Effects of biochar amendments on available P, P fractions, soil properties and plant nutrient contents in Ferralsols from Angola

E. Auxtero[a], M. Madeira[a] and C. Horta[b]

[a]*Centro de Estudos Florestais, Instituto Superior de Agronomia, Tapada da Ajuda, 1349-017 Lisboa, Portugal*
e-mail: eauxtero@iol.pt
[b]*Escola Superior Agrária, Quinta da Senhora de Mércoles, 6001-909 Castelo Branco, Portugal*

INTRODUCTION

Low phosphate (P) availability is one of the major problems in most Ferralsols from Angola, due to the strong ability of these soils to adsorb P, thereby limiting its bioavailability for crop production (Ucuassapi, 2006). Application of biochar as soil amendment, along with superphosphate and rock phosphate fertilizers may be useful in increasing supply of available P. However, appropriate P management strategies may require information on the fate of biochar and applied P fertilizers in the soil as well as on their interaction with soil colloidal constituents. Therefore, information on soil P availability using different methods, and P forms (inorganic and organic) by Hedley modified fractionation procedure (Tiessen and Moir, 1993), early plant growth performance and P content in plant after biochar amendment along with different rates of P fertilizers, is crucial for making appropriate fertilizer and biochar recommendations for crops.

OBJECTIVES

This study was conducted to i) determine the availability of P by different methods and the amount of different P forms in soil amended with biochar along with different rates of P fertilizers by sequential fractionation, ii) evaluate the early plant growth performance of rye (*Secale cereale*) on these soils, and iii) determine the relationships of content of available P by different methods and forms of fractionated P with plant nutrient uptake and with soil properties.

MATERIALS AND METHODS

Samples (Ferralsols) from the surface (0-20 cm) horizon of soils from the Chianga Agricultural Experiment Station (about 2,550 ha), Huambo, central plateau of Angola, which lies between 12º 14' and 12º 16' latitude and between 15º 48' and 15º 52' longitude (Fig. 1) were used. Their main properties are shown in Fig. 2. Each soil was amended with 30 t biochar per ha^{-1} along with two inorganic containing P fertilizers at different rates, (Fig. 3) according to its P sorption maxima.

Fig. 1- Location of the study area

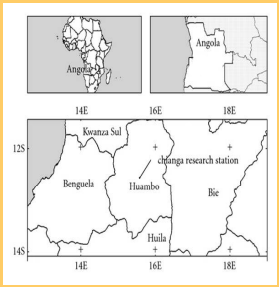
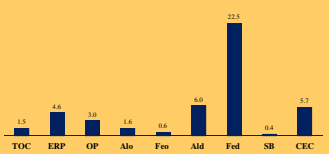


Fig. 2- Main properties of studied soils



The surface horizon contains high amount of total organic C (TOC), (g kg^{-1}) extractable P by Egner Riéhm (ERP) and Olsen (OP), extractable iron and Al by ammonium oxalate (Feo, Alo) and by citrate-dithionite (Fed, Ald) (g kg^{-1}), and high values of cation exchange capacity (CEC) and sum of bases (SB) (cmol$_c$ kg^{-1}). This horizon has high values of Fed, suggesting high content of crystalline form of Fe.

Fig. 3- Soil samples and treatments

Biochar at the rate of 30 t ha^{-1} along with superphosphate (18% P_2O_5) and finely ground (< 150 µM) rock phosphate (fertigafsi) (26.5% $P2O_5$) at the rates of 0, 100, and 200 mg P kg^{-1} were mixed thoroughly with 200 g air dried soils (< 2 mm) from surface (0-20 cm) horizon in plastic bag and then transferred to plastic pots

Ten treatments arranged in randomized complete block design (in quadruplicate) were as follows: 1) C- control (soil without amendments); 2) B- soil + 30 t biochar ha^{-1}; 3) S1- soil + 100 mg kg^{-1} superphosphate (S); 4) S2- soil + 200 mg kg^{-1} S; 5) R1- soil + 100 mg kg^{-1} rock phosphate (R); 6) R2- soil + 200 mg kg^{-1} R; 7) B + S1; 8) B + S2; 9) B + R1; and 10) B + R2

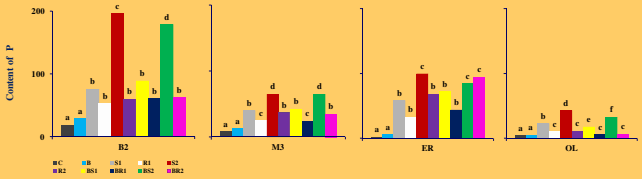
Treated soils were kept in incubation chamber under controlled conditions (day/night temperature: 25/18 ºC, relative humidity: 60%, photoperiod: 960/480 (16h/8h) and PAR: 1000 µmol m^{-2} s^{-1} photon flux density) for one month and thereafter, Rye (*Secale cereale)* was grown on each treatment for two cycles.

Fig. 4- Laboratory procedures

Chemical analysis	Method	References
pH H_2O and 1 M KCl	glass electrode	
Total organic carbon	Wet oxidation using the Springer and Klee method	De Leenheer and Van Hove (1950)
Bray 2 P	0.03 N NH_4F + 0.1 N HCl (pH 2.6)	Bray (1945)
Mehlich 3 P	0.013 N HNO_3 + 0.2 N CH_3COOH + 0.015 N NH_4F + 0.25 N NH_4NO_3 + 0.001 N EDTA (pH 2.5)	Mehlich (1984)
Egnér Riehm P	0.1 N lactic acid + 0.4 N CH_3COOH + 0.1 N NH_4OH (pH 3.7)	Egnér et al. (1960)
Olsen P	0.5 M $NaHCO_3$ (pH 8.5)	Olsen et al. (1954)
P determination	Molybdenum blue method	Murphy and Riley (1962)
P fractionation	Modified Hedley procedure	Tiessen and Moir (1993)

RESULTS AND DISCUSSION

Effects of biochar amendments along with superphosphate and fertigafsa application on the content of available P determined by Bray (B2), Mehlich 3 (M3), Egnér Riehm (ER) and Olsen (OL) methods (mg kg^{-1})



- Available P content extracted by the B2, M3, ER and OL methods were higher in soils amended with biochar along with superphosphate and rock phosphate application than the control and soil amended with biochar alone.
- Soils treated with 200 mg superphosphate kg^{-1} alone and combined with biochar showed higher content of available P extracted by the B2, M3, ER and OL methods than other treatments.

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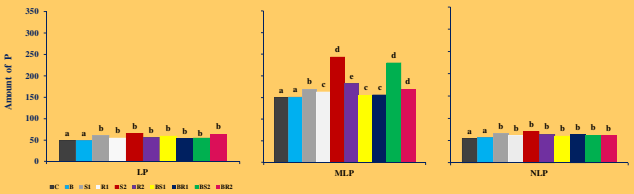
Effects of biochar amendments along with different rates of superphosphate and rock phosphate (Fertigafsa) on the amount of labile (LP), moderately labile (MLP), and non labile (NLP), fractions (mg kg^{-1})



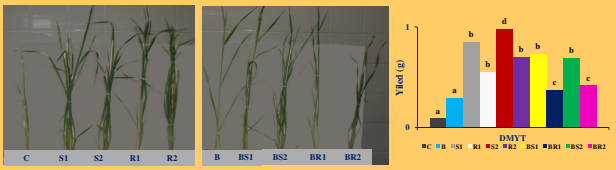
- The amount of MLP fraction in all treatments were higher than those of the LP and NLP fractions. The amount of LP ,MLP and NLP fractions increased with biochar amendment along with P fertilizer application. Higher values were observed in soils applied alone with 200 mg kg^{-1} of superphosphate alone than other treatments

Effects of biochar amendments along with different rates of superphosphate and rock phosphate (Fertigafsa) on soil properties

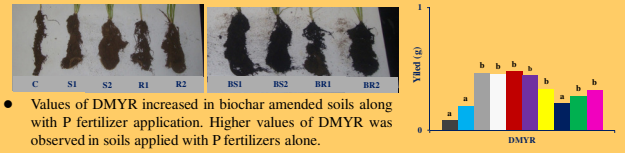
Treatment	pH		TOC	Ca^{2+}	Mg^{2+}	K^+	SB
	H_2O	KCl	(g kg^{-1})	(cmol$_c$ kg^{-1})			
C	4.59a	4.29a	9.59 ± 1.14 a	0.35 ± 0.02a	0.14 ± 0.01a	0.17 ± 0.03a	0.70 ± 0.03a
B	6.63b	5.74b	24.50 ± 2.94b	1.93 ± 0.08b	0.34 ± 0.03b	0.39 ± 0.05b	2.69 ± 0.14b
S1	4.95c	4.34c	10.01 ± 1.27a	1.10 ± 0.14c	0.12 ± 0.01a	0.06 ± 0.03a	1.29 ± 0.18a
R1	4.92c	4.33c	10.32 ± 1.76a	0.68 ± 0.08a	0.15 ± 0.01a	0.13 ± 0.07a	0.96 ± 0.12a
S2	4.93c	4.37c	10.80 ± 1.75a	1.82 ± 0.31b	0.13 ± 0.01a	0.16 ± 0.11a	2.14 ± 0.37c
R2	4.95c	4.35c	10.64 ± 1.29a	0.73 ± 0.11a	0.14 ± 0.01a	0.08 ± 0.03a	0.99 ± 0.11a
BS1	6.28d	5.58d	24.29 ± 2.21b	2.53 ± 0.11d	0.33 ± 0.01b	0.21 ± 0.01a	3.09 ± 0.14b
BR1	6.35e	5.65e	24.99 ± 2.67b	1.98 ± 0.10b	0.35 ± 0.02b	0.33 ± 0.02b	2.70 ± 0.17b
BS2	6.19f	5.63e	24.47 ± 2.12b	3.16 ± 0.17e	0.35 ± 0.03b	0.22 ± 0.04a	3.77 ± 0.24d
BR2	6.30d	5.48g	27.10 ± 3.10b	1.98 ± 0.16b	0.34 ± 0.02b	0.28 ± 0.03a	2.64 ± 0.13b

- Values of soil pH (H_2O and KCl) and sum of bases, and content of total organic C (TOC), Ca^{2+}, Mg^{2+} and K^+ increased with the biochar amendment and/or combined with superphosphate and rock phosphate fertilizers.

Effects of biochar amendments along with different rates of superphosphate and rock phosphate (Fertigafsa) on early plant growth performance . Symbol: dry matter yields of plant top (DMYT) and root (DMYR)



- The highest increase in the values of DMYT was shown in soils applied with 200 mg superphosphate kg^{-1} alone.
- The values of DMYT also increased in biochar amended soils along with P fertilizer application.



- Values of DMYR increased in biochar amended soils along with P fertilizer application. Higher values of DMYR was observed in soils applied with P fertilizers alone.

Correlation coefficient (*r*) of plant parameters with available P by different methods, content of nutrient in plant and P fractions, and some soil properties in biochar amended P fertilized Ferralsols

Parameter	*r, p*													
	Methods				Nutrient content in plant					P fractions			Soil properties		
	B2	M3	ER	OL	P	K	Ca^{2+}	Mg^{2+}	Mn^{4+}	MLP	TPi	TP	TOC	Mg^{2+}	K^+
DMYT	0.74***	0.85***	0.37***	0.82***	0.78***	−0.69***	0.39***	0.52***	−0.55***	0.63***	0.80***	0.63***	ns	ns	−0.51***
DMYR	ns	0.25**	0.24**	ns	0.28**	ns	ns	0.32***	ns	0.35**	0.53***	0.36**	−0.35**	ns	−0.53***
PH	0.37***	0.43***	ns	0.42***	0.26**	−0.46***	ns	ns	−0.55***	ns	0.32**	ns	ns	ns	ns
LN	0.72***	0.82***	0.37***	0.83***	0.78***	−0.71***	0.41***	0.58***	−0.52***	0.80***	0.87***	0.78***	ns	−0.33**	−0.50***

Symbol: PH (plant height in cm), LN (number of leaf), TPi (total inorganic P), TP (soil total P) (**, *** $p < 0.01$ and < 0.001, respectively; ns, not significant)

- Values of DMYT and LN were positively correlated with the content of available P extracted by the B2, M3, ER and OL methods. DMYR values showed positive correlation only with the content of available P by the M3 and ER methods, while PH showed positive correlation only with those by the B2, M3 and OL methods.
- Values of DMYT and LN were also positively correlated with P, K^+ Ca^{2+}, Mg^{2+} and Mn^{4+} content in the plant. A positive correlation between values of DMYR and P content in plant was also observed. The values of PH only showed positive correlation with the P, K^+ and Mn^{4+} content in the plant.
- Values of DMYT, DMYR and LN were positively correlated with the content of MLP, TPi, and TP fractions in the soil, while PH was only positively correlated with soil TPi fraction.
- Values of DMYT, DMYR and LN were negatively correlated with K^+ content in the soil. A negative correlation between DMYR values and soil TOC content, and between LN values and Mg^{2+} content in the soil was observed.

CONCLUSIONS

- Application of superphosphate (200 mg kg^{-1}) was more effective in improving the soil P supply and early plant growth performance in Ferralsols, than rock phosphate (Fertigafsa). Plant dry matter yield and P content in plant also improved with biochar amendment along with P fertilizer application.
- Mehlich 3 and Olsen are better methods in assessing available P in biochar amended P fertilized Ferralsols.
- Biochar amendment in P fertilized Ferralsols increased all soil P fractions, and improved the nutrient content in plant, soil pH, content of total organic C and basic cations (Ca^{2+}, Mg^{2+} and K^+).
- Results may differ when amplified under field conditions, hence field experiments are needed to evaluate such effects *in situ*. The effects in combination with lime on uptake of P by plants also need to be addressed further.

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