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NUTRIENT DYNAMICS UNDER UNMANAGED RUBBER, COCOA, AND OIL PALM PLANTATIONS IN A SANDY SOIL UNDER HUMID LOWLAND TROPICAL CLIMATIC CONDITIONS

Joel Bob and Patrick S. Michael*
Department of Agriculture, PNG University of Technology
PMB, LAE, MP 411, Papua New Guinea
*Corresponding author: patrick.michael@pnguot.ac.pg

Abstract

Changes in land use are an important issue in many farms that affect soil biological, chemical, and physical properties temporarily under cropping cycles or when the land is permanently allocated to perennial tree crops, e.g., in agroforestry. This study investigated the changes in sandy soil chemistry induced by three perennial tree crops (rubber, cocoa, and oil palm) growing in 30-year-old unmanaged and abandoned plantations and the surrounding grasslands dominated by cogon grass. A disruptive approach was used to collect soil samples from the top 60 cm under all the tree crops and in the grassland soils. A 500-gram sample of each soil originating from under each tree crop and the grassland were carefully packed into pre-labeled paper bags in triplicate (n=3) and sent to the laboratory for analysis of a selected number of primary and secondary macronutrients, micronutrients, and other soil parameters. The results showed N, K, Mg, Cu, Zn, and S were generally deficient in the sandy soil. A tree crop-specific soil organic matter, organic carbon, carbon stock contents, and water holding capacity measured were high under rubber and cocoa only. The variation in pH, electrical conductivity, bulk density, total porosity, and particle composition were generally similar except that the sand composition was lower in the soils under rubber and oil palm.

Keywords: Agroecosystem, Unmanaged plantations, Soil parameters, Sandy soil

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1. Introduction

Growing tree crops, like coffee (*Coffea arabica*), tea (*Camellia sinensis*), oil palm (*Elaeis guineensis*), rubber (*Hevea brasilliensis*), and cocoa (*Theobroma cacao*) in the humid tropics is important to the socio-economic wellbeing of the rural livelihood and the economy of the many tropical countries (Asubonteng *et al*., 2018). An increase in the production of these crops is driven by the global demand and income needs of the rural people. The large-scale plantations of the crops in the humid tropics are owned by commercial entities and production is extensive with larger capital inputs (Alo and Pontius, 2008). In most economies, commercial plantations are limited to the production of a number of them. On the other hand, production of these crops on a smaller scale is carried out by smallholders (comprising of individual family units or a group) and is semi-intensive or limited to small plantations. Comparatively, crop production and husbandry practices are standard in commercial plantations than in smallholder plantations although some standard operations (e.g. fertilizer, weed and pests, and disease management) are practiced in order to allow the produces to be sold to the commercial plantations that own the factories or processing plants.

Continuous operation of smallholder plantations is affected at tough times as capital and labor inputs become limited, often leading to abandoning and loss of businesses. This scenario is often experienced even in commercial plantations when companies opt to leave as operations become unviable (Asante-Poku and Angelucci, 2013). When a tree crop plantation is abandoned, one of two things is expected to happen. Firstly, the land may be cleared and another land use option is considered (Asubonteng *et al*., 2018), such as planting an annual crop. This is the case where arable land is limited and the need for land use is high (Sathish *et al*., 2022). Secondly, the trees are left standing for a period of time until the next land-use plan is considered (Dawoe *et al*., 2014). Leaving the tree crops to remain on the land from a general agriculture land use perspective is important because soil nutrients are considered to be continuously removed (Bais *et al*., 2006; Michael, 2018). The opposite of the removal of soil nutrients, that is, building up and cycling instead of loss, also happens (Michael, 2014; Paudel *et al*., 2011). These perennial crops shed plant materials in the form of litter and encourage beneficial soil microbes to establish (Warren and Zou, 2002; Bell *et al*., 2005) which in turn help maintain and cycle soil nutrients (Michael *et al*., 2015; 2016; 2017). Returning plant matter and cycling nutrients in an agroecosystem is an important ecological service provided to the soil by plants (Wardle, 2002), particularly to ones that lack nutrients under agricultural land use (Olujobi, 2016; Imogie *et al*., 2006).

Studies investigating the changes in soil chemistry induced by tree crops are available (e.g. Ajami *et al*., 2006; Vagen *et al*., 2006), however, the results are contradictory and cannot be extrapolated due to the differences in objectives or locations of studies (Michael, 2019). An early study conducted in West Africa reported an increase in soil fertility in the first five years of plantation life and thereafter K, Mg and pH decreased and the organic carbon remained constant under oil palm (Tinker, 1963). Similar results have been reported in Malaysia (e.g. Kang, 1977). Hartemink (2003; 2005) pointed out that the decline in soil fertility under plantation cropping is low because of higher nutrient inputs during the times of active operations but the long-term nutrient trends when the inputs cease are not clear. Similarly, the changes in soil chemical, physical and biological properties reported by studies have high spatial variability (Gooverts, 1998) due to differences in soil types, locations, climate, age and population of tree crops, pedogenic characteristics (Basaran *et al*., 2006), and crop production management systems (Ogunkunle, 1986; Ogunkunle and Eghaghara, 1992; Shittu *et al*., 2006). We hypothesized that in abandoned plantations, the tree crops, as well as the undergrowth, would deplete the soil nutrients, and the turnover of plant matter would replenish them (Michael, 2017; 2018; Michael and Reid, 2018). This hypothesis is important for sustainable management of rundown or old tree crop plantations for agro-forestry as well as management of marginal soils, such as the sandy soil considered in this study.

Based on the hypothesis, the aim of this study was to evaluate the variability in soil chemistry caused by three tree crops (rubber, cocoa, and oil pam) in three 30-year-old abandoned plantations at the PNG University of Technology, Papua New Guinea (PNG). The study was intended to establish the spatial variability (depletion and cycling) of soil nutrients to assist in land use planning and development.

2. Materials and Methods

2.1 Description of site

The PNG University of Technology is located 8 kilometers outside of Lae city (6°43'19"S and 146°59'06"E) at an altitude of 65 m above sea level with a mean annual rainfall of up to 3,800 mm, which is fairly distributed throughout the year. The average daily temperature is 26.3 ^{o}C, with an average daily minimum of 22.9 ^{o}C and an average daily maximum of 29.7 ^{o}C. Annual evaporation (US Class A pan) is 2,139 mm and rainfall exceeds evaporation each month. The climate is classified as Af (Koppen), i.e. a tropical rainy climate that exceeds 60 mm of rain in the driest month. The soil at the experimental site is well-drained, derived from alluvial deposits, and is classified as a sandy, mixed isohyperthermic, TypicTropofluvent (US Soil Taxonomy) or EutricFluvisol (World Reference Base) (Aipa and Michael, 2018). The plantations from which the soil samples were taken were under unmanaged agro-ecosystems of over 30 years. Figure 1 shows the unmanaged conditions of the plantations as physically observed during soil sampling.

Figure 1. Images show the unmanaged conditions of the plantations: (a) rubber, (b) cocoa, (c) oil palm and (d) grassland.

2.2 Sample collection

Soil samples were collected from a depth of 60 cm between two trees (~1.5 m apart) from every 100 m throughout the plantations using a disruptive approach and nearly 50 samples each was collected. The control soil samples were collected from the unplanted sites, 1.5 m away from the edge of the plantations dominated by cogon grass (*Imperata cylindrica*) (henceforth referred to as grassland). All the samples were composited by placing them in several pre-labeled 20 l buckets and brought to the greenhouse for processing. A total of 200 samples (~5 kg wet soil each), and 50 samples each for the three tree crops and for the grassland as control were processed. All the soil samples were sun-dried under greenhouse conditions (26±2 °C) for three days and sieved using a 1 mm sieve. A 500-gram each in triplicate (n=3) were weighed into pre-labeled paper bags and sent to the laboratory for measurement and analysis of selected soil parameters (acidity, pH; sodicity, electrical conductivity; nutrients, e.g. NPK; organic carbon, particle composition, bulk density, and porosity).

2.3 Measurements

The soil samples collected were used to determine soil pH, soil organic carbon (SOC), water-holding capacity (WHC), and bulk density (BD) at the University Analytical Services Laboratory (USAL), PNG University of Technology, PNG. pH was measured in standard dilution (pH meter (1:5 soil: water w/v)) using a pH meter (potentiometry) (e.g. Michael *et al*., 2015). Electrical conductivity was measured using a Direct Soil EC meter (Spectrum Technologies Inc., 12360S Industrial Dr. East Plainfield, IL 60585) in a solution (1:5 soil: water w/v) (potentiometry). The SOC content (%) was measured using the weight loss-on-ignition method (Schutle and Hopkins, 1996). A 5 g of the soil samples were placed in a crucible by weighing and heated in a muffle furnace for 12 h at 105 °C to remove moisture (W_f) and combusted again at 375 °C for 17 h, cooled for 2 h. The soil residue in the crucibles was combusted in the muffle furnace at 800 °C for 12 h, cooled for 2 h, and reweighed (F_w). The SOC contents were calculated as equation (1) (Michael, 2020):

$$\text{SOC}\ (\%) = [((W_f - F_w) \div W_f) \text{ x } 100] \div 1.724 \qquad (1)$$

where the SOC content determined using the weight loss-onignition method and 1.72 is a conversion factor. The conversion factor was used to convert the organic matter content to organic C, assuming there was 58% C in the organic matter. The organic matter contents of the soil (SOM) were estimated using the SOC content and the conversion factor (Cf, 1.72) as:

$$\text{SOM} = [(\text{SOC}) \text{ x } C_f)] \qquad (2)$$

Bulk density (g soil cm^{-3}) was calculated by oven-drying of the cores at 105 °C for 48 h followed by re-weighing (Aipa and Michael, 2018). The oven dry weights (ODW) were divided by the volume of the core (VOC) and kept as the bulk density (BD) of the 60 cm (sampling profile).

$$\text{BD (g soil cm}^{-3}) = [(\text{ODW (g)} \div \text{VOC (cm}^{-3}))] \qquad (3)$$

Total porosity (TP) was determined as per Landon (1999):

$$\text{TP} = \left(1 - \frac{\text{BD}}{\text{d}}\right)100 \qquad (4)$$

TP (%) and BD were as described and *d* is particle density equals to 2.65 g cm^{-3}.

The size of the C stock in each 60 cm profile was calculated as the sum of the individual C fractions (%) × BD (g soil cm^{-3}) × profile depth (PD, cm) and expressed as g C ha^{-1}.

C_{stock} (g C ha^{-1}) = [(SOC x BD x PD)] (5)

The water-holding capacity (WHC) was estimated as per Michael (2015) by setting soil samples at 100% WHC after soaking in water and draining through a filter overnight. These were weighed for the wet weight (Ww) and dried in an oven at 105^0C for 48 hours and reweighed to obtain the oven-dry weight (ODw). WHC was determined as:

WHC (%) = [((Ww-ODw) ÷ODw) x 100% (6)

All the soil nutrients were measured as per Michael (2020) using standard analytical procedures: Kjeldhal (Buchi K436 speed digester and Buchi K-350 Kjeldahl distillation unit) for N, and OLSEN (Shimadzu 1800 UV/VIS spectrophotometer, Mettler Toledo, Model UV5Bio) for available P and S, and exchangeable Ca, Mg, K, B, Cu and Zn using ICP-OES (Spectro ARCOS brand) following 1M NH_4Cl extraction. Where possible, data in milli-equivalent (mEq./100 g soil) were converted to milligram (mg) as per Michael (2020):

mg = [(mEq x atomic weight) ÷ valence] (7)

The soil moisture content was estimated based on the differences of the initial wet weight and dry weight after oven drying at 105 °C for 48 hrs, and expressed as percentage. The units for the data presented in Tables 2 – 3 are as per equations 1 – 6.

3. Results and Discussion

3.1 Soil nutrient dynamics

In the grassland dominated by *I. cylindrica*, almost all the soil nutrients except available P and Ca were very low (Table 1), corresponding to the low EC measured (Table 3). Under the cocoa agroecosystem, only available P was higher than Ca and the rest of the nutrients. The results for the rubber agroecosystem were similar, with P>Ca>Cu and Zn>the other nutrients (Table 1). Comparing these results with those of the oil palm, Ca>Cu>the other nutrients. These results demonstrated that often a careful land-use strategy is required in sandy soil when considering it for agricultural land use, such as planting the perennial crops considered in this study for high yield and profitability. These results also indicated that sandy soils are poor in essential soil nutrients and proper fertilizer plans are required. For example, crops such as cocoa and oil palm need significant amounts of P to be present at the onset of flowering and K at the fruit development stage. The results showed these were not the cases and even sulfur which is required during the growth and development of the pods or fruits was below the detection limit (therefore, data not shown), demonstrating that a sulfur plan is important under cocoa or oil palm production in plantations established on sandy soil. Under all the soil conditions, Ca content was high, implying this nutrient is dominant in the sandy soil.

Table 1. Soil nutrient status under three tree crops under unmanaged agroecosystems.

Land use	Soil nutrient status (mg kg^{-1})							
	N	P	K	Ca	Mg	B	Cu	Zn
Grassland*	0.11±0.3	15.21±0.4	0.12±0.1	6.52±0.2	0.72±0.1	0.02±0.1	0.22±0.3	0.01±0.2
Cocoa	0.32±0.2	5.40±0.4	0.01±0.2	4.81±0.5	0.32±0.3	0.13±0.2	1.03±0.2	1.03±0.3
Oil palm	0.13±0.1	0.71±0.2	0.12±0.4	5.03±0.1	0.61±0.2	0.12±0.1	2.24±0.4	0.01±0.4
Rubber	0.22±0.3	12.12±0.3	0.03±0.1	3.82±0.3	0.22±0.4	0.13±0.5	1.48±0.3	1.48±0.2

*The control soil samples were sampled from the grassland. The values are mean ± standard error of three replicates (*n*=3). Note, sulfur data were beyond detection limit, therefore, not shown.

Correlation analysis between the nutrients and the soil parameters is shown in Table 4. For example, a low N content was observed as pH increased compared to P. An increase in SOC resulted in an increase in K concentration, pointing out maybe that organic carbon from organic matter is important for K cycling (Michael, 2018). In most soils, a 45% mineral matter content is needed for ideal plant growth and all the ecosystems studied were nutritionally poor. Summarily, the primary (N, P, and K) and secondary (Mg, Ca, and S) macronutrients were low just like the micronutrients (B, Cu, and Zn) (Table 1). Further, low concentrations of the highly leachable plant nutrients (N, P, K, Mg, and S) being measured meant that the chances of these nutrients leaching (compared to Ca which is moderately leached) in the sandy soil was high.

3.2 Soil organic matter, soil organic carbon, carbon stock, and water holding capacity

The SOM contents when compared were rubber>cocoa>oil palm>grassland (Table 2) and an increase in SOM resulted in an increase in SOC and carbon stock, and WHC (Table 5). The SOC under the different ecosystems was similar with more organic carbon being added in the soil under rubber than in the grassland. Similarly, the highest carbon stock was measured under rubber with over 1100 g C ha^{-1} (Table 2). The least

C stock was measured from the grassland ecosystem. Under rubber, the canopy was not closed as it was under cocoa, and grasses and undergrowth were present (Fig. 1a). Turnover of SOM from them contributed to the higher carbon stock measured. The physical observation made showed that more plant litter was added to the soil under cocoa and from the crop alone (Fig.1b). There was no other plant species or undergrowth to contribute to the SOM under cocoa. This is probably the reason SOM and the carbon stock was lower compared to the rubber agroecosystem. In the oil palm agroecosystem, the undergrowth was predominantly a fern species (Fig.1c), which may have contributed little organic matter which resulted in the much smaller amount of SOM, SOC, and carbon stock measured (Table 2). Under general soil use conditions, a 5% organic matter is ideal for plant growth, and the results in Table 2 show there was sufficient under the rubber, cocoa, and oil palm agroecosystems.

Table 2. Soil organic matter assessment and its impacts on soil properties. The values are means ± standard error of three replicates (n=3).

	SOM (%)	SOC (%)	C_{stock} (g ha^{-1})	WHC (%)	Moisture (%)
Grassland	2.58±0.2	1.5±0.2	232.2	16.92±0.4	35.24
Cocoa	4.64±0.4	2.7±0.4	751.68	78.98±0.5	37.74
Oil palm	4.13±0.2	2.4±0.2	594.72	34.01±0.6	29.84
Rubber	5.68±0.3	3.3±0.5	1,124.64	56.84±0.3	33.65

There was a clear relationship between the SOM and WHC (Table 2). The higher the SOM, the higher the WHC was which was reflected in the carbon stock. For example, the higher SOM content under rubber resulted in higher WHC except under oil palm where only 34% was measured, matching the amount of SOM added to the soil by the crop. The invasive cogon grass (Fig.1d) had the lowest SOM which resulted in the lowest carbon stock and WHC (Table 2). The relationship between WHC (Table 2) and particle composition (Table 3) was not evident. In some instances, high WHC was measured when the sand composition was high, e.g. under cocoa agroecosystem, whereas the opposite was observed, e.g. under rubber (Table 2). There was variability in the association between the WHC and the clay content although the variations were small. The smallest clay content (3.92%), for example, was measured under oil palm which had the lowest WHC (34%). As the clay content increased, e.g. under cocoa to 5.75% (an increase by 1.83%), the WHC increase to 78.98% (an increase by 45%). The soil moisture contents measured were cocoa>grassland>rubber>oil palm (Table 2) consistent with the surface litter observed (Fig. 1) where there was a more organic matter under cocoa than the rest of the agroecosystems but not quite agreeing with the other soil parameters which influence soil moisture contents shown in Table 2. For instance, the SOM content under grassland was the lowest at 2.58% whereas the second-highest moisture content of 35.32 was present (Table 2). Interestingly, the soil moisture content was high as the clay content was high. The highest soil moisture content was measured where the clay contents were high in the soils under rubber (8.82%) and grassland (8.31%), compared to cocoa or oil palm where the clay content was between the range of 5.8 - 3.9% (Table 3). The near 30% or more soil moisture is an important indication that the tree crops are able to produce sufficient SOM (Table 2) and conserve soil moisture.

3.3 Soil pH, electrical conductivity, bulk density, total porosity, and particle composition

Soil pH, EC, BD, TP, and particle composition (CP) measured under the grassland and under the tree perennial tree crops are presented in Table 3. Under the tree crops, soil pH remained fairly constant within a range of 6.0 – 6.4 units with the highest measured under rubber with high SOM, SOC, and carbon content, agreeing with the findings of our previous studies (e.g. Michael *et al*., 2015; 2016). The pH of the soil under all the crops was circumneutral and similar to the grassland, indicating the plants had no effect on it. Under natural conditions, sandy soil acidifies quickly due to its low buffering capacity unless limed by the turnover of organic matter from plants. The optimal pH range of crops differs but most grow well within a range of 6.5 to 7.0. This is important because when pH drops below 5.5, Mn, Zn, and Al become toxic to plants (Friedman, 2005) and increases the solubility of plant nutrients (e.g. Mn, Zn, Cu, and Fe), increasing the possibility of leaching and resultant nutrient deficiency (Michael, 2021).

Electrical conductivity, like pH, is a good indicator of soil fertility and is often affected by land-use conditions, organic matter, WHC, and soil types. The EC tends to be high in clayey soil than in sandy soil as confirmed by the results being near 0 dSm-1 (Table 3). A soil of low EC (0 dSm-1) lacks nutrients and the low EC measured reflected the poor nutrient status of the soils under the tree crops compared to the 0 – 0.75 dSm-1 considered safe for optimal plant growth and development in most soil types. The results showed the variability in SOM content measured and the type (size) further influence the BD. The bigger and heavier a plant was, the higher the bulk density was and within a very narrow range (1%). The normal expectation is that the TP is high when BD is low and the sand composition is high. This was not the case under some conditions. High BD and lower sand composition resulted in higher TP, e.g. under oil palm and rubber (Table

3). These variations have resulted from the type and nature of the roots. The bigger and much more extensive rooting systems, e.g. of oil palm and rubber, resulted in higher TP, compared to the much shallower rooting like that of the cogon grass although cocoa roots may be much more extensive. Comparatively, 50% porosity is an indication of normal plant growth and this was evident under rubber and the grassland even though TP of the oil palm and cocoa agroecosystem were ideal (Table 3).

Table 3. Variability in pH, EC, BD, TP and particle composition.

	pH	EC (dSm^{-1})	BD (g cm^{-3})	TP (%)	*PC (%)
Grassland	6.30±0.1	0.00±0.1	1.07±0.4	52.08±0.5	1.31, 8.31, 90.4
Cocoa	6.02±0.0	0.02±0.2	1.27±0.3	30.57±0.6	0.89, 5.78, 93.3
Oil palm	6.32±0.0	0.03±0.0	1.44±0.4	45.66±0.7	7.41, 3.92, 88.7
Rubber	6.43±0.3	0.02±0.2	1.84±0.2	52.08±0.4	4.85, 8.82, 86.3

The values are means ± standard error of three replicates (*n*=3). *The values under PC are in the order silt, clay and sand.

The PC under all the soil conditions was such that the silt under oil palm (7.41%)>rubber (4.85%)>the grassland (1.31%)>cocoa (0.89%) (Table 3), indicating that the silt composition was significantly high under oil palm and rubber. The clay content was high under rubber (8.82%)>the grassland (8.31%)>cocoa (5.78%)>oil palm (3.92%). Usually, as the SOC content increases, the clay composition increases. Our results showed high SOC content resulted in high clay content. For example, the higher SOC content (3.3%) under rubber resulted in the high clay content (8.82%). The sand composition was high, ranging from 88.7% under oil palm to 93.3% under cocoa. In the grassland, the sand composition was 90%, which increased to 93% under cocoa, whereas under oil palm and rubber, the composition decreased to 88.7% and 86.3% instead, respectively. In general, as pointed out earlier, the PC affected TP, WHC, and to some extent, the carbon stocks of the soil. The sandier the soil was the smaller the carbon stock and the SOM contents measured (Table 2).

3.4 The interrelationship among the soil parameters measured

The analysis of the interrelationships among the soil nutrients and the other soil parameters is shown in Table 4. The influence of all the soil parameters except pH and the silt on nitrogen content was positive with nearly 78% with the SOC content. Phosphorus had a positive relationship with BD, TP, and the clay content and those of K were only with silt and clay content. Among the two secondary primary macronutrients, Ca had a positive value with the sand content and Mg with sand. The trace elements showed similar variability in their associations, B with WHC, Cu with WHC and silt content, and Zn with SOC and BD being the strongest (Table 4).

Table 4. Interrelationships between the soil nutrients and soil parameters measured.

	N	P	K	Ca	Mg	B	Cu	Zn
SOM	0.56	-0.34	-0.73	-0.98	-0.79	0.27	0.76	0.68
SOC	0.78	-0.29	-0.85	-1.00	-0.93	0.30	0.60	0.85
WHC	0.04	-0.71	-0.10	-0.60	-0.21	0.51	0.99	0.03
pH	-0.58	0.31	-0.04	-0.09	0.13	-0.57	0.23	-0.15
EC	0.74	-0.30	-0.17	-0.12	-0.35	0.57	-0.15	0.35
BD	0.72	0.04	-0.96	-0.95	-0.96	-0.03	0.38	0.93
TP	0.19	0.92	-0.50	0.05	-0.31	- 0.79	-0.78	0.48
Silt	-0.24	-0.53	0.03	-0.43	-0.02	0.27	0.89	-0.14
Clay	0.01	0.96	-0.50	0.001	-0.27	0.43	-0.64	0.43
Sand	0.23	-0.18	0.37	0.46	0.24	0.43	-0.43	-0.19

The association between nitrogen and P (-20%), K (-76%), Ca (-73%), Mg (-83%) were all negative compared to B (39%), Cu (17%) and Zn (87%) which were positive. Only Ca (28%) and Zn (17%) had positive relationships with P compared to K (-24%), Mg (-1%), B (-95%), and Cu (-79%). Potassium had a strong association with Ca (84%), Mg (97%), and B (17%), and negative with Cu (-12%), and Zn (-98%). Calcium had a strong association with Mg (91%) and was negative with all three micronutrients. The association of Mg with B, Cu, and Zn was negative, the values being less than -1%. Boron had a strong association with Cu (63%) but negative with Zn (-0.1%) and that of Cu with Zn was 0.1%, respectively. These results showed that all nutrients have no clear interrelationships in sandy soil.

The interrelationship between soil parameters measured, apart from the nutrients, is shown in Table 5. The SOM had a strong influence on most of the soil parameters except EC, TP, and sand composition. Only WHC, BD, and the silt content positively correlated with SOC whereas the pH was weak (Table 5). Similarly, the association of EC with the rest of the soil parameters was weak except with silt composition (82%). Bulk density positively correlated with all the soil parameters and that with sand was negative. The TP and its interrelationships were variable with more than 50% with clay. There was no strong association among the soil particles with all correlation values being negative (Table 5).

Table 5. Interrelationships between the soil parameters measured.

	SOM	SOC	WHC	pH	EC	BD	TP	Silt	Clay	Sand
SOM	—	0.95	0.75	0.26	-0.07	0.89	-0.19	0.34	0.04	-0.39
SOC		—	0.55	-0.004	0.21	0.94	-0.18	0.62	-0.10	-0.57
WHC			—	0.39	-0.31	0.36	-0.75	-0.22	-0.11	0.31
pH				—	-0.98	0.15	0.03	-0.68	0.85	0.05
EC					—	0.07	0.04	0.82	-0.81	-0.22
BD						—	0.27	0.60	0.18	-0.77
TP							—	0.36	0.54	-0.80
Silt								—	-0.43	-0.71
Clay									—	-0.33
Sand										—

The broken line (—) means the interaction between a soil parameter itself, e.g. SOM and SOM was not analyzed as it is not necessary.

4. Conclusion

The changes in soil chemistry induced by tree crops under unmanaged agroecosystems are important for subsequent land use and soil fertility management plans. When tree crop plantations are unmanaged, soil nutrients are expected to be depleted by the crops. On the other hand, and depending on the types of tree crops, the turnover of plant litter would supplement the resultant nutrient deficiency. The data showed turnover of plant matter had no significant contribution to the primary macronutrients (N and K) and secondary macronutrients (Mg and S), respectively. The status of the remaining micronutrients under all of the agroecosystems were similar with crop-specific variabilities. The changes in other soil parameters measured were entirely dependent on the crop-specific SOM contents. The findings imply that leaving tree crops for a longer period in abandoned plantations has negative impacts on sandy soil nutrient dynamics.

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