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Soil Fertility Dynamics In Bambara Groundnuts (Vigna Subterranea) And Nerica Rice (Oryza Sativa) Intercrop System In Small Holder Farms In Western Kenya.

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ABSTRACT

Agricultural production in Kenya has stagnated since 1980s resulting in malnutrition in over 89% of Kenya's population. Food insecurity has been identified as the prime cause of malnutrition. Low agricultural productivity due to declining soil fertility resulting from poor cropping systems and use of non adapted exotic crop species has worsened this situation. Intercropping offers advantages if well planned including improved soil fertility and yields. Bambara groundnuts have shown high yield in low fertility soils and have been described as a complete food. NERICA rice has been reported to offer higher yields and shorter growing seasons. Cropping systems that combine both these crops in production systems will help alleviate malnutrition and food insecurity as well as enhance soil fertility. The objective of this study was to assess the soil fertility variation in bambara groundnut and NERICA rice intercrop system in small holder farms in Western Kenya. Five treatments including T1: Sole crop of bambara groundnuts, T2: Rice NERICA 4 without intercropping with bambara groundnuts, T3: Rice NERICA 4 intercropped with bambara groundnuts, T4: Rice NERICA 11 without intercropping with bambara groundnuts and T5: Rice NERICA 11 intercropped with bambara groundnuts were used. Soil analyses including nitrogen, phosphorous, pH and soil moisture were done to evaluate soil fertility variations in the course of the intercrop system. Data obtained was subjected to analysis of variance (ANOVA) to determine if the treatment effects were significant at 5% level. Separation of means was done by Least Significant Difference (LSD) at 5% level. Soil fertility under intercropping system was significantly higher in the subsequent seasons as compared to the initial season with bambara groundnuts replenishing the soil N through its association with N fixing bacteria. This study provides an understanding of the effect of NERICA rice and bambara groundnuts intercrop system on soil fertility. This allows us to understand the response mechanisms both below and above ground of the two crops to resources.

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INTRODUCTION

Agricultural production in Kenya has stagnated since 1980s resulting in malnutrition in over 89% of Kenya's population. Food insecurity has been identified as the prime cause of malnutrition. Low agricultural productivity due to declining soil fertility resulting from poor cropping systems and use of non adapted exotic crop species has worsened this situation. Intercropping offers advantages if well planned including improved soil fertility and yields. Bambara groundnuts have shown high yield in low fertility soils and have been described as a complete food. NERICA rice has been reported to offer higher yields and shorter growing seasons. Cropping systems that combine both these crops in production systems will help alleviate malnutrition and food insecurity as well as enhance soil fertility

Grain legume-cereal intercropping is a method to obtain greater and more stable crop yields, improve plant resource utilization (water, light, nutrients), increase input of leguminous symbiotic nitrogen fixation (SNF) to the cropping system and reduce negative impacts on the environment (Frye and Blevins, 1989).

Intercropping offers the potential for: generating more stable yields, due to self-regulation in the crop, giving the farmer better insurance against crop failure and will safeguard the farmer's earnings. Similarly it will provide product quality such as greater protein content of cereals via planned competition. An ecological balance via competition and natural regulation mechanisms and planned biodiversity to manage weeds and pests will be achieved. This will enhance reduce the cost of energy for weed and pest control, and improving the synchrony between microbial immobilization-mineralization and crop N demand, due to differences in the quality of the residues and thereby aiding in the conservation of N in the cropping system (Andre *et al.*, 2007).

Implementation of grain-legume-cereal intercropping into viable crop rotations may solve some of the problems current farming practices are facing. However, knowledge of competitive interactions in intercrops required to better predict and manage the outcome of competition and thus the SNF input into the cropping system is scarce. Therefore evaluation of interactions between traditional legume bambara groundnut *(Vigna subterranean* (L) Verdic) on soil fertility and productivity of NERICA rice (*Oryza sativa L*) would give a sustainable intervention on soil fertility and food security problem in many farming families in Kenya.

Legume cover crops have long been grown because of their ability to biologically "fix" nitrogen through a symbiotic relationship with *Rhizobia* bacteria living in nodules on the roots. These leguminous crops can biologically fix or accumulate (as in the case of non- legumes) from 14500 to 90800 kilograms of nitrogen per acre, and can replace or greatly reduce the need for manufactured nitrogen fertilizer. Giller (2001) reported that the amount of nitrogen actually contributed to subsequent crops varies considerably, and depends on environmental conditions, carbon to nitrogen (C: N) ratios of the cover crop, available N in the soil and soil microbial activity. In addition to the quantity of nitrogen available in a legume cover crop, the rate of decomposition, or mineralization, must be matched with crop N- uptake requirements for optimum yield. A study by Sullivan *et al*. (1991) which evaluated the contribution of hairy vetch and a mixture of hairy vetch and bigflower vetch to corn production, N-uptake rates in corn following the vetch cover crops closely paralleled N-uptake rates of 70 kg N/ha. But N-uptake in the corn was considerably higher at 210 kg/ha, which also produced higher corn yields. Therefore, addition of some supplemental N fertilizer to the vetch crop treatments would have been required to achieve maximum yield.

In a study by Suwanarit *et al.* (1984), maize grown following among bean crop produced higher yields than any rate of manufactured nitrogen fertilizer; however the addition of 100 kg N/ha to the corn following a vetch crop produced the highest corn yields in the experiment, as well as generated the highest net return to the producer. The N-fertilizer equivalency of non-legume cereals, such as wheat and barley, is low or negligible (sometimes negative) due to a lower N content and higher C: N ratio, which often results in the tie up, or immobilization of N during the cropping season. These non-legume species may not contribute N to the crop immediately following the cover crop; however they play an important role in scavenging nitrate N from the soil that may be lost to leaching and cycling of nutrients. Although most research on cover crop contributions to soil fertility has concentrated on N cycling, cover crops also store other major plant nutrients in their tissues. Microbial decomposition of plant tissues following incorporation as a green manure crop helps make the nutrients available for subsequent crop uptake.

Nitrogen contribution to cropping systems by leguminous crops occur majorly through; legume green manures, improved fallows to subsequent crops in relay cropping or in intercrops to companion crops (Giller, 2001). Giller, (2001) using peas, reported that at the time of harvest, 22% to 46% of the below-ground N had been shed into the rhizosphere. This N "rhizodeposition" has not been widely assessed and has been underestimated to be about 10%. Interactions in intercropping system is principally due to modification of the environment for the succeeding crops due to residual effect (Gan *et al.*, 2009). For example comparisons of the N benefits after four leguminous crops showed that all the rice yields were greater than those achieved with the addition of 120 kg N/ha as urea (Giller, 2001). Singh *et al.* (1986) reported that soybeans have the ability to provide nitrogen to adjacent sorghum crops in the range of 30 and 40-80 kg/ha, respectively.

Giller (2001) reported that the yields of upland rice increased linearly with the amount of N added by a wide range of green manures. He also reported that yields for maize were higher after mucuna cover crop if the soil had been cropped continuously for several years. The fertilizer value of mucuna cover crop in farmers fields is estimated to be between 38- 66 kg/ha as urea, and this is increased to 74-76 kg/ha where the mucuna has been grown. Giller (2001) reported that pure stands of Slender leaf (*Crotolaria ochroleuca)* gave almost double the yield increase than where it had been intercropped with maize.

Researchers have shown that most legumes do not utilize soil N in deeper layers of the profile as efficiently as cereals. A greater concentration of soil inorganic N is often found following a pea crop than a cereal crop (Evans *et al*., 1989) and this may give rise to a greater nitrate leaching potential (Jensen, 1996). Furthermore, the net mineralization of N in soil, when aboveground residues are removed, is greater after pea than after barley (Jensen, 1996). Incorporation of aboveground crop residues causes a greater net mineralization in pea than in barley amended soil, due to differences in the quality of the residues, especially the concentrations of soluble C and N (Jensen, 1996). However, no information is available on the effect of mixing Bambara groundnuts and NERICA rice residues on the short-term turnover of C and N in soil. Residue management may be a key to improve soil N and C turnover and thereby the synchrony between microbial mineralization and crop nutritional demands.

Organic acids released by the decomposition of organic matter in the soil can also accelerate the transformation of mineral P into more plant available forms (Stevenson, 1986). Wheat intercropped with white lupin (*Lupinus albus*) has access to a larger pool of P, manganese, and nitrogen than wheat grown in monoculture. The former two nutrients were probably mobilized by exudates from the lupin roots, and then taken up by the closely-associated wheat roots. Based on pot experiments, Rodale (1990) concluded that burr medic (*Medicago polymorpha*) and barrel medic (*Medicago truncatula*) are not as efficient at absorbing soil phosphorus as is subterranean clover (*Trifolium subterraneum*). Annan and Amberger (1989) investigated P uptake by buckwheat (*Fagopyrum esculentum*) as a cover crop in relation to morphological features and chemical changes in the rhizosphere and found that root weight and length, and frequency of root hairs were higher when plants were grown under P deficiency. In addition, whereas P uptake rates were only moderate; concentrations of phosphorus in the shoot were high (1.8% of dry weight) Annan and Amberger (1989).

Therefore the objective of this study was to evaluate the effect of intercropping Bambara groundnuts and NERICA rice on soil fertility dynamics in small holder farms in Western Kenya.

MATERIALS AND METHODS

Butere district lies between latitudes $34^0 29^1$ E and longitudes $0^0 12^1$N of the equator. The total area of the district is 209.8 sq. km. The district has varying topography with altitudes ranging from 1250 meters to 2000 meters above sea level. There are two rain seasons in the district: the long rains start in March and end in August with the peak in May; and the short rains begin in September and end in December with a peak in October. The driest months are December, January and February. The mean annual rainfall is 1750 mm. The district has high temperatures all the year round with slight variations in mean maximum and minimum ranges of 23^0C to 32^0C and 11^0C to 13^0C, respectively. The major soil types in the district are classified as moderately deep Acrisols and Ferralsols. They are well drained, moderately deep to deep, dark yellowish brown to dark reddish brown, friable sandy clay to clay with an acidic humic top soil (Andre *et al.,* 2007).

Five treatments including T1: Sole crop of bambara groundnuts, T2: Rice NERICA 4 without intercropping with bambara groundnuts, T3: Rice NERICA 4 intercropped with bambara groundnuts, T4: Rice NERICA 11 without intercropping with bambara groundnuts and T5: Rice NERICA 11 intercropped with bambara groundnuts were used. The experiment was conducted in two locations; Marama north location and Marenyo location. In each location the experiments were conducted twice during the long rain and short rain seasons of 2007, respectively.

Soil Sampling And Analysis

Before planting, soil sampling was conducted in the whole plot area by taking three samples from each subplot. This was combined to form one composite sample that was used to determine soil characteristics at the research site. In the course of the experiment soil sampling was done at planting time and harvesting time for analysis of N, organic carbon, pH and P dynamics within the root zones of both intercrop and mono-crop systems. In each plot coring was done both within and between rows at two points each.

Available Nitrogen

Available nitrogen was determined according to methods by Munson and Nelson (1990) and Buresh *et al*. (1982). 30 g air-dry soil (2 mm) was weighed into a 250-mL Erlenmeyer flask, and 150 mL 2 M potassium chloride solution added. The flasks were stoppered, shaken for 1 hour on an orbital shaker at 200 - 300 rpm, and were filtered using Whatman No. 42 filter paper. The pH-meter was calibrated, 0.01 N H_2SO_4 standardized in the AutoTitrator,as is the case for Kjeldahl-N. Before starting distillation, the distillation unit was steamed for at least 10 minutes. The steam rate was adjusted to 7 - 8 mL distillate per minute. Water was allowed to flow through the condenser jacket at a rate sufficient to keep distillate temperature below 22°C. Distillation was carried out as described by Munson and Nelson (1990) and Buresh *et al*. (1982).

Extractible Phosphorous

Extractible P was determined by the sodium bicarbonate procedure as described by Olsen *et al.*, (1954). 1.5 g air-dry soil (2-mm) was weighed into a 250-mL Erlenmeyer flask and 100 mL 0.5 M sodium bicarbonate solution added. 2. The flask was closed with a rubber stopper and shaken for 30 minutes on a shaker at 200 - 300 rpm. One flask containing all chemicals but no soil was included (Blank). 3. The solution was filtered through a Whatman No. 40 filter paper, and 10 mL clear filtrate pippeted into a 50-mL volumetric flask. 4. This was acidified with 5 N sulfuric acid to pH 5.0. This was done by taking 10 mL 0.5 M $NaHCO_3$ solution and determining the amount of acid required to bring the solution pH to 5.0, using P-nitrophenol indicator (color change was from yellow to colorless). Then the required acid was added to all the unknowns. 1 mL 5 N H_2SO_4 was added to acidify each 10 mL $NaHCO_3$ extract. Swirling of the flasks immediately after adding 1 mL 5 N H_2SO_4 was avoided to prevent excessive frothing. A standard curve was prepared and P determined as described by Olsen *et al.* (1954). The pH of the soil samples was determined according to methods described by McKeagne (1978) while the electrical conductivity was determined according to Richards (1954). Organic carbon was determined according to methods described by Okalebo *et al.* (1993).

RESULTS

Sole cropping and intercropping significantly ($P \leq 0.05$) affected the different soil nutrients evaluated in the course of the experiment during the long and short rains seasons at both Marama north and Marenyo locations in Butere division.

Nitrogen

At marama north location during the long rain season at harvesting time, the soil available nitrogen was significantly (P≤0.05) affected. The level of soil N was observed to reduce as compared to the values at the commencement of the experiment. Sole cropped bambara groundnuts plots showed significantly (P≤0.05) higher soil available N than all other lots. This was followed by intercropped treatments which had similar nitrogen levels but significantly (P≤0.05) higher than N level in NERICA sole cropped plats (Table 1).

During the second experiment at the same site no fertilizer was added to the plots and the soil analyses at the harvesting time during the short rain season showed significant (P≤0.05) reduction in soil N levels. Sole cropped bambara groundnuts plots had significantly (P≤0.05) higher soil N levels than all other treatments. The N level in all NERICA sole cropped and intercropped was statistically similar and less than 10 kg/ha (Table 1).

At Marenyo location, the level of soil N reduced significantly (P≤0.05) in both sole and intercropped plots in both long and short rain seasons (Table 3). During the long rain season bambara groundnuts sole cropped plots had significantly (P≤0.05) higher N levels than all other treatments. The intercropped plots had similar N levels than NERICA sole cropped plots though, the level of N in NERICA 11 intercropped plots with bambara and sole cropped NERICA 4 was similar (Table 3).

During the short rain season, the N level was significantly (P≤0.05) reduced by NERICA 11 intercropping with bambara as compared to all other treatments. Sole cropped NERICA 4 and 11 plots had similar N content with intercropped NERICA 4 but significantly (P≤0.05) less than N level in sole cropped bambara groundnuts (Table 3).

Phosphorous

Phosphorous content of the soil was observed to reduce slightly at harvesting time in both the locations during the long rain season in all the plots. At Marama north location, phosphorous levels were observed to be similar in bambara groundnuts and NERICA intercropped plots and significantly (P≤0.05) higher as compared to all sole cropped bambara and NERICA plots during the long rain season (Table 1).

The P content was observed to reduce further during the short rain season with significant (P≤0.05) reduction in bambara sole cropped plots but similar to P levels in NERICA 11 sole cropped plots (Table 1).

At Marenyo location during long rain season at harvesting time the level of P in intercropped bambara and NERICA plots was significantly (P≤0.05) higher than all other treatments (Table 3). Sole cropped bambara groundnuts plots had significantly lower P content.

The soil P content was significantly (P≤0.05) higher at the same site during short rain season in bambara and NERICA intercropped plots (Table 3). All the sole cropped bambara and NERICA plots had similar P content.

Potassium

Potassium levels in the soil were observed to reduce slightly though significant (P≤0.05) within the different treatments in both locations within the two seasons of rain. At marama north location during the long rain season, K content was significantly (P≤0.05) lower in bambara and NERICA 11 intercropped plots than sole cropped bambara and intercropped bambara and NERICA 4 plots (Table 1). All other treatment showed similar K levels.

Soil analyses at the same site at harvesting time during the short rain season did not reveal any statistical differences within the different treatments.

Analyses at Marenyo location showed significantly (P≤0.05) higher K levels in sole cropped bambara plots than all other treatments during the long rain season (Table 3). All other treatments showed similar levels of K except sole cropped NERICA 4 which had significantly (≤0.05) higher K levels than NERICA 4 intercropped with bambara groundnuts.

Potassium values during the short rain season at the same site were similar in all the treatments except sole cropped bambara groundnuts which showed significantly (P≤0.05) higher K contents.

Table 1: Available nitrogen, phosphorous, potassium, pH and organic carbon content of the soil in the two locations in Butere division before the onset of the experiment during the long rain season of 2007

	Marama North	Marenyo Location
Nitrogen (kg /ha)	47.87	55
Phosphorous (P_2O_5/100g)	54.38	51.87
Potassium (mg K_2O/100g)	15.54	13.87
pH	6.2	6.5
Organic carbon (%)	0.98	1.2

Table 2: Effect of sole cropping and intercropping bambara groundnuts and NERICA rice on soil nitrogen, phosphorous, potassium, pH and organic carbon content during long and short rain seasons of 2007 at Marama north location in Butere division at harvesting time.

Marama North Location					
2007 Long rains	Nitrogen (kg N/ha)	Phosphorous (mg P_2O_5/100g)	Potassium (mg K_2O/100g)	pH	Organic C OC(%)
Sole bambara groundnuts	37.23	43.52	14.26	6.60	1.03
Sole NERICA 4	15.30	44.90	13.94	6.47	0.95
Intercropped NERICA 4	18.45	48.37	14.40	6.65	0.95
Sole NERICA 11	11.76	44.56	13.63	6.67	0.94
Intercropped NERICA 11	16.74	48.64	13.22	6.48	0.96
$LSD_{5\%}$	0.14	0.05	0.07	ns	0.03
CV(%)	2.48	0.65	1.37	1.31	0.96
2007 Short rain	kg N/ha	mg P_2O_5/100g	mg K_2O/100g	pH	OC(%)
Sole bambara groundnuts	24.83	40.60	12.49	6.51	1.27

Sole NERICA 4	6.43	42.64	12.09	6.48	0.98
Intercropped NERICA 4	7.69	44.57	12.15	6.53	1.07
Sole NERICA 11	6.91	41.24	10.99	6.51	0.99
Intercropped NERICA 11	5.95	45.65	10.28	6.46	0.99
LSD5%	0.31	0.05	ns	ns	0.02
CV(%)	7.61	0.67	4.49	2.33	0.83

Table 3: Effect of sole cropping and intercropping bambara groundnuts and NERICA rice on soil nitrogen, phosphorous, potassium, pH and organic carbon content during long and short rain seasons of 2007 at Marenyo location in Butere division at harvesting time.

	Marenyo Location				
2007 Long rains	Nitrogen (kg N/ha)	Phosphorous (mg P_2O_5/100g)	Potassium (mg K_2O/100g)	pH	Organic C OC(%)
2007 Long rains	kg N/ha	mg P_2O_5/100g	mg K_2O/100g	pH	OC(%)
Sole bambara groundnuts	42.86	39.91	12.75	6.47	1.24
Sole NERICA 4	22.43	41.99	11.09	6.67	0.92
Intercropped NERICA 4	26.13	45.57	10.22	6.65	0.98
Sole NERICA 11	18.84	42.52	10.78	6.49	0.91
Intercropped NERICA 11	23.97	45.60	10.47	6.65	0.99
LSD5%	0.10	0.06	0.08	ns	0.02
CV(%)	1.55	0.83	1.76	1.10	0.73
2007 Short rains	kg N/ha	mg P_2O_5/100g	mg K_2O/100g	pH	OC(%)

Sole bambara groundnuts	29.28	37.56	11.42	6.2 7	1.25
Sole NERICA 4	12.49	39.28	8.53	6.1 5	0.94
Intercropped NERICA 4	11.89	41.56	7.04	6.2 6	1.10
Sole NERICA 11	11.70	38.24	8.47	6.0 3	0.96
Intercropped NERICA 11	9.59	41.68	7.47	6.0 8	0.70
LSD5%	0.19	0.06	0.24	ns	0.18
CV(%)	3.76	0.83	5.90	3.2 2	6.96

Soil pH

The soil pH in all the two seasons at both locations did not show significant differences (Table 1 and 3).

Organic carbon

The soil organic carbon changed slightly in the course of the experiment though statistical analyses showed some significant differences among the treatments (Table 1). During the long rain season at Marama north location, sole cropped bambara groundnuts plot had significantly ($P \leq 0.05$) higher OC content as compared to all other treatments which had similar levels of soil OC.

At short rain season their was a slight increase in soil OC with sole cropped bambara groundnuts showing significantly ($P \leq 0.05$) higher values than other treatments (Table 1). NERICA 4 intercropped plots showed higher soil OC than other treatments though it was significantly less than OC in sole cropped bambara groundnuts.

At Marenyo location during the long rain season, sole cropped bambara groundnuts had significantly ($P \leq 0.05$) higher soil OC than all other treatments (Table 3). The sole cropped NERICA plots showed the lowest OC levels.

During the short rain season, the soil organic carbon was similar in all plots except sole cropped bambara which had significantly ($P \leq 0.05$) higher OC than NERICA 11 intercropped plots (Table 3).

DISCUSIIONS AND CONCLUSIONS

Inorganic N utilization was intense in intercropped treatment plots than in sole cropped treatments. The level of soil N in sole cropped bambara groundnuts plots was significantly higher as compared to all other treatments. In the small holder farms where the experiment was conducted for several seasons with residues being returned to the plots and without any artificial fertilizer application the changes in soil inorganic N was gradual. The reduction of N was higher during the on farm experiments as compared to the on station experiments.

These results are in agreement with Hauggaard *et al*., (2001). He reported a reduction in inorganic N in intercropped plots from 30 kg N/ha to an average of 5 kg N/ha at between 74 DAS and 111 DAS when pea was intercropped with barley. He observed non significant differences at harvesting time in soil N status in both intercropped and sole cropped plots. Significantly greater soil inorganic N content in the pea sole crop plots compared to the barley sole crop and pea-barley intercrop plots 46 days after emergence were reported (Hauggaard *et al*., (2001).

Higher competitive ability of cereals for inorganic soil N have been reported (Chalk, 1998). Evans *et al*. (1989; 1991) found less soil N was taken up by lupin than adjacent cereal crops in an intercrop system. Utilization of soil inorganic N seems to be efficient in intercropping system as compared to intercrop. Thorsted *et al*., (2006), reported better soil nitrogen economy under low nitrogen levels in legume cereal intercrop systems. Bambara groundnuts are leguminous crops and therefore can biologically fix nitrogen within soil in to available forms. This reduces competition for soil N with the associated crop (NERICA rice) resulting in better utilization by the cereal crop. Similar observation have been made by (Jones & Clements, 1993) working on wheat and clover intercrop system in which wheat showed better competitive ability for N than when sole cropped. Higher competitiveness of cereals over legumes for soil N has been reported in a barley and pea intercrop, where pea only acquired 6% of the total soil N taken up by the intercrop (Jensen, 1996). Oikeh *et al*., (2008) reported higher dry matter production among different NERICA varieties when nitrogen fertilizer was applied, though he recommended levels less than 12g/m^2. Bambara groundnuts being a leguminous crop seems a weak competitor for soil N and therefore this promoted growth of NERICA rice when intercropped since. The pH of soil and phosphorous levels and a mount of soil organic carbon did not vary much during the experimental period, though the repeated return of the harvested residues to the plots was observed to influence slightly the amount of soil OC.

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