Study of Soil Profile and Properties in Long-Term Cocoa (*Theobroma cacao* L.) Agro-Eco System in Matale

R.G.D. JAYASENA[1], T.E. WEERAWARDENA[2], P.R. IDAMEKORALA[2] and K.G.A.P.K. AMARASINGHE[1]

[1]*Department of Plantation Management, Faculty of Agriculture and Plantation Management, Wayamba University of Sri Lanka, Makandura, Gonawila (NWP), 60170, Sri Lanka*

[2]*Soil Science and Plant Nutrient Division, Central Research Station, Department of Export Agriculture, Matale, 21000, Sri Lanka*

ABSTRACT

Cocoa (*Theobroma cacao* L.), is an important cash crop, which provides main ingredient (cocoa beans) used in the chocolate industry. Department of Export Agriculture promotes cultivation of cocoa under plantation crops to maximize the resource utilization. However, no information is available on soil development, chemical and biological changes in a cocoa agro-eco system, that are important to take decisions on soil fertility management. Therefore, this research was carried out to identify pedologic alterations in more than 20 years old cocoa agro-eco system under woody perennials, compared to an abandon forest and continuously vegetable cultivating land. Soil profiles were examined and bulk density, pH, organic carbon (OC), total nitrogen (N), available phosphorous (P), exchangeable potassium (K), magnesium (Mg) and mycorrhizal spore contents in each horizon were evaluated. Characteristics of soil profile of Immature Brown Loam soil in cocoa land was not physically altered due to long term existence of cocoa. Top soil of cocoa land was significantly ($P<0.05$) higher in OC (2.39%) and K (307 ppm) with a favorable bulk density (1.31 gcm^{-3}). The pH (5.98), total N (0.21%), Mg (520 ppm) contents were also good and similar to the forest land, whereas available P (3.26 ppm) was very low. Accordingly, it is clear that soil of cocoa agro-ecosystem is physically and nutritionally sustainable, but insufficient in P for a better cocoa production. The study revealed that a long term cocoa agro-ecosystem to be more productive even under minimum management practices.

KEYWORDS: Cocoa agro eco system, Soil profile, Soil properties

INTRODUCTION

Cocoa (*Theobroma cacao* L.), which belongs to family Malvaceae, is one of the important cash crop grown in humid tropics. Cocoa bean, economically important part of cocoa, is the main ingredient of chocolate. World production of cocoa beans, primarily for the manufacturing of chocolate and cocoa powder currently stand at 4.23 million metric tonnes (Anon, 2016). In Sri Lanka, cocoa is cultivated around 2,521 ha of lands and produce 2,453 mt of beans (Anon, 2009). Increase of cocoa lands as a monocrop is not applicable in Sri Lanka due to lack of suitable lands. Therefore, Department of Export Agriculture promotes cultivation of cocoa under plantation crops such as rubber and coconut (Anon, 2001) to maximize the use of resources. Because, cocoa is a well-adapted agro-forestry plantation crop and cocoa agro-eco systems are more specific due to microclimate under shade and litter fall. However, less information is available on soil development and soil chemical, physical and biological changes in cocoa agro-eco systems under Sri Lankan conditions especially to take decisions on soil nutrient management for high quality cocoa production. Therefore, this research was carried out to identify the soil profile, selected physical, chemical and biological characters in a long term cocoa agro-eco system comparatively to an abandoned forest and a vegetable cultivating land in the same vicinity.

MATERIALS AND METHODS

The experiment was carried out at Soil Science and Plant Nutrition Division, Central Research Station, Matale from January to May 2016. The main experiment site was a cocoa land cultivated under woody perennials which was more than 20 years old and maintained organically for more than ten years. For the comparison, a forest land and a vegetable cultivating land (cultivated land) in the same vicinity were selected. All sites were belonging to mid country intermediate zone (IM_{3a}). Soil profiles were studied in three sites and the different soil layers (horizons) running parallel to soil surface were identified. Physical properties of the soil horizons such as color, texture, structure, depth of soil, *etc.* were studied by vertical examination of soil profile.

Three disturbed and undisturbed soil samples were collected from each horizon with the aid of soil core sampler and soil augers. Bulk density was determined with the undisturbed soil samples (Blake and Hartage, 1987). Soil chemical properties such as soil pH (1: 2.5 soil: liquid ratio) was measured using pH meter (McLean, 1982). Total soil nitrogen (N)

(%) was determined by Micro kjeldahl method (Bremner, 1965). Olsen's bicarbonate method (Olsen *et al.*, 1954) was used to determine available soil phosphorous (P; ppm). Exchangeable potassium (K) and magnesium (Mg) (ppm) were determined by NH_4OAc extraction and spectrophotometer method (Thomas, 1982). Soil organic carbon (OC) was determined by Walkley and Black method (Nelson and Sommers, 1982). As a biological property, mycorrhizal spore density (Brundrett *et al.*, 1996) was estimated. Data were analyzed using Statistical Analysis System (SAS) version 9.1.

RESULTS AND DISCUSSION

Soil Profile Descriptions

Soil Profile of Cocoa Agro-ecosystem

The experimental land was gently undulated and covered with cocoa and well grown woody trees. Soil was moderately deep, well drained and locally classified as Immature Brown Loam. Genetic horizon sequence was Ap, Bw, B/C and C (Figure 1, A). The respective soil colors of each soil horizon were dark brown, dark brown, dark yellowish brown and light yellowish brown. Surface soil depth was 20/28 cm. The structure of the surface soil is moderately developed sub angular blocky. Texture of the surface soil was sandy clay loam. Compactness and porosity of the surface were moderate, whilst stickiness was moderate. Many coarse and fine roots were in the surface soil. Bw horizon was up to 50 cm. Structure and texture, were weak sub angular blocky and sandy clay respectively. Further porosity, compactness and stickiness of the sub soils were respectively few, hard and moderate. Many coarse root and few fine roots were appeared in the sub surface. Ferro-manganese stains were available in lower part of the sub soil.

Soil Profile of Forest Land

This land was gently sloppy land dominated by woody perennials. Soil was moderately deep well drained soil, locally classified as Immature Brown Loam. Genetic horizon sequence was A, Bw and B/C (Figure 1, B). Soil color of each soil horizon was dark brown, light brown and yellowish brown respectively. Surface soil depth was 15/20 cm. In surface soil, moderately developed sub angular blocky structure and sandy loam texture was observed. Compactness and porosity of sub soil were moderate, whilst stickiness was low. Many coarse and fine roots were present in surface soil. Bw horizon was between 15/20-48/70 cm in depth. Structure and texture were weak sub angular blocky and sandy clay loam respectively. Porosity, compactness and stickiness were few, hard, and sticky respectively. Many coarse and fine roots were present. Ferro-manganese stains were also available in sub surface soil.

Soil Profile of Vegetable Cultivated Land

The selected land has been routinely cultivated with vegetables and regularly tilled and chemically fertilized. It was a gently sloppy land near to the valley and soil was very deep and well-drained, which is locally classified as Reddish Brown Latosolic. Genetic horizon sequence of the soil was Ap, A/B and B (Figure 1C). Soil color of each soil horizon was brown, dark brown and reddish brown respectively. Surface soil depth was around 40 cm. The structure was weak sub angular blocky and texture was sandy clay loam. Compactness was high and many macro spores could be observed. Stickiness was moderate. Many fine roots were present. Second horizon (A/B) was between 40– 80 cm. Soil structure was strong sub angular blocky and texture was clay loam. Porosity of the sub soil was few whereas compactness and stickiness were high. Further, few roots could be seen in sub surface soil.

According to above study, either the characteristics of soil profile of cocoa agro-ecosystem was not physically different from the typical soil profile of Immature Brown Loam (De Silva and Dassanayake, 2002). In other words, soil profile of Immature Brown Loam soil in cocoa land has not been physically altered due to long term existence of cocoa.

Soil Properties of Top Soil

Soil pH in three sites were in the range of 5.8 to 6.14 and was favorable for plant growth and nutrient availability (Table 1). As the favorable pH range for cocoa plant growth is 5 to 6.5 (Anon, 2001), soils of all experimental sites were under favorable conditions.

Bulk Density (BD)

Bulk density of all sites were significantly different ($P<0.05$) from each other. Forest soil showed the highest (1.48 gcm^{-3}) bulk density and cocoa soil showed the lowest (1.31 gcm^{-3}) bulk density (Table 1). Well distributed cocoa canopy and highly accumulation of un-decomposed organic matter content on soil surface may be the reasons for low bulk density in cocoa land. Higher BD in forest land is attributed with compactness with heavy rain due to presence of open spaces in between forest trees.

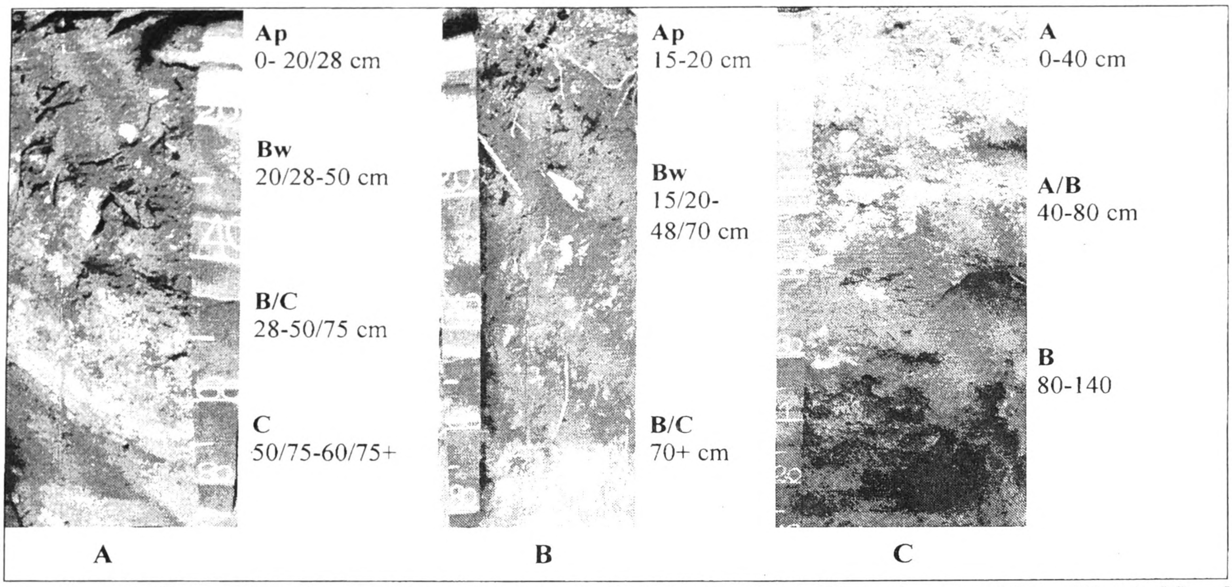

Figure 1. Soil profiles of cocoa agro-eco system (A), forest land (B) and vegetable cultivated land (C)

Soil Organic Carbon (OC)

Organic carbon (OC) content (%) in cocoa land (2.39%) was significantly ($P<0.05$) higher compared to that of forest land (1.87%) and cultivated land (1.83%; Table 1). The reason for high OC content of cocoa may be the collection of biomass with high litter fall of cocoa and shaded trees. However forest land also having high litter fall but canopy density was less compared to cocoa land, therefore wash out of organic matter may takes place under heavy rain. Litter accumulation does not usually occur in cultivated land, most probably due to continuous disturbances and nutrient removal.

Soil Total Nitrogen (N)

No significant difference was observed in total N (%) content of soil between cocoa (0.21%) and forest lands (0.22%) while the lowest was observed in cultivated land (0.11%) (Table1). As forest land is usually a sustainable ecosystem, proper nutrient recycling may be the reason for high nitrogen content. Similarly, high N in cocoa proves the ability of cocoa for nitrogen recycling with biological transformations even under long term organic management. In cocoa land, both litter from shaded trees and cocoa make a considerable contribution to the cycling of nutrients particularly N in the plantations (Santana and Cabala- Rosand, 1982). Less litter accumulation, continuous disturbance, nutrient removal and run off may be the reasons for the lowest N content in cultivated land.

Soil Exchangeable Potassium (K)

Soil K (ppm) in cocoa land was significantly ($P<0.05$) higher (307 ppm) compared to that of forest land (107 ppm) and cultivated land (191 ppm; Table 1). High level of K has been recorded in cocoa litter (Sreekala *et al.*, 2001) as well as in cocoa pod husk (Ajayi *et al.*, 2007). Thus, decomposition of fallen litter and fallen immature cocoa pods may be the reasons for K richness in cocoa land.

Soil Exchangeable Magnesium (Mg)

No significant difference was observed in Mg content among three sites. But values were considerably high (367- 520 ppm; Table 1) as soil of Matale is naturally dominant with Mg and Ca (De Silva *et al.*, 2005).

Available Soil Phosphorus (P) and Density of Mycorrhizal Spores

Available P levels were low in all sites while the highest level of available P content

Table 1. Soil properties of top soil of experimental sites

Experimental site	Bulk density (gcm^{-3})	Organic C (%)	K (ppm)	Mg (ppm)	Total N (%)	P (ppm)	pH	Mycorrhizal spores (kg^{-1} Soil)
Cocoa	1.31^c	2.39^a	307^a	520^a	0.21^a	3.26^b	5.98^{ab}	766
Forest	1.48^a	1.87^b	107^b	502^a	0.22^a	2.52^b	5.80^b	480
Cultivated	1.40^b	1.83^b	191^b	367^a	0.14^b	8.37a	6.14^a	413
CV (%)	2.23	9.65	19	15.27	13.35	13.56	2.49	

Means with different letters within the same column represent significant difference at $p<0.05$ level. CV- Coefficient of variation

Table 2. Soil properties of sub soil of experimental sites

Experimental site	Bulk density (gcm^{-3})	Organic C (%)	K (ppm)	Mg (ppm)	Total N (%)	P (ppm)	pH	Mycorrhizal spores (kg^{-1} Soil)
Cocoa	1.62^a	1.19^a	82^c	305^a	0.12^a	2.24^b	5.3^a	366
Forest	1.57^a	1.25^a	136^a	238^a	0.11^a	1.88^b	5.8^a	40
Cultivated	1.46^a	0.97^a	104^b	258^a	0.07^b	3.21^a	6.2^a	40
CV %	8.67	6.35	5.01	11.71	11.13	9.21	7.62	

Means with different letters within the same column represent significant difference at $p < 0.05$ level. CV- Coefficient of variation

was recorded from cultivated land (8.37 ppm). It may be due to application of phosphate fertilizers with the removal of nutrients during vegetable cultivation. The lowest P content (2.52 ppm) was observed in forest land which was not significantly different from cocoa land (3.26 ppm). Literature revealed that concentration of P in cocoa litter was found to be lower than the other nutrients such as N, K, and Mg in Indian cocoa lands (Sreekala *et al.*, 2001). Similarly, the highest micorrhizal spore count (766 kg^{-1} soil) was observed in cocoa land, followed by forest land (480 kg^{-1} soil) and the lowest spore count (413 kg^{-1} soil) in cultivated land (Table 1). Evidently literature revealed that increasing P concentration may negatively affect for the colonization of mycorrhiza (Naher *et al.*, 2013).

According to results, top soil of cocoa land was significantly rich in OC and K with a favorable bulk density and pH, whilst total N, Mg, P also similar to the forest land, but available P was very low in both lands. Therefore, P fertility is essential for such cocoa lands, by applying phosphate fertilizers or organic manure.

Soil Properties of Sub Soil

No significant difference were observed in bulk density and organic C content (%) of sub soil of all sites. There was a significant difference ($P<0.05$) in total N content (%) between cocoa (0.12%) and cultivated land (0.07%) but no significant difference was found in forest land (0.11%; Table 2). Leaching and cycling of nutrients in soil rhizosphere may be the reason for high N content even in sub soil of cocoa and forest lands. However, the reason for significantly low ($P<0.05$) K content in sub soils of cocoa land (82 ppm) is unknown. No significant differences were observed in Mg content among three sites. There was a significant difference ($P<0.05$) in available P content between cocoa (2.24 ppm) and cultivated land (3.21 ppm) but values were very low as in top soil (Table 2). Accordingly, even the sub soil of cocoa land is fertile with organic C and N, but it was poor in P.

CONCLUSIONS

According to the study, characteristics of soil profile of Immature Brown Loam soil in cocoa land was not physically altered due to long term existence of cocoa. Therefore, it is clear that cocoa agro ecosystem is physically sustainable even for a longer period. Top soil of cocoa land was significantly rich in Organic C and K with a favorable bulk density and pH, whilst having adequate amounts of total N and Mg but with insufficient P. Sub soil layer also had considerable amount of nutrients except K and P. It indicates that nutrient cycling and internal balancing of nutrients occurs properly in a cocoa agro-forestry system. Therefore the long term cocoa agro ecosystem studied in Matale is physically and nutritionally sustainable even under minimum management practices.

ACKNOWLEDGEMENTS

Authors wish to acknowledge Mr. W.M.S.R. Bandara, Principal Technical Officer and the staff members of Soil Science Division of Central Research Station Matale for their valuable cooperation.

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