Soil & Tillage Research 132 (2013) 1–11

Contents lists available at SciVerse ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Increasing negative charge and nutrient contents of a highly weathered soil using basalt and rice husk to promote cocoa growth under field conditions

Markus Anda [a,*], J. Shamshuddin [b], C.I. Fauziah [b]

[a] Indonesian Center for Agricultural Land Resource Research and Development, Agency of Agricultural Research and Developement, Jalan Tentara Pelajar No. 12, Cimanggu Bogor 16114, Jawa Barat, Indonesia

[b] Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

ARTICLE INFO

Article history:
Received 14 January 2013
Received in revised form 13 April 2013
Accepted 24 April 2013

Keywords:
Basalt
Rice husk
Surface charge
Oxisols
Cocoa

ABSTRACT

Technology intervention is a key success to restore properties and productivities of a highly weathered soil (Oxisols). The main challenge is to find materials with the ability to generate soil negative charge, release various nutrients and suppress toxic elements. The objective of this study was to increase negative charge and nutrient content, and suppress Al and Mn toxicities of an Oxisol using finely ground basalt and rice husk compost (RHC) to promote cocoa growth under field conditions. Factorial field experiment of 4 × 4 used finely ground basalt and rice husk compost and arranged in a randomly complete block design and planted to cocoa as a test crop. Finely ground basalt and rice husk compost were incorporated to the soil at 0–20 cm depth and rates varied from 0 to 20 t ha^{-1} each. Soils were periodically sampled for 24 months for analyses of soil negative charge, organic C content, various cations, pH and toxic elements. Results showed the rice husk compost (RHC) application significantly increased soil organic C content. The solid state cross polarization magic angle spinning ^{13}carbon nuclear magnetic resonance (CP/MAS ^{13}C NMR) indicates RHC application was able to increase soil organic C functional groups (O-alkyl, di-O-alkyl and carboxyl C), accompanied by the appearance of aromatic, alkyl and methoxyl C as new functional groups. The carboxyl C plays a major role in generating soil negative charge, suggesting RHC is suitable to restore organic C and negative charge of Oxisols. Basalt, RHC and their combination were able to increase markedly the negative charge of Oxisols as revealed by the decreases in pH_0 and point zero net charge (PZNC) values. The decrease in pH_0 and PZNC values resulted in the increase of net negative charge of an Oxisol from 0.8 (a control soil) to 2.8, 4.1 and 5.0 $cmol_c\ kg^{-1}$ for basalt, RHC and their combinations, respectively. *In situ* soil solution study (a new technique) under field conditions showed basalt and RHC applications either singly or in combination significantly increased the concentrations of Ca, Mg, K, Na and Si, while concentrations of toxic Al and Mn significantly reduced below a toxic level. Overall improvement of Oxisol chemical properties attributed by basalt and RHC applications significantly increased cocoa growth as revealed by the increase in height and stem diameter of cocoa which are two to three times faster than the control within a 24-month period.

1. Introduction

Oxisols, highly weathered soils, are unproductive soils owing to advanced stage of development. According to von Uexkull and Mutert (1995), Oxisols occupied 727 million ha (18.4%) of the total world's acid soils (3950 million ha). In Malaysia, the Oxisols have little capacity to retain cations because of very limited negative charge under natural conditions. Anda et al. (2008a) reported that the Malaysian Oxisol (Segamat series) at natural conditions has heavy clay (79–81%), very low cation exchange capacity (CEC) (<3.2 $cmol_c\ kg^{-1}$) and cation contents (sum of cations < 0.40 $cmol_c\ kg^{-1}$) but has high Al saturation (77–83%) within the upper two soil horizons.

It appears that Oxisols strongly need intervention of technology to increase their negative surface charge, replenish their nutrient loss and alleviate Al and Mn toxicities. By using technology, the natural basalt could be processed as a potential material to generate soil negative charge, increase soil pH and released most of the essential cations (Gillman et al., 2002; Anda et al., 2009), thereby it offers a good insight to solve the problems of a highly weathered soil such as Oxisols.

In soils, the negative charge derived from inorganic functional groups (hydroxyl of Si, Al and Fe) and organic functional groups (enolic, phenolic and carboxyl) (Charlet and Sposito, 1987; Duquette and Hendershot, 1993). The intrinsic charge of soil particles consisted of permanent charge and variable charge

* Corresponding author. Tel.: +62 02518323012; fax: +62 02518311256.
E-mail address: markusandas@yahoo.com (M. Anda).

0167-1987/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.still.2013.04.005

components (Sposito, 1989; Chorover et al., 2004). According to Gillman (2007) permanent charge (negative or positive) is the structural charge resulted from isomorphous substitution during crystal formation and the magnitude is not altered by the change in the pH or ionic strength of the surrounding solution. In contrast, the variable charge (negative or positive) is the charge that develops on (principally) surface hydroxyl groups by protonation and deprotonation reactions. The magnitude of the variable charge is dependent on pH and ionic strength of surrounding solution.

Oxisols have lost ability to retain base cations owing to low or limited amount of negative charge, low pH and high Al content, which collectively became major limiting factors for crop growth. Hence, the key success in using Oxisols for agricultural practices mainly relies on technology intervention to manipulate their existing constraint chemical properties and lack of nutrients. Manipulation of chemical properties and increasing nutrient content of highly weathered soils using finely ground basalt have been carried out under laboratory conditions (Gillman et al., 2002; Anda, 2006) and glasshouse conditions (Anda et al., 2009). Results from both laboratory and glasshouse conditions showed that application of finely ground basalt on Oxisols (highly weathered soils) were able to increase negative charge (cation exchange capacity), exchangeable cations and suppress Al and Mn contents. The improvement of soil properties has significantly improved cocoa growth under glasshouse conditions (Anda et al., 2009). However, environmental factors, especially temperature and soil moisture regimes, are fully controlled under laboratory and glasshouse conditions. These factors are difficult to control under field conditions, therefore, the field experiment is needed to observe the ability of basalt in increasing soil negative charge and improving cocoa growth. Since basalt dissolution took place under the condition that sufficient soil moisture content (field capacity) or during a rainy season, attempts should be made (*e.g.* compost application) to increase soil water contents under field conditions, thereby more basalt dissolution. Hence, the experiment was designed using basalt and organic matter applications under field conditions to restore properties and nutrient content of a highly weathered soil to support optimal crop growth. It is expected that the field experiment could show similar results to basalt applications under laboratory and glasshouse conditions.

Rice husk distributed in the rice mills as the main by-product and agro-waste that cause serious environmental problems (Kapur, 1985). It is being produced in more than 75 countries around the world (Natarajan et al., 1998) and the annual world output is about 116 million tons (FAO, 2002). Although rice husk was quite resistant to microbial decomposition due to its high cellulose and lignin contents (Anda et al., 2008b), it could provide special benefit to crops when used as a soil ameliorant. This beneficial effect is related to prolonged residual effect, which was really needed in tropical conditions due to rapid decomposition of organic matter as a result of being exposed to high temperature and rainfall. It has been confirmed that rice husk compost has a long resident time in soil and hence it is a good source of SOM (Anda et al., 2010). Currently, no information is available for applying rice husk for upland soils in association with cocoa growth. The objective of this study was to increase negative charge and nutrient content, and suppress Al and Mn toxicities of a highly weathered soil using finely ground basalt and rice husk compost (RHC) to promote cocoa growth under field conditions.

2. Materials and methods

2.1. Location and materials

The field experiment was carried out at the Malaysian Cocoa Board (MCB) Experimental Station in Jengka, Pahang, Malaysia. The site selected was former forest and had been cleared for the extension of the cocoa research area by MCB. The soil is classified as a fine clayey, kaolinitic, isohyperthemic, Rhodic Hapludox (Soil Survey Staff, 2010). Mineralogical composition of the clay fraction of the soil studied had been reported by Anda et al. (2008a), where kaolinite was dominant (83%) followed by goethite (10%) and hematite (5%). The area had been planted with *Gliricidia sepium* as preparation to shade the young cocoa. Rice husk compost was bought from the private company. The basalt was supplied by Pacific Mineral Developments Pty Ltd, Australia, in the form of finely ground basalt rock. The particle sizes were $\leq$50 μm (53%), 50–106 μm (26%), 105–250 μm (14%), 250–500 μm (5%) and 500–2000 μm (2%). In the present study, the particle size of $\leq$250 μm was used. Major chemical compositions obtained from X-ray fluorescence (XRF) analyses provided by the company were CaO (8.97%), MgO (10.70%), K_2O (1.79%), Na_2O (2.59%), SiO_2 (43.20%), Al_2O_3 (12.90%), Fe_2O_3 (12.90%), P_2O_5 (0.77%), and SO_2 (<0.01%).

The cocoa seedlings were prepared as top-budding using the collection seedling of MCB as the root stock and that the KKM22 and PBC 123 cultivars as the top-plant. After top-budding, the seedlings were grown in the nursery for 6 months and then selected to obtain the relatively uniform growth to be transplanted to the experimental plots.

The average annual rainfall at the station is 1887 mm with 165 rain days. The wet season (monthly rainfall >200 mm) occurs from October to December, the moist seasons (monthly rainfall 100–200 mm) occur from March to May and from July to September, and the dry seasons (monthly rainfall <100 mm) occur in January, February, and June. The amount of annual evaporation is much lower (42 mm) than the annual rainfall, so there is always sufficient soil moisture. The annual minimum (20–23 °C) and maximum (30–33 °C) temperatures are relatively constant throughout the year, with an average of 26–28 °C. Some relevant soil properties prior to field trial of the studied Oxisol is given in Table 1. The soil pH was strongly acid, very limited amounts of exchangeable cations (<0.4 $cmol_c\ kg^{-1}$), low organic matter content and high Al saturation in the topsoil (77–83%).

Table 1
Selected physical and chemical properties of the Oxisol studied.

Horizon	Depth (cm)	Particle size (%)			C (%)	N (%)	pH		Al ($cmol_c\ kg^{-1}$)	Exchangeable cation ($cmol_c\ kg^{-1}$)				Sum cat. ($cmol_c\ kg^{-1}$)	CEC pH 7 ($cmol_c\ kg^{-1}$)	Al sat. (%)
		Clay	Silt	Sand			H_2O	KCl		Ca	Mg	K	Na			
A	0–14	79	17	3	1.4	0.13	4.19	4.00	1.41	0.15	0.23	0.02	nd	0.41	7.6	77
Bo1	14–45	81	15	3	1.0	0.10	4.27	4.08	1.12	0.09	0.11	0.02	nd	0.23	7.6	83
Bo2	45–85	82	15	3	0.9	0.08	4.25	4.36	0.38	0.09	0.14	0.02	nd	0.24	7.5	61
Bo3	85–117	81	16	3	0.8	0.07	4.49	4.57	0.16	0.08	0.19	0.02	nd	0.29	7.2	35
Bo4	117–165	84	13	3	0.8	0.05	4.58	4.58	0.16	0.10	0.08	0.02	nd	0.20	7.3	44

Adapted from Anda et al. (2008a).
nd, not detected; Sum cat., sum of cations; Al sat, Al saturation.