Journal of Sustainable Society
Vol. 2, No. 1, 2013, 36-48
DOI: 10.11634/216825851302360

Assessment of Nutrient and Biomass Yield of Medium and Long Duration Pigeon Pea in a Pigeon Pea-Groundnut Intercropping System in Malawi

Austin Tenthani Phiri[1, 3*], John J. Msaky[1], Jerome Mrema[1], George Yobe Kanyama-Phiri[2] and Rebbie Harawa[4]

[1] *Sokoine University of Agriculture, Morogoro, Tanzania*
[2]*University of Malawi, Bunda College of Agriculture, Lilongwe, Malawi*
[3]*Bvumbwe Agricultural Research Station, Limbe, Blantyre, Malawi*
[4]*Alliance for a Green Revolution in Africa, Nairobi, Kenya*

Preliminary assessment of the performance of the medium and long duration pigeon pea in a pigeon pea-groundnut intercropping system was conducted at Chitedze Agricultural Research Station (S 13^0 59' 23.2", E033^0 38' 36.8") in the 2011/2012 cropping season. An experiment involving eight treatments replicated three times in a randomized complete block design was established. Two pigeon pea varieties, long (ICEAP 04000) and medium duration (ICEAP 00557) and groundnut (CG 7) were grown as monocultures and intercrops. The intercrops involved planting either of the pigeon pea varieties with groundnut. Baseline soil data indicate that the 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, with mostly low to marginally adequate total nitrogen content both in the top (mean=0.08-0.14%) and the sub soil (mean=0.09-0.13%). The soil organic carbon content was medium in the top soil (mean=0.9-1.6%) as well as sub soil (mean=1.1-1.6%) across the treatment plots. At the same time 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}), suggesting low soil fertility. The assessment of the above ground groundnut biomass indicate a mean yield range of 479-656 kg ha^{-1}. While the assessment of the total biomass yield of the pigeon pea varieties indicate a mean yield range of 2,034-2,593 kg ha^{-1}. In terms of estimated nitrogen yields returned to the soil, the medium duration pigeon pea-groundnut intercrop (mean=50.6 kg N ha^{-1}) and the long duration pigeon pea-groundnut intercrop (mean=49.6 kg N ha^{-1}) gave significantly ($p<0.05$) higher yields than by the monocultures of long duration pigeon pea (mean=41.1 kg N ha^{-1}) and medium duration pigeon pea (mean=41.0 kg N ha^{-1}). Statistically ($p<0.05$), the lowest amount of estimated nitrogen yield was generated by the groundnut sole crop (mean=12.8 kg N ha^{-1}). Overall, the intercrops showed yield advantage (total LER >1.0) compared with the monoculture on equal land area. For the Malawian smallholder farmers, this suggests that mineral N supplementation in a legume-cereal rotation system for enhanced crop productivity might be less in the double legume-cereal rotation mode than in a legume monoculture-cereal rotation system.

Keywords: Maize, pigeon pea and rotation groundnut, intercrop

Introduction

The smallholder agricultural sector in Malawi is characterized by low productivity and land constraints (Phiri et al., 2012). The latter constraint has been aggravated by population increase. For instance the population grew from 9,933,868 in 1998 to 13,066,320 in 2008, representing an increase of 32 percent (NSO, 2008). This is exerting pressure on the already limited arable land for the smallholder farmers, which by the year 2000 had fallen from 1.53 ha per household in 1968 to 0.80 ha per household (GoM, 2001). This has led to continuous cropping principally of maize, the main cereal crop, without rotation of crops resulting into low soil fertility and productivity in most of the farmers' fields (Phiri et al., 2012). The noted trend necessitates the generation of agricultural technologies, that will allow for the optimal use of the limited arable land for increasing crop production while at the same time rejuvenating and maintaining soil fertility. One of such technologies is intercropping pigeon pea with groundnut in rotation with maize. Intercropping is often thought to be more stable interms of soil fertility, yield and financial returns than monocropping. The stability under intercropping can be attributed to the partial restoration of diversity that is lost under monocropping (Machado, 2009).Thus intercropping provides high insurance against crop failure, particularly in places prone to extreme weather conditions such as drought and floods. Worth noting is the fact that intercropping accords greater financial stability for farmers, making it appropriate for the Malawian labor-intensive smallholder farms. In the event that a crop fails because of

*Corresponding author

ISSN 2168-2585 Print/ ISSN 2168-2593 Online
World Scholars; http://worldscholars.org

unfavourable weather conditions farmers reduce their risk for total crop failure by growing more than one crop in their field (Clawson, 1985). This makes intercropping much less risky than monocropping. Intercropping with legumes is an excellent practice for controlling soil erosion and sustaining crop production (El-Swaify et al., 1988). For instance in a pigeon pea groundnut intercropping system, the deep roots of the pigeon pea can penetrate far into the soil breaking up hardpans and use moisture and nutrients from deeper layers in the soil. While the shallow roots of the groundnut can bind the soil at the surface and thereby help to reduce erosion. Other advantages of the system include weed suppression, and reduced damage from pests and diseases (Machado, 2009).

On the other hand, annual crop legumes grown in rotation with cereal crops can improve yields of the cereals and contribute to the total soil N pool. Reported yield responses to previous legume crops are in the range of 50-80% increases over yields in cereal-cereal sequence (Hayat, 2005). Benefits of legumes have also been attributed to control of cereal diseases and insect pests and improvements in soil structure.

This study was conducted to (i) assess the effect of intercropping medium and long duration pigeon pea with groundnut on pigeon pea growth rate and (ii) assess the effect of intercropping on the yield components of the legumes. This was done inorder to establish if significant competition for above and below ground growth resources exists in the system and provide a basis for quantifying the contribution of the legumes of biologically fixed N to the soil N pools in the pigeon pea-groundnut maize rotation system.

Materials and Methods

Study site

The study was conducted on station at Chitedze Agricultural Research Station (S 13^0 59' 23.2", E033^0 38' 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. During the 2011/2012 growing season, a total of 870 mm was recorded. The site has an acid soil with low N, marginally adequate P and low organic carbon. The soil has a good soil structure as it has a sandy clay loam texture.

Materials

A photo and thermo insensitive medium duration pigeon pea variety (ICEAP 00557, potential yield is up to 2.5 t ha^{-1}) which matures in 5-6 months, a long-duration pigeon pea variety (ICEAP 04000, potential yield is 1.6-2 t ha^{-1}) maturing in 8-9 months, groundnut (CG 7, potential yield is 3 t ha^{-1}), early maturing maize variety (SC 403 potential yield is 6 t ha^{-1}) and Triple Super Phosphate (TSP).

Experimental design

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; and 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. In the second season, the biomass in all the plots having the legumes, except plots with treatment 7, 8 and 1 (sole maize) will have their biomass ploughed into the soil. All the plots will then be planted with maize. As such this will allow for the comparison of the performance of maize between the plots with legume biomass incorporated into the soil and the plots with legume biomass removed from the field plus a plot where a cereal was grown without incorporating its biomass into the soil.

Treatment plot description

The gross plot size was 20 m x 10 m. Ridges were spaced at 75 cm apart. In the intercrop three pigeon pea seeds were planted per station at 90 cm apart while the groundnut was planted in between the pigeon pea planting hills at 15 cm apart, with one seed per station. In the pure stands three pigeon pea seeds were planted per station at 90 cm apart while the groundnut was planted at 15 cm apart, with one seed per station. Maize was planted on the ridges at 25 cm between planting hills with one seed per planting station. This was done in January 2012.

Application Triple Super Phosphate

At planting, all the treatment plots except where maize was planted were treated with Triple Super Phosphate (TSP) at the rate of 25 kg P ha^{-1} to offset limitation in N fixation by the legumes due to inadquate soil phosphorus. At planting time, except for the pigeon pea sole crop treatment plot all the ridges were split open to a depth of 5 cm and 93.3 g of TSP was evenly spread on each ridge. While in the sole pigeon pea treatment 8.4 g of TSP was applied per planting station. This was done to achieve the rate of 25 kg P ha^{-1} for the enhancement of nitrogen fixation and the growth and productivity of the legumes.

Data collection and analysis

Soil sample collection

The trial field was demarcated into three block each having eight plots. Top (0 -20 cm) and sub (20 - 40 cm) soils were sampled at random before treatment application to plots (Okalebo et al., 2000). Samples (4 borings from each plot) were taken. A composite sample was made for each plot. The samples were air dried at Chitedze Agricultural Research Laboratory and then passed through a 2 mm sieve in preparation for soil physical and chemical analysis.

Rainfall data

Monthly rainfall data for a thirteen year period for the study area were obtained from Chitedze Meteorological Station. Rainfall data for the year of study were also obtained. Monthly rainfall means were then computed for the thirteen year period and graphs were plotted (Figure 1 & 2). It was observed that the study area receives moderate amount of rainfall (875 mm) and that dry spells are a common phenomenon. The mean rainfall amount is suitable for the production of maize, pigeon pea and groundnuts. Worth noting is the fact that a two week dry spell occurred soon after planting. This stressed the crops and affected their productivity.

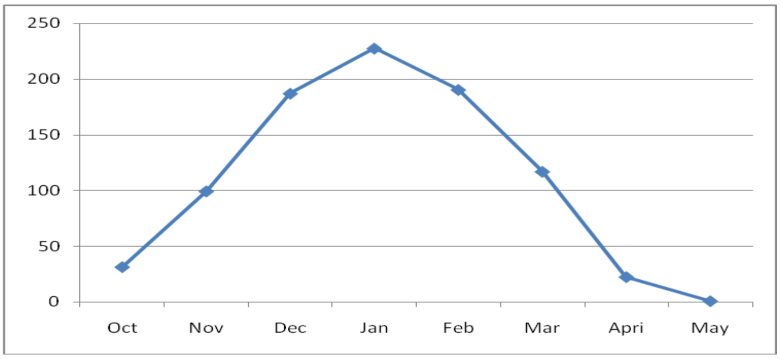

Figure 1. Rainfall (mm) distribution in the project area, thirteen year means (1999/00 to 2011/12).

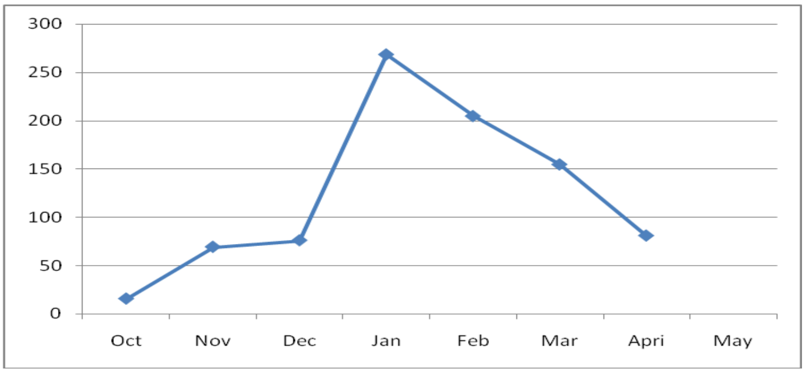

Figure 2. Rainfall (mm) distribution in the project area for the 2011/12 season.

Pigeon pea height measurement

At three weeks from emergence in each plot which had the pigeon pea in all the blocks, four randomly selected pigeon pea plants were tagged. The height of each was taken using a measuring ruler. This exercise was repeated after every two weeks from the day of each measurement until harvest time. Mean height for the pigeon pea in a plot on each day of height measurement was computed by summing up the height of the four tagged plants in each treatment plot and calculating the average. Growth rate was calculated by dividing the measured height with the number of days from planting. The calculated growth rate was plotted against the days from planting (Figure 3).

Biomass and grain yield assessment for the pigeon pea

Grain yield assessment was done at physiological maturity of the two pigeon pea varieties. Pods were harvested from a 2 m x 2 m net plot. These were shelled and weighing of the grains and the husks was done. This was conducted in September, 2012. To assess the amount of litter for each treatment plot, the litter was collected from the ground on one planting station (90 cm x 75 cm). This was done in October, 2012. Fresh leaves and twigs were also weighed from the 2 m x 2 m net plot. These were oven dried for 24 hours at 70 ^oC to a constant weight. In the field the pigeon pea was then ratooned at a height of 30 cm.

Biomass and grain yield assessment for the groundnut

Grain yield assessment was conducted at physiological maturity of the groundnut in June, 2012. Pods were dug from a 2 m x 2 m net plot. The pods were shelled and weighing of the grains and the husks was done. These were later oven dried for 24 hours at 70 ^oC to a constant weight. Estimation of the mean number of pods per plant was done by counting the total number pods from the net plot and dividing by the number of planting stations in the net plot to get the mean. Groundnut haulms were also weighed in the field and their dry weight measured after oven drying at 70^oC for 24 hours. Agronomic data was collected for the maize plant which include maize grain and stover yield.

Evaluation of the productivity of the intercropping systems

The Land Equivalent Ratio (LER) was used to evaluate the productivity of the doubled up legume intercrops against the monocultures. The LER is a measure of the yield advantage obtained by growing two or more crops or varieties as an intercrop compared to growing the same crops or varieties as a collection of separate monocultures (Andrews and Kassam, 1976). The LER is calculated using the formula LER= $\sum$ (Ypi/Ymi), where Yp is the yield of each crop or variety in the intercrop or polyculture, and Ym is the yield of each crop or variety in the sole crop or monoculture. For each crop (i) a ratio is calculated to determine the partial LER for that crop, then the partial LERs are summed to give the total LER for the intercrop. An LER value of 1.0 indicates no difference in yield between the intercrop and the collection of monocultures (Mazaheri & Oveysi, 2004). Any value greater than 1.0 indicates a yield advantage for intercrop. A LER of 1.2 for example, indicates that the area planted to monocultures would need to be 20% greater than the area planted to intercrop for the two to produce the same combined yields

Data analysis

Soil analysis was done in order to characterize soil properties. Soil samples were analyzed for Bulk density, Texture, OC, total N, available P, exchangeable K, Mg, Ca and soil pH (H_2O). Soil analysis for P, K, Mg and Ca was done using Mehlich 3 extraction procedures (Mehlich, 1984) while OC was determined using the colorimetric method (Schumacher, 2002) and total N was determined using Kjeldahl method (Amin & Flowers, 2004). All the soil and agronomic data were analyzed using Genstat statistical package and were subjected to analysis of variance at 95% level of confidence.

Results

Soil characterization of the study site

Baseline physical and chemical properties of soil used during the study

Laboratory analytical results indicated that the soil texture was predominantly sandy clay loam 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 (McKenzie et al., 2004). 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. At this range of soil reaction the macro nutrients were likely less available to an extent compared to the micronutrients (Akinrinde, 2006).

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%) with mean medium level of soil organic carbon content in the top soil (mean=0.9-1.6%) and sub soil (mean=1.1-1.6%) across the treatment plots. At the same time 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}). This suggested that P supply for crop uptake was low. The crops under study were nodulating legumes which require high supply of P to enhance biological nitrogen fixation (Singh & Oswalt, 1995). As such the low and variable level of soil P necessitated the external supply of the nutrient for enhanced yield. 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}). 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}).

Tables 1 summarize baseline physical and chemical properties of soil used during the study.

Table 1. Baseline soil data

Treatment	BD g/cc 0-20 cm	BD g/cc 20-40 cm	pH^{H2O} 0-20 cm	pH^{H2O} 20-40 cm	Total N% 0-20 cm	Total N% 20-40 cm	OC% 0-20 cm	OC% 20-40cm	P (mg/kg) 0-20 cm	P (mg/kg) 20-40 cm	% K 0-20cm	%K 20-40cm	Mg cmol kg^{-1} 0-20 cm	Mg cmol kg^{-1} 20-40 cm	Ca cmol kg^{-1} 0-20 cm	Ca cmol kg^{-1} 20-40 cm
Sole Maize	1.2	1.2	5.5	5.4	0.12	0.12	1.4	1.4	27.6	22.7	0.26	0.17	0.32	0.34	3.30	3.2
Medium duration pigeon pea	1.2	1.3	5.4	5.5	0.10	0.12	1.1	1.4	18.8	20.9	0.13	0.16	0.38	0.36	3.10	4.4
Long duration pigeon pea	1.1	1.2	5.6	5.5	0.08	0.10	0.9	1.1	16.8	20.8	0.16	0.17	0.35	0.28	3.20	3.0
Sole groundnut	1.2	1.2	5.5	5.4	0.14	0.13	1.6	1.5	17.6	23.4	0.10	0.21	0.48	0.52	3.04	3.4
Medium duration pigeon pea + Groundnut	1.3	1.3	5.4	5.4	0.12	0.09	1.4	1.1	18.9	21.3	0.25	0.13	0.30	0.31	3.13	2.8
Long duration pigeon pea + Groundnut	1.2	1.1	5.7	5.5	0.12	0.12	1.4	1.4	22.1	20.4	0.13	0.35	0.34	0.34	3.52	3.3
Medium duration pigeon pea + groundnut	1.3	1.2	5.6	5.6	0.12	0.12	1.4	1.4	26.6	21.4	0.29	0.20	0.42	0.37	3.87	3.1
Long duration pigeon pea + Groundnut	1.2	1.2	5.6	5.5	0.14	0.13	1.6	1.6	23.4	25.6	0.26	0.20	0.42	0.16	3.32	3.8
CV%	11.7	14.2	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
$LSD_{0.05}$	0.23	0.30	0.43	0.35	0.05	0.05	0.06	1.40	7.02	7.2	0.22	0.40	0.23	0.21	1.3	1.2

BD= BD= Bulk density

Growth rate for the long duration and medium duration pigeon pea

Figure 3 below shows the growth rate of long and medium duration pigeon pea for both intercrops and pure stands. For the first forty days after planting, medium duration pigeon pea intercropped with groundnut had the fastest growth rate. This was followed by the long duration pigeon pea-groundnut intercrop, long duration pigeon pea in the pure stand and medium duration pigeon pea in the pure stand. Beyond the fortieth day generally growth rate in all the stands slowed down with the medium duration pigeon pea-groundnut intercrop registering a marked reduction in the rate of growth. This contrasted sharply with the observation made in the medium duration pure stand in which growth rate slowed down gradually. Between the fortieth to the sixty seventh day from planting, intriguingly, though at a slower rate, the long duration pigeon pea-groundnut intercrop registered a slightly higher growth rate than the long duration pigeon pea in the pure stand. After this phase growth rate increased sharply in the pure stand and eventually slowed down, while in the intercrop growth rate reduced slowly.

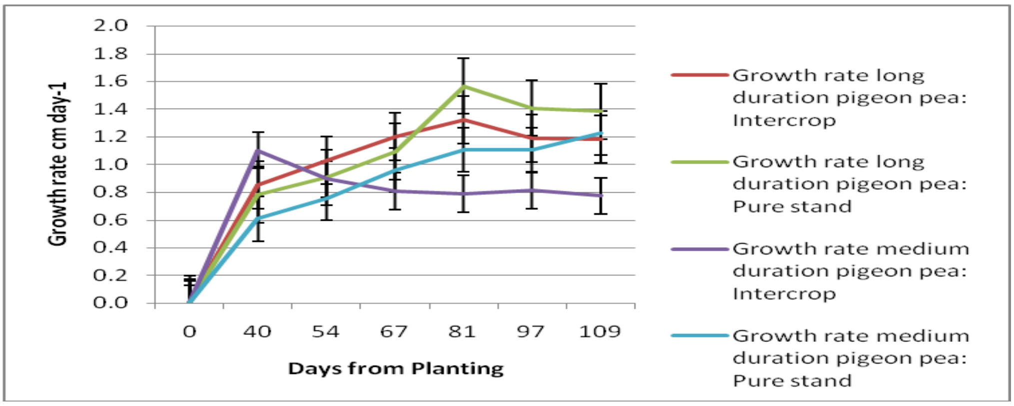

Figure 3. Growth rate of long and medium duration pigeon pea in intercrops and pure stands.

The table 2 shows the mean nutrient concentration in the litter, leaves and twigs for the pigeon pea in the long and medium duration pigeon pea. In the treatments where biomass was incorporated into the soil, no significant differences ($p>0.05$) were observed in the mean concentration of nitrogen (N), phosphorus (P) and potassium (K) across the treatments. For N, this ranged from 0.59% to 0.72% for the litter, while for the fresh leaves, this ranged from 2.4% to 3.4%. In the twigs, the concentration of N ranged from 2.0% to 2.6%.

For P in these treatments, the mean concentration ranged from 0.18% to 0.30% in the litter, while for the fresh leaves, this ranged from 0.15% to 0.33%. In the twigs, the mean concentration of P ranged from 0.14% to 0.19%. While for K, this ranged from 0.25% to 0.31% in the litter, while for the fresh leaves and twigs, the mean concentration ranged from 0.78% to 1.51%.

For calcium (Ca) no significant differences were observed in the mean tissue concentration in the litter and twigs. This ranged from 1.21% to 1.64% in the litter and 1.3% to 1.9% in the twigs. However, significant differences ($p>0.05$) of mean Ca concentration in the fresh leaves were recorded. The highest mean was registered by the medium duration pigeon pea grown in the pure stand (2.9%) while the lowest mean concentration of Ca (2.0%) was observed in the long duration pigeon pea-groundnut intercrop. For magnesium (Mg), no significant differences in the mean tissue concentration were observed in the litter, fresh leaves and twigs across the treatments. For the litter, this ranged from 0.31% to 0.36%, while for the fresh leaves this ranged from 6.4% to 8.3%. The mean tissue concentration of Mg in the twigs ranged from 6.6% to 7.2%.

Table 2. Nutrient concentration in pigeon pea biomass: Litter, Fresh Leaves and Twigs.

Treatment	%N (L)	%N (F)	%N (T)	%P (L)	%P (F)	%P (T)	%K (L)	%K (F)	%K (T)	%Ca (L)	%Ca (F)	%Ca (T)	%Mg (L)	%Mg (F)	%Mg (T)
1. Sole Maize	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2. Medium duration Pigeon pea	0.65	2.4^{ab}	2.4^{ab}	0.20	0.33	0.15	0.25	1.51	1.04	1.21	2.6^{ab}	1.3	0.35	6.4	6.6
3. Long duration Pigeon pea	0.69	2.9^{ab}	2.0^{b}	0.18	0.15	0.17	0.31	1.04	0.78	1.40	2.7^{ab}	1.9	0.31	7.9	6.9
4. Sole Groundnut	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5. Medium duration Pigeon pea + Groundnut	0.59	3.1^{ab}	2.6^{ab}	0.30	0.19	0.14	0.28	0.87	0.93	1.64	2.9^{a}	1.5	0.36	6.9	6.9
6. Long duration Pigeon pea + Groundnut	0.72	3.4^{a}	2.3^{ab}	0.18	0.25	0.19	0.29	0.78	1.51	1.64	2.0^{b}	1.8	0.35	8.3	7.2
7. Medium duration Pigeon pea + Groundnut	0.78	2.9^{ab}	3.2^{a}	0.17	0.16	0.15	0.29	0.69	0.87	1.33	2.0^{b}	2.0	0.35	7.7	11.5
8. Long duration Pigeon pea + Groundnut	0.71	2.4^{b}	2.4^{ab}	0.17	0.26	0.21	0.28	0.93	0.69	1.53	2.6^{ab}	1.7	0.34	7.7	7.2
CV %	36.2	15.5	25.7	20.9	47.7	40.1	32.4	40.5	40.5	18.00	9.4	30.8	9.33	11.8	4.4
LSD	0.45	0.81	1.2	0.08	0.20	0.12	0.17	0.99	0.99	0.48	0.42	0.95	0.06	1.9	25.9

Means with different superscripts within a column are significantly different $p<0.05$; Number of replicates (N) = 3, L=Litter, F=Fresh leaves, T=Twigs.

Pigeon pea biomass and nutrient yield: Litter, Fresh Leaves and Twigs

Table 3 shows the mean pigeon pea biomass and nutrient yield for the litter, fresh leaves and the twigs on a hectare basis. It is worthwhile to state that grain yield for the pigeon pea has not been reported as this was extremely low across the treatment. This was due to flower abortion and poor podding. No significant differences were observed in the mean biomass yield for the litter and fresh leaves across the treatments. For the litter, this ranged from 1,047 kg ha^{-1} to 1,753 kg ha^{-1} in the treatments where biomass was incorporated into the soil. While for the twigs the mean yield ranged from 332 kg ha^{-1} to 553 kg ha^{-1}. Significant differences ($p<0.05$) were observed in the mean yield of twigs with the sole crop of long (861 kg ha^{-1}) and medium duration pigeon pea (654 kg ha^{-1}) registering the highest mean yield. The long duration pigeon pea-groundnut intercrop (494 kg N ha^{-1}) and the medium duration pigeon pea-groundnut intercrop (370 kg ha^{-1}) gave the lowest mean yield.

For these treatments, no significant differences were observed in the mean N yield for the litter and fresh leaves across the treatments. This ranged from 7.7 kg N ha^{-1} to 11.6 kg N ha^{-1} for the litter, while for the fresh leaves this ranged from 11.7 kg N ha^{-1} to 16.1 kg N ha^{-1}. While for the twigs, significant mean yield differences were obtained across the treatments. The sole crop of medium duration (19.8 kg N ha^{-1}) and long duration pigeon pea (17.5 kg N ha^{-1}) gave the highest mean yield while the long duration-groundnut intercrop (12.7 kg N ha^{-1}) and the medium duration pigeon pea-groundnut intercrop (11.6 kg N ha^{-1}) yielded the lowest.

For the mean P yield, no significant differences were observed across the treatments in the litter, fresh leaves and twigs. This ranged from 2.2 kg P ha^{-1} to 3.2 kg P ha^{-1} for the litter, while for the fresh leaves, this ranged from 0.77 kg P ha^{-1} to 0.97 kg P ha^{-1}. In the twigs, the mean yield of P ranged from 0.91 kg P ha^{-1} to 1.7 kg P ha^{-1}.

For the mean yield of K, no significant differences were observed across the treatments in the litter and fresh leaves. This ranged from 9.7 kg K ha^{-1} to 12.3 kg K ha^{-1} for the litter, while for the fresh leaves, this ranged from 3.8 kg K ha^{-1} to 6.5 kg K ha^{-1}. Significant differences in the mean yield of K in the twigs were observed. The highest yield of K was obtained in the sole crop for the long duration pigeon pea (5.2 kg K ha^{-1}) followed by the sole crop for the medium duration pigeon pea (4.5 kg K ha^{-1}), long duration pigeon pea-groundnut intercrop (3.6 kg K ha^{-1}) and medium duration pigeon pea-groundnut intercrop (2.4 kg K ha^{-1}).

For the mean Ca and Mg yield, no significant differences were observed across the treatments in the litter, fresh leaves and twigs. Mean calcium yield in the litter ranged from 20.1 kg Ca ha^{-1} to 26.5 kg Ca ha^{-1}. While in the fresh leaves this was 6.9 kg Ca ha^{-1} to 12.3 kg Ca ha^{-1}. For the twigs this ranged from 7.0 kg Ca ha^{-1} to 11.5 kg Ca ha^{-1}.

For Mg the mean yield in the litter ranged from 5.1 kg Mg ha^{-1} to 7.1 kg Mg ha^{-1}, while in the leaves this ranged from 26.2 kg Mg ha^{-1} to 39.3 kg Mg ha^{-1}. For the twigs this ranged from 29.9 kg Mg ha^{-1} to 49.5 kg Mg ha^{-1}.

Concentration of nutrients in groundnut pods, haulms and grain

Table 4 shows nutrient concentration in the pods, haulms and grains for the groundnut in different treatments. No significant differences ($p>0.05$) were observed in the mean concentration of N for the treatments in which biomass was incorporated into the soil. This ranged from 0.61% to 1.04% for the pods, while for the haulms, this ranged from 2.4% to 3.2%. In the grain, the mean concentration of N ranged from 4.6% to 6.5%.

For P in these treatments, the mean concentration in the haulms and grains was statistically the same, but statistically different in the pods. Higher mean P concentration was detected in the pods of the groundnut intercropped with medium duration pigeon pea (0.12%), sole cropped groundnut (0.10%) and groundnut intercropped with long duration pigeon pea (0.10%) in the eighth treatment. The lower mean P concentration for the pods was given by the groundnut intercropped with long duration pigeon pea (0.09%) in treatment six. For the haulms P concentration ranged from 0.15% to 0.30% while for the grain this ranged from 0.81% to 0.92%. No significant differences ($p>0.05$) were observed in the mean concentration of K in the pods, haulms and grains. This ranged from 0.99% to 1.47% for the pods, while for the haulms it ranged from 0.33% to 0.59%. In the grains the mean K concentration ranged from 0.84% to 1.02%.

For calcium (Ca) no significant differences were observed in the mean tissue concentration for the pods and the haulms. This ranged from 0.44% to 0.66% in the pods and 0.74% to 1.08% in the haulms. However significant differences ($p<0.05$) of Ca concentration in the grain were recorded. The highest mean was registered by the sole groundnut treatment (0.84%) while the other treatments had statistically similar mean concentration of Ca.

For magnesium (Mg), no significant differences in the mean tissue concentration were observed for the pods and the haulms. This ranged from 1.5% to 1.7% in the pods and 0.11% to 0.14% in the haulms. However significant differences ($p>0.05$) of Mg concentration in the grain were recorded. The highest mean was registered by the sole groundnut treatment (0.31%) and groundnut in the medium duration pigeon pea-groundnut intercrop (0.28%). The groundnut in the long duration pigeon pea-groundnut intercrop had the lowest mean concentration of Mg (0.23%).

Table 3. Pigeon pea biomass and nutrient yield: Litter, Fresh Leaves and Twigs.

Treatment	Yield L kg ha^{-1}	Yield F kg ha^{-1}	Yield T kg ha^{-1}	N kg ha^{-1} (L)	N kg ha^{-1} (F)	N kg ha^{-1} (T)	P kg ha^{-1} (L)	P kg ha^{-1} (F)	P kg ha^{-1} (T)	K kg ha^{-1} (L)	K kg ha^{-1} (F)	K kg ha^{-1} (T)	Ca kg ha^{-1} (L)	Ca kg ha^{-1} (F)	Ca kg ha^{-1} (T)	Mg kg ha^{-1} (L)	Mg kg ha^{-1} (F)	Mg kg ha^{-1} (T)
1. Sole Maize	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2. Medium duration Pigeon pea	1,047	531^{a}	654^{ab}	7.7	13.5^{abc}	19.8^{a}	2.4	0.97^{a}	1.5^{b}	9.7	5.8	4.5^{b}	23.5	10.6^{a}	9.8	6.3	36.8	42.6
3. Long duration Pigeon pea	1,235	479^{ab}	861^{a}	8.0	15.6^{ab}	17.5^{ab}	2.2	0.82^{a}	1.7^{b}	11.7	3.8	5.2^{a}	26.5	12.3^{a}	11.5	5.6	35.07	49.5
5. Medium duration Pigeon pea + Groundnut	1,753	460^{ab}	370^{bc}	8.9	16.1^{a}	11.6^{b}	3.2	0.80^{a}	1.06^{b}	10.7	4.8	2.4^{d}	20.1	12.0^{a}	7.0	5.1	39.3	29.9
6. Long duration Pigeon pea + Groundnut	1,620	332^{ab}	494^{bc}	11.6	11.7^{abc}	12.7^{b}	2.9	0.77^{a}	0.91^{b}	12.3	6.5	3.6^{c}	26.4	6.9^{ab}	8.7	7.1	26.2	40.6
7. Medium duration Pigeon pea + Groundnut	1,467	217^{bc}	275^{c}	10.7	6.5^{bc}	10.6^{b}	2.6	0.42^{ab}	1.06^{b}	9.0	2.1	1.9^{e}	16.3	5.2^{b}	11.2	3.3	18.4	40.2
8. Long duration Pigeon pea + Groundnut	2,114	123^{c}	760^{a}	12.0	6.2^{c}	25.4^{a}	3.6	0.35^{b}	3.9^{a}	9.5	3.0	2.8^{d}	17.4	4.7^{b}	13.5	3.9	13.95	57.3
CV %	48.9	37.1	29.8	32.7	35.4	23.8	43.1	38.3	35.8	22.06	33.2	44.1	37.7	33.7	20.01	37.8	34.98	29.5
LSD	1,370	255.1	327.3	5.9	9.3	8.5	2.07	0.61	1.30	4.2	3.3	0.5	14.9	6.6	4.5	4.5	22.4	28.2

Means with different superscripts within a column are significantly different $p<0.05$; Number of replicates (N) = 3, L=Leaves, F=Fresh leaves and T=Twigs

Table 4. Concentration of nutrients in groundnut pods, haulms and grain.

Treatment	%N (P)	%N (H)	%N (G)	%P (P)	%P (H)	%P (G)	%K (P)	%K (H)	%K (G)	%Ca (P)	%Ca (H)	%Ca (G)	%Mg (P)	%Mg (H)	%Mg (G)
1. Sole Maize	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2. Medium duration Pigeon pea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3. Long duration Pigeon pea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4. Groundnut	0.93	2.4	4.6	0.10^{ab}	0.30	0.82	1.30	0.33	0.87	0.44	0.86	0.84^{a}	1.5	0.11	0.31^{a}
5. Medium duration pigeon pea + Groundnut	0.84	3.2	6.1	0.12^{a}	0.24	0.87	1.47	0.43	0.91	0.47	0.81	0.45^{b}	2.0	0.14	0.26^{bc}
6. Long duration pigeon pea + Groundnut	0.61	2.4	5.5	0.09^{b}	0.17	0.81	0.99	0.59	0.86	0.52	1.08	0.44^{b}	1.3	0.12	0.23^{c}
7. Medium duration Pigeon pea + Groundnut	0.86	2.9	6.5	0.12^{a}	0.17	0.92	1.16	0.42	1.02	0.57	0.93	0.47^{b}	1.7	0.13	0.28^{ab}
8. Long duration pigeon pea + Groundnut	1.04	2.7	5.0	0.10^{ab}	0.15	0.85	1.12	0.48	0.84	0.66	0.74	0.44^{b}	1.7	0.12	0.25^{c}
CV %	39.6	21.1	27.4	15.0	48.9	7.34	41.7	28.8	30.3	18.7	34.4	9.31	27.4	17.8	10.9
LSD	0.64	1.10	2.90	0.03	0.19	0.12	0.95	0.24	0.51	0.18	0.57	0.08	0.86	0.04	0.05

Means with different superscripts within a column are significantly different $p<0.05$; Number of replicates (N) = 3, P=Pods, H=Haulms and G=grain

Groundnut pod, haulms, grain and nutrient yield

The table 5 below shows the groundnut biomass and nutrient yield for the pods, haulms and the grain on a hectare basis. No significant differences were observed in the mean biomass yield for the pods, haulms and grain across the treatments. This suggests that intercropping did not depress these yield components of the groundnut. For the pods, this ranged from 136 kg ha^{-1} to 619 kg ha^{-1}. While for the haulms this ranged from 413 kg ha^{-1} to 656 kg ha^{-1}. The mean grain yield ranged from 549 kg ha^{-1} to 873 kg ha^{-1}.

For the mean N yield, significant differences were observed for the pods across the treatments in which biomass was incorporated. Higher mean N yield was observed in the groundnut pods in the sole groundnut (2.4 kg ha^{-1}) and in the fifth treatment (Long duration pigeon pea-groundnut intercrop-1.8 kg ha^{-1}). This was followed by the sixth treatment (Long duration pigeon pea-groundnut intercrop-0.98 kg ha^{-1}).

For the mean P yield, no significant differences were observed across the treatments in the pods, haulms and grains. This ranged from 0.15 kg P ha^{-1} to 0.20 kg P ha^{-1} for the pods. For the haulms statistically higher mean P yields were obtained in all the treatments except the eighth treatment (0.6 kg P ha^{-1}). In the grain no significant differences were obtained and this ranged from 4.7 kg P ha^{-1} to 6.7 kg P ha^{-1}.

For the mean K yield, no significant differences were observed across the treatments in the pods, haulms and grain. This ranged from 1.9 kg K ha^{-1} to 2.8 kg K ha^{-1} for the pods, while for the haulms, this ranged from 2.0 kg K ha^{-1} to 3.5 kg K ha^{-1}. In the grain this ranged from 4.3 kg K ha^{-1} to 7.1 kg K ha^{-1}.

Significant differences in the mean yield of K in the twigs, was observed. The highest yield of K was obtained in the sole crop for the long duration pigeon pea (5.2 kg K ha^{-1}) followed by the sole crop for the medium duration pigeon pea (4.5 kg K ha^{-1}), long duration pigeon pea-groundnut intercrop (3.6 kg K ha^{-1}) and medium duration pigeon pea-groundnut intercrop (2.4 kg K ha^{-1}).

For the mean Ca yield, no significant differences were observed across the treatments in the pods. The mean calcium yield in the litter ranged from 20.1 kg Ca ha^{-1} to 26.5 kg Ca ha^{-1}. While in the fresh leaves this was 6.9 kg Ca ha^{-1} to 12.3 kg Ca ha^{-1}. For the twigs this ranged from 7.0 kg Ca ha^{-1} to 11.5 kg Ca ha^{-1}.

For Mg the mean yield in the litter ranged from 5.1 kg Mg ha^{-1} to 7.1 kg Mg ha^{-1}, while in the leaves this ranged from 26.2 kg Mg ha^{-1} to 39.3 kg Mg ha^{-1}. For the twigs this ranged from 29.9 kg Mg ha^{-1} to 49.5 kg Mg ha^{-1}.

Estimated nitrogen and phosphorus yield returned to the soil

Table 6 below indicates the estimated mean nitrogen and phosphorus yield returned to the soil after biomass incorporation in each treatment that had the biomass buried into the soil. Estimated yield for N and P returned to the soil for the intercrops was obtained by summing up the respective yield from the pigeon pea and groundnut. The medium duration pigeon pea-groundnut intercrop (50.6 kg N ha^{-1}) and the long duration pigeon pea-groundnut intercrop (49.6 kg N ha^{-1}) gave statistically higher mean yield than the long duration pigeon pea sole crop (41.1 kg N ha^{-1}) and the medium duration pigeon pea sole crop (41.0 kg N ha^{-1}). Low mean N yield was generated by the groundnut sole crop (12.8 kg N ha^{-1}).

Significant differences were obtained in the mean yield of P across the treatments. For the treatments that had the biomass buried treatment five, medium duration pigeon pea-groundnut intercrop (6.5 kg P ha^{-1}) gave the highest yield, this was followed by treatment six, long duration pigeon pea-groundnut intercrop (5.4 kg P ha^{-1}), medium duration pigeon pea sole crop (4.9 kg P ha^{-1}), long duration pigeon pea sole crop (4.7 kg P ha^{-1}) and groundnut sole crop (1.9 kg P ha^{-1}).

Table 5. Groundnut pod, haulms, grain and nutrient yield.

Treatment	Pods yield kg ha^{-1}	Haulms yield kg ha^{-1}	Grain yield kg ha^{-1}	N kg ha^{-1} (P)	N kg ha^{-1} (H)	N kg ha^{-1} (G)	P kg ha^{-1} (P)	P kg ha^{-1} (H)	P kg ha^{-1} (G)	K kg ha^{-1} (P)	K kg ha^{-1} (H)	K kg ha^{-1} (G)	Ca kg ha^{-1} (P)	Ca kg ha^{-1} (H)	Ca kg ha^{-1} (G)	Mg kg ha^{-1} (P)	Mg kg ha^{-1} (H)	Mg kg ha^{-1} (G)
1. Sole Maize	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2. Medium duration Pigeon pea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3. Long duration Pigeon pea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4. Groundnut	188	656	647	2.4^{a}	12.8	29.0	0.17	1.87^{a}	5.3	2.8	3.5	4.3	1.10	5.7^{a}	9.7	4.6	0.74^{a}	1.8
5. Medium duration pigeon pea + Groundnut	619	612	569	1.8^{ab}	13.6	27.7	0.15	1.41^{ab}	4.7	2.1	2.8	5.7	0.72	1.4^{c}	11.4	2.1	0.83^{a}	1.4
6. Long duration pigeon pea + Groundnut	182	479	691	0.98^{b}	11.5	38.12	0.16	0.81^{ab}	6.07	2.1	2.0	7.1	1.10	4.0^{b}	7.7	2.9	0.58^{b}	1.9
7. Medium duration Pigeon pea + Groundnut	136	498	549	1.3^{b}	14.0	29.59	0.19	0.86^{ab}	4.7	1.9	2.7	5.3	0.64	4.7^{ab}	9.7	1.8	0.64^{a} b	1.6
8. Long duration pigeon pea + Groundnut	240	413	873	2.5^{a}	10.9	39.53	0.20	0.60^{b}	6.7	2.0	2.2	6.6	1.10	3.1^{b}	12.5	4.4	0.50 b	2.0
CV %	61.0	9.9	50.7	30.2	22.03	29.85	45	56	36.1	27.9	32.3	36.7	32.3	19.9	21.9	47.3	17.7	25.4
LSD	732.6	732.6	636.1	1.02	5.2	18.43	0.15	1.18	3.7	1.2	1.61	4.0	0.55	1.7	4.2	2.8	0.22	0.84

Means with different superscripts within a column are significantly different $p<0.05$; Number of replicates (N) = 3,
NB: The maize control plot yielded a mean grain yield of 646 kg ha^{-1} and a mean stover yield of 327 kg ha^{-1}

Table 6. Estimated nitrogen and phosphorus yield returned to the soil.

Treatment	N kg ha^{-1} (PP/L)	N kg ha^{-1} (PP/F)	N kg ha^{-1} (PP/T)	N kg ha^{-1} (GN/P)	N kg ha^{-1} (GN/H)	N kg ha^{-1} (GN/G)	N returned to soil kg ha^{-1}	P kg ha^{-1} (PP/L)	P kg ha^{-1} (PP/F)	P kg ha^{-1} (PP/T)	P kg ha^{-1} (GN/P)	P kg ha^{-1} (GN/H)	P kg ha^{-1} (GN/G)	P returned to soil kg ha^{-1}
1.Sole Maize	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2. Medium duration Pigeon pea	7.7	13.5^{ab}	19.8^{a}	-	-	-	41.0^{b}	2.4	0.97^{a}	1.5^{a}	-	-	-	4.9^{c}
3. Long duration Pigeon pea	8.0	15.6^{ab}	17.5^{ab}	-	-	-	41.1^{b}	2.2	0.82^{ab}	1.7^{a}	-	-	-	4.7^{d}
4. Groundnut only	-	-	-	2.4^{a}	12.8	29.0	12.8^{c}	-	-	-	0.17	1.9	5.3	1.9^{e}
5. Medium duration Pigeon pea + Groundnut	8.9	16.1^{a}	11.6^{b}	1.8^{ab}	14.0	27.7	50.6^{a}	3.2	0.80^{ab}	1.1^{b}	0.15	1.41	4.7	6.5^{a}
6. Long duration Pigeon pea + Groundnut	11.6	11.7^{ab}	12.7^{b}	0.98^{b}	13.6	38.1	49.6^{a}	2.9	0.77^{ab}	0.91^{b}	0.16	0.81	6.1	5.4^{b}
CV %	32.7	35.4	23.8	30.2	22.03	29.9	2.71	43.1	38.3	35.8	45	56	36.1	1.86
LSD	5.9	9.3	8.5	1.02	5.2	18.43	2.0	2.07	0.61	1.28	0.15	1.18	3.7	0.2

Means with different superscripts within a column are significantly different $p<0.05$; Number of replicates (N) = 3, PP/L= Pigeon pea litter, PP/F= Pigeon pea fresh leaves. PP/T= Pigeon pea twigs. GN/P= Groundnut pods, GN/H= Groundnut haulms and GN/G= Groundnut grain

Table 7 shows the evaluation of the productivity of the intercrops using the LER on the basis of biomass production. In general all intercrops registered a yield advantage above the monocultures of both the pigeon pea and groundnut. The higher yield advantage over the monocultures was registered by the medium duration pigeon pea-groundnut intercrop.

Table 7. Evaluation of the productivity of the intercrop against the monocultures: Biomass.

Treatment	Total Pigeon pea biomass (leaves plus twigs)	Groundnut Haulms (kg/ha^{-1})	Partial LER= ∑ (Ypi/Ymi)-Pigeon pea	Partial LER= ∑ (Ypi/Ymi) Groundnut	LER= ∑ (Ypi/Ymi)
1.Sole Maize	-	-	-	-	-
2. Medium duration Pigeon pea	2,034	-	-	-	-
3. Long duration Pigeon pea	2,636	-	-	-	-
4. Groundnut only	-	656[a]	-	-	-
5. Medium duration Pigeon pea + Groundnut	2,245	612[a]	1.10	0.93	2.03
6. Long duration Pigeon pea + Groundnut	2,593	479[b]	0.98	0.73	1.71
CV%	29.2	9.9	-	-	-
$LSD_{0.05}$	1,322	98.9	-	-	-

Means with different superscripts within a column are significantly different $p<0.05$; Number of replicates (N) = 3; LER=Land equivalent ratio.

Discussion

Growth rate of medium and long duration pigeon pea in sole stands and intercrops

In general, for the first forty days after planting, the medium duration pigeon pea intercropped with groundnut had the faster growth rate. This was followed by the long duration pigeon pea intercropped with groundnut, long duration pigeon pea in the pure stand and medium duration pigeon pea in the pure stand. Beyond this, generally, growth rate in all the stands slowed down with the medium duration pigeon pea-groundnut intercrop registering a marked reduction in the rate of growth. This contrasted vividly with the observation made in the medium duration pure stand in which a gradual slowing down of the growth rate was noticed. The observed trend could be attributed to increased competition for growth factors in the intercrop between the pigeon pea and groundnut. The competition effect might have been less pronounced in the medium duration pigeon pea pure stand hence the gradual slowing down of the growth rate. Between the fortieth to the sixty seventh day from planting, intriguingly, though at a slower rate, the long duration pigeon pea-groundnut intercrop registered a slightly higher growth rate than the long duration pigeon pea in the pure stand. After this phase growth rate increased sharply in the pure stand and eventually slowed down, while in the intercrop growth rate reduced slowly.

The effect of intercropping on the yield components of the pigeon pea and groundnut

The evaluation of the intercrops against the monocultures (Table 5) on LER basis revealed that, intercropping of the two legumes is more productive than growing each of the crops separately. This was in agreement with the findings of other researchers (Schilling & Gibbons, 2002, Phiri et al., 2013). This yield advantage was not only observed at cropping system level but also at the yield component level of the crops in the cropping system (Tables 2b and 3b). The advantage of the pigeon pea-groundnut double legume intercropping system over the monocultures of either of the legumes was fortified further by the estimated yield of nitrogen obtain from the system. Both the medium duration and long duration pigeon pea-groundnut intercrop gave statistically similar estimated mean nitrogen yield (Table 4). This was higher than the estimated mean yield of nitrogen that was generated by the monocultures of the two legumes with the groundnut sole crop generating the lowest estimated yield of nitrogen. It is worthwhile to note that the estimated mean nitrogen yield for the pigeon pea monocultures and the pigeon pea-groundnut intercrop could have been slightly higher given the fact that mean nitrogen yield estimate in the roots and stems of the legume was not conducted hence this was not included in the assessment. The legume biomass was incorporated into the soil. However, going by the estimated mean yield of nitrogen both for the monocultures and the intercrops, it is evident that external supplement of nitrogen will be required for the succeeding maize crop if yield is to be enhanced. The question that might require investigation however is, after incorporation of the legume biomass into the soil how much of this external nitrogen will be required to optimize yield while reducing the cost accrued by purchasing the external source of nitrogen.

The mean yield of phosphorus across the treatments was very low. As such partial supply of phosphorus requirements to the succeeding maize crop using the legume biomass alone is not possible. This has been further aggravated by the prevailing soil reaction which tends to increase the fixation of the nutrient. Use of external mineral source of phosphorus on the subsequent maize crop is therefore indispensable.

Conclusion

The study revealed that the soil on which the trial was mounted had soil texture that was predominantly sandy clay loam, with variable pH. The soil reaction ranged from acid to moderately acid. This range of soil reaction might have reduced the availability of the macronutrients for crop uptake. This was further compounded by the inherently low soil nitrogen, marginally adequate soil phosphorus, calcium and low magnesium content. Though phosphorus was externally supplied through TSP to make up for the shortfall, the rate used might not have been high enough to offset a possible high phosphorus fixation capacity of the soil, going by the soil reaction values. This could have had a net effect of depressing a phosphorus response in the crops.

The study however has confirmed the viability of the pigeon pea-groundnut intercropping system, discounting the observed low grain yield of the groundnut and extremely low grain yield of the pigeon pea. This was explainable interms of late planting, a prolonged dry spell soon after the emergence of the crops and soil fertility factors. Not with standing this it was observed that the other yield components of the crops in the system were not compromised. Over and above, the nitrogen yields for the cropping system were deemed to be reasonably high. Employing this system in rotation with maize might reduce to an extent the amount and hence the cost of mineral fertilizer required for maize production. The reduction in the amount of mineral fertilizer will come about not only due to the mineralization of the organically bound nitrogen but also due to the buffering effect that the organic residues have on the soil pH and the potential to increase the cation exchange capacity of the soil. However the question that might need to be answered empirically is, how much of this external nitrogen will be required to optimize yield while reducing the cost accrued by purchasing the external source of nitrogen.

Acknowledgement

The authors would like to thank the Alliance for Green Revolution in Africa (AGRA) through Sokoine University of Agriculture, Tanzania for funding the work. We are also deeply thankful for the Ministry of Agriculture and Food Security in Malawi who through the Department of Agricultural Research Services provided the requisite material and moral support for the execution of the project. This support came inform provision of experimental land at Chitedze Agricultural Research Station, access to laboratory facilities at Bvumbwe and Chitedze Agricultural Research Stations and support staff.

References

Amin, M., & Flowers, T. H. (2004). Evaluation of the Kjeldahl Digestion Method. *Journal of Research (Science)*15 (2):159-179.

Andrews, D.J., & Kassam, A.H. (1976). The importance of multiple cropping is increasing world food supplies. *Am. Soc. Agron*., 27, 1-10.

Clawson, D. L. (1985). Harvest security and intraspecific diversity in traditional tropical agriculture. *Econ Bot* , 39:56-67.

El-Swaify, S.A., Lo A.K.F., Joy, R., Shinshiro, L., & Yost R.S. (1988). Achieving conservation effectiveness in the tropics using legume-intercrops. *Soil Technol* 1:1-12.

GoM (Government of Malawi), (2001). State of Environment Report for Malawi 2001, Lilongwe: Ministry of Natural Resources and Environmental Affairs

Hayat, R. (2005). Sustainable legume-cereal cropping system through management of biological nitrogen fixation in Pothwar. PhD thesis, University of Arid Agriculture, Rawalpindi.

Machado, S. (2009). Does intercropping have a role in modern agriculture? *Journal of Soil and Water Conservation* 64: 2.

Mazaheri, D. & Oveysi, M. (2004). Effects of intercropping of two corn varieties at various nitrogen levels. *Iranian Journal of Agronomy*. 7: 71-76.

McKenzie N.J., Jacquier D.J., Isbell R.F., & Brown K.L. (2004). Australian Soils and Landscapes an Illustrated Compendium. CSIRO Publishing: Collingwood, Victoria.

Mehlich, A. (1984). Mehlich 3 soil test extractant: A modification of mehlich 2 extractant. *Community of Soil Science & Plant Analysis*, 15(12), 1409-1416.

NSO (National Statistical Office), (2002). Statistical yearbook 2002. Zomba: National Statistical Office.

Okalebo, J.R., Pal, C.A., Lekasi, J.K., Nandwa S.M., Othieno C.O., Waigwa M., & Ndungu K.W. (2000). Use of organic and inorganic resources to increase maize yields in some Kenyan infertile soils: A five-year experience.

Phiri A.T., Mhango W.G., Njoloma J.P., Kanyama-Phiri G.Y. & Lowole M.W. (2012). Farmers' evaluation of integrated soil fertility management methods in Northern Kasungu Central Malawi, *Journal of Agricultural Extension and Rural Development* ,4(11), 340-346, 27 June, 2012.

Phiri A.T., Njoloma J.P., Kanyama-Phiri G.Y., Sieglinde S. & Lowole M.W. (2013). Effects of intercropping systems and the application of Tundulu Rock phosphate on groundnut grain yield in Central Malawi. *International Journal of Plant and Animal Sciences*, 1 (1), 011-020.

Schillings, R. & Gibbons, R. (2002). Groundnut London and Oxford: Macmillan Education Ltd. p. 146.

Schumacher B.A., (2002). *Method for the determination of total organic carbon (TOC) in soils and sediments*. United States Environmental Protection Agency Environmental Sciences Division National Exposure Research Laboratory, Las Vegas.

Singh, F. & Oswalt, D.L. (1995). Groundnut production practices. Skill Development Series no.3 Retrieved from: www.icrisat.org