Poultry manure application and fallow improves peanut production in a sandy soil under continuous cultivation

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Abstract**—** *To meet our food security demands, Papua New Guinea (PNG) needs to improve smallholder subsistence agriculture by promoting the production of cash crops that mature early and have a high market value. Peanut is a typical example of a cash crop which potentially has a high market value, but pod yields are low due to declinein soil quality. A field experiment was conducted under 4 different land use systems (LUS) to evaluate the effects of continuous peanut cultivation on peanut pod yield and on selected soil properties. Peanut pod yield declined significantly under the continuous peanut and peanut/corn rotation systems; while the poultry manure and land fallow systems significantly increased pod yield. Over the 3 cropping seasons, significant changes in organic carbon; extractable potassium and CEC in all cropping systems occurred, while changes in total N was significant in the peanut/corn rotation and poultry manure cropping systems only. No significant changes in bulk density; field capacity; electrical conductivity; soil pH and available phosphorus were observed in all the 4 LUS over the 3 cropping seasons. We suggest that adequate fallow periods of more than 1 year and poultry manures are applied to enhance soil quality and improve peanut productivity and/or sustain peanut production in marginal lands under continuous cultivation.*

Keywords**— *Continuous cultivation, land use systems, peanut pod yield, soil properties.***

I. INTRODUCTION

In PNG, agriculture supports the livelihood of more than 85% of the people who live mostly in the rural areas. Food security is therefore often perceived to be food secure; however, the lack of basic services and rural infrastructure indicate that most of the people are poor [1] and live far below the poverty line [2, 3];at 38% [4]. To meet the demands for food and the Government's Vision 2050 become a food secure country; policies need to be targeted at improving smallholder subsistence agriculture in the rural areas and integrate domestic markets to improve food security [5]. The peanut (*A. hypogaea* L.), is a cash crop that has a potentially high economic value [6, 7]. Peanut is high in protein and carbohydrates, and is a good source of food for human and livestock. In addition, peanut is rich in minerals like copper, manganese, potassium, calcium, iron, magnesium, zinc and selenium.

Reports show that peanut is the second most important oilseed crop cultivated in most parts of the tropical, subtropical and warm temperate climate regions [8, 9]. In PNG, peanut is amongst the top five income generating cash crops [6]. Peanut is widely grown and marketed from the coastal lowlands to the mid–high altitude highlands of PNG, mainly in family owned subsistence farming systems. The crop has therefore become increasingly important as a cash crop and plays a significant role in family owned subsistence farming systems. Although the peanut has a high market potential, large-scale production in PNG is limited due to lack of high–yielding varieties, seed supply and suitable cost–effective farming practices [6].

The peanut, at the farm level has the ability to nourish soils, when grown in rotation or in combination with other food crops. As a result of rotation and/or intercropping, peanut has been implicated to increase yields of succeeding crops in rotation and/or component crops in intercrop systems. This is attributed to the activity of soil microbes that enhance productivity and quality of agricultural soils as a result of their influence on nutrient cycling, detoxification processes and soil aggregate stability, among other functions [10]. It has been reported that frequent use of peanut in crop rotation resulted in increase in soil–borne pathogens and relatively poor crop performance [11]. In continuous peanut cultivation systems, low peanut yields were associated with reductions in soil quality brought about by the changes in soil microbial community [12]. Continuous cultivation of peanut also reduced bacteria species and quantity of bacteria and actinomycetes, lower the number of fungi species and increase mould quantity [13]. Similar effects have been reported in peanut by [14; 15] and in cucumber by [16]. One of the reasons for continuous cultivation in tropical regions is population pressure on land.

The global human population grows at an annual rate of 1.7% and it is projected to double at this rate in 40 years. The [17] reported that PNG's annual population growth rate is 2.3%. This has resulted in the decline in productive arable croplands under cultivation and farming communities have resorted to continued cultivation on existing croplands. The practice of continuous crop cultivation on the same piece of land has led to rapid nutrient mining and it is believed to be more severe in the tropical regions. In PNG and most parts of the tropics, shifting cultivation and bush fallow systems were practiced to restore soil fertility; however, fallow periods are shorter now due to increasing pressure on existing cropland by rapid increases in population. On a global scale, the degradation of the soil physical, chemical and biological properties is a major concern as 40% of agricultural land degradation is induced by anthropogenic processes [18]. Although the peanut industry is not fully developed in PNG, peanut can be used as an alternative cash crop in crop rotation and/or intercropping systems to improve soil quality.

This paper reports the results of a field experiment conducted under rain fed conditions in four (4) different land use systems focused particularly on continuous peanut cultivation over a period of three (3) consecutive cropping seasons. The objectives were two fold; evaluate (i) the effects of continuous peanut cultivation system compared to peanut/corn rotation, and (ii) poultry manure and fallow LUS on peanut pod yield and on selected soil properties.

II. MATERIALS AND METHODS

2.1 Experimental Site

The study was conducted between 2003 and 2004 at the agriculture model farm of PNG University of Technology, Lae in the Morobe Province. The farm (6^o41'S, 146^o98'E) is located 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. Average daily temperature is 26.3^oC, with an average daily minimum of 22.9^oC and average daily maximum of 29.7^oC. 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. It is classified as a sandy, mixed isohyperthermic, Typic Tropofluents (US Soil Taxonomy) or EutricFluvisol (World Reference Base).

2.2 Experimental Treatments

The experiment was conducted with peanut (*A.hypogaea L.*) as the test crop. The field experimental design consisted of a replicated (n=4) randomized complete block design with 4 treatments (LUS), i.e. continuous peanut cultivation, crop rotation (corn), deep litter poultry manure (15 kg/replicate/25 m^2 plots) and natural fallow (planting to maturity of peanut as the test crop) for comparison. Chicken manure was applied at rate of 15kg/plot, which is equivalent to 6 tonnes per ha^{-1} by broadcasting over each plot and mixed into soil by raking before planting. In the continuous cultivation treatment, peanut was continuously cultivated for 3 consecutive cropping seasons at a spacing of 30 cm (within row) by 50 cm (between rows) giving a plant density of 187 plants per plot (25 m^2). In the rotation treatment, corn was planted during the second cropping season and in the fallow treatment, the plots were given a rest from planting to harvesting of peanut. In the chicken manure treatment, peanut was planted continuously for the 3 consecutive cropping seasons and 15 kg of chicken manure was applied to each plot measuring 5 m x 5 m (25 m^2).

2.3 Peanut Pod Yield Measurement

Each plot of peanut was harvested 110 to 115 days after actual field planting. For the measurement of peanut pod yield, plots of peanut for all the treatments were harvested on the same day to avoid discrepancies in pod weight and on soil properties. After harvesting, the peanut pods were thoroughly washed with the root stalks intact and sun-dried. The sun-dried peanut pods were removed from the root stalks and pod yield was determined by measuring fresh weight of pods using a scale (Dillon type).

2.4 Measurement of Soil Properties

Soil samples for chemical analysis were collected from the experimental site before and after each cropping season and air-dried. The initial soil sample was collected before the experimental site was put to mechanical cultivation. Subsequent samples were taken after harvesting at the end of each cropping season to determine changes in soil properties. Particle size distribution was determined using the hydrometer method as described by [19]; bulk density using the soil core method, field capacity by taking moisture measurements of air-dried soil; electrical conductivity measurements by a standard dilution method of a 1:5 (w:v) using a conductivity meter and pH was measured with a 1:5 (w:v) ratio of soil to deionized water using a pH meter.

To determine soil chemical properties, air-dried soil samples were subjected to soil chemical analytical methods of [20] followed the procedures used by the National Analytical Laboratory (NAL), PNG University of Technology, PNG. Organic carbon was determined using the rapid wet oxidation method, in which soil samples were oxidized by a solution of 0.133 mol L^{-1} $K_2Cr_2O_7$ – 18.4 mol L^{-1} H_2SO_4 in an oil bath and excess $K_2Cr_2O_7$ was titrated with 0.2 mol L^{-1} $FeSO_4$, and thus organic matter content was obtained by multiplying the carbon value by a factor of 1.72. Total nitrogen was measured by the Semi-micro Kjeldahl method after soil samples were digested with $HClO_4$ and HF. Available phosphorus was extracted with a 0.5 mol L^{-1} $NaHCO_3$ solution and determined by molybdenum-blue colorimetry. Extractable potassium was extracted with 0.5 mol L^{-1} NH_4OAc (pH 8.5) and then determined by flame photometry. Cation exchange capacity was measured by a 0.01 mol L^{-1} $(AgTU)^+$ method and then determined by atomic absorption spectrometry (AAS).

2.5 Statistical Analysis

All basic statistical analyses were performed using MS Office XLSTAT and SPSS 14 (SPSS Inc. ILL. Canada). One-way analysis of variance (ANOVA) was performed followed by Tukey's Multiple Comparison Test to determine significance ($p= 0.05$) of mean differences between peanut pod yield and selected soil properties between the 4 LUS and the 3 cropping seasons.

III. RESULTS AND DISCUSSION

3.1 Peanut Pod Yield

Highest peanut pod yield was obtained from the continuous and manure systems during the first cropping season and the poultry manure and fallow systems during the third cropping season (Tables1). Peanut pod yields declined in the continuous and manure systems during the second cropping season. Yield decline from the continuous peanut system indicates the loss of soil quality resulting from continuous tillage. The decline in peanut pod yield from the poultry manure system shows that the applied manure rom the first cropping season did not affect peanut pod yield. In the rotation and fallow systems, peanut was rotated with corn and the plots were given a break in the second cropping season, respectively, thus no peanut pod yield data is provided. On an aggregate basis, peanut pod yield was higher in the poultry manure system than the continuous peanut, rotation and fallow systems (Table 1).

Peanut pod yield declined by 36% after the second cropping season and 16% after the third cropping season in the continuous peanut cropping system and 29% after the third cropping season in the crop rotation system (Table 1). The declines in peanut pod yield under these cropping systems could be attributed to declines in nutritional status of the soils shown by this study and studies by other researchers like [21; 22] and [23]. The continual application of chicken manure at 15 kg/plot led to a decline in peanut pod yield by 13% after the second cropping season but increased by 31% after the third cropping season (Table 1). In the fallow system, there was an increase in pod yield by 28% after the plots were fallowed for a period of 110 to 115 days during the second cropping season.

TABLE 1
PEANUT POD YIELD IN t ha^{-1} UNDER 4 DIFFERENT LAND USE SYSTEMS OVER 3 CROPPING SEASONS (2003–2004).

Cropping Season	Cropping systems				
	Continuous	Rotation	Manure	Fallow	Mean
1	3.54±0.03a	3.22±0.29a	3.66±0.08bc	3.01±0.12b	3.36a
2	2.60±0.22bc (36–)	–	3.25±0.13c (13–)	–	1.46b
3	2.25±0.11c (16–)	2.50±0.14b (29–)	4.25±0.11a (31+)	3.85±0.29a (28+)	3.23a
Mean	2.81bc	1.91d	3.72a	2.29cd	
LSD (0.05)	0.455	0.735	0.401	0.805	

All values are means of 4 replicates per cropping season for each cropping system and mean values within columns and rows followed by the same letter are not significantly different (p= 0.05). Numbers in parentheses () shows % decline (–) or increase (+) in peanut pod yield over the 3 cropping seasons

Peanut pod yield declined progressively in the continuous peanut LUS and peanut/corn rotation LUS (Table 1, Figure 1). In the poultry manure LUS, peanut pod yield declined after the second cropping season and increased after the third cropping season; while in the fallow system, pod yield increased after the plots were rested for 110 to 115 days. The application of deep litter poultry manure benefited the 3rd crop of peanut. The most likely reason is that nutrients from the applied poultry manure were made available to peanut during the 3rd cropping season and also due to improvement in soil quality in both the manure and fallow systems. Similar results were reported by[24; 25]. During the first and second cropping seasons, mean peanut pod yield between the 4 LUS's were not significantly different ($p= 0.05$); however, after the third cropping season, mean peanut pod yield were significantly different ($p= 0.05$).

In the continuous peanut LUS, peanut pod yield determined by one–way ANOVA showed significant differences between the 3 cropping seasons at F ((2, 9) = 84.4, $p= 0.000$). The Tukey post–hoc test revealed that peanut pod yield was significantly lower after taking cropping season 2 (2.60 ± 0.22 min, $p= 0.000$) and cropping season 3 (2.30 ± 0.11 min, $p= 0.037$) compared to cropping season 1 (3.54 ± 0.03 min). There was no significant difference observed between continuous peanut cropping seasons 2 and 3, $p= 0.037$ (Table 1, Figure 1). Soil bulk density, pH and total N analysis showed consistent results and thus, the results of this study failed to justify the reasons for the declining peanut pod yield. The significant changes observed for extractable K and CEC suggests that the declining peanut pod yield in continuous peanut cropping systems was attributed to K and Ca interaction resulting from the higher values observed in this study. Similar results have been reported on declining peanut pod yield due to K and Ca interaction in other studies [9; 26].

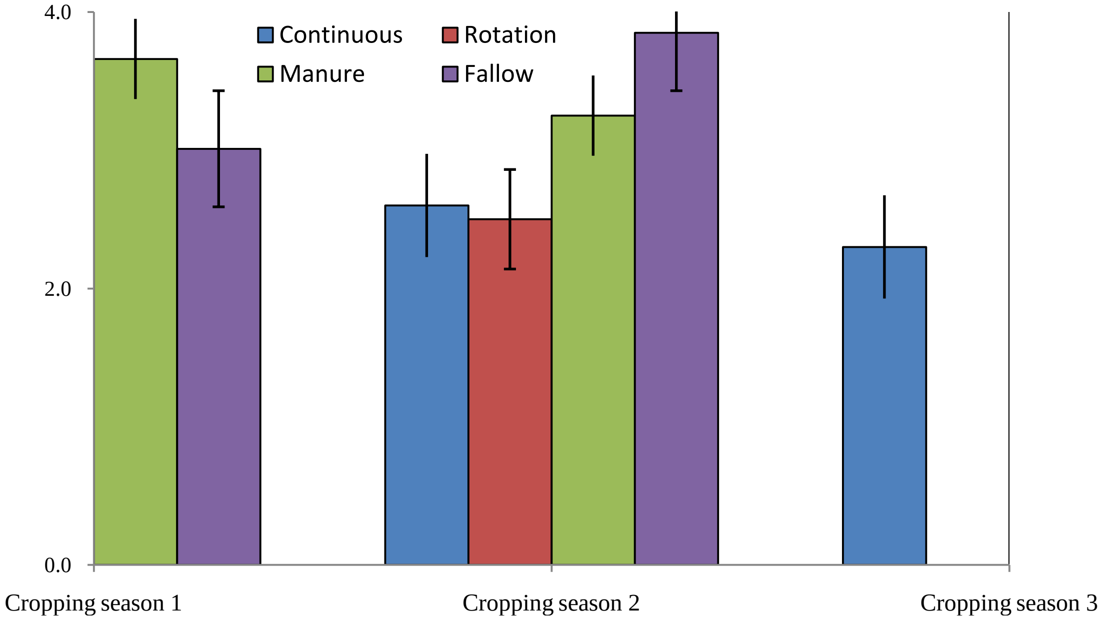

FIGURE 1. MEAN PEANUT POD YIELD OF THE DIFFERENT LAND USE SYSTEMS OVER 3 CROPPING SEASONS. ERROR BARS ARE MSE AND MSE FOLLOWED BY THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT ($p= 0.05$).

The declining trend observed in peanut pod yield in the continuous peanut LUS conforms to the many well documented evidences of yield declines in continuous cropping systems, not only in peanut, but other crops as well. Yield decline in the rotation system after the third cropping season resulted from nutrient removal by corn during the rotation season (cropping season 2). The importance of a good rotation was evident in this study (data for corn not shown). The increase in peanut pod yield observed in the manure and fallow LUS's were attributed to residual effects from previous fertilization [27] and nutrient accumulation over the duration of the applied poultry manure and short fallow periods. Based on our results, there is sufficient evidence to say that the progressive declines in peanut pod yield in the continuous peanut LUS could be a direct result of the antagonistic effects due to interactions between different nutrients, particularly K and Ca interactions.

3.2 Soil properties

In the continuous peanut cropping system, bulk density, pH and total N remained constant, while field capacity, electrical conductivity, organic carbon, available P, extractable K and cation exchange capacity declined over the cropping seasons, compared to results from a natural control plot from the experimental study. Bulk density in the continuous peanut LUS was high compared to the natural control (NC) that showed a declining trend. Soil pH also remained constant over the cropping seasons, which does not support our assumption that the declining peanut pod yield was attributed to an increase in soil acidity. There was no change in total N levels, while available P declined by 39% after the third cropping season. ANOVA showed no significant ($p= 0.05$) changes in bulk density, FMHC, EC, pH, total N and available P. We observed significant ($p= 0.05$) changes in OC, extractable K and CEC activity over the 3 cropping seasons (Table2).

Peanut was rotated with corn in the crop rotation system in the second cropping season. Bulk density and pH remained constant, when compared to the natural control. FMHC and available P declined and increased again after the third cropping season; while EC and extractable K declined. With the rotation system, there was an increase in organic C, total N and CEC, compared to the continuous peanut, manure and fallow systems. Similar results of these soil chemical properties were observed in the natural control. ANOVA showed no significant ($p= 0.05$) changes in bulk density, FMHC, EC, pH and available P, but there were significant ($p= 0.05$) changes in OC, total N, extractable K and CEC. The changes in OC, total and CEC were positive and for extractable K was negative (Table, 2).

Manure was applied at a rate of 15 kg per plot (25 m^2) and peanut was planted continuously over the 3 cropping seasons. In the manure system, bulk density and pH declined after the first crop and remained constant thereafter, a phenomenon that was similar to the other cropping systems when compared to the results of the natural control plot. Manure positively affected FMHC and CEC by increasing moisture retention and CEC. Organic C declined after the second crop but increased after the third crop. The continual application of deep litter poultry manure resulted in an increase in organic C compared to the other cropping systems. Total N, available P and extractable K, all declined progressively over the 3 cropping seasons. The changes observed were not significant ($p=0.05$) for bulk density, FMHC, EC, pH and available P. With the continual application of manure, signification ($p=0.05$) changes in OC, total N, extractable K and CEC (Table2).

In the fallow treatment, plots were fallowed for 110 to 115 days, which was the length of the peanut growing season. There were no changes in soil bulk density and pH over the 3 cropping seasons. FMHC, total N and CEC saw a slight decline after the first crop, but increased again after the third crop. EC, organic C and available P declined after a fallow, while extractable K increased after the land was fallowed. Our results showed that the changes in bulk density, FMHC, EC, total N and available P were not significant ($p=0.05$). After the land was given a break, significant ($p=0.05$) changes were observed in organic C, extractable K and CEC, for example, extractable K increased by 41% (Table 2). The higher peanut pod yield attained after the fallow period shows the importance of land fallows, in this case a significant increase in peanut pod yield (Table, 1) compared to the continuous peanut cropping system.

TABLE 2
INITIAL STATUS AND CHANGES IN SELECTED SOIL PROPERTIES OF DIFFERENT LAND USE SYSTEMS OVER 3 CROPPING SEASONS (2003–2004)

Land use system	Cropping season	Soil properties								
		D_b	FMHC	EC	pH	OC	Total N	P_{av}	K_{ext}	CEC
		(g/cm^3)	(%)	($dS\ m^{-1}$)	(1:5)	(%)	(%)	(mg/kg)		(mEq./100g)
Continuous	Initial	1.4	26	5.6	6	1.4	0.24	117	373	26
	1	1.4	27	5.3	5.9	1.5	0.14	166	470	30
	2	1.4	27	4.5	5.9	1.4	0.14	111	430	26
	3	1.4	26	4.5	5.9	1.4	0.14	101	410	26
	Mean	1.4ns	27ns	4.8ns	5.9ns	1.43*	0.14ns	126ns	437*	27*
	LSD (0.05)	0.13	0.48	0.12	0.01	0.04	0.13	5.54	15.35	65.1
Rotation	Initial	1.4	26	5.6	6	1.4	0.24	117	373	26
	1	1.4	25	5.4	5.9	1.3	0.14	140	490	27
	2	1.4	26	4.6	5.9	1.4	0.17	137	480	29
	3	1.4	24	4.6	5.9	1.4	0.2	138	478	29
	Mean	1.4ns	25ns	4.9ns	5.9ns	1.37*	0.17*	138ns	483*	28.3*
	LSD (0.05)	0.13	0.46	0.13	0.01	0.04	0.13	5.54	15.35	64.7
Manure	Initial	1.4	26	5.6	6	1.4	0.24	117	373	26
	1	1.4	24	5.1	6	1.7	0.16	144	510	28
	2	1.4	25	4.5	5.9	1.4	0.14	119	410	30
	3	1.4	27	4.5	5.9	1.7	0.12	120	400	31
	Mean	1.4ns	25ns	4.7ns	5.9ns	1.6*	0.14*	128ns	440*	30*
	LSD (0.05)	0.13	0.44	0.12	0.01	0.04	0.13	5.35	15.65	64.51
Fallow	Initial	1.4	26	5.6	6	1.4	0.24	117	373	26
	1	1.3	28	5.1	5.9	1.4	0.14	159	520	31
	2	1.3	26	4.2	5.9	1.3	0.13	145	530	29
	3	1.3	28	4.2	5.9	1.3	0.14	144	560	30
	Mean	1.3ns	27ns	4.5ns	5.9ns	1.3*	0.14ns	149ns	522*	30*
	LSD (0.05)	0.13	0.48	0.12	0.01	0.04	0.13	5.54	15.15	64.1
Natural Control	Initial	1.4	26	5.6	6	1.4	0.24	117	373	26
	1	1.4	27	6.3	5.9	2	0.2	111	430	30
	2	1.2	24	8	5.9	2	0.21	120	730	29
	3	1.2	28	8.4	5.9	2.1	0.27	124	774	30
	Mean	1.3ns	26ns	7.6*	5.9ns	2.0ns	0.23*	118*	645*	30*
	LSD (0.05)	0.13	0.48	0.13	0.01	0.04	0.13	5.64	15.85	65.4

Mean values with an asterisk (*) within rows indicate significant changes (ANOVA, p = 0.05); ns = not significant. D_b= bulk density, FMHC = field moisture holding capacity, EC = electrical conductivity, pH = soil pH, OC = organic carbon, Total N = total nitrogen, P_{av} = Available phosphorus, K_{ext} = extractable potassium, CEC = cation exchange capacity

In a natural control plot, bulk density declined as expected. This is similar to results of no tillage experiments by [28] and by [29]. FMHC and CEC declined after the second crop and increased after the third. No soil pH changes were observed. EC, organic C, total N, available P and extractable K all increased as expected. Changes in bulk density, FMHC, pH and organic C were not significant ($p=0.05$). On the contrary, changes in EC, total N, available P, extractable K and CEC were significant ($p=0.05$). The results of the selected soil properties evaluated in this study confirm that land under crop cultivation loses its quality especially under continuous cropping. It is therefore suggested that both organic and inorganic materials be supplied; good crop rotations practiced and the land given a sufficient break to improve soil quality to sustain peanut pod yield.

IV. CONCLUSION

We evaluated peanut growth responses under the following land use systems: continuous peanut, peanut/corn rotation, continuous peanut with poultry manure and fallow systems in a sandy loam soil from 2003 to 2004. Our evaluation of peanut pod yield and selected soil properties showed the poultry manure and fallow systems were more favourable for peanut cultivation than the continuous peanut and peanut/corn rotation systems. The application of poultry manure at 15 kg per plot (25 m^2) is equivalent to 6t/ha and a break period of 110 to 115 days produced better peanut pod yield and had favourable effects on soil properties. Although the study results showed that the nutritional status of the soil was adequate to sustain peanut growth and productivity, soil pH and soil water retention capacity were factors that could hinder peanut production. The peanut can generate high economic returns for smallholder farmers; therefore to improve soil quality for better peanut production, poultry manure and fallows are recommended.

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