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Effect of Pigeon Pea-Groundnut Intercropping System on Selected Soil Properties

Austin Tenthani Phiri[1,3*], John J. Msaky[1], Jerome Mrema[1], George Yobe Kanyama-Phiri[2] and Balthazar M. Msanya[1]

[1]Soil Science Department, Sokoine University of Agriculture, Morogoro, Tanzania.
[2]Crop and Soil Science Department, Lilongwe University of Agriculture and Natural Resources, Bunda College Campus, Lilongwe, Malawi.
[3]Soils and Agricultural Engineering Commodity Group, Bvumbwe Agricultural Research Station, Limbe, Blantyre, Malawi.

Authors' contributions

This work was carried out in collaboration between all authors. Author ATP designed the study, collected data, performed the statistical analysis, and wrote the first draft of the manuscript; Authors JJM and JM managed literature in the manuscript, Author GYK back stopped technical implementation of the study in the field and Author BMM managed soils data in the manuscript. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

On average Malawi is losing of 40 kg N ha^{-1} and 6.6 kg P ha^{-1} annually. Additionally, nutrient use efficiency (NUE) is low as a result of declining levels of soil organic matter (SOM) and associated deficiencies of other macro and micronutrients. This is usually below 20 kg maize grain kg^{-1} of nutrients applied. To investigate on the possibility of improving NUE a study was initiated in the 2011/12 cropping season with a parallel trial mounted along side in the second season, both were laid in a randomized complete block design replicated three times. The trials involved planting of pigeon pea as monocultures or as intercrops. The main trial had eight treatments while the parallel trial had ten treatments. After the first season legume biomass in some plots of the main trial was buried into the soil. Soil characterization was conducted before treatment application in the first and second year. Data were analyzed using genstat and subjected to analysis of variance at 5% level of confidence. Means were separated using the least significant difference. Generally, the soil chemical characteristics for soil samples collected in all the

**Corresponding author: E-mail: phiriaustin923@gmail.com;*

treatment plots both in the main and parallel trial indicate that the soil has low fertility. The organic carbon (OC), cation exchange capacity CEC (NH_4OAc), and total N (%) was low, and was at 1.4 %, 3.5-3.6 cmol (+)/kg soil, 0.12%, while available phosphorus (Mehlich 3) was marginally adequate (mean=21.5 mg kg^{-1} and 22.1 mg kg^{-1}). The soil texture which was predominantly sandy clay loam to sandy clay coupled to the low CEC suggest potential high leacheability of nutrient elements more especially nitrogen as nitrate. Inevitably, if the soil is not properly managed crop yield could be reduced drastically.

Keywords: Soil fertility; cation exchange capacity; biomass; nutrient use efficiency.

1. INTRODUCTION

Malawian smallholder farms' productivity is constrained by a myriad of limitations that are biophysical, economic and social in nature. One of the outstanding biophysical constraints is the inherent low fertility status of the soils which is being aggravated by the continuous loss of nutrients like nitrogen (N) and phosphorus (P). On average Malawi is losing of 40 kg N ha^{-1} and 6.6 kg P ha^{-1} annually [1]. Additionally, nutrient use efficiency (NUE) is low [2], as a result of declining levels of soil organic matter (SOM) and associated deficiencies of other macro and micronutrients. According to [3] the NUE is usually below 20 kg maize grain kg^{-1} of nutrients applied.

For the past 20 years, national yields of maize have averaged 1.3 t ha^{-1} [4] against a yield potential range of 6 to 10 t ha^{-1} of many maize hybrid varieties currently grown by Malawian farmers. In the 2005/06 season, the national average maize yield was estimated to be at 1.6 t ha^{-1}. A strong Government-led Farm Input Subsidy Program (FISP) increased the nation average maize yield to over 2.5 t ha^{-1} in the 2006/07 season [5]. The sustainability of the program has been questioned due to its high dependence on donors and the sole use of inorganic fertilizers without addition of organic matter to the soil. It has been argued that this approach will continue to chemically degrade the soils [6]. Overtime, crop response to applied mineral fertilizer will continue to diminish. A proposition has been made that one way out of this quandary is the large scale integration of legumes like the pigeon pea in the maize production systems [7,8]. Recently, intercropping pigeon pea with groundnut has been touted to be a viable soil fertility improving technology [7]. This has been attributed to increased N and organic carbon (OC) input by the legumes into the soil. However, the below ground processes and interactions that enhance N fixation and NUE in this system are yet to be well understood. There is need therefore to further investigated for the development of sustainable soil fertility management technologies in the drive to increase crop production and hence food security. To investigate on the possibility of improving NUE through the technology a study was initiated in the 2011/12 cropping season. The soil on which the trial was mounted was characterized before planting of crops in the first and second year. The objectives were: i) to characterize the soil at the trial site in terms of the chemical and physical characteristics and hence the fertility status, ii) to assess changes of key soil fertility parameters as a result of legume biomass incorporation.

2. MATERIALS AND METHODS

2.1 Study Site

The study was conducted on station at Chitedze Agricultural Research Station (S 13º59' 23.2", E033º38' 36.8") in Lilongwe, Malawi. The site falls within the Lilongwe plain and receives an average annual rainfall of 875 mm. The rainy season starts in November and ends in April. Thirteen year mean rainfall data confirmed this [9]. The mean rainfall amount is suitable for the production of maize, pigeon pea and groundnut. The site has an acid soil with low N, marginally adequate P and low organic carbon. The soil has a good soil structure with top soil having predominantly a sandy clay loam texture [9].

2.2 Materials

Hand held XRF machine (Plate 1 a & b), core soil samplers, soil auger, a photo and thermo insensitive medium duration pigeon pea variety (ICEAP 00557) a long-duration pigeon pea variety (ICEAP), groundnut (CG 7), early maturing maize variety (SC 403) and Triple Super Phosphate (TSP).

Plate 1a & b. Hand held XRF machine for soil analysis, department of geological survey, Zomba Malawi

2.3 Experimental Design

In the first season the experiment was laid out in a randomized complete block design replicated three times. The treatments were as follows: 1) Sole maize (control); 2) Medium duration pigeon pea (control); 3) Long duration pigeon pea (control); 4) Sole groundnut (control); 5) Medium duration pigeon pea + groundnut. 6) Long duration pigeon pea + groundnut. 7) Medium duration pigeon pea + groundnut. 8) Long duration pigeon pea + groundnut. The medium duration pigeon pea-groundnut and long duration pigeon pea-groundnut intercrop was repeated (treatment 7 and 8) purposively. At harvest (June and September, 2012) for the first season, the biomass in all the plots having the legumes, except plots with treatment 7, 8 and 1 (sole maize) was ploughed into the soil, allowing for comparison of the effect of biomass incorporation on key soil parameters and the effect this might have had on the performance of the succeeding maize crop. A second set of soil samples were collected in December, 2012 just after the commencement of the second season. All the plots were then planted with maize. A parallel trial alongside the main trial was run in the second season with similar treatments to the first season for comparison of the performance of the legumes across seasons with the following treatments; 1) Long duration pigeon pea, 2) Medium duration pigeon pea, 3)Sole groundnut, 4)Sole groundnut + TSP-25 kg ha^{-1}, 5) Medium duration pigeon pea + TSP-25 kg ha^{-1}, 6) Long duration pigeon pea + TSP-25 kg ha^{-1}, 7) Long duration pigeon pea + groundnut, 8) Long duration pigeon pea + groundnut + TSP-25 kg ha^{-1}, 9) Medium duration pigeon pea + groundnut, 10) Medium duration pigeon pea + groundnut + TSP-25 kg ha^{-1} laid in randomised complete block design (RCBD) replicated 3 times. The plot size was 3 m by six ridges spaced at 75 cm apart. TSP was applied in some treatment plots to enhance N fixation by the legumes, for subsequent comparison with non treated plots. Soil samples (4 borings from each plot) were taken. A composite sample was made for each plot.

2.4 Data Analysis

Laboratory soil analysis was done in order to characterize soil properties. Soil samples were analyzed for OC, total N, available P, and soil pH (H_2O). Soil analysis for P, K, Mg and Ca was done using Mehlich 3 extraction procedures [10] while OC was determined using the colorimetric method [11] and total N was determined using Kjeldahl method [12]. Soil cation exchange capacity (CEC) was determined by the sodium acetate method [13]. Bulk density was determined using the core sample method [14]. Copper (Cu), Manganese (Mn), Molybdenum (Mo), Zinc (Zn) and Selenium (Se) were analyzed using the hand held XRF machine (plate 1 a & b). Biomass yield for the legumes was assessed at the end of the first season before incorporation into the soil. All the soil and biomass data were analyzed using Genstat statistical package and were subjected to analysis of variance at 95% level of confidence. Means were separated by the least significant difference.

3. RESULTS

3.1 Soil Characterization of the Study Site

3.1.1 Baseline physical and chemical properties across experimental plots of soil at the trial site

Tables 1a to 2b summarize baseline physical and chemical properties of soil in the main trial and parallel trial. Laboratory analytical results indicated that the soil texture was predominantly sandy clay loam in the top soil with the mean bulk density value both in the top and sub soil in all treatment plots being less than 1.6 g/cc. In the main trial the mean soil pH was acid to moderately acid both in the top (mean=5.4-5.7) and the sub soil (mean=5.4-5.6) in all the treatment plots (Table 1a) while in the parallel trial soil pH was acid both in the top and sub soil (mean=5.0-5.4) (Table 2a). For the main trial the mean total nitrogen content was largely low to marginally adequate both in the top (mean=0.08-0.14%) and the sub soil (mean=0.09-0.13%). While in the parallel trial this was largely low to marginally adequate in the top soil (0.09-0.13%) and low in the sub soil (0.09-0.11%). The mean level of soil organic carbon content for the main trial was medium in the top soil (mean=0.9-1.6%) and sub soil (mean=1.1-1.6%) across the treatment plots while in parallel trial this was medium both in the top (1.02-1.46%) and sub soil (1.01-1.34%). In all the trials the soil's cation exchange capacity was below 5 CEC me/100g both in the top and sub soil in all treatment plots. Concurrently, in the main trial the mean soil phosphorus was low to marginally adequate in the top soil (mean=16.8-27.6 mg kg^{-1}) and marginally adequate in the sub soil (mean=20.8-25.6 mg kg^{-1}) while this was low both in the top (mean=7.2-13.1 mg kg^{-1}

to 8.9-16.7 mg kg^{-1}) for the parallel trial. Total molybdenum (Mo) content in the main trial ranged from 5.4 ppm and 26.4 ppm in the top soil while in the sub soil this ranged from 11.5 ppm and 25.4 ppm (Table 1b). While in the parallel trial this ranged from 9 ppm to 23 ppm in the top soil and 10 ppm to 22.3 ppm in the sub soil (Table 2b). Both the main and parallel trial had mean soil potassium falling within the adequate range in the top soil (mean=0.10-0.29%, 0.30-0.48 cmol kg^{-1}) and sub soil (mean=0.13-0.35%, 0.16-0.37 cmol kg^{-1}).

Fig. 1 below show the yield of biomass for the pigeon pea and groundnut. Pigeon pea biomass yield in all the treatments and across the varieties was statistically the same ($p>0.05$). For groundnut higher biomass yield was registered in the pure stand and in the medium duration pigeon pea-groundnut intercrop. Overall, the intercrops gave the highest biomass yield above the monocultures of pigeon pea and groundnut.

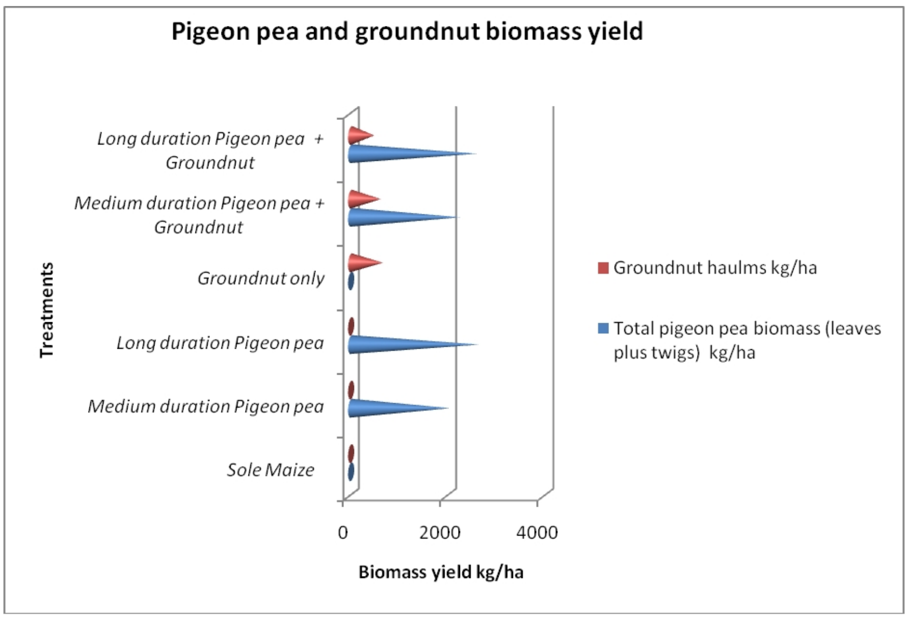

Fig. 1. Pigeon pea and groundnut biomass yield
Data source: Phiri et al., 2013

Table 3 below shows some of the soil chemical properties in the second season after the incorporation of legume biomass. Soil organic carbon remained largely in the medium range while total soil nitrogen levels stood at low to marginally adequate. Plant available phosphorus decreased in some treatment plots. Soil pH and potassium values did not differ markedly from those recorded in the first season while an increase in the mean level of soil plant available magnesium and calcium was observed in plots where legume biomass was incorporated.

Table 1a. Soil chemical parameter for the trial site-Main trial, first season

Treatment	CEC me/100g 0-20 Cm	CEC me/100g 20-40 Cm	pH_{H2O} 0-20 Cm	pH_{H2O} 20-40 Cm	OC% 0-20 Cm	OC% 20-40 Cm	Total N% 0-20 cm	Total N% 20-40 Cm	P (mg/kg) 0-20 cm	P (mg/kg) 20-40 cm	% K 0-20 cm	%K 20-40 Cm	Mg cmol kg^{-1} 0-20 cm	Mg cmol kg^{-1} 20-40 cm	Ca cmol kg^{-1} 0-20cm	Ca cmol kg^{-1} 20-40 cm
1.Sole Maize	3.5^{ab}	3.3^{bc}	5.5	5.4	1.4	1.4	0.12	0.12	27.6^{a}	22.7	0.26	0.17	0.32	0.34^{bc}	3.30	3.2^{b}
2.Medium duration pigeon pea	4.3^{a}	3.9^{ab}	5.4	5.5	1.1	1.4	0.10	0.12	18.8^{b}	20.9	0.13	0.16	0.38	0.36^{bc}	3.10	4.4^{a}
3.Long duration pigeon pea	2.6^{b}	3.5^{abc}	5.6	5.5	0.9	1.1	0.08	0.10	16.8^{b}	20.8	0.16	0.17	0.35	0.28^{bc}	3.20	3.0^{b}
4.Sole groundnut	3.6^{a}	3.2^{bc}	5.5	5.4	1.6	1.5	0.14	0.13	17.6^{b}	23.4	0.10	0.21	0.48	0.52^{a}	3.04	3.4^{ab}
5.Medium duration pigeon pea + Groundnut	4.0^{a}	4.3^{a}	5.4	5.4	1.4	1.1	0.12	0.09	18.9^{b}	21.3	0.25	0.13	0.30	0.31^{bc}	3.13	2.8^{b}
6.Long duration pigeon pea + Groundnut	4.1^{a}	4.0^{ab}	5.7	5.5	1.4	1.4	0.12	0.12	22.1^{ab}	20.4	0.13	0.35	0.34	0.34^{bc}	3.52	3.3^{b}
7.Medium duration pigeon pea + groundnut	3.7^{a}	3.5^{abc}	5.6	5.6	1.4	1.4	0.12	0.12	26.6^{a}	21.4	0.29	0.20	0.42	0.37^{ab}	3.87	3.1^{b}
8.Long duration pigeon pea + Groundnut	2.4^{b}	2.8^{c}	5.6	5.5	1.6	1.6	0.14	0.13	23.4^{ab}	25.6	0.26	0.20	0.42	0.16^{c}	3.32	3.8^{ab}
CV%	18.00	14.4	4.40	3.70	25.5	26.9	25.5	26.9	18.7	18.2	47.1	38.3	35.4	35.5	22	20.6
$LSD_{0.05}$	0.92	0.83	0.43	0.35	0.06	1.40	0.05	0.05	7.02	7.2	0.22	0.40	0.23	0.21	1.3	1.2

Means with different superscripts within a column are significantly different p<0.05; Number of replicates (N) = 3

Table 1b. Soil chemical parameter for the trial site, XRF data-Main trial, first season

Treatment	Total Mn ppm 0-20 cm	Total Mn ppm 20-40 cm	Total Mo ppm 0-20 cm	Total Mo ppm 20-40 cm	Total Zn ppm 0-20 cm	Total Zn ppm 20-40 cm	Total Se ppm 0-20 cm	Total Se ppm 20-40 cm
1.Sole Maize	601.3	634.0	10.7^{bc}	16.4^{ab}	25.4^{ab}	23.23	-	2.2
2.Medium duration pigeon pea	523.0	436.0	26.4^{a}	22.1^{ab}	41.3^{ab}	42.76	4.0	6.2
3.Long duration pigeon pea	637.0	598.7	5.4^{c}	12.5^{b}	42.0^{ab}	43.23	-	3.2
4.Sole groundnut	537.0	447.0	22.4^{ab}	11.5^{b}	50.3^{a}	34.76	14.0	3.2
5.Medium duration pigeon pea + Groundnut	620.0	489.0	11.6^{bc}	14.8^{ab}	39.0^{ab}	50.68	-	8.2
6.Long duration pigeon pea + Groundnut	456.0	731.0	9.9^{bc}	18.4^{ab}	17.0^{b}	55.57	4.0	-
7.Medium duration pigeon pea + groundnut	705.0	540.7	-	25.4^{a}	55.4^{a}	56.01	-	2.2
8.Long duration pigeon pea + Groundnut	683.3	497.0	-	13.1^{ab}	50.0^{a}	41.68	-	8.2
CV%	29.7	33.5	27.8	32.8	38.7	43.1	-	-
$LSD_{0.05}$	309.3	320.7	13.8	12.8	31.1	59.54	-	-

Means with different superscripts within a column are significantly different p<0.05; Number of replicates (N) = 3

Table 2a. Soil chemical parameter for the trial site-Parallel trial, second season

Treatment	pH_{H2O} 0-20 cm	pH_{H2O} 20-40 cm	CEC me/100g 0-20cm	CEC me/100g 20-40cm	%OC 0-20 cm	%OC 20-40 cm	Total N% 0-20 cm	Total N% 20-40 cm	P (mg/kg) 0-20 cm	P (mg/kg) 20-40 cm	% K 0-20 cm	%K 20-40 cm
1.Long duration pigeon pea + groundnut + TSP	5.3	5.4	3.9[a]	1.3	1.32	1.27	0.11[ab]	0.11	8.8	8.9	0.16	0.16
2.Medium duration pigeon pea + TSP	5.1	5.0	1.7[b]	2.1	1.46	1.24	0.13[a]	0.11	9.9	10.4	0.16	0.12
3 .Groundnut only	5.4	5.2	3.5[a]	2.9	1.24	1.23	0.11[ab]	0.10	8.6	9.9	0.17	0.14
4.Medium duration pigeon pea + groundnut	5.4	5.4	3.8[a]	4.3	1.29	1.29	0.11[ab]	0.11	9.7	10.6	0.18	0.15
5.Long duration pigeon pea + groundnut	5.3	5.1	3.3[a]	2.6	1.20	1.26	0.10[ab]	0.11	12.2	13.8	0.17	0.11
6.Groundnut + TSP	5.4	5.3	2.1[ab]	2.9	1.26	1.12	0.11[ab]	0.10	10.4	13.4	0.19	0.16
7.Long duration pigeon pea + TSP	5.4	5.3	3.5[a]	4.2	1.25	1.01	0.11[ab]	0.09	7.2	10.8	0.18	0.14
8.Medium duration pigeon pea + groundnut + TSP	5.2	5.1	3.4[a]	4.1	1.02	1.03	0.09[b]	0.09	8.6	7.7	0.15	0.13
9.Long duration pigeon pea only	5.4	5.3	3.2[a]	3.4	1.11	1.22	0.09[b]	0.11	7.9	9.1	0.23	0.19
10.Medium duration pigeon pea only	5.0	5.3	3.7[a]	4.1	1.05	1.34	0.09[b]	0.11	13.1	16.7	0.17	0.16
CV%	4.03	3.41	23.5	34.3	23.2	28.0	22.7	28.90	36.1	50.1	45.8	33.6
$LSD_{0.05}$	0.39	0.33	1.29	18.8	0.49	0.58	0.04	0.05	5.96	9.57	0.14	0.08

Means with different superscripts within a column are significantly different p<0.05; Number of replicates (N) = 3

Table 2b. Soil chemical parameter for the trial site XRF data-Parallel Trial, second season

Treatment	Mn ppm 0-20 cm	Mn ppm 20-40 cm	Mo ppm 0-20 cm	Mo ppm 20-40 cm	Zn ppm 0-20 cm	Zn ppm 20-40 cm	Se ppm 0-20 cm	Se ppm 20-40 cm
1.Pigeon pea medium duration + Groundnut	497.3	381.7	21.3	21.0	83.6	16.1[c]	9.1[b]	8.2
2.Sole Pigeon pea long duration + TSP-25 kg ha^{-1}	349.7	324.4	16.3	18.3	-	22.3[c]	6.1[b]	6.2
3.Groundnut + TSP	467	506.4	19.6	10.0	46.3	58.8[a]	7.3[b]	5.2
4.Pigeon pea medium duration	405.3	412	13.0	19.6	34.6	32.0[bc]	3.9[b]	6.4
5.Pigeon pea long duration + Groundnut	427.7	452.4	14.1	11.0	-	43.3[ab]	3.5[b]	6.8
6.Pigeon pea medium duration + TSP-25 kg ha^{-1}	638.3	453.0	17.4	22.3	98.9	22.6[c]	9.1[b]	5.2
7.Pigeon pea long duration + Groundnut + TSP-25 kg ha^{-1}	475.0	565.0	16.0	10.0	27.9	34.2[bc]	28.1[a]	4.2
8.Pigeon pea medium duration + groundnut + TSP-25 kg ha^{-1}	468.0	547.0	23.0	15.3	77.6	41.3[bc]	6.1[b]	5.0
9.Groundnut	633.2	521.0	19.2	18.8	45.9	20.0[c]	-	-
10.Sole Pigeon pea long duration	529.7	522.0	9.0	11.6	27.6	46.3[ab]	4.3[b]	9.2
CV%	45.95	32.48	60.9	57.6	23.1	19.4	14.7	56.3
$LSD_{0.05}$	433.2	268.0	22.0	17.00	74.3	20.0	6.8	21.7

Means with different superscripts within a column are significantly different p<0.05; Number of replicates (N) = 3

Table 3. Soil chemical properties for the main trial, second season

Treatment	pH 0-20cm	pH 20-40cm	OC% 0-20cm	OC% 20-40cm	Total N% 0-20cm	Total N% 20-40cm	P mg/kg 0-20cm	P mg/kg 20-40cm	K cmols/kg 0-20cm	K cmols/kg 20-40cm	Mg cmols/kg 0-20cm	Mg cmols/kg 20-40cm	Ca cmols/kg 0-20cm	Ca cmols/kg 20-40cm
1.Sole Maize	5.0	5.1	1.1^{a}	1.4^{ab}	0.09^{bc}	0.12^{ab}	9.3^{b}	18.34	0.29^{c}	0.26^{ab}	1.0^{b}	1.3	5.5^{b}	4.6^{b}
2.Medium Duration Pigeon Pea	5.2	5.4	1.5^{a}	1.4^{ab}	0.13^{a}	0.12^{ab}	12.9^{ab}	19.75	0.52^{a}	0.19^{bc}	2.8^{a}	1.9	10.6^{ab}	12.5^{ab}
3.Long Duration Pigeon Pea	5.1	5.0	1.1^{a}	1.4^{ab}	0.07^{c}	0.10^{b}	12.4^{ab}	18.63	0.47^{ab}	0.17^{c}	3.1^{a}	2.0	11.5^{a}	18.3^{a}
4.Sole Groundnut	5.3	5.5	1.3^{ab}	1.3^{a}	0.11^{ab}	0.11^{ab}	13.4^{ab}	19.74	0.39^{b}	0.39^{a}	2.5^{a}	2.1	11.4^{a}	11.0^{ab}
5.Medium Duration Pigeon Pea + Groundnuts	5.1	5.2	1.3^{ab}	1.3^{b}	0.11^{ab}	0.11^{ab}	15.6^{a}	18.95	0.47^{ab}	0.34^{ab}	3.1^{a}	2.1	5.8^{ab}	6.1^{b}
6.Long Duration Pigeon Pea + Groundnuts	5.3	5.4	1.6^{a}	1.7^{a}	0.14^{a}	0.11^{ab}	14.7^{a}	19.98	0.46^{ab}	0.30^{ab}	2.5^{a}	2.1	13.9^{a}	12.4^{ab}
7.Medium Duration Pigeon Pea + Groundnuts	5.1	5.0	1.3^{ab}	1.3^{b}	0.12^{ab}	0.14^{a}	14.3^{a}	17.87	0.42^{abc}	0.26^{ab}	1.3^{b}	1.5	5.4^{b}	5.3^{b}
8.Long Duration Pigeon Pea + Groundnuts	5.3	5.0^{a}	1.6^{a}	1.4^{ab}	0.14^{a}	0.12^{ab}	15.5^{a}	19.44	0.29^{c}	0.26^{ab}	1.8^{ab}	1.2	4.9^{b}	4.4^{b}
CV%	7.8	8.5	19.0	17.5	19.7	18.53	18.2	27.26	20.3	36.80	24.9	40.9	30.7	39.1
$LSD_{0.05}$	0.7	0.7	0.4	0.4	0.04	0.04	4.3	4.30	0.15	0.18	1.2	1.6	5.9	8.2

Means with different super scripts within a column are statistically different p<0.05; Number of replicates (N) = 3

4. DISCUSSION

Laboratory analytical results indicated that the soil texture was predominantly sandy clay loam in the top soil and sandy clay in the sub soil with the mean bulk density value both in the top and sub soil in all treatment plots being less than 1.6 g/cc. This suggested that root growth and development of crops was not restricted under this soil environment [15]. In main trial the mean soil pH was acid to moderately acid both in the top (mean=5.4-5.7) and the sub soil (mean=5.4-5.6) in all the treatment plots (Table 1a) while in the parallel trial soil pH was acid both in the top and sub soil (mean=5.0-5.4) (Table 2a). At this range of soil reaction the macro nutrients were likely less available to an extent compared to the micronutrients [16]. For the main trial the mean total nitrogen content was largely low to marginally adequate both in the top (mean=0.08-0.14%) and the sub soil (mean=0.09-0.13%). In the parallel trial this was largely low to marginally adequate in the top soil (0.09-0.13%) and low in the sub soil (0.09-0.11%). This calls for N supply from either inorganic or organic sources for increased crop yield. The mean level of soil organic carbon content both for the main trial and parallel trial was medium in the top soil (mean=0.9-1.6%, 1.02-1.46%) and sub soil (mean=1.1-1.6%, 1.01-1.34%) across the treatment plots. Both in the main and parallel trial the soil's cation exchange capacity was below 5 CEC me/100g both in the top and sub soil in all treatment plots (Table 1a and 2a). This indicates that the soil has low clay and organic matter content, low water holding capacity, and could be prone to leaching of nitrate (NO_3), Ammonium (NH_4), potassium (K) and magnesium (Mg) [17]. Concurrently, in the main trial the mean soil phosphorus was low to marginally adequate in the top soil (mean=16.8-27.6 mg kg^{-1}) and marginally adequate in the sub soil (mean=20.8-25.6 mg kg^{-1}) while this was low both in the top and sub soil (mean=7.2-13.1 mg kg^{-1}, 8.9-16.7 mg kg^{-1}) for the parallel trial. This suggested that P supply for crop uptake was low [9]. The crops under study were nodulating legumes which require high supply of P to enhance biological nitrogen fixation [18]. As such the low and variable level of soil P necessitated the external supply of the nutrient for enhanced yield. In the main trial total molybdenum (Mo) content ranged from 5.4 ppm and 26.4 ppm in the top soil while in the sub soil this ranged from 11.5 ppm and 25.4 ppm (Table 1b). For the parallel trial this ranged from 9 ppm to 23 ppm in the top soil and 10 ppm to 22.3 ppm in the sub soil (Table 2b). In both cases this was within the range reported for surface soils in other parts of the world [17]. In the main trial mean soil potassium in the top soil (mean=0.10-0.29%) and sub soil (mean=0.13-0.35%) was adequate across the treatment plots with low magnesium content for both the top soil (mean=0.30-0.48 cmol kg^{-1}) and sub soil (mean=0.16-0.37 cmol kg^{-1}). In the parallel trial mean potassium content was within the adequate range both in the top (mean=0.16-0.23 cmol kg^{-1}) and sub soil (0.11-0.19 cmol kg^{-1}) Calcium was marginally adequate both in the top soil (mean=3.04-3.87 cmol kg^{-1}) and sub soil (mean=2.8-4.4 cmol kg^{-1}) in the main trial.

Second season soil data after the incorporation of legume biomass indicated that soil organic carbon remained largely in the medium range while plant total soil nitrogen levels stood at low to marginally adequate. On the other hand plant available phosphorus decreased in some treatment plots largely due to uptake by the legumes. Soil pH and potassium values did not differ markedly from those recorded in the first season. However in plots where legume biomass was incorporated, it was noticed that exchangeable calcium and magnesium levels increased substantially. This could be as a result of the corresponding high calcium and magnesium yield of the biomass that was returned to the soil [9].

5. CONCLUSION

Generally, the soil chemical characteristics for soil samples collected in all the treatment plots both in the main and parallel trial indicate that the soil has low fertility evidenced by the low CEC, nitrogen and phosphorus status. The soil reaction values which are largely acid suggest possible low availability of both the macro and micro-plant nutrients for uptake by crops. The soil texture which is predominantly sandy clay loam to sandy clay coupled to the low CEC suggest potential high leacheability of nutrient elements more especially nitrogen as nitrate. Inevitably, if the soil is not properly managed crop yields will be drastically reduced. Furthermore nutrient use efficiency of crops cultivated on this soil will be low as the applied nutrients will be rendered unavailable for uptake either due to fixation or leaching. This challenge potentially can be circumvented through burying into the soil of high quality organic residues.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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