidos húmicos de solos escuros da Amazônia (Terra Preta de Índio)**. 2005. 118 f. Tese de Doutorado. Universidade Federal Rural de Rio de Janeiro. Rio de Janeiro, 2005.

CUNHA, T. J. F; NOVOTNY, E. H.; MADARI, B. E.; BENITES, V. M.; MARTIN NETO, L.; SANTOS, G. A. CARBONO PIROGÊNICO. In TEIXEIRA, W. G.; KERN, D. C.; MADARI, B. E.; LIMA, E. N.; Woods, W. I. **As Terras Pretas de Índio da Amazônia: Sua Caracterização e Uso deste Conhecimento na Criação de Novas Áreas**. 1° ed. Manaus: Embrapa Amazônia Ocidental. 2009.p. 263-284.

GEHRING, C. O ambiente do trópico úmido e o manejo sustentável dos agrossistemas. In: MOURA, E. G.; AGUIAR, A. das C. F. **O desenvolvimento rural como forma de ampliação dos direitos no campo: Princípios e Tecnologias**. São Luis: UEMA, 2006. p. 101-140.

GLASER, B.; HAUMAIER, L.; GUGGENBERGER, G.; ZECH, W. **The Terra Preta phenomenon – a model for sustainable agriculture in the humid tropics.** Naturwissenschaften, Berlin, v. 88, n. 1, p. 37–41, 2001

GLASER, B., LEHMANN, J., ZECH, W. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal-a review. **Biology and Fertility of Soils** n.35, p. 219–230. 2002.

HAMMES, K.; SMERNIK, R. J.; SKJEMSTAD, J. O.; HERZOG, A.; VOGT, U. F.; SCHMIDT, M. W. I. Synthesis and characterisation of laboratory-charred grass straw (Oryza sativa) and chestnut wood (Castanea sativa) as reference materials for black carbon quantification. **Organic Geochemistry**, Oxford, v. 37, n. 11, p. 1629-1633, 2006.

HÖLSCHER, D.; MOELLER, R.F.; DENICH, M.;FÖLSTER, H. Nutrient input-output budget of shifting agriculture in eastern Amazonia. **Nutriente Cycling in Agroecosystems**, v.47, p. 49-57. 1997.

KERN, D. C.; KÄMPF, N. ANTIGOS ASSENTAMENTOS INDÍGENAS NA FORMAÇÃO DE SOLO COM TERRA PRETA ARQUEOLÓGICA NA REGIÃO DE ORIXIMINÁ, PARÁ. **REVISTA BRASILEIRA DE CIÊNCIA DO SOLO**, VIÇOSA, MG, v. 13, p. 219-225, 1989.

KERN, D. C.; KÄMPF, N.; WOODS, W. I.; DENEVAN, W. M.; COSTA, M. L. DA; FRAZÃO, F. J. L. **AS TERRAS PRETAS DE ÍNDIO NA AMAZÔNIA**. 1999.

KERN, D. C. **GEOQUÍMICA E PEDOGEOQUÍMICA DE SÍTIOS ARQUEOLÓGICOS COM TERRA PRETA NA FLORESTA NACIONAL DE CAXIUANÃ (PORTEL-PA).** 1996. 124 F. TESE (DOUTORADO EM GEOLOGIA)- CENTRO DE GEOCIÊNCIAS, UNIVERSIDADE FEDERAL DO PARÁ, BELÉM, [1996].

LEHMANN, J., KERN, D.C., GLASER, B.; WOODS, W.I. **Amazonian Dark Earths: Origin, Properties, Management**. Kluwer Academic Publishers, The Netherlands. 2003. 523p.

LEHMANN, J.; JOSEPH, S**., BIOCHAR FOR ENVIORONMENTAL MANAGEMENT**. London: Earthscan, 2009. 405p.

MORAES, J.F.L.; VOLKOFF, B. CERRI, C.C.; BERNOUXX, M. Soil properties under Amazon forest changes due to pasture installation in Rondônia, Brasil. **Geoderma**, Amsterdam, v.70, p.63-81.1996.

MUNIZ, F.H. A vegetação da região de transição entre a Amazônia e o Nordeste, diversidade e estrutura. In: Moura, E.G. **Agroambiente de transição**. UEMA, São Luis, 2006. p.53-69.

OGUNTUNDE, P.G., FOSU, M., AJAYI, A. E., VAN DE GIESEN, N. Effects of charcoal production on maize yield, chemical properties and texture. **Biology and Fertility of Soils,** v.39, p. 295–299, 2004.

SANTOS, K.W.S., SOUZA, R.J., SILVA, D.C. Fabricação de carvão vegetal a partir do fruto da palmeira babaçu, *Orbignya speciosa* (Mart.). Disponível em www.viagemnosaofrancisco.blogspot.com/2010/04/carvao-do-coco-do-babacu-projeto-da-apa.html. Acesso em 10.09.2011.

SBS – Sociedade Brasileira de Silvicultura. Fatos e Números do Brasil Florestal 2005 – SBS, 2006. Disponível em www.sbs.org.br. Acesso em 10.09.2011.

TEXEIRA, M.A. **Biomassa de babaçu no Brasil. Encontro de Energia Meio Rural**, São Paulo, Ano 4, 2002.

TROMPOWSKY, P. M.; BENITES, V. M.; MADARI, B. E.; PIMENTA, A. S.; HOCKADAY, W. C., Hatcher, P.G. Characterization of humic like substances obtained by chemical oxidation of eucalyptus charcoal. **Organic Geochemistry**, Oxford, v. 36, n. 11, p. 1480-1489, 2005.

Short-term effects of babassu charcoal on soil chemistry and maize development in an Ultisol with contrasting fertilizer regimes in northeastern Amazonia

Capítulo II

Short-term effects of babassu charcoal on soil chemistry and maize development in an Ultisol with contrasting fertilizer regimes in northeastern Amazonia

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ABSTRACT

Black carbon / biochar could be of potentially large importance as a multi-purpose low-cost production factor in tropical agriculture. This study investigates the effects of fine (i.e. ‘residual’) charcoal of babassu palm nuts on an Ultisol, in ‘intermediate’ (30 Mg ha^{-1}) and ‘high’ (60 Mg ha^{-1}) application rates. We follow the question of interactions between biochar and nutrients with three fertilizer regimes in a bifactorial scheme. Contrary to field studies over a season or several years, we follow the first 45 days of development of maize as our bio-indicator. Charcoal application strongly increased soil pH and reduced potential soil acidity. Both phosphorus and potassium concentrations increased strongly and near linearly with charcoal application rate, both in the soil (resin-extraction) and in maize tissue. Low P and K concentrations of babassu charcoal exclude the possibility of significant direct inputs via charcoal and call for the existence of indirect mechanisms for such increases. Whereas ‘intermediate’ charcoal dose was beneficial for maize development (biomass, root density), high charcoal application rate proved to be excessive and depress maize development under zero- and synthetic fertilizer regimes, but even more beneficial with organic fertilization. This study points to considerable short-term benefits of charcoal on soil fertility and thus to the great potential of biochar for tropical agriculture.

Keywords:

Attalea speciosa; Biochar; K-availability; organic fertilization; synthetic fertilization; P-availability.

1 INTRODUCTION

Next to Oxisols, Ultisols predominate throughout most of Amazonia (Jacomini and Camargo, 1996) and the humid tropics as a whole. These highly weathered soils are dominated by low-activity caolinite clays, are acid and frequently also subject to strong P-fixation (Sanchez, 1976). Under such problematic conditions, traditional slash-and-burn agriculture with increasing land-use pressure (shortened fallow-periods) rapidly turns unsustainable (McGrath et al. 2001). Under these circumstances, most 'conventional' (i.e. mechanization, high external input) efforts of agricultural innovation invariably fail (Zinn et al. 2005), with the notable exception of 'Terra Preta de Índio' (TPI) with very successful conventional operations. Soil organic matter is long known to be the key for tropical soil fertility, but efficient management of organic matter is hampered by the very fast decomposition dynamics caused by favorable equatorial temperature and humidity regimes (Tiessen et al. 1994). Effects of improved management efforts such as substitution of slash-and-burn by slash-and-mulch (Meléndez, 2004; Denich et al. 2005) are short-lived and tend to result in small net gains of soil organic matter as most carbon is lost to the atmosphere by respiration (Fearnside, 2000). Stabilization of organic matter in agroforestry systems via large mulch quantities does substantially increase soil organic matter (Aguiar et al. 2010), but most of this increase likewise is of labile character (Koutika, 2005) and therefore dependent on continuous high levels of organic matter input for its persistence.

Carbonization of organic matter increases its recalcitrance against decomposition, due to condensation of molecules and to the formation of aromatic compounds. This makes 'black carbon' or 'biochar' not only key for the high organic matter contents of TPI soils, but also an interesting production tool and management option for modern day agriculture (Topoliantz et al. 2005; Forbes et al. 2006; van Zwieten et al. 2010). Slash-and-char could constitute a promising alternative to slash-and-burn and slash-and-mulch forms of land preparation (Lehmann et al. 2006). Less radically, 'residual' (i.e. fine, without commercial value) charcoal constitutes a locally available resource in many tropical settings. We take the case of fine charcoal derived from the babassu palm nut with key socioeconomic importance in the region (Pinheiro and Frazão, 1995) and other large parts of peripheral Amazonia (Teixeira and Carvalho, 2007).

Charcoal application will pursue a set of differential objectives, ranging from improving soil physical and hydrological (Glaser et al. 2002; and Teixeira and Martins, 2003), chemical (Schimidt and Noack, 2000; MacKenzie et al. 2008) and biological (Pietkainen et al. 2000; Rondon et al. 2007; Warnok et al. 2007) characteristics, to its use for reduction of methane and nitrous oxide (McHenry, 2009; Zwieten et al. 2009) emissions. Even small amounts of charcoal entries in slash-and-burn events, i.e. 1.6-2% in some Amazonian secondary forests (Fearnside et al. 2009) could be enough to accumulate in repeatedly-burned shifting cultivation fields to be relevant for long-term C-sequestration (Czimcik et al. 2005; Rumpel et al. 2006). On the other hand, relevance of charcoal in tropical agriculture may more likely be found in intensive high-input systems. Research on TPI soils clearly indicates the interaction between biochar and high organic nutrient inputs in the surroundings of extinct Indian settlements (Novotny et al, 2008). In analogy, charcoal could exert highest gains in horticulture with constantly high rates of manure application - or under very contrasting conditions - in anaerobe irrigated rice agriculture with synthetic fertilization.

The present research investigates the effects of fine (≤ 2 mm, i.e. 'residual') charcoal of babassu palm nuts on an Ultisol, in two charcoal application rates: 30 Mg ha^{-1} as 'intermediate' rate similar to many field studies, and 60 Mg ha^{-1} as (very) 'high' rate. We follow the question of interactions between biochar and organic or synthetic nutrients with three fertilizer regimes in a bifactorial scheme. Contrary to field studies over a season or several years, we follow the first 45 days of development of maize as our bio-indicator.

2 METHODS

2.1 Study region and soil

This study was conducted in a greenhouse of the M.Sc.-course in Agroecology of Maranhão State University, São Luis, MA, Brazil, at 2º30'S and 44º18'W, in the northeastern periphery of Amazonia. Climate according to the Köppen classification is *Aw*, with a mean annual temperature of 26.7º C and a mean annual precipitation of 2000 mm. We conducted this experiment at the end of the dry season in November – December 2010.

We collected and thoroughly homogenized 0-20 cm topsoil of an Arenic Hapludult (EMBRAPA, 2006), the dominant soil formation of the region and beyond.

The soil is infertile, acid and sandy (Table 1) had never before received fertilizer or liming, and originated from a 4-yr.-old secondary forest regrowing after slash-and-burn agriculture.

Table 1. Key physical and chemical characteristics of the topsoil (0-20 cm) investigated in this study

Soil texture				
Coarse sand	Fine sand	Silt	Clay	Silt : Clay
........................%...........................				
56	26	8	10	0.8

Soil chemical characteristics								
[1]OM	pH	[2]P	[3]K^{+3}	[3]Ca^{+2}	[3]Mg^{+2}	Na	[4]BS	CEC
g dm^3	($CaCl_2$)	mgdm^{-3}		..........................mmol$_c$dm^{-3}				
16	4.5	1.4	0.6	4	10	1.4	16	42

[1]$Na_2CrO_2+H_2SO_4$; [2]Amberlite IRA-140 resin; [3]Amberlite IRA -120 resin; [4] base saturation

2.2 Treatments and layout

We investigate the effects of and the interactions between (i) 3 charcoal application rates (0, 30 and 60 Mg ha^{-1}, equivalent to 0, 12 e 24 g kg^{-1}soil), and (ii) 3 fertilizer regimes (none, organic and synthetic). Table 2 shows the 3 x 3 bifactorial layout of the experiment, with 4 replications each resulting in 36 pots.

Table 2. Treatments

Control	Soil
C1	Soil + charcoal ‘intermediate’ dose (30 Mg ha^{-1})
C2	Soil + charcoal ‘high’ dose (60 Mg ha^{-1})
O	Soil +organic fertilizer (cow manure, 15 Mg ha^{-1})
C1+O	Soil + charcoal ‘intermediate’ dose + organic fertilizer
C2+O	Soil + charcoal ‘high’ dose + organic fertilizer
S	Soil + synthetic fertilizer (Hoagland nutrient solution)
C1+S	Soil + charcoal ‘intermediate’ dose + synthetic fertilizer
C2+S	Soil + charcoal ‘high’ dose + synthetic fertilizer

2.3 Charcoal

We investigated charcoal effects in two differing doses, (i) ‘intermediate’ rate, similar with application rates in many field trials (Yamato et al. 2006; Steiner, 2006), and (ii) (very) ‘high’ rate.

We used charcoal produced locally (in traditional kerns of smallholder farmers, unknown temperatures and oxygen conditions during carbonization) of the endocarp of the babassu (*Attalea speciosa* MART.) palm nut. Charcoal was ground and sieved to ≤ 2 mm, in order to (i) guarantee charcoal homogeneity and accelerate possible charcoal action and (ii) to simulate cost-free locally available fine charcoal as a by-product of mainly smallholder farmers / extractivist babassu charcoal production with great socioeconomic importance in our region. Table 3 shows key physical and chemical characteristics of our charcoal.

Table 3. Physico-chemical characteristics of the charcoal derived from the endocarp of the babassu palm and ground to ≤ 2mm.

Texture			
2-0.2 Mm	0.2-0.02 mm	0.02-0.002 Mm	< 0.002 mm
..........%..........			
58	18	9	15
Chemical characteristics			
P[1]	K[1]	Ca[1]	Mg[1]
.........mg kg^{-1}.............			
0.96	5.13	0.36	0.47

[1]total extraction with concentrated H_2SO_4 according to Raij et al. (2001), quantified with an OES (Optical Emissions Spectrometer)/ VARIAN 720-ES.

2.4 Fertilizer regimes

This study compares ‘control’ (no fertilization) with two contrasting fertilizer schemes, ‘organic’ and ‘synthetic’.

We take cow manure as organic fertilizer source. Manure was locally-derived and applied at 7.5 g kg^{-1}soil, equivalent to 15 Mg ha^{-1} (for 0-20 cm topsoil, following recommendations of EMBRAPA (2006) for maize cultivation. Table 4 shows key chemical characteristics o four manure.

Table 4. Chemistry of organic fertilizer (cow manure)

Ph	[1]OM	N	[2]P	[3]K	[3]Ca	[3]Mg	S
(H_2O)	........%....		mg dm^{-3}	.................g kg^{-1}..............			
8.1	27	1.22	3.2	11.5	7.1	4.8	2.1

[1]Na_2CrO_2+H_2SO_4; [2]Amberlite IRA-140 resin; [3]Amberlite IRA -120 resin.

As synthetic fertilizer source we used Hoagland solution which provides a balanced mixture of all macro and micronutrients, with pH calibrated at 6.0 (Hoagland and Arnon, 1939). We applied Hoagland solution on a weekly basis, starting with 10 days after germination. We applied 50 mL solution in the first week, 100 mL in the second and third week, and 200 mL in the fourth week.

Table 5 summarizes nutrient inputs via fertilizer and charcoal applications. Higher rates of organic nutrients were designed to account for slower nutrient-release rates from cow manure, whereas immediate nutrient-availability of synthetic nutrient solution was taken into account via repeated applications tuned to plant development. Even with high application rate, nutrient inputs via charcoal are very small in relation to nutrient inputs with the organic or synthetic fertilizer treatments.

Table 5. Quantity of macronutrients applied via charcoal and fertilizer treatments.

	N	**P**	**K**	**Ca**	**Mg**
	.... g applied per kg soil.............				
C1 - ‘Intermediate’ charcoal (30 Mg ha^{-1})	-	0.056	0.31	0.02	0.03
C2 - ‘High’ charcoal (60 Mg ha^{-1})	-	0.112	0.62	0.04	0.06
O – Organic fertilization (cow manure)	91.5	24	86.2	53.2	36.0
S – Synthetic fertilization (nutrient solution)	18.9	2.8	21.1	18.0	4.4

2.5 Experimental details

We utilized 5 liter polyetilene pots, arranged in a completely randomized block layout on tables in a greenhouse at the M.Sc.-course in Agroecology, Maranhão State University. As bioindicator we planted maize cultivar BR-106, with initially 5 pregerminated seeds per pot, at 10 days age the 4 smallest seedlings were eliminated. Maize was watered daily, maintaining soil at approximately field capacity (avoiding both drought stress and over-watering). We didn’t observe any case of insect or disease attack.

2.6 Biometrics of maize

Growth dynamics of maize along our experiment was monitored weekly between 10 and 41 days after germination. We measured length of the largest leaf of each plant, and calculated leaf area as 0.5 x length of largest leaf x correction factor. Correction factor was established by measurement of length and width of all leaves of three representative plants per measuring event, following a methodology established by Montgomery (1911).

The experiment terminated at 45 days after germination at the onset of flowering with destructive measurement of maize above- and belowground biomass. Roots were extracted via extensive rinsing over 3 consecutive sieves (2, 1 and 0.25mm mesh size). Leaves and 70% of roots were dried at 60ºC for 1 week in a forced-circulation oven for dry weight biomass determination and were subsequently ground for chemical analyses. Root density was determined in the remaining 30% of roots, following methodology established by Tennant (1975).

2.7 Chemical analyses

Chemical analyses were conducted in the Soil Laboratory of Maranhão State University. We determined foliar nutrient concentrations after total extraction with sulfuric acid, following methodology established by Tedesco et al. (1995). Available macronutrients were determined according to standard resin extraction methods described by Raij et al. (2001). We furthermore quantified different P-pools less available than resin-P with successive extractions established by Hedley et al. (1982) with modifications according to Condron et al. (1985).

We quantified tissue N via Kjeldåhl digestion, and P, K, Ca and Mg of tissue and soil extracts with a VARIAN 720-ES optical emissions spectrometer.

2.8 Statistics

We checked for normality of data-distribution visually (histograms) and with Kolmogorov-Smirnov and Lilliefor’s tests. Most data followed normal distribution or could be normalized via ln or ln+1 transformation, thus allowing for parametric analyses. We analyzed factor effects of charcoal dose and fertilizer regime and interaction terms between both with a bi-factorial ANOVA. For foliar area we additionally included a repeated measure design. We also conducted monofactorial ANOVAs and post-hoc comparisons of means with the Spjøtfoll-Stoline test (Tukey for unequal replication numbers, necessary since one maize plant in the C2+S treatment had died). Analyses were conducted with Statistica8.0 (StatSoft, 2007) and graphics were generated with SigmaPlot 11.0 (Systat, 2008).

3 RESULTS

3.1 Maize as indicator plant

3.1.1 Charcoal effects on maize leaf area

Bifactorial repeated measure ANOVA of maize leaf area did not identify significant effects of charcoal and fertilizer regime, but interactions of these factors among another and a long time. By contrast, charcoal dosage was significant in all three monofactorial repeated measure ANOVAs separately per fertilizer regime, as were day-to-day differences of all measuring events from 20 – 41 days under all three fertilizer regimes (Figure 1). Contrast between bifactorial and monofactorial ANOVAs is caused by (i) the similarity of zero and synthetic fertilizer regimes with strongest leaf area increment at ‘intermediate’ (30 Mg ha^{-1}) charcoal dosage, as opposed to (ii) organic fertilizer regime with ‘high’ (60 Mg ha^{-1}) charcoal dosage outperforming intermediate charcoal rate.

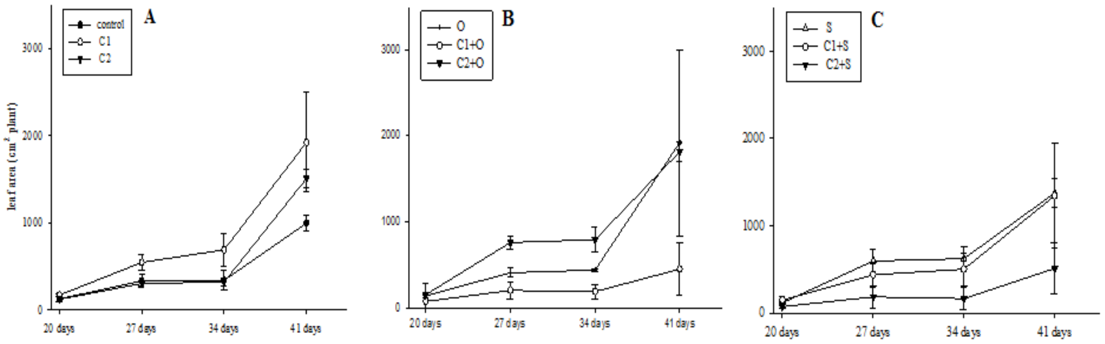

Figure 1. Maize leaf area along the experiment: Effects of charcoal applications under (A) zero-fertilizer, (B) organic fertilizer and (C) synthetic fertilizer regimes. Means ± SE, monofactorial ANOVAs indicate significant charcoal effects in each fertilizer regime as well as separately for all 4 measuring dates.

Ranking between treatments remained almost unchanged throughout the 4 weeks period, but the relative or absolute range of differences between treatments did shift and tended to increase with time. ‘Intermediate’ (30 Mg ha^{-1}) charcoal application significantly increased leaf area under all three fertilizer regimes relative to zero charcoal application. In marked contrast ‘high’ (60 Mg ha^{-1}) charcoal application resulted in depression of leaf area increment both under non-fertilized and synthetic fertilizer regimes, whereas under organic fertilizer regime leaf area increment was further increased with high charcoal application.

3.1.2 Charcoal effects on maize leaf and root biomass

Bifactorial ANOVA of leaf biomass indicates significant effects of charcoal dose and of fertilizer regime, and significant interactions between the two. Under zero-fertilizer and synthetic fertilizer regimes, 30 Mg ha^{-1} charcoal application significantly increased aboveground biomass relative to zero-charcoal, but leaf biomass in the treatments with very high (60 Mg ha^{-1}) charcoal application decreased to levels similar with the control treatment (Figure 2). Interaction between charcoal-dose and fertilizer-regime was significant because of the organic fertilizer treatments, where biomass continued to increase at very high charcoal application rate, attaining maximum values in the C2+O treatment.

Root biomass was affected by fertilizer regime (with largest values obtained with organic fertilization), but not by charcoal application. Root biomass tended non-significantly to be highest in the C2+O treatment and lowest in the C2 and S+C2 treatments.

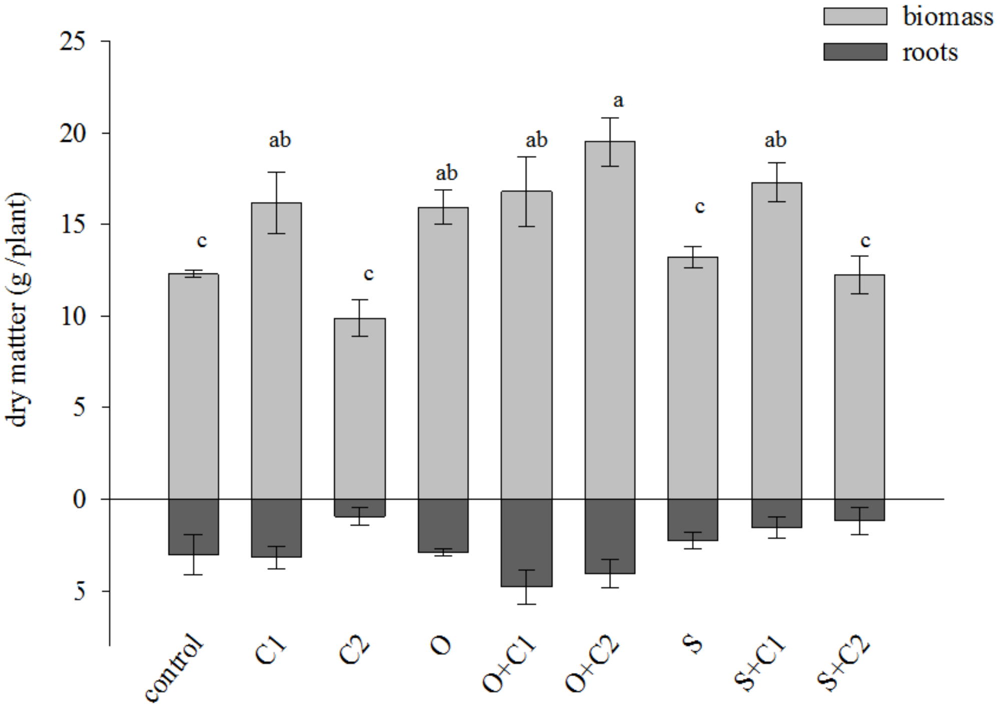

Figure 2. Above- and belowground biomass of maize as bioindicator: means ± SE. Columns without common letters differed in aboveground biomass as indicated by monofactorial ANOVA and post-hoc Spjøtfoll-Stoline test. For treatment abbreviations see Table 2.

3.1.3 Charcoal effects on root density

Bifactorial analysis of root density indicates significant effects of charcoal dose and of fertilizer regime as well as significant interactions between the two. Root density was strongly and significantly reduced in the C2 and S+C2 treatments, whereas the O+C2 treatment was second-highest of all (Figure 3).

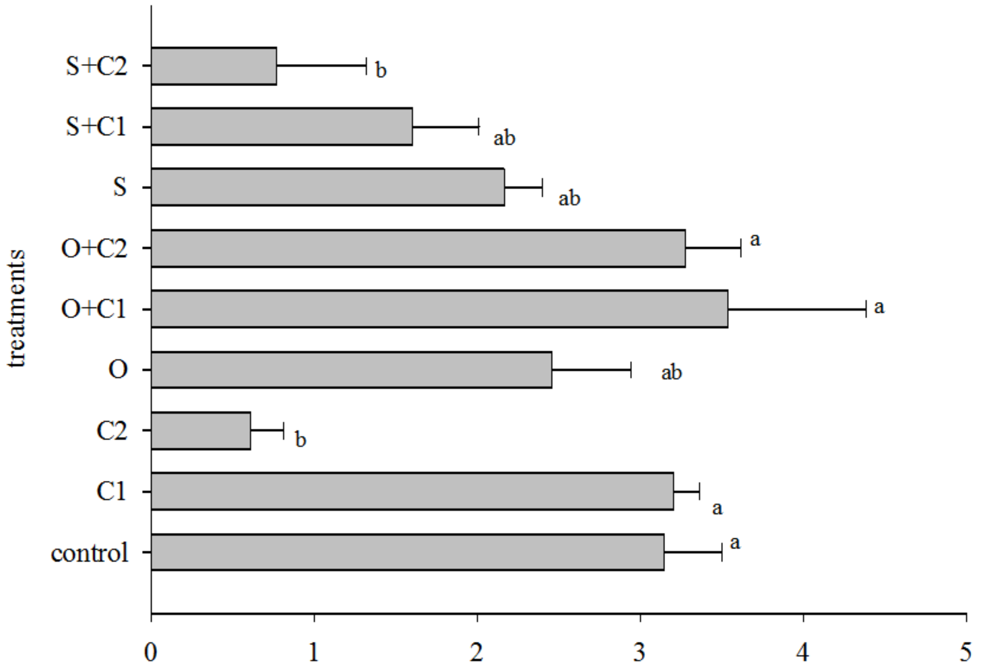

Figure 3. Maize root density: means ± SE. Columns without common letters differed in root density as indicated by monofactorial ANOVA and post-hoc Spjøtfoll-Stoline test. For treatment abbreviations see Table 2.

3.2 Nutrients

3.2.1 Charcoal effects on nutrients in maize leaves

Bifactorial ANOVA indicates significant charcoal effects both on maize P and K concentrations. Foliar P-concentration (Figure 4A) increases approximately linearly with charcoal rate, and foliar K-concentrations (Figure 4B) more in form of a saturation curve. The relative increase in concentrations between zero and high charcoal rate are on average 19.2% in P and 31.6% in K. Fertilizer regime did not affect P-concentrations but did significantly affect K-concentrations.

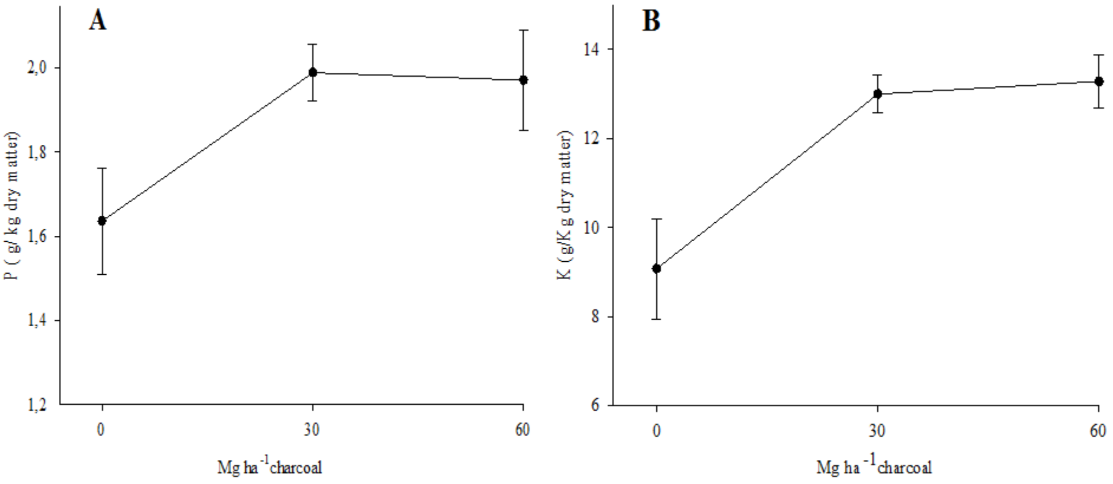

Figure 4. Foliar concentrations of (A) phosphorus and (B) potassium in dependency of charcoal dosage: 0, 30 and 60 Mg ha^{-1}, means ±SE over the 3 fertilizer regimes combined.

Contrary to maize P and K concentrations, foliar N-concentration were not affected by charcoal application nor by contrasting fertilizer regimes. Ca and Mg contents were boosted by organic fertilization but were not affected by intermediate or high charcoal applications (data not shown).

Regression analyses between maize biometric variables (leaf area, biomass, root density) and foliar nutrient content did not reveal any significant relationships (data not shown).

3.2.2 Charcoal effects on soil chemistry

Bi-factorial analyses of resin-extractable soil P- and K-contents reveal significant charcoal effects on both variables, whereas contrasting fertilizer regimes failed to affect both P and K, nor were there any sizeable between-factor interactions. Soil P-availability (resin-extraction) increases approximately linearly and nearly triples (298%) between zero and high application-rate (Figure 5A).

Soil K-availability likewise increases approximately linearly and very strongly (539%) between zero and high charcoal application-rate (Figure 5B). K-increase with charcoal was very similar for zero-fertilizer and organic fertilizer regimes, but tended to be lower with organic fertilization.

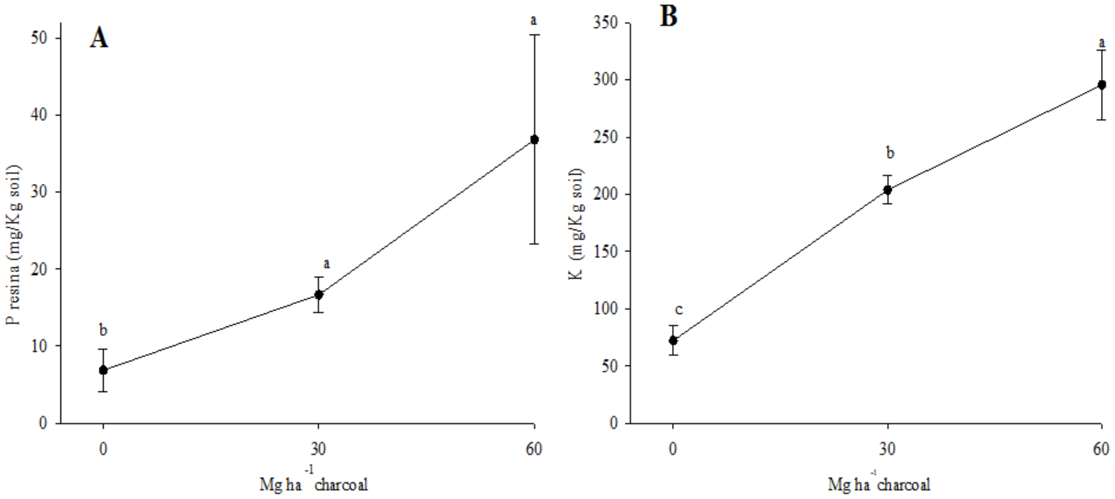

Figure 5. (A) resin-extractable P and (B) resin-extractable K in an Ultisol in dependency of charcoal dosage: 0, 30 and 60 Mg ha^{-1}, means ±SE over the 3 fertilizer regimes combined, different letters indicate significant differences identified by post-hoc Spjøjtvoll-Stoline test.

Contrary to strong charcoal effects on resin-extractable soil P, the less labile (P-$HCO_3$and P-NaOH) P-pools were not affected by charcoal application under any fertilizer regime (data not shown).

Charcoal application dose linearly increased soil pH (Figure 6A) and decreased potential acidity (Figure 6B) of our sandy and infertile study soil. Linear regression between charcoal dose and soil pH suggest a 0.03 pH-increment for each ton of charcoal (r^2=0.52, p<0.001). Contrary to charcoal, fertilizer regime did not affect pH or potential acidity (data not shown).

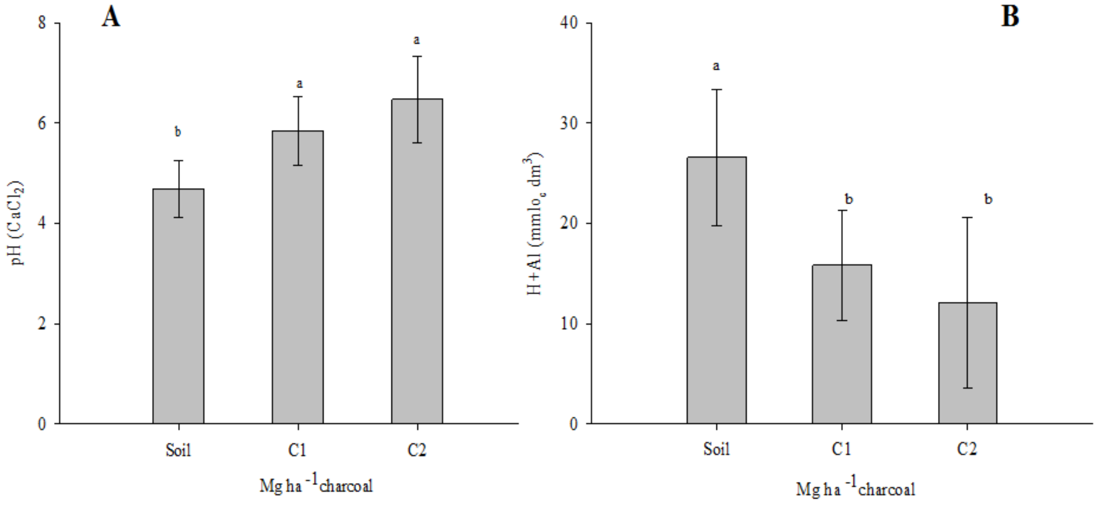

Figure 6. (A) pH and (B) H+Al in an Ultisol in dependency of charcoal dosage: 0, 30 and 60 Mg ha^{-1}, means ±SE over the 3 fertilizer regimes combined, different letters indicate significant differences identified by post-hoc Spjøjtvoll-Stoline test.

As to be expected, soil pH increased P-availability, though this relationship was not very strong (r^2 = 0.22; p<0.01).

There were no significant relationships between soil chemical data and leaf area-increment, leaf or root biomass. Regression analyses did however show significant (though not very close) negative association between root density and resin-extractable soil P (r^2=0.18; p=0.01), Ca (r^2=0.15; p=0.03) and Mg (r^2=0.18; p=0.01).

4 DISCUSSION

Babassu charcoal substantially altered chemical fertility indicators of this nutrient-poor and acid Ultisol, with linear increases of soil pH, P and K-availability.

The very low nutrient contents in our charcoal exclude the possibility of significant contamination with ashes or of high contents due to high-temperature carbonization (McHenry, 2009). Due to these low nutrient concentrations, nutrient inputs via charcoal applications are low even with high charcoal dosage, and irrelevant in dimension relative to nutrient additions via organic or synthetic fertilization (Table 5). Thus, direct nutrient-inputs via charcoal are not a viable explanation for the consistent increases in both soil and plant P and K levels, raising the question which other mechanisms could be responsible for these strong charcoal effects.

Soil pH increased near linearly and substantially with charcoal dosage from 4.6 (zero) – 5.8 (intermediate) – 6.4 (high charcoal dosage). In close analogy, H^+ and Al^{+3} decreased with charcoal dosage, presumably due to reaction with OH^- of the charcoal's surface (Brennan et al. 2001). Similar results have been reported by (Mbagwu and Piccolo, 1997) testing differing charcoal types and dosages on a variety of soils.

The increase in pH provides a partial explanation for the large increase in soil P-availability. Both variables were interrelated, but relationship was rather weak ($r^2 = 0.22$; $p<0.01$) and therefore insufficient to alone explain the surge in labile P. Liang et al. (2006), Cheng et al. (2008) and Lehmann and Stephen (2009) propose the generation of P exchange capacity on the charcoal surfaces as responsible for this increase in P-availability.

Following initial resin extraction, $NaHCO_3$- and NaOH-extractable P-pools, representing 'partially available' or 'refractory' P-pools were all unaffected by charcoal application, likely as consequence of the short duration of this experiment. Long-term field trials would be required to assess possible charcoal effects on these less labile P-pools, but the strong charcoal effects on resin-P do make such shifts in P-pools seem likely and warrants further research.

Even high charcoal dosage did not reduce N-availability. This is contrary to findings compiled in Lehmann et al. (2003) on charcoal-induced temporary N-immobilization, supposedly as consequence of the high C:N-ratio of charcoal (Chan and Xu, 2009) and a high capacity of porous structures of charcoal to absorb ammonium ions (Berglund et al, 2004).

Research on 'Terra Preta de Índio' suggests that benefits of BC on soil fertility occur especially when combined with high doses of organic nutrients, as this promotes the formation of carboxylic groups and ultimately the formation of cation exchange capacity (Novotny et al. 2008). The porous structure and high surface area of charcoal, frequently between 200 m^2 g^{-1} and 400 m^2 g^{-1}, likely is important for this to happen (Kishimoto and Sugira, 1985). As we utilized fine (ground to ≤ 2 mm) charcoal, surface area of our charcoal is sure to be on the high side.

Charcoal itself can also have significant CTC, especially when carbonized at high (i.e. > 400° C) temperatures (Mc Henry, 2009). Such high charcoal CTC occurs because of high quantities of aromatic compounds on the charcoal surfaces (Schimidt and Noack, 2000). On the other hand, the CTC buildup of TPI soils is thought to be a mid- to long-term process, over many months to years, due to negative charge buildup via surface oxidation processes which increase phenolic, hydroxylic, carbonylic and quinone compounds (Cohen-Ofri et al. 2006).

The present study was conducted over a time-period of 45 days, rather than time-scales of many months to years as in most field studies. On the other hand, this study utilizes quite high charcoal doses, in fine-sieved (i.e. reactive) form. Thus, time appears to partially be compensable by quantity.

Babassu charcoal not only strongly improved soil chemical fertility indicators of our Ultisol, it also strongly affected maize as our bioindicator. ‘Intermediate’ (30 Mg ha^{-1}) application accelerated maize leaf area accumulation and boosted maize biomass and root density relative to zero charcoal-treatment.

Contrary to the results of our plant and soil chemical analyses (where pH, P and K all increased approximately linearly with charcoal application rate), above- and belowground development of maize as our indicator crop showed a distinctly different pattern, with leaf area and biomass and root density increases with ‘intermediate’ (30 Mg ha^{-1}) charcoal application relative to zero-application, but with reduced values at ‘high’ (60 Mg ha^{-1}) charcoal application rate relative to the intermediate dosage. This holds true both for the zero-fertilizer and the synthetic fertilizer regimes, but not for the organic fertilizer regime.

Charcoal-induced nutritional deficiency can be discarded as explanation, since we did not find any indications of nitrogen immobilization as stated above. Toxicity of babassu charcoal at excessive application rates therefore is a possibility which needs to be considered. In another (unpublished data) experiment we found a linear relationship between babassu charcoal dose and earthworm mortality. The hypothesis of toxicity is supported by our observations of very low root mass and root density in C2 and S+C2 treatments, and the mortality of one maize plant in the S+C2 treatment. Results of Guan (2004) and Schnitzer et al. (2007) report on the formation of smoke vinegar with biocidal effects in charcoals derived from chicken manure. Future research urgently needs to investigate the possibility of biocidal effects of babassu-derived charcoal.

Organic matter is known to be capable of detoxifying or immobilizing toxic substances (Miyasawaet al. 1992). Organic matter input via cow manure could well have neutralized such charcoal toxicity even at high application rate and thus made possible the further increase in indicator plant growth, biomass and root density observed in the C2+O treatment. In the absence of charcoal toxicity, high charcoal dosage under organic fertilizer regime promotes maximum plant development, as positive effects of high charcoal (nutrient-increases as outlined above) prevail under this combination.

5 CONCLUSIONS

Babassu charcoal profoundly improves (initial – 45 days) soil chemistry of this sandy, acid and infertile Amazonian Ultisol. Maize was boosted by intermediate charcoal rates. Our study supports the idea of positive interactions between biochar and organic nutrients. In the humid tropics, such conditions are ideally met in (both rural and peri-urban) horticulture operations at all scales.

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7 REFERENCES

Aguiar, A.C.F., Bicudo, S.J., Costa Sobrinho, J.R.S., Martins, A.L.S., Coelho, K.P., Moura, E.G., 2010. Nutrient recycling and physical indicators of an alley cropping system in a sandy loam soil in the pre-Amazon region of Brazil. Nutr. Cycl. Agroecosys. 86, 189–198.

Berglund, L.M., Deluca, T.H., Zackrisson, T.H., 2004. Activated carbon amendments of soil alters nitrification rates in Scots pine forests. Soil Biol. Biochem. 36, 2067–2073.

Brennan, J.K., Bandosz, T.J., Thomson, K.T., Gubbins, K.E., 2001. Water in porous carbons. Colloid Surface A 187–188, 539–568.

Chan, K.Y., Xu, Z., 2009. Biochar: nutrient properties and their enhancement, in: Lehmann, J., Joseph, S. (Eds.), Biochar for Environmental Management: Science and Technology. Earthscan, London, pp. 67 – 84.

Cheng, C.H., Lehmann,J., Engelhard, M., 2008. Natural oxidation of black carbon in soils: changes in molecular form and surface charge along a climosequence. Geochim. Cosmochim. Acta. 72, 1598–1610.

Cohen-Ofri, I., Weiner, L., Boaretto, E., Mintz, G., Weiner, S., 2006. Modern and fossil charcoal: aspects of structure and diagenesis. J. Archaeol. Sci. 33, 428–439.

Czimczik, C.I., Schmidt, M.W.I., Schulze, E.-D., 2005. Effects of increasing fire frequency on black carbon and organic matter in Podzols of Siberian scots pine forests. Eur. J. Soil Sci. 56, 417–428.

CONDRON, L.M.; GOH, K.M.; NEWMAN, R.H. 1985.Nature and distribution of soil phosphorus as revealed by a sequential extraction method followed by 31P nuclear magnetic resonance analysis. J. Soil Sci., Oxford, 36, 199-207.

Denich, M., Vlek, P.L.G., Sá, T.D.A., Vielhauer, K., Lücke, W., 2005. A concept for the development of fire-free fallow management in the Eastern Amazon. Agr. Ecosyst. Environ. 110, 43–58.

EMBRAPA – Empresa Brasileira de Agropecuária, 2006. Sistema Brasileiro de classificação de solos. Embrapa, Brasília.

Fearnside, P.M., 2000. Global warming and tropical land-use change: greenhouse gas emissions from biomass burning, decomposition and soils in forest conversions, shifting cultivation and secondary vegetation. Climatic Change 46, 115–158.

Fearnside, P.M., Barbosa, R.I., Alencastro Graça, P.M.L., 2009. Burning of secondary forest in Amazonia: Biomass, burning efficiency and charcoal formation during land preparation for agriculture in Apiaú, Roraima, Brazil. For. Ecol. Manage. 242, 678-687.

Forbes, M.S., Raison, R.J., Skjemstad, J.O., 2006. Formation, transformation and transport of black carbon (charcoal) in terrestrial and aquatic ecosystems. Sci. Total Environ. 370, 190–206.

Hedley, M.J., Stewart, J.W.B., Chauhan, B.S., 1982.Changes in inorganic and organic soil phosphorus fractions induced by cultivation practices and by laboratory incubations. Soil Sci. Soc. Am. J. Madison. 46, 970–976.

Hoagland, D.R., Arnon, D.I.,1950. The water culture method for growing plants without soil, third ed., Berkley, California.

Jacomine, P.K.T., Camargo, M.N., 1996. Classificação nacional pedológica em vigor, in: Alvarez, V.H., Fontes, L.E.F., Fontes, M.P.F. (Eds.), Solos nos grandes domínios morfoclimáticos do Brasil e do desenvolvimento sustentado. Brazilian System of Science Soil – Federal University of Viçosa, pp. 675–689.

Kishimoto, S., Sugira, G., 1985. Charcoal as a soil condition, in: Symposium on forest product research international: achievements and the future, 1985, Pretoria. Abstract.Pretoria: National Timber Research Institute, 5, 22-26.

Koutika, L.-S., 2005. Leguminous fallows improve soil quality in south-central Cameroon as evidenced by the particulate organic matter status. Geoderma. 125, 343–354.

Lehmann, J., Silva, J. P. da, Steiner, C., Nehls, T., Zech, W., Glaser, B., 2003. Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments. Plant Soil. 249, 343 – 357.

Lehmann, J., Gaunt, J., Rondon, M., 2006. Bio-char sequestration in terrestrial ecosystems – a review. Mitig. Adapt.Strat. Global Change 11, 403–427.

Lehmann, J., Joseph, S., 2009. Biocharfor envioronmental management. Earthscan, London.

Liang, B., Lehmann, J., Solomon, D., Kinyangi, J., Grossman, J., O'Neill, B., Skjemstad, J.O., Thies, J., Luizao, F.J., Petersen, J., Neves, E.G., 2006. Black carbon increases cation exchange capacity in soils. Soil Sci. Soc. Am. J. 70, 1719–1730.

MacKenzie, M.D.; McIntire, E.J.B.; Quideu, S.A.; Graham, R.C. 2008. Charcoal distribution affects carbon and nitrogen contents in forest soil of California. Soil Sci. Soc. Am. J. 72: 1774-1785.

Mbagwu, J.S.C., Piccolo, A., 1997. Effects of humic substances from oxidized coal on soil chemical properties and maize yield, in: Drozd, J.,Gonet, S.S., Senesi, N., Weber, J. (Eds.), The role of humic substances in the ecosystems and in environmental protection. IHSS, Polish Society of Humic Substances, Wroclaw, pp. 921–925.

McGrath, D.A., Smith, C.K., Gholz, H.L., Oliveira, F.A., 2001. Effects of land-use change on soil nutrient dynamics in Amazonia. Ecosystems 5, 625–645.

McHenry, M.P., 2009. Agricultural bio-char production, renewable energy generation and farm carbon sequestration in Western Australia: certainty, uncertainty and risk. Agric.Ecosys. Environ. 129, 1–17.

Meléndez, G., 2004. Slash-and-mulch system: Frijol Tapado in Costa Rica. in: Eilittä, M., Mureithi, J., Derpsch, R. (Eds.), Green manure / cover crop systems of smallholder farmers. Kluwer Acad. Publ., Doordrecht, pp. 37–64.

Montgomery, E.G., 1911. Correlation studies of corns. Annual report, 24th. Agricultural Experiment Station, Nebraska.

Myasawa, M., Chierice, G.O., Pavan, M.A., 1982. Amenização da toxicidade de alumínio às raízes de trigo pela complexação com ácidos orgânicos. Rev. Bras. Ciênc. Solo 16, 209–215.

Novotny, E.H., Romeiro, G.A., Figueiredo, M.K.K., Rocha, J.D., De Azevedo, E.R., Bonagamba, T.J., Hayes, M.H.B. 2008. ^{13}C-NMR Spectroscopy evaluation of different pyrolysis feedstock. Poster presentation, International Biochar Initiative Conference, Newcastle, UK. http://wenku.baidu.com/view/095bb41cb7360b4c2e3f64b4.html?from=related. Accessed 20 june 2011.

Oguntunde, P.G., Fosu, M., Ajayi, A.E., van de Giesen, N., 2004. Effects of charcoal production on maize yield, chemical properties and texture. Biol. Fert. Soils 39, 295–299.

Pietkainen, J., Kikkila, O., Fritze, H., 2000. Charcoal as a habitat for microbes and its effect on the microbial community of the underlying humus. Oikos 89, 231–242.

Pinheiro, C.U.B., Frazão, J.M.F., 1995. Integral processing of babassu palm (*Orbignya phalerata,* Arecaceae) fruits: village level production in Maranhão, Brazil. Econ. Bot. 49, 31–39.

Raij, B., Andrade, J.C., Cantarella, H., Quaggio, J.A. Análise química para avaliação da fertilidade de solos tropicais. 2001. Instituto Agronomico de Campinas-Campinas Agronomic Institut, p285.

Rondon, M., Lehmann, J., Ramírez, J., Hurtado, M., 2007. Biological nitrogen fixation by common beans (*Phaseolus vulgaris* L.) increases with bio-char additions. Biol.Fert. Soils 43, 699–708.

Rumpel, C., Alexis, M., Chabbi, A., Chaplot, V., Rasse, D.P., Valentin, C., Mariotti, A., 2006. Black carbon contribution to soil organic matter composition in tropical sloping land under slash and burn agriculture. Geoderma 130, 35–46.

Sanchez, P.A., 1976. Properties and management of soils in the tropics. John Wiley&Sons, New York.

Steiner, C.; Teixeira, W. G.; Lehmann, J.; Nehls, T.; de Macêdo, J. J. V.; Blum, W. E. H.; Zech, W., 2007. Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. Plant Soil 291,.275-290.

Steiner, J.; Zech, W. Teixeira, W. G., 2006. Microbial activity as soil quality indicator in annual and perennial plantations treated with charcoal, mineral or organic fertilizer in a highly weathered Amazonian upland soil. In: 18th World congress of soil science, 2006. Abstract. Philadelphia, Pennsylvania: SSSA.

Schmidt, M.W.I., Noack, A.G., 2000. Black carbon in soils and sediments: analysis, distribution, implications, and current challenges. Global Biogeochem. Cycle 14, 777–793.

Schnitzer, M.I., Monreal, C.M., Facey, G.A., Fransham, P.B., 2007. The conversion of chicken manure to biooil by fast pyrolysis I. Analyses of chicken, biooils and char by C-13 and H-1NMR and FTIR spectrophotometry. J. Environ. Sci. Heal. B 42, 71–77.

StatSoft Inc., 2007. Statistica for windows (Software-system for data-analysis). Version 8.0, Tulsa, USA.

Systat Software Inc., 2008. Sigmaplot for windows, Version 11.0.

Tedesco, M.J., 1995. Análise de solo, plantas e outros minerais. Federal University of Rio Grande do Sul, Soil Department. Faculto f Agronomy, Porto Alegre, Brazil.

Teixeira, W.G., Martins, G.C., 2003. Soil physical characterization,in:Lehmann, J., Kern, D.C., Glaser, B., Woods, W.I. (Eds.), Amazonian dark earths: origin, properties, management. Kluwer, Doordrecht, pp. 271-286.

Teixeira, M.A., Carvalho, M.G., 2007. Regulatory mechanism for biomass renewable energy in Brazil, a case study of the Brazilian babassu oil extraction industry. Energy 32, 999–1005.

Tiessen, H., Cuevas, E., Chacon, P., 1994. The role soil organic matter in sustaining soil fertility. Nature 371, 783–785.

Tennant, D.A., 1975. Test of a modified line intersect method of estimating root length. J. Ecol. 63, 995–1001.

Topliantz, S., Ponge, J.F., Ballof, S., 2005. Manioc peel and charcoal - potential amendment for sustainable soil fertility in the tropics. Biol. Fert. Soils 41, 15–21.

Van Zwieten, L., Kimber, S., Morris, S., Chan, K.Y., Downie, A., Rust, J., Joseph, S.,Cowie, A., 2010. Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. Plant Soil 327, 235–246.

Warnock, D.D., Lehmann, J., Kuyper, T.W., Rillig, M.C., 2007. Mycorrhizal responses to biochar in soil - concepts and mechanisms. Plant Soil 300, 9–20.

Yamato, M.; Okimori, Y.; Wibowo, I. F.; Anshori, S.; Ogawa, M., 2006. Effects of the application of charred bark of *Acacia mangium* on the yield of maize, cowpea, peanut and soil chemical properties in south Sumatra, Indonesia. Soil Sci. Plant Nutr.. 52, 489-495.

Zinn,Y.L., Lal,R., Resck, D.V.S., 2005. Changes in soil organic carbon stocks under agriculture in Brazil. Soil Tillage Res. 84, 28–40.

Zwieten, L.V., Singh, B., Joseph, S., Kimber, S., Cowie, A., Yin Chan, K., 2009. Biochar for environmental management: biochar and emissions of non-CO_2 greenhouse gases from soil. Sci. Tec., 13, 227-243.

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O artigo foi escrito nas normas da revista Geoderma, porém os gráficos e tabelas ficaram no corpo do texto para melhor entendimento dos leitores da banca e serão normatizados conforme as normas da revista para que o artigo possa ser enviado. As normas seguem a baixo:

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