Fertility Capability and Responses of Oxisols to Agricultural Wastes Biochar Application

T. Limwikran[1], I. Kheoruenromne[1,*], A. Suddhiprakarn[1], N. Prakongkep[2] and R.J. Gilkes[3]

[1] Department of Soil Science, Faculty of Agriculture, Kasetsart University, Bangkok 10900, Thailand
[2] Office of Science for Land Development, Land Development Department, Bangkok 10900, Thailand
[3] School of Agriculture and Environment, Faculty of Science, University of Western Australia, Crawley 6009, Australia
* Corresponding author Email: irbs@ku.ac.th
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ABSTRACT

This study focused on fertility capability and responses of Oxisols to agricultural wastes biochar application. All Oxisols in the study were Rhodic Kandiustox including three locations. S1, S2 and S3 of Pak Chong series and one location, S4 of Chok Chai series. Soil samples were from topsoil, 0–20 cm depth and from base of topsoil to 60 cm depth and classified by the FCC (Fertility Capability Classification) system. Topsoils were incubated with pineapple peel, durian shell and palm kernel shell biochars for 1, 2, 4 and 8 weeks. After incubation, soil samples were analyzed for soil pH, soil EC, extractable K, Ca and available P. Results of the study revealed FCC units of these soils as S1 = LCdim, S2 = LCdim, S3 = Cdim and S4 = LCdim. After 8 weeks of incubation, most of the soil pH and all EC values increased. Extractable K, Ca and available P in soils incubated with pineapple peel and durian shell biochar increased while soils incubated with palm kernel shell biochar had extractable Ca increased and extractable K and available P decreased. The study results provide useful information about responses of Oxisols to short term effects of agricultural wastes biochar application. They also indicate that the dynamic exchange of mineral nutrients between soils and biochars exist.

Keywords: Oxisols, biochar

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INTRODUCTION

Oxisols in Thailand comprise about 6,080 km^2, approximately equivalent to 1.2 percent of the country total land area (Soil Survey and Classification Division, 1999a; 1999b; 1999c). Most of them have developed on limestone and basic igneous rock under tropical savanna (ustic soil moisture regime) and tropical monsoonal (udic soil moisture regime) climates (Moncharoen, 1992). Oxisols are mainly distributed in Southeast Coast, Northeast Plateau, and Peninsular Thailand. Some areas of Oxisols are also important resource areas for gem mining industry (Wisawapipat *et al*., 2012). Their agricultural land uses are mostly upland crop such as corn, cassava, sorghum, tropical fruit trees, and their natural vegetations are mixed deciduous and rain forests. These soils are deep. Their textures are mostly clay loam or clay in the surface horizon and clay in the subsoil with well developed granular structure, and they have good internal drainage. Their bulk densities are generally low to moderately low. They generally have moderately acid surface horizon and they have low available water capacity.

Their pH, organic matters (OM), cation exchange capacity (CEC), and base saturation percentage (%BS) are generally low. High phosphorus adsorption is commonly found in these soils because of their high Fe contents (Trakoonyingcharoen *et al*., 2005).

Thailand is one of the world's leading countries in pineapple, durian and oil palm production. The considerable amounts of wastes are produced. Biochar production is seen as a key part of a strategy to effectively recycle biomass carbon and nutrients (Kammann *et al*., 2015). Low temperature biochar can also potentially be used as a low-cost sorbent (Ioannidou and Zabaniotou, 2007) or as a way of reusing agricultural waste including crop residue and livestock manure. The application of biochar has been well documented on its ability to enhance soil fertility and improve crop yield (Lehmann *et al*., 2006; Steiner, 2007; Gang Xu *et al*., 2016; Qin *et al*., 2016). Most nutrient elements present in organic materials persist in biochar albeit in different compounds (Keiluweit *et al*., 2010) and these nutrient elements mostly exist in crystalline compounds in biochar (Prakongkep *et al*., 2015) so the availability of nutrient elements to plants will depend on the extent and rate of dissolution of these compounds in biochar in the soil. Biochar addition to acid soils was found to lead to a higher adsorption capacity of the soils for selective nutrients (Steiner *et al*., 2008; Novak *et al.,* 2009; Sohi *et al*., 2010). Additionally, dynamics of carbon mineralization in biochar–amended soil was reported to exist (Junna Sun *et al*., 2016).

Soil fertility capability classification (FCC) system has been developed to interpret soil taxonomy and soil tests in a quantitative manner that is relevant for growing plants (Sanchez *et al*., 1982; Sanchez *et al*., 2003). The FCC system version 4.0 consists of two categorical levels. The first category (type) describes topsoil texture and is expressed in capital letters. The second category (condition modifier) indicates soil conditions affecting plant growth with quantitative limits. Each condition modifier is expressed as a lower case letter. The FCC system can be used to identify basic potential fertility of the soils (Sanchez *et al*., 2003). Therefore, the objectives of this study are (1) to assess the fertility capability of Oxisols and (2) to assess and elucidate practicability of using biochars on highly weathered tropical soils for agricultural practices.

MATERIALS AND METHODS

Soil Sampling and Analysis

Soil samples were taken from top soil 0–20 cm depth and base of topsoil to 60 cm depth of four different agricultural fields in Nakhon Ratchasima province Thailand. These samples were air–dried, gently crushed and passed through a 2 mm sieve before analysis. The soil samples were analyzed for pH and EC in a 1:5 soil water extract. Exchangeable K, Na, Ca and Mg were measured by ammonium saturation method at pH 7.0 (National Soil Survey Center, 1996). Available phosphorus was determined by Colwell method using an extracting solution of 0.5M $NaHCO_3$ adjusted to pH 8.5 with NaOH, a soil solution ratio of 1 g soil: 25 mL $NaHCO_3$ solution and an extraction time of 16 h at 25°C (Rayment and Lyons, 2011). Phosphorus was determined colorimetrically. The soil texture was determined by pipette method (Gee and Bauder, 1986). The results of soil chemical analyses are evaluated by three replicates for all samples.

Biochars and Incubation Experiment

Pineapple peel, durian shell and palm kernel shell were dried to 20–30% moisture before the carbonization procedure. Biochar was produced in a 200 L cylindrical container filled with the dried samples and placed in a controllable muffle furnace under limited oxygen. The carbonization temperature was 400°C with a 5 hours residence time. The biochar samples were allowed to cool to room temperature, they were crushed and sieved to a size range of 4 to 2 millimeters for the incubation experiment.

The incubation experiment was carried out in the laboratory using rectangular plastic 310 cm^3 containers. A 100 g soil sample was placed in the container with 1 g of biochar placed at 2 cm depth, sandwiched between two sheets of

1 mm nylon mesh and two equal layers of soil. The treatments were incubated in the dark at 25°C at 90% field capacity which was maintained by adding deionized water gently to the soil surface every 3 days. After 1, 2, 4 and 8 weeks incubation, the soil and biochar were separated and dried at room temperature. Only topsoil samples were used in the incubation experiment. Three replicates were used in the experiment.

RESULTS AND DISCUSSIONS

Classification and Properties of Oxisols

Two soil series, Pak Chong (Pc) and Chok Chai (Ci), were identified and their classification at subgroup level and chemical properties are shown in Tables 1 and 2. All of them are red Oxisols in areas where their land uses are alternated corn and cassava in limestone karst corrosion plain (S1, S2 and S3) and cassava in highly weathered basalt (S4). Clay content of the soils ranged from 320 to 843 g kg^{-1} in topsoils and 437 to 895 g kg^{-1} in subsoils. The organic carbon content ranged from 6.70 to 12.95 g kg^{-1} in topsoils and from 1.56 to 5.70 g kg^{-1} in subsoils. Their electrical conductivity (EC) was low ranging from 51 to 97 µS cm^{-1} in topsoils and 10 to 16 µS cm^{-1} in subsoils. Cation exchange capacity (CEC) of the soils varied from 6 to 17 cmol kg^{-1}. The concentrations of Ca in topsoils ranged from 2.3 to 8.2 cmol kg^{-1} and 1.6 to 7.0 cmol kg^{-1} in subsoils. Extractable Mg ranged from 1.4 to 2.1 cmol kg^{-1} in topsoils and low concentrations of Mg in subsoils. Similarly, extractable Na in all soil depths were rated as low. Extractable K ranged from 0.3 to 2.1 cmol kg^{-1} in topsoils and 0.0 to 0.6 cmol kg^{-1} in subsoils. The available P ranged from 47 to 106 mg kg^{-1} in topsoils and 16 to 25 mg kg^{-1} in subsoils. In general, these soils have poor fertility status and the values of available P in topsoils clearly indicated fertilizer management.

Table 1 Soil series, classification and parent material of soils

Code	Soil series	Classification	Parent material
S1	Pak Chong1 (Pc1)	Rhodic Kandiustox	Residuum and colluvium from limestone
S2	Pak Chong2 (Pc2)	Rhodic Kandiustox	Residuum and colluvium from limestone
S3	Pak Chong3 (Pc3)	Rhodic Kandiustox	Residuum and colluvium from limestone
S4	Chok Chai (Ci)	Rhodic Kandiustox	Residuum and colluvium from basalt

Source: Soil Survey Staff (2014)

Table 2 Physicochemical properties of the soils

Code	Horizon (cm)	pH	EC ($\mu S\ cm^{-1}$)	Clay ($g\ kg^{-1}$)	OC	Ca	Mg	Na ($cmol\ kg^{-1}$)	K	CEC	Avai. P $mg\ kg^{-1}$
S1	Topsoil	6.4	53	320	12.95	5.2	2.1	0.0	2.1	12	76
	Subsoil	5.9	15	437	5.37	7.0	0.1	0.1	0.6	11	25
S2	Topsoil	4.8	51	360	13.65	4.1	1.4	0.0	0.3	12	65
	Subsoil	4.4	16	474	5.70	4.8	0.0	0.3	0.1	10	15
S3	Topsoil	5.5	97	843	10.74	8.2	2.1	0.1	0.6	17	106
	Subsoil	5.7	16	895	3.99	6.6	0.1	0.4	0.0	9	19
S4	Topsoil	5.0	61	318	6.70	2.3	0.5	0.1	0.3	10	47
	Subsoil	4.7	10	610	1.56	1.6	0.1	0.2	0.0	6	16

Remark: pH and EC by 1:5 H_2O extraction, Extractable Ca, Mg, Na and K by NH_4OAc at pH 7.0, Available P by Colwell method (Rayment and Lyons, 2011), Topsoil = Ap (0–20 cm), Subsoil = horizon under Ap (20–60 cm), OC = organic carbon.

Properties of Biochars Used in The Study

The pH, EC and total element concentrations in three biochars are shown in Table 3. The pH of pineapple peel biochar, durian shell biochar and palm kernel shell biochar were 7.9, 8.3 and 5.9 respectively. The EC of biochars ranged from 363 to 13,273 $\mu S\ cm^{-1}$ where the EC of fruit waste biochars (pineapple peel and durian shell) were much higher than that of the palm kernel shell biochar. Plant nutrient elements in pineapple peel biochar and durian shell biochar were also much higher than in palm kernel shell biochar.

Table 3 The pH, EC and total element concentrations of biochars*

Raw materials	pH	EC $\mu S\ cm^{-1}$	Ca	K	Mg	Mn ($mg\ kg^{-1}$)	Na	P	S
Pineapple peel	7.9	13,273	6,466	32,528	2,231	235	333	4,211	1,555
Durian shell	8.3	12,093	6,099	27,730	5,428	54	380	13,424	1,435
Palm kernel shell	5.9	363	4,149	722	127	18	548	1,220	89

Remark: *Biochar samples digested in mixed acid 5:2, HNO_3:$HClO_4$, measured by ICP–OES, pH and EC by 1:5 H_2O extraction.

Fertility Capability of Oxisols in the Study

Based on the soil fertility capability classification (Table 4), types of this soils were L or C (loamy or clayey) textures in the topsoils and C (clayey) textures in the subsoils. The condition modifiers relevant to the soils were (i) strong dry season "d", having ustic moisture regime, (ii) high phosphorus fixation by iron and aluminum oxides "i" (Oxisols), (iii) low organic carbon saturation "m", that less than 80% total organic carbon saturation in the topsoil. The FCC units of these soils were S1 = LCdim, S2 = LCdim, S3 = Cdim, S4 = LCdim (Tables 4 and 5). The FCC units of these soils indicated their potential problems of cropping practices on dry condition, high P fixation and low organic matter (Sanchez *et al.*, 2003).

Table 4 Some identifying criteria used for soil fertility capability classification version 4.0

Identifying criteria	Symbols
Fertility capability class	
Surface soil texture (Type)	S, L, C, O
Subsurface soil texture (Substrata type)	S, L, C, O
Identifying criteria of modifiers	
1. Aluminum toxicity for most common crops (pH in 1:5 H_2O < 3.5)	a
2. Basic reaction (pH in 1:5 H_2O > 7.3)	b
3. Sulfidic (pH < 3.5 after drying present of jarosite mottles)	c
4. Dry (soils have ustic, aridic or xeric moisture regimes)	d
5. Low cation exchange capacity (sum of base extracted by NH_4OAc < 7 cmol kg^{-1})	e
6. High P fixation by Fe and Al oxides (oxisols and oxic groups)	i
7. Low K reserve (exchangeable K < 0.20 cmol kg^{-1} soil)	k
8. Low organic C saturation (< 80% total organic carbon saturation in the topsoil)	m

Remark: S = sandy texture, L = loamy texture (<35% clay but not loamy sand and sand), C = clayey texture (>35% clay), O = organic soil (>12% of organic carbon).

Source: Sanchez *et al*. (2003)

Table 5 Soil fertility limitations and fertility capability classification

Code	Horizon (cm)	Texture	Modifiers			FCC
			d	i	m	
S1	Topsoil	Loam	+	+	+	LCdim
	Subsoil	Clay	+	+	+	
S2	Topsoil	Loam	+	+	+	LCdim
	Subsoil	Clay	+	+	+	
S3	Topsoil	Clay	+	+	+	Cdim
	Subsoil	Clay	+	+	+	
S4	Topsoil	Loam	+	+	+	LCdim
	Subsoil	Clay	+	+	+	

Remark: Topsoil = Ap (0–20 cm), Subsoil = horizon under Ap (20–60 cm), L = Loam, C = clay, d = dry, i = high P fixation by Fe and Al oxides, m = low organic carbon saturation.

Chemical Response of Soils to Biochar During Incubation

Some chemical changes of soils incubated with pineapple peel biochar are shown in Figure 1. Generally, the change occurred during two weeks of incubation. Soil pH increased and became stable after two weeks (Figure 1a). Soil EC increased sharply in the first week of incubation and later most of the soil EC became stable throughout 8 weeks of incubation. However, the EC of S1 increased steadily after two weeks towards the end of the 8 weeks incubation (Figure 1b). Extractable K in these soils showed variable response to biochar during the incubation period (Figure 1c). S1 which had high K content showed a decrease of extractable K in the first two weeks and became stable towards the end of the incubation period. Other soils had a slight increase of the extractable K during the first two weeks and later became stable. Extractable Ca in all soils showed a slight increase during the first two weeks and later became stable (Figure 1d). However, the trend of available P in the soils during incubation period varied but the noticeable change also occurred in the first two weeks (Figure 1e).

From these data it could be concluded that short term effect of pineapple peel biochar application to soils was real and it depended on the initial properties of the soils.

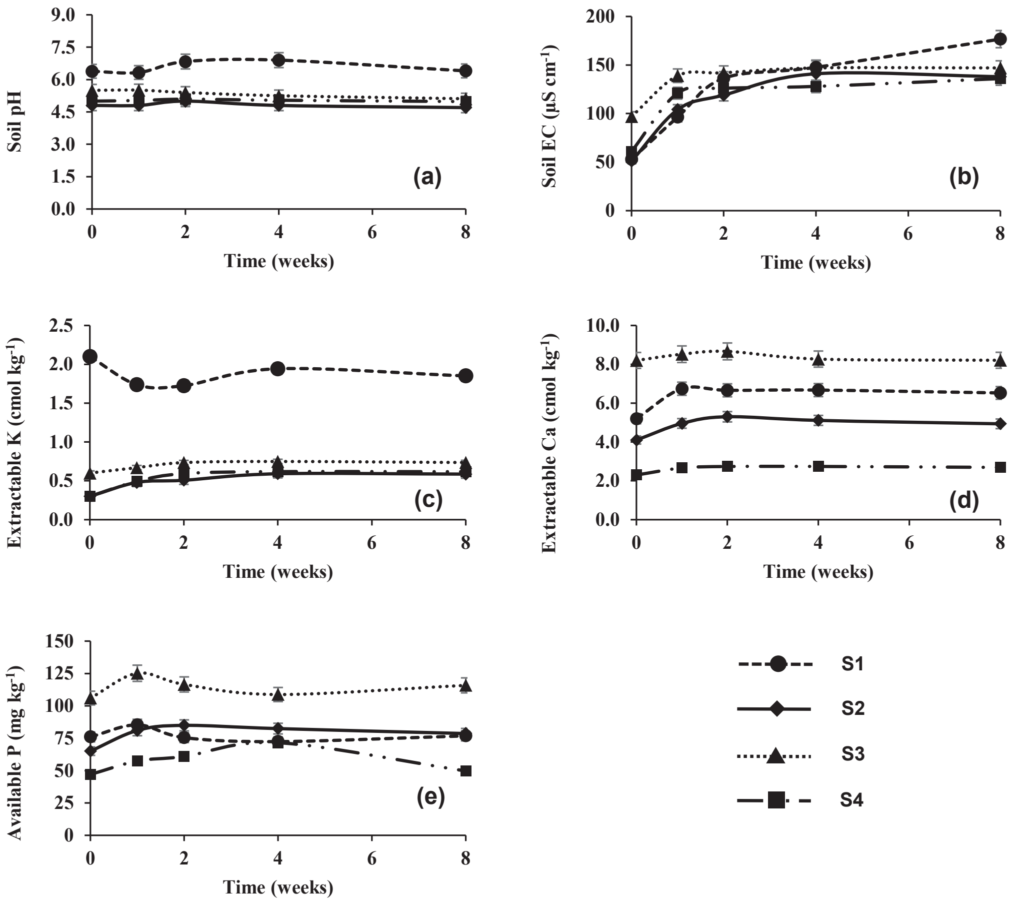

Figure 1 The chemical properties of four soils incubated (S1–S4) with pineapple peel biochar. (a) soil pH (1:5 H_2O), (b) soil EC (1:5 H_2O), (c, d) soil exchangeable K, Ca, (e) soil available P. Each data point represents the mean of three replications with standard error

The chemical change of soils incubated with durian shell biochar is shown in Figure 2. The change also occurred in the first two weeks of incubation. The soil pH increased and later remained stable throughout the incubation period (Figure 2a). The EC of most soils (S2, S3 and S4) increased during the first two weeks of incubation and later remained stable towards the end of the incubation period. The EC of S1 however increased throughout the 8 weeks of incubation (Figure 2b). The soil extractable K showed a similar trend with that incubated with pineapple peel biochar (Figure 2c). The extractable K of S1 decreased in the first weeks then remained stable while the extractable K of others increased and later remained stable. For extractable Ca in soils, the trend of change was similar to that incubated with pineapple peel biochar (Figure 2d). The very interesting change of soil available P is shown in Figure 2e. The available P of all soils increased and remained stable for S2, S3 and S4 but the available P in S1 increased throughout the incubation period.

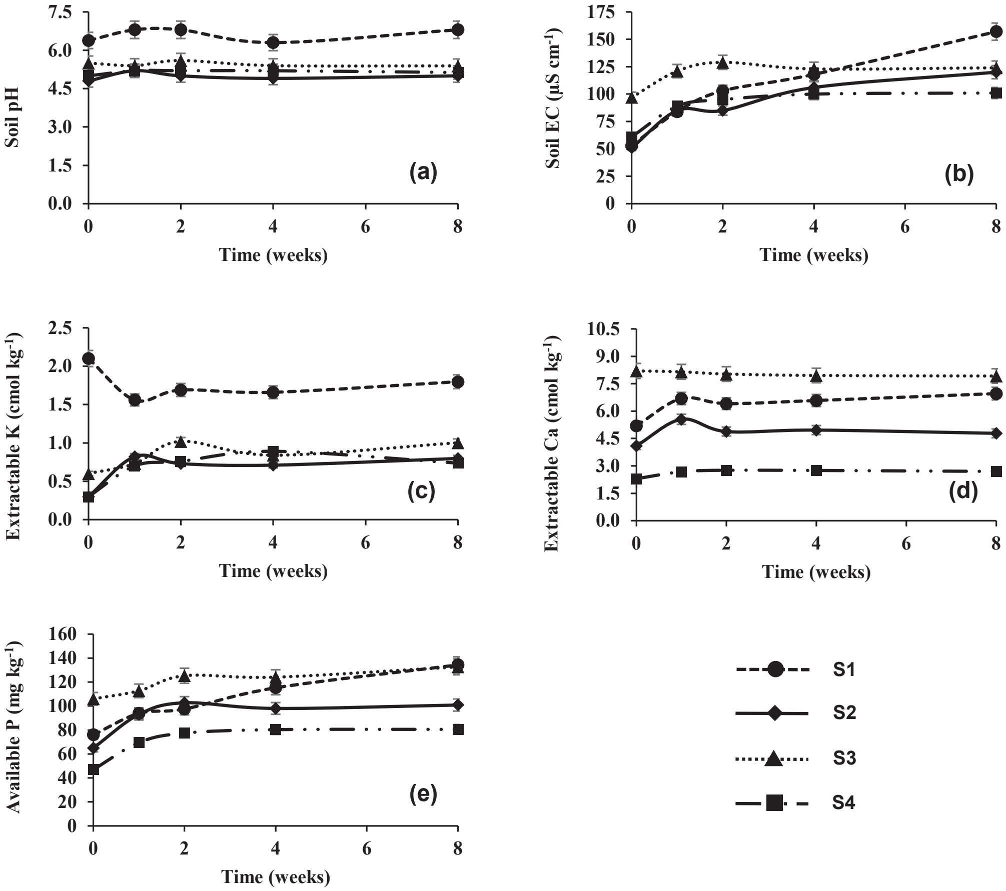

Figure 2 The chemical properties of four soils incubated (S1–S4) with durian shell biochar. (a) soil pH (1:5 H_2O), (b) soil EC (1:5 H_2O), (c, d) soil exchangeable K, Ca, (e) soil available P. Each data point represents the mean of three replications with standard error

These conditions of chemical change in soils indicated that the increase/decrease of chemical values in soils incubated with different biochars were strongly related to the properties, content and the source of individual biochar.

The chemical change of soils incubated with palm kernel shell biochar is shown in Figure 3. The change also occurred mainly in the first two weeks of incubation. The soil pH increased slightly and remained stable (Figure 3a). The soil EC trends of change were similar for all soils. They increased at first then remain stable during the incubation period (Figure 3b). The extractable K of all soils decreased and remained stable throughout the period of incubation (Figure 3c). The extractable Ca of soils generally increased and remained stable during the incubation period (Figure 3d). The changes of available P in soils were rather variable. S2 and S3 had available P decreased in the first week then increased and remained stable while available P of S1 and S4 increased and later remained stable (Figure 3e).

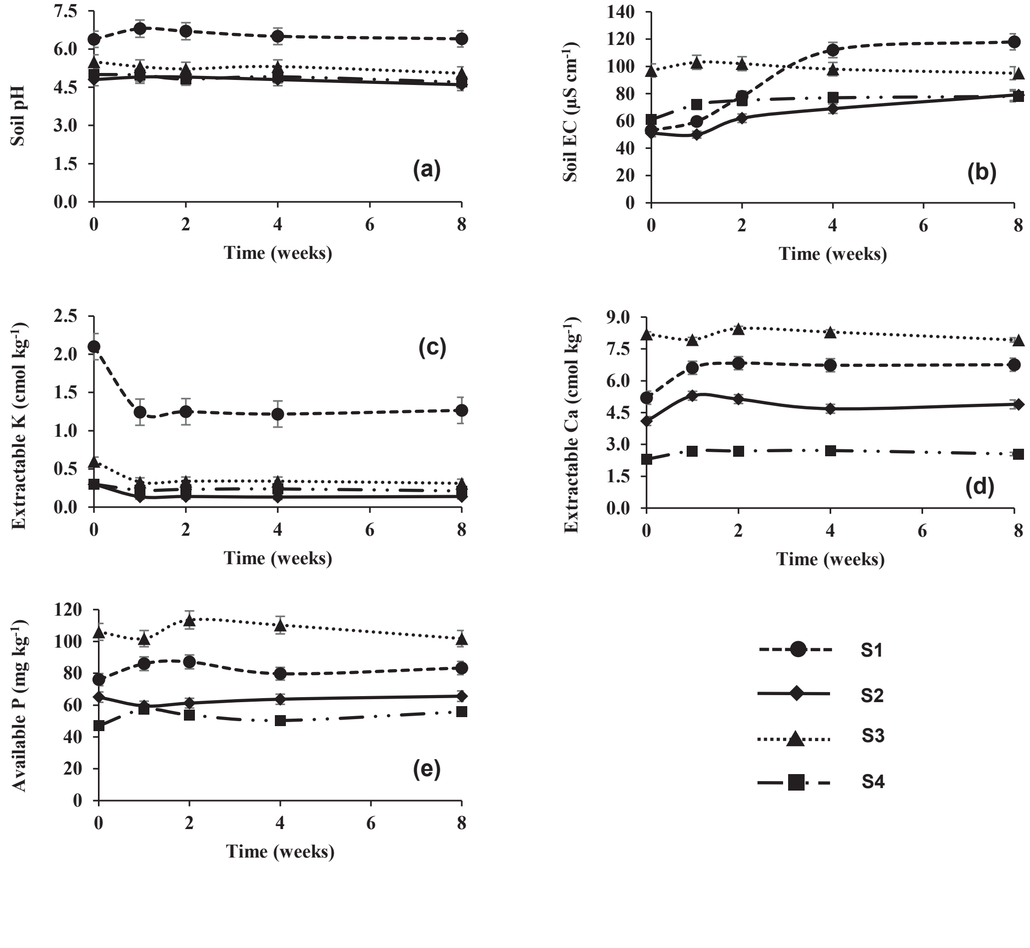

Figure 3 The chemical properties of four soils incubated (S1–S4) with palm kernel shell biochar. (a) soil pH (1:5 H_2O), (b) soil EC (1:5 H_2O), (c, d) soil exchangeable K, Ca, (e) soil available P. Each data point represents the mean of three replications with standard error

Results on the change of soil properties during incubation period indicated clearly that all biochars had the same effect on soil pH and EC that at time they could increase soil pH and EC. They had slightly different effect on extractable Ca, but the change of extractable Ca did not give a very clear trend. The more interesting effect of biochars to these soils were on the changes of extractable K and available P which were generally variable in short term. The responses of soils to biochar on these two essential nutrients were two ways. The soil could lose extractable K and available P to biochars and they could also gain extractable K and available P from biochars depending on condition of soils and type of biochars. Nevertheless, these findings confirmed that short term effect of biochars on soils was real.

Soil Fertility After Incubation

After the 8 weeks of incubation, pineapple peel and palm kernel shell biochar application (Figures 4a and 6a) had little effect on the soil pH that values slightly decreased in all soils, except for a small pH increase in the soils incubated with durian shell biochar (Figure 5a). The EC values of the four soils before incubation ranged from 51 to 97 µS cm^{-1}. After incubation, soil EC values increased for pineapple peel biochar to 136 to 177 µS cm^{-1} (changing from 50 to 124 µS cm^{-1}) (Figure 4b), durian shell biochar from 101 to 157 µS cm^{-1} (changing from 27 to 104 µS cm^{-1}) (Figure 5b) and with palm kernel shell biochar from 78 to 118 µS cm^{-1} (changing from 2 to 65 µS cm^{-1}) (Figure 6b).

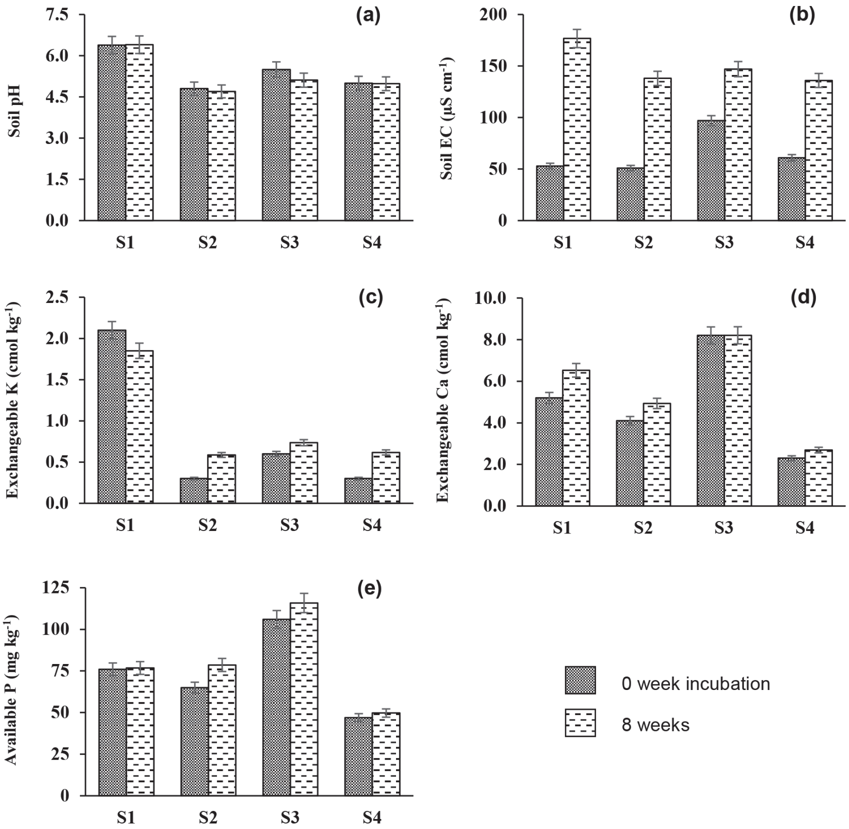

Figure 4 The chemical properties of four soils incubated with pineapple peel biochar at for eight weeks. (a) soil pH (1:5 H_2O), (b) soil EC (1:5 H_2O), (c, d) soil exchangeable K, Ca, (e) soil available P. Three replications were used for each treatments

Pineapple peel and durian shell biochar had slightly increased extractable K in the S2, S3 and S4 (Figures 4c and 5c). Both biochars had a majority of the K soluble after incubation to soil. Palm kernel shell biochar had decreased K in the soils (Figure 6c) because they contained much less K and receiving K from the soil solution. The soil extractable Ca content showed a small increase after incubation with pineapple peel, durian shell and palm kernel shell biochars (Figures 4d, 5d and 6d). The available P from soils incubated with biochars had increased (Figures 4d, 5d and 6d) except for S3 incubated with palm kernel shell biochar that available P had little decreased.

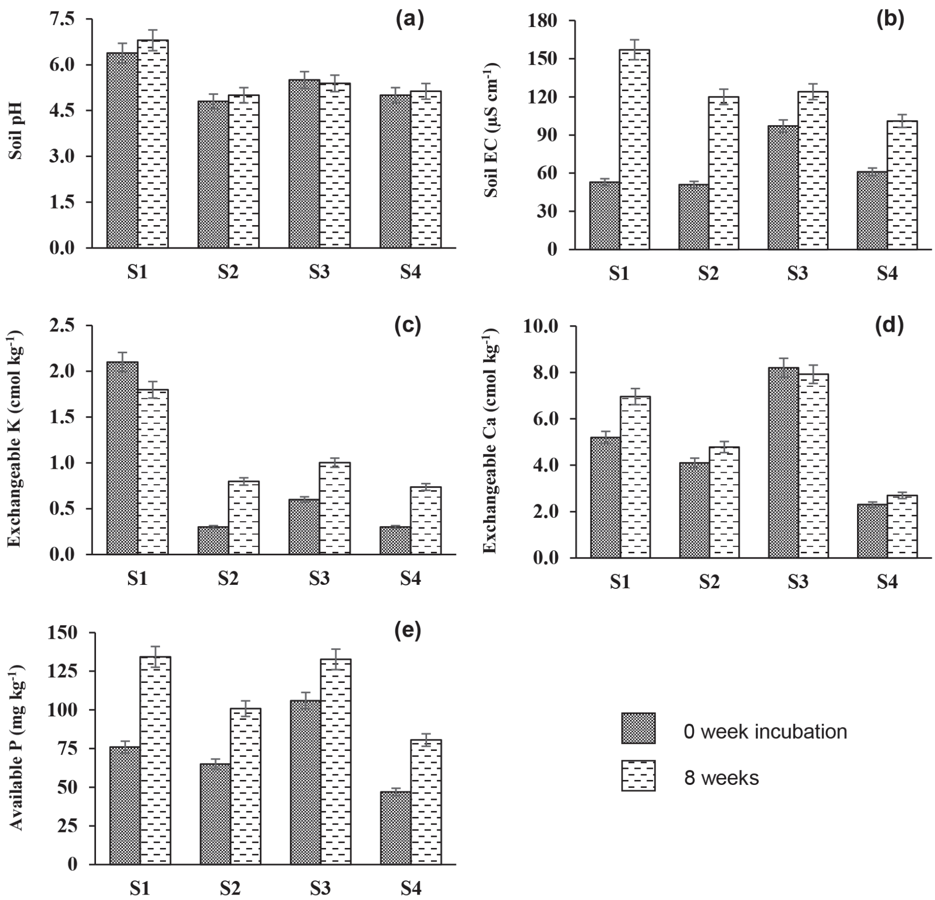

Figure 5 The chemical properties of four soils incubated with durian shell biochar at for eight weeks. (a) soil pH (1:5 H_2O), (b) soil EC (1:5 H_2O), (c, d) soil exchangeable K, Ca, (e) soil available P. Three replications were used for each treatments

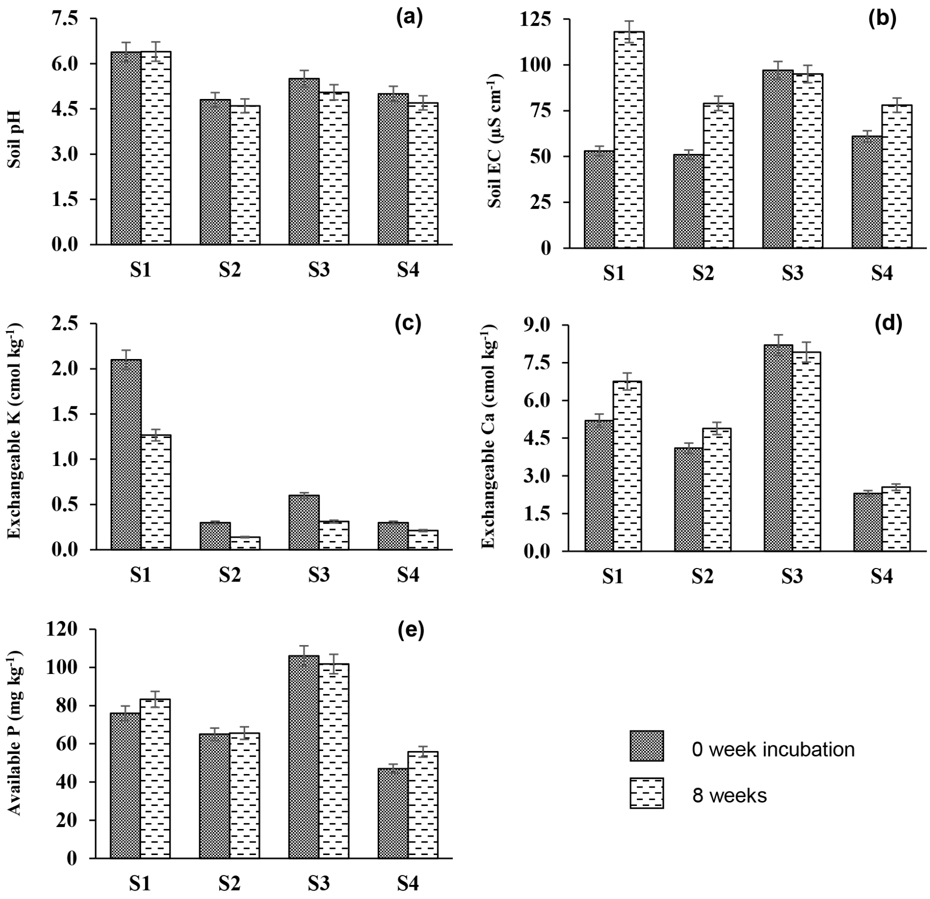

Figure 6 The chemical properties of four soils incubated with palm kernel shell biochar at for eight weeks. (a) soil pH (1:5 H_2O), (b) soil EC (1:5 H_2O), (c, d) soil exchangeable K, Ca, (e) soil available P. Three replications were used for each treatments

Soils incubated with pineapple peel biochar and durian shell biochar for 8 weeks had extractable K and available P increased. They had shown that soil fertility limitation decreased while soils incubated with palm kernel shell biochar for the same period did not clearly show any decrease in their fertility limitation. A reason for this was that the palm kernel biochar contained much less K than did the pineapple peel biochar and the durian shell biochar so they had taken K from the soils.

These response of Oxisols to the three agricultural wastes biochar application indicated well that soils with similar properties could be influenced differently by types of agricultural wastes biochar. The natures of agricultural wastes were generally different and after they had become low temperature biochars their components varied so their dissolution natures in the soils also varied (Limwikran *et al.*, 2018). These showed variable effects in soils. However, even in short term their effects were real and variable with time. The interchange of mineral nutrients between the soils and biochars could occur somewhat dynamically with time. The change occurred in soils with different biochars in this short term revealed the fact that individual biochar could be both sink and source of some nutrients affected by the vital nature of the soils. In this case the highly leached nature and the sesquioxides in the Oxisols affected the interchange of available K and P during the incubation period. One certain aspect of biochars that the soils responded well in this study was the increase of EC of acidic soils. This could be beneficial to soil fertilizes management in cropping. However, this short term incubation of biochars though decreased fertility limitation it did not clearly change fertility capability of these Oxisols.

CONCLUSION

Soil fertility limitations that characterized Oxisols area were low nutrient capital reserve, high leaching potential and were classified in soil fertility capability classification as LCdim, LCdim, Cdim and LCdim. The responses of these Oxisols to the addition of biochars on soil pH, EC, extractable K, Ca and available P varied with the content of biochars and time. Biochars produced from different agricultural wastes contained different amount of plant nutrients. Biochars from agricultural fruit wastes (pineapple peel and durian shell biochar) had more K and Ca while biochar from oil palm industry (palm kernel shell) had less plant nutrients. The responses of Oxisols to these agricultural wastes biochars were clear on the increase of EC and dynamic responses to some mineral nutrients particularly K and P in the biochars. This study provided useful information about responses of Oxisols on short term biochar application. It also showed that biochars had a potential as soil amendments and the dynamics of being sink and sources for mineral nutrients of biochars in the soils should be carefully considered in cropping practices.

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