# Different land use systems improve soil fertility status of sandy soil and increase the yield of rice under rain-fed wet lowland tropical climatic conditions in Papua New Guinea

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***Abstract*— *The pratical use of different land use systems(LUS) as a management strategy and the effect of the LUSon soil proprties as an indicator of soil fertility status, and the understanding of the long-term effect of the LUS, are important to maintaining optimal soil fertility and yeild of crops. In the rain-fed wet lowlandtropical soils, studies related to rice production and the associated effectson soil properties are limited to a few studies. In this study, we investigated the effects of four LUS (crop rotation, continuous cropping, manure application and fallow) on soil properties that influence soil fertility status and yield of crops under a rain-fed wet lowland tropical sandy soil conditions.The data were compared with the natural soil data obtained prior to and at the end of the study. All the LUS had no to small effects on bulk density, moisture content, electrical conductivity and pH.Soil organic carbon, total nitrogen, available phosphorus, extractable potassium, and cation exchange capacity were all higher in all the LUS.Crop rotation increased soil organic carbon and cation exchange capacity, fallow increased total nitrogen, and manure application increased available phosphorus and extractable potassium contents, respectively.The LUS had no significant effects on particle composition except that small increases in the silt contentswere observed in the continuous, rotation and fallow systems. In almost all cases, soil organic carbon content influenced the fertility status of the sandy soil and yield of rice. Higher soil organic carbon contentresulted in higher available phosphorous and extarvale potassium,enhence reulted in higher yield of rice but decreased the total nitrogen content.Our results implied that the soil organic carbon content of sandy soils needs to be managed properly for optimal soil fertility and higher yieid.*

***Keywords*— *land use systems, soil fertility, yield of rice, rain-fed, sandy soil.***

## I. INTRODUCTION

In agriculture, a good soil in terms of fertility is a soil which is able to deliver to the roots of crops nutrients that are needed for optimum growth and development. A fertile soil required for crop production is an attribute of the biophysical and biochemical composition of the soil [1; 2; 3]. Some of the important physical components of soils are particle size distribution, bulk density, field capacity, and soil color, whereas the chemical components include pH, electrical conductivity, organic matter, cation exchange capacity (CEC), and carbon to nitrogen (C: N) ratio. The third component of the soil system is the biological component, mostly all the living things.

The physical, chemical and biological components of the soil affect several processes important to crop production[4]. For instance, particle size distribution affects infiltration rate and CEC[5], soil pH and redox affect soil nutrient status and availability to crop plants[6; 7; 8].The biological component provides important ecological services in evolution of soil fertility and management of problem soils through decomposition of organic matter [9].In agricultural crop production, it is important properties are managed as their interactions that govern nutrient and availability to crops are affected by on the farm soil use systems [10] and affect farmers who depend on them [11; 12; 13].

The LUS is affected by the economic status of the farming community, the type of crop produced and thelevel of production. Farmers in the developed nations are able to afford farm machineries and farming technologies for intensive crop production. In the poor economies, affordability of farming equipment is a major concern, complicated by lack of investment and technical knowledge to intensify crop production. Regardless of where and how crop is produced, the increase in the human population and too many mouths to feed worldwide means more and more farm land and continuous crop production. In the tropics, continuous farming is solely monocropping of stables; sweet potato (*Ipomoea batatas*), taro (*Colocasia esculenta*), cassava (*Manihot esculenta*) and yam (*Discorea* sp.) in the tropical and rice (*Oryza sativum*),maize (*Zea mays*) and wheat (*Triticum assertivum*) in the temperate regions are dominating the farms.

Continuous farming of sole crops (monocropping) has advantages however loss of soil fertility and the implications on sustainable crop production is a common global issue, calling for a need to manage the soil (physical, chemical and the biological properties) to prevent decline in soil fertility and loss of crop productivity (yield). In PNG, the soils are strongly weathered and poor in soil fertility in some areas, making a few ‘dominant crops’(sweet potato, taro, cassava, yam and Irish potato) to be widely grown. Among these staples are the recently introduced cereals – rice, sorghum and maize. Maize is widely cultivated by locals in food gardens, sorghum’s potentials are yet to be realized and rice production is limited to a few places. In the light of these, rice feeds billions of people worldwide and in PNG is widely consumed in the major towns and cities. The main problems for large-scale production of some of these crops, despite the demand, are poor research for development and non-existence of extension services.

The global literature on soil fertility status, management and rice yield under different cropping systems that are region-specific, e.g. for tropical regions is limited, and where there is information available, cannot be widely adapted because of region-specific variations in climatic and soil conditions[14], local farmers inability to adapt [15] and use them [16]. Therefore, this study was conducted to evaluate the soil fertility status and yield of rice under different LUS in a sandy, mix isohyperthermic, TypicTropo fluvents soil (Soil Survey Staff, 2014) under rain-fed wet lowland tropical conditions.

## II. MATERIAL AND METHODS

### 2.1 Study location

The study was conducted in the field at the PNG University of Technology Agriculture Farm, Lae, Morobe Province, PNG (Fig. 1) and completed by a battery of laboratory analysis. The farm (6°41’S, 146°98’’E) is located at an altitude of 65 meters above sea level, with an annual rainfall of up to 3,800 mm, which is fairly distributed throughout the year. Average daily temperature is 26.3$^0$C (daily minimum of 22.9 $^0$C and daily maximum of 29.7$^0$C). Annual evaporation (US Class A pan) is 2,139 mm and rainfall exceeds evaporation in each month. The climate is classified as Af (Koppen), i.e. a tropical rainy climate that exceeds 60 mm rain in the driest month. The soil at the experimental site is well drained and derived from alluvial deposits and classified as a sandy, mixed isohyperthermic, TypicTropofluents[17] or EutricFluvisol[18].

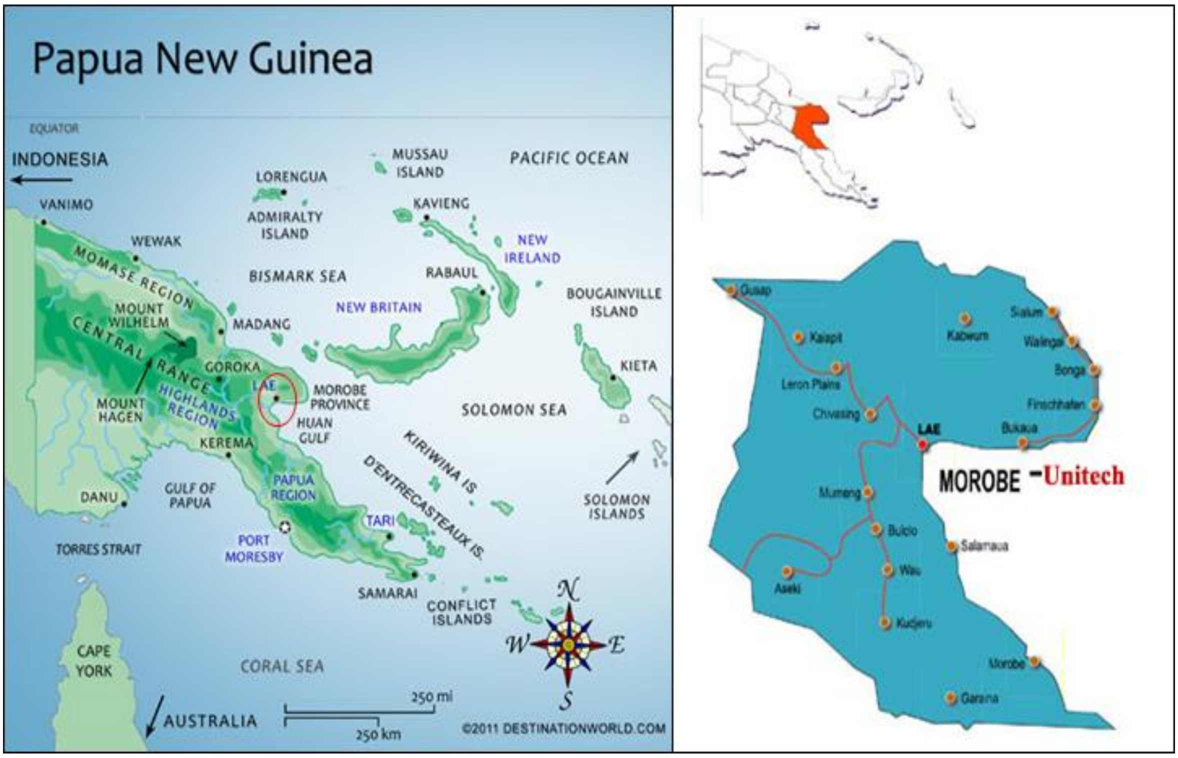

**FIGURE 1. Locality of study site, Lae, Morobe Province, Papua New Guinea.**

### 2.2 Treatments

The properties of the surface soil (0-15 cm depth) measured prior to and at the end of study are shown in Table 1. Prior to the study, the flat land on which the study was conducted was harrowed. Rice was used as the test crop and planted at a spacing of 30 cm x 30 cm in a plot size of 5m x 5m (25 m$^2$), giving a plant density of 289 hills per plot. The 4 LUS as treatments were replicated 4 times (n=4) and setup in a randomized complete block design. Data from only three replicates are presented. The LUS were “continuous rice cultivation”, “rotation with maize”, “deep litter poultry manure application (DLPM)” and “natural fallow”.

In the continuous cropping treatment, rice was continuously grown to maturity for 3 consecutive cropping seasons. In the rotation treatment, maize was planted during the second cropping season after rice. In the DLPM treatment, rice was planted continuously for the 3 cropping seasons following the addition of 15 kg of DLPM per replicate per plot, which is equivalent to 6 tonnes per ha$^{-1}$. The DLPM was applied by broadcasting and mixed into soil by raking. In the fallow treatment, the plots were rested for 4 months. The duration of a cropping cycle was four months, and throughout the cycles, weeds were controlled manually using small handheld tools, and no chemical fertilizer was applied.

**TABLE 1**
**SOIL PHYSICAL AND CHEMICAL PROPERTIES STATUS PRIOR TO AND AT THE END OF THE STUDY.**

| Soil properties | Unit | Average$^{A}$ | Average$^{B}$ |
|---|---|---|---|
| Particle size | | | |
| ○ Sand | % | 84.7 ±0.0 | 83.30±0.3 |
| ○ Silt | % | 13.3 ±0.0 | 12.70±0.2 |
| ○ Clay | % | 2.0 ±0.0 | 4.00±0.1 |
| Bulk density | g cm$^{-3}$ | 1.4 ±0.0 | 1.28±0.1 |
| Water holding capacity | % | 26 ±0.6 | 26.33±0.2 |
| Electrical conductivity | dS m$^{-1}$ | 5.6 ±0.0 | 7.57±0.3 |
| Soil pH | pH unit | 6.0 ±0.0 | 5.9±0.1 |
| Organic carbon | % | 1.4 ±0.0 | 2.03±0.1 |
| Total nitrogen | % | 0.2 ±0.1 | 0.23±0.2 |
| Available phosphorus | mg kg$^{-1}$ soil | 117 ±1.0 | 118.33±0.2 |
| Extractable potassium | mg kg$^{-1}$ soil | 373 ±12 | 644.67±0.1 |
| CEC mEq./100 g soil | | 25.4 ±2.1 | 29.73±0.1 |

***The superscripts denote measurements of the natural control soil prior to ($^{A}$) and after ($^{B}$) the study. The values are average of three replicates ± standard error (s.e.).***

## 2.3 Maturity and Harvesting

The maturity times of the rice plants per the three cropping season were 114, 112, and 110 days, respectively. During harvest, the tillers were cut using a sharp sickle. The cut tillers with grains attached were taken to a central location and threshed onto a canvas to remove the grains. The yield per plot on a fresh weight (kg) basis was taken by weighing. Data (fresh weight) from the three replicates were obtained in a similar manner, pooled, averages taken and kept as the final data. The average yield data were converted into maximum possible yields (tonnes ha$^{-1}$). Except for milled rice, a recovery rate of 60% was considered in determining the final yield of rice (t ha$^{-1}$) after determining the yield of the threshed rice. As an example, the total yield of threshed and milled rice from continuous cropping is: **(1)**

- Average yield of 4 plots = 70.96 kg
- Average yield of threshed rice per plot = 17.74 kg
- Total yield of threshed rice per ha = 7.10 tonnes
- Total yield of milled rice with 60% recovery = (60/100*7.10)

  = 4.26 tonnes

## 2.4 Measurements

Prior to the study, soil samples (gram, g) were taken from the “natural control soil”, air dried and analysed. The data obtained are presented in Table 1. Data from subsequent sampling of the natural control soil at the end of each cropping season are presented in Table 2. There was no tillage in the natural control soil. The soil particle size distribution was determined using a modified hydrometer method of [19]. A sample of soil was pre-treated with 5 ml of 6% hydrogen peroxide to oxidise organic matter. This was transferred quantitatively to a measuring cylinder and 30 ml of 5% sodium hexameta phosphate

(Calgon) was added to promote dispersion. The content was thoroughly mixed with a plunger with gentle strides and hydrometer readings were taken at pre-determined time intervals of 5 minutes (sand) and 2 hours silt. Particle size was determined as:

$$\mathbf{S\ (\%) = [((R{=}R_L + r) \div W)\ x100} \tag{2}$$

Where S is percentage of material in suspension, R is hydrometer reading, $R_L$ is calibration correction, W is oven-dry weight (ODW) of soil samples (g), and r is a temperature correction factor.

Bulk density (BD) was measured using the soil core method of [20]. A cylindrical metallic core sampler was driven horizontally into the sharpened edges of the soils and carefully removed with a known volume of 100 $cm^3$ of soil (V, field volume of soil in $cm^3$). Extra soil extending from the edge of the cylinder was trimmed off to maintain the required volume. The core samples were oven dried in an oven at 105 $^0$C for 24 hours and the ODW obtained by weighing. BD was measured as:

$$\mathbf{BD = (ODW \div V)} \tag{3}$$

Field capacity (FC) was measured by weighing 100 g of soil at 100% FC following saturation. These samples were weighed for the fresh weights (FW) and oven dried for 48 hours in an oven at 110$^o$C and reweighed for the ODW. The FC was determined on gravimetric basis as:

$$\mathbf{FC\ (\%) = [((FW{-}ODW) \div FW)\ x\ 100} \tag{4}$$

The electrical conductivity (EC) and pH were measured using standard dilution (conductivity meter and pH meter (1:5, soil: water w/v)) methods [e.g. 21], respectively. Salinity was measured by shaking the suspension in an end-over-end shaker for 1 hour and left overnight for 12 hours. The overnight suspensions were filtered through a Whatman No. 40 filter paper to obtain a soil: water extract. The extracts were agitated in an end-over-end shaker at room temperature for 1 hour and left to settle for another hour then EC measured in the supernatant of the extract (1:5 w/v).

Soil organic carbon (SOC), total nitrogen, available phosphorus, extractable potassium, and CEC were determined using air dried soil samples following the soil analytical methods of [22] as described in [23]. SOC was determined using the rapid wet oxidation method in which soil samples were oxidized in 0.5 M sodium chromate-sulfuric acid solution ($Na_2Cr_2O_7.2H_2O$–$H_2SO_4$) in an oil bath. Excess $Na_2Cr_2O_7$ was titrated with a 0.2 mol $L^{-1}$ $FeSO_4$ solution. The soil particles were allowed to settle by cooling followed by calculation of the SOC from the amount of $Cr^{3t}$ ion formed using a calometric procedure at 600 nm with sucrose as standards [24].The organic matter content was obtained by multiplying the carbon value by a factor of 1.72.

Total nitrogen was measured by the semimicro-Kjeldahl method after soil samples were digested with $HClO_4$ and HF. Finely ground soil samples were digested using sulfuric acid and sodium sulfate, using selenium as catalyst. The solution was allowed to settle for 30 minutes followed by an addition of 10 ml of $H_3BO_3$ and 25-30 ml of 60% NaOH solution. The solutions were diluted for 5 minutes at a rate of 8 ml per minute under a constant temperature of 40$^0$C. The distillate was titrated by adding 5-6 drops of Bromocresol Green-Methyl Red mix indicator with standard 0.01 M HCl. Ammonium N in the diluted Kjeldahl digest was determined using an automated isocyanurate calometric procedure similar to that of [25] as:

$$\mathbf{Total\ N\ (\%) = [(0.014\ X\ (V_1{-}V_2))]} \tag{5}$$

where $V_1$ is sample titration value (ml) and $V_2$ is blank titration value (ml).

Available phosphorus was extracted with a 0.5 mol $L^{-1}$ $NaHCO_3$ solution and determined by molybdenum-blue colorimetry. This method is a modified method of the original bicarbonate procedure developed by [26]. The soil extracts were filtered with Whatman filter paper (P-free) followed by addition of 50 ml of deionised water and 2 ml of 1 M sulfuric acid to the filtered soil extracts and mixed. A further 5 ml of the 1 M sulfuric acid was added to the extract and left overnight to completely remove $CO_2$.The $CO_2$ free soil extracts were mixed again with 8 ml colour reagent, 8 ml ammonium molybdate-sulfuric acid-Sb solution, and 25 ml phosphorus as standard. The mixture was left for 30 minutes then a manual colometric finish procedure [27] was used to measure the absorbance at 882 nm. The bicarbonate-extractable phosphorus (P) was determined as:

$$\mathbf{P = (Sample\ value - Reagent\ blanks)\ mg\ kg^{-1}} \tag{6}$$

The first part of the K extraction procedure is similar to that of P described above. Extractable K was extracted with 0.5 mol $L^{-1}$ $NH_4OAc$ (pH 8.5) and then determined by flame photometry. The soil extracts were filtered with Whatman filter paper (K-free) followed by addition of 50 ml of deionised water and 2 ml of 1 M sulfuric acid to the filtered soil extracts and mixed. A further 5 ml of the 1 M sulfuric acid was added to the extract and left overnight to completely remove $CO_2$. The $CO_2$ free soil extracts were mixed again with 8 ml colour reagent, 8 ml ammonium molybdate-sulfuric acid-Sb solution, and 25 ml K as standard. The mixture was left for 30 minutes then the aliquot was determined by flame emission spectrometry (FES). The bicarbonate-extractable Kwas determined as:

$$\mathbf{K = (Sample\ value - Reagent\ blanks)\ mg\ kg^{-1}} \qquad \mathbf{(7)}$$

The CEC was measured using the 0.01 mol $L^{-1}$ $(AgTU)^+$ method [28]and atomic absorption spectrometry(AAS). A soil/silver-thiourea solution (1:50 w/v) was shaken in an end-over-end shaker for 16 hours at room temperature. The solution was centrifuged until a clear supernatant was obtained. Some of the supernatant were diluted to a 1+9 with $Sr/Cs/(AgTu)^+$ solution. Same volume of both the supernatant (soil extract) and $(AgTu)^+$ standard were then diluted 80-fold with CsCl solution (1.0 g Cs $L^{-1}$). The CEC was determined by measuring the $Ag^+$ in the diluted standard and the soil extract by an ASS using an air/$C_2H_2$ flame and a 328.1 nm spectral line instrument. The CEC determined is based on $CEC_{AgTu}$ (mEquiv./100 g) soil on an oven dry basis.

### 2.5 Statistical analysis

All the average data were analysed using SPSS 14 (SPSS Inc. ILL., Canada). The significance ($p<0.05$) of mean differences between rice yield and the soil properties between the LUS and the 3 cropping seasons was determined by One-way ANOVA followed by Tukey’s Multiple Comparison Test.

## III. RESULTS AND DISCUSSION

The statuses of the soil properties of the ‘natural control soil’ in which the study was conducted before and after are shown in Table 1. The changes in the soil chemical properties measured under the four different LUS are shown in Table 2. Compared to the natural control soil, there was no significant change in the bulk density, soil moisture content, electrical conductivity and pH. The bulk density was between 1.3–1.4 g $cm^{-3}$ (Table 2) within the range of 1.2 –1.8 g $cm^{-3}$ as reported for sandy soil by [29]. The total nitrogen contents of all the LUS were within the range of the natural control soil, except in the fallow soil where the content increased to 0.5%, consistent with the results of [30] where natural fallow increased the total nitrogen content in tropical Ghana. There is evidence too of increase in sandy soil nutrients,hence fertility with increasing fallow durations [31]. In a semi-arid area in Mexico, a land fallowed for 22 years resulted in total nitrogen recovery by 62% [32]. In Senegal, fallow did not significantly increase the nutrient content of sandy soils [33], similar to the small increase (0.5%) of this study.

**TABLE 2**
**CHANGES IN SOIL PROPERTIES UNDER DIFFERENT LAND USE SYSTEMS.**

| Lands use system | Statistical parameter | $D_b$ (g $cm^{-3}$) | FMHC (%) | EC (dS $m^{-1}$) | pH (1:5) | SOC (%) | Total N (%) | $P_{av}$ (mg $kg^{-1}$) | $K_{ext}$ (mg $kg^{-1}$) | CEC (mEq./100 g) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Mean | 1.4 | 26 | 5.3 | 5.9 | 1.8* | 0.19 | 136 | 410* | 37* |
| | S.E | 0.0 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 4.5 | 10.0 | 0.2 |
| 2 | Mean | 1.4 | 26 | 5.4 | 5.9 | 2.1* | 0.2 | 143 | 302* | 33* |
| | S.E | 0.0 | 1.2 | 0.0 | 0.0 | 0.0 | 0.1 | 6.3 | 30.0 | 1.4 |
| 3 | Mean | 1.4 | 25 | 5.4 | 5.9 | 2.0* | 0.2 | 184 | 509* | 34* |
| | S.E | 0.0 | 0.6 | 0.0 | 0.0 | 0.1 | 0.0 | 19.3 | 34.4 | 6.3 |
| 4 | Mean | 1.3 | 26 | 5.1 | 5.9 | 1.8* | 0.5 | 145 | 504* | 29* |
| | S.E | 0.0 | 0.6 | 0.0 | 0.0 | 0.1 | 0.3 | 10.4 | 37.0 | 1.0 |
| 5 | Mean | 1.4 | 27 | 4.8 | 5.9 | 1.4* | 0.1 | 126 | 437* | 27* |
| | S.E | 0.0 | 1.2 | 0.7 | 0.0 | 0.0 | 0.0 | 38 | 108.1 | 0.5 |

***1 = Continuous, 2 = rotation, 3 = deep litre poultry manure, 4=fallow and 5 = natural control soil. An asterisk (*) indicates significant differences ($p<0.05$). $D_b$ = bulk density, FMHC = field moisture holding capacity, EC = electrical conductivity, pH = soil pH, SOC = organic carbon, Total N = total nitrogen, $P_{av}$ = available phosphorus, $K_{ext}$ = extractable potassium, CEC = cation exchange capacity, and S.E = standard error. The changes in soil particle size composition are shown in Fig.2.***

In sandy soils, phosphorus loss through leaching is possible [34] however in all the LUS the available phosphorus content increased, the highest amount measured in the DLPM treatment (Table 2). The available phosphorus content in the natural control soil measured at the end of the study was higher too, compared to the content measured prior to the study but the increase was small, 126 mg kg$^{-1}$ soil (Table 2). The increase in available phosphorus content following addition of DLPM although are from a sandy soil in a rain-fed wet lowland tropical conditions are similar to the results of [35] where addition of cattle manure increased the phosphorus content by 35.4 mg kg$^{-1}$ soil in a semiarid sandy soil in Brazil.

Changes in soil phosphorus content following addition of manure is widely reported in a range of soil types [e.g. 36; 37; 38; 39] but under tropical condition is not often reported. This study shows DLPM can help improve the fertility of sandy soil (that is increase the content of NPK) (Table 2) and increase the yield of crops like rice (Fig. 2). The potassium content was within the range of the natural control soil (Table 1), ranging from between 302 mg kg$^{-1}$ soil in the rotation treatment to 509 mg kg$^{-1}$ soil in the DLPM treatment. This indicates that the net change in the extractable potassium content was negligible. Contrastingly, [40] reported that addition of chicken manure to a semiarid sandy soil classified as LuvicCalcisol, FerralicArenosol, or VerticLuvisol[41] increased the potassium content in Botswana.

Soil pH and CEC are constraints to crop production, especially in sandy soil because the former affects nutrient availability and the latter provides a buffer against pH and influences nutrient retention [42]. The CEC was high in the continuous, rotation and DLPM, whereas in the fallow was within the range of the natural control soil. Under all the LUS, pH remained the same and EC rates increased. These results are consistent with the results of [43] where an increase in CEC rate resulted in no change in pHin a semiarid sandy loam soil. As widely known, a positive correlation between the SOC and CEC was found, an increase in SOC content resulted in higher CEC. For instance, when the SOC was 2.1%, the CEC was 34 mEq./100 g under rotation, and 1.43% SOC and 27 mEq./100 g CEC in the natural control soil, respectively (Table 2).

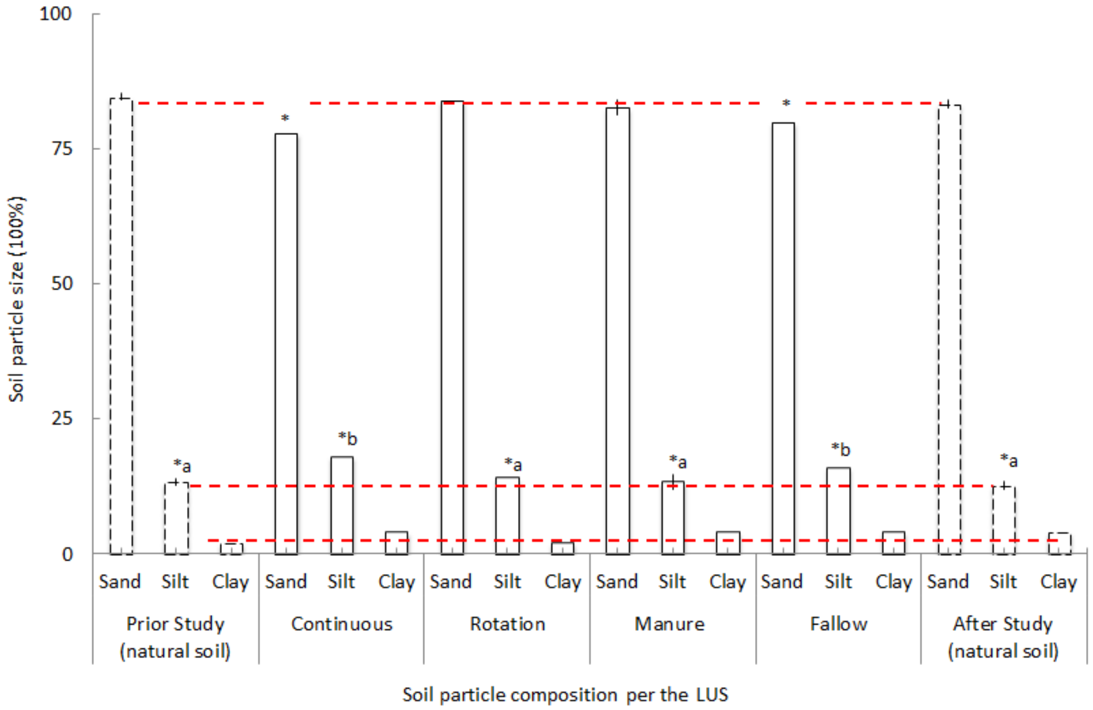

**FIGURE 2. Soil particle composition of the four lus. The broken horizontal lines indicate the composition of the soil particles prior to and after the study of the natural control soil. The values are means ± standard error of three replicates (n=3). An asterisk indicates significant changes ($p<0.05$) between the LUS and the natural control soil. Columns with same letters are not significantly different from each other.**

In the soil physical properties, there was no significant change in the bulk density and moisture content (Table 2). The soil particle size composition was fairly the same in all the LUS except a small decrease in the sand composition under the continuous and fallow soils (Fig. 2). Continuous cultivation and fallow increased the silt contents when compared to the natural control soil, measured prior to (natural soil) and at the time of crop harvest (natural soil) (Fig. 2). The clay composition was fairly the same in all the soils of the LUS, even if the content measured prior to the study was lower, comparatively. No significant change in particle size distribution in sandy soil under rice cultivation under tropical condition has been reported [44], indicating poor soil physical condition similar to ours as reported by [45].

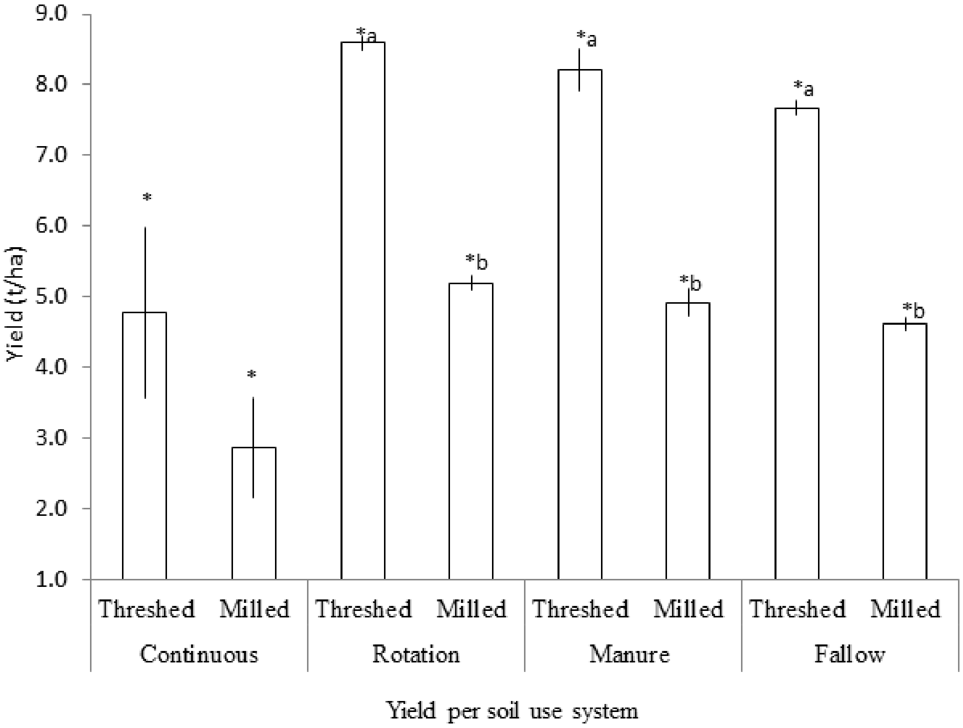

**FIGURE 3. Yield of rice under the four different LUS. The values are means ± standard error of three replicates (n=3). An asterisk indicates significant difference ($p<0.05$) between the LUS. Columns with same letters are not significantly different from each land use system.**

Figure 3 shows the threshed and milled rice yields obtained as per the calculation shown in Eq. 1. Among the LUS, continuous use of the soil resulted in low threshed yield. Similarly, the quantity of milled rice produced from continuous cropping was smaller than the amount of rice produced from the other LUS. These low yields under continuous cropping resulted from depletion of the SOC and total nitrogen (Table 2). Comparatively, again, rotation with maize slightly increased the amount of milled rice (Fig. 2) but poor yield was reported by others when rotated with barley [46]. Compared to our results, rice yield is reported to be low under other LUS in sandy soil [47]. As expected, addition of DLPM increased the SOC content and improved the nutrient status (NPK) (Table 2), hence the yield was higher from this LUS (Fig. 2).

Generally, fallow improves the soil nutrient status as a result of turnover of plant organic matter [48]. Therefore, the increased in SOC and in the nutrients of the sandy soil shown in Table 2 are not exceptional. Similarly, crop rotation, especially with legumes, improves the nutrient status of soils, again, because of organic matter turnover and the basic difference in soil use system created as a result of planting a different crop. Our data show improved SOC and NPK content of the sandy soil when rice was rotated with maize but the changes were small, similar to those in the fallow (Table 2). The main reason for these changes lies around the explanation that during the fallow period (4 months), the sandy soil was dominated by *Imperata cylindrical*, *Saccharum spontaneum* and *Rottboellia cochinchinesis*, and the crop rotated with rice was maize - all grass species of the Poaceae family. The presence of the grass species indicated poor soil quality associated with modifiable soil properties as pointed out by [49]. In PNG, it is a common knowledge that poorly weathered soils are dominated by these grasses, most often in areas where other vegetation types fail to colonise and establish.

## IV. CONCLUSION

Crop rotation and addition of DLPM helped improve the poor fertility status of the sandy soil. Consequently, crop rotation and DLPM addition increased yields of rice (both threshed and milled) by a tonne, compared to the yield obtained under continuous cropping and fallow systems. The mechanisms for these appear to be addition of carbon and nutrients (NPK) to the sandy soil and these LUSs' potential to increase the CEC facilitated nutrients to be available to the rice plants. High SOC content resulted in low total nitrogen but higher available phosphorus and extractable potassium content. When rice cropping was rotated with peanut as a legume under the same conditions in a similar study, in almost all cases, yield of rice was smaller. These results imply that the main source of soil fertility, hence higher yield of rice on the sandy soil was SOC and not total nitrogen. These findings have implications for management and improvement of sandy soil fertility status to improve the yield of crops under rain-fed wet lowland tropical conditions.

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