NITROGEN UPTAKE AND YIELDS FOR THE PIGEON PEA-GROUNDNUT INTER CROP MAIZE ROTATION CROPPING SYSTEM

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ABSTRACT

An experiment involving eight treatments replicated three times in a randomized complete block design was established at Chitedze Agricultural Research Station (13o 59’ 23.2” S, 033o 38’ 36.8” E) in the 2012/2012 cropping season in order to assess nutrient uptake and yields for the crops in a legume-cereal rotation cropping system. 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. At harvest time legume biomass was buried into the soil and each plot split into four subplots to accommodate four different levels of N (0, 50, 100, 150 kg N ha^{-1}) were applied at top dressing to the succeeding maize crop in the 2012/2013 cropping season. During planting, in the 2012/2013 cropping season the maize crop was basal dressed with 50 kg P ha^{-1}. Top dressing with N was conducted three weeks after emergence. For groundnut, results from statistical analysis indicated non significant differences ($p>0.05$) in the yields of grain. The grain yields ranged from 1,513 to 3,025 kg ha^{-1}. N concentration in the grain ranged from 2.9% to 3.2% translating into N yields that ranged from 46.9 kg N ha^{-1} to 98.8 kg N ha^{-1}. The N yields for grain were higher than N yields for the shells and haulms. The concentration of N in the maize grain ranged from 1.1% to 2.1%, while maize grain yields ranged from 1,775 to 5, 806 kg ha^{-1} and the N yields ranged from 23 to 115 kg N ha-1. This was higher than N yields for stover and rachids. The data indicated that more N in the groundnut and maize plant is translocated to the grain as such there is net export of N from the field.

Keywords: groundnut, intercrop, maize, nutrient, pigeon pea and rotation

Introduction

Intercropping and rotation farming are common practices by smallholder farmers in Africa (Sakala *et al.*, 2000). Pigeon pea (*Cajanus cajan* (L.) Millspaugh), performs optimally under both systems with adequate moisture, warm temperature and appropriate day length (Cook *et al.*, 2005). On the continent in general and Malawi in particular, traditional production of pigeon pea involves medium and late maturing varieties either intercropped with cereals (Sakala *et al.*, 2000) or other short duration legumes and vegetables (Atachi and Machi, 2004). Pigeon pea has the capacity to biologically fix up to 235 kg nitrogen (N) ha^{-1} per season (Peoples *et al.*, 1995).

Nitrogen is one of the most abundant elements on earth (Vance, 2001), yet the most limiting nutrient for crop production (Graham and Vance, 2003) due to inherent deficiencies in most soils. Comparatively, pigeon pea yields more N per unit area from plant biomass than other legumes (Odeny, 2007). This makes pigeon pea a desirable crop for sustainable agricultural production in the maize based farming systems of Malawi. Furthermore, pigeon pea's high nutritive value appears to be the prime reason for its integration in smallholder farms of Africa (Odeny, 2007). The high protein contained in its grain ≥ 21%, (Aihou *et al.*, 2006) makes pigeon pea suitable supplement to common carbohydrate rich-diets of most Africans (Odeny, 2007). Reddy, *et al.* (2011), observed that when pigeon pea is grown in a monoculture, relatively the crop is inefficient due to the initial growth rate which is slow and a low harvest index. Intercropping pigeon pea with other crops helps the legume to efficiently utilize available growth resources like nutrients and moisture (Reddy *et al.*, 2011). Important factors limiting the productivity of pigeon pea include; unbalanced fertilization and terminal stress (Reddy *et al.*, 2011).

Groundnut (*Arachis hypogea* L.) is among the most important legumes grown in Malawi (Chiyembekeza *et al.*, 1998). Groundnut is a source of food and cash income for Malawian smallholder farmers (Dzilankhulani *et al.*, 1998). Its grains contain 43–55% edible oil and 25–28% protein ((Reddy *et al.*, 2003). Just like pigeon pea, groundnut has high P requirement (Singh and Oswalt, 1995). Phosphorus plays an important role in root development, photosynthesis, N fixation, crop maturation, and other vital processes (Uchida, 2000). Nutritionally in crops, P deputises nitrogen (Davis and Westfall, 2009). Due to its widespread deficiency, it is generally regarded to be among the plant nutrients that are most limiting in tropical soils, Malawian's soil inclusive (Phiri *et al.*, 2010). Phosphorus deficiency not only limits crop response to other nutrients like N, but also affects gross soil fertility and productivity (Sahrawat *et al.*, 2001).

Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) are required for crop growth and development (Ashraf *et al.*, 2008). Stress factors like soil acidity and drought affect the uptake of the aforementioned nutrient elements, and consequently the yields of crops (Karnataka, 2007). Drought affects nutrient uptake and concentrations in plant tissues due to reduction of nutrient transportation to plant roots and impaired root development (Fageria *et al.*, 2002; Junjittakarn *et al.*, 2013). Reduced nutrient uptake by plants under moisture stress is principally due to low transpiration, impaired active transport and membrane permeability culminating into crippled nutrient absorbing by roots (Junjittakarn *et al.*, 2013). Work by Bassirirad and Caldwell (1992) mentioned that nutrient uptake by plant decreases with increasing water stress. Furthermore Kolay (2008) reported that water stress at flowering, pegging, pod formation and pod development stages reduced groundnut pod yields together with the uptake of N, P, K, Ca, Mg and S. It is on record that under moisture stress conditions, available soil N ($NO3^-$ and $NH4^+$) and N_2 fixation is markedly reduced resulting into low N accumulation, low dry matter production and low crop yields (Pimratch *et al.*, 2008; Pimratch *et al.*, 2013). Notwithstanding the above however, Ikisan (2000) indicated that the groundnut plant possess a unique ability to utilize nutrients that are relatively unavailable to other crops and is very effective in extracting nutrients from soils of low nutrient supply. This has been attributed to the mycorrhizal association between roots of groundnut and soil fungi or due to phosphobacteria found in the rhizosphere (Ikisan, 2000). This trait, coupled with the N fixation capability positions the crop to be the right candidate for the rejuvenation of soil fertility and production.

Maize (*Zea mays* L.) is cultivated over a variety of climatic conditions, with unique seasonal rainfall distribution patterns as well as amounts (Asare, 2011). Maize thrives best on fertile soils having enough moisture during the cropping season (Asare, 2011). The crop tolerates dry spells, particularly during the first three to four weeks of growth (Asare, 2011). Maize is a main source of energy and protein in people's diets on the continent (Enyisi *et al.*, 2014). Overall, in Malawi maize is the most important food staple (Minot, 2010). Per capita consumption is pegged to be at 133 kg, and it accounts for over half (54%) of the caloric intake of Malawian households (Minot, 2010). According to a study conducted by Enyisi *et al.* (2014), nutritionally, the approximate composition of maize and maize products is; 44.8 – 69.6% carbohydrate, 4.5 – 9.87% protein, 2.17 – 4.43% fat, 2.10 – 26.77% fibre and 1.10 – 2.95% ash.

In maize production, stresses like nutrient and moisture affect biomass and grain yields (Asare, 2011). One of the major nutrients highly demanded by maize for growth is nitrogen (Zotarelli *et al.*, 2008). The high demand of nitrogen by maize principally is due to the accumulation of above ground dry matter which forms a large N sink (Zotarelli *et al.*, 2008). Henry and Raper, (1991) indicated that N uptake by maize depends on the availability of soluble carbohydrates in the roots coupled to environmental factors like temperature, water and nitrate availability (Scholberg *et al.*, 2002). Ayad *et al.* (2010) mentioned that the rate of N uptake can be influenced by the crop rooting depth, root length, density and the duration of assimilation. On the other hand maize requirement for P is high (PDA, 2008). The crop is sensitive to low P availability, mostly in the early growth stages since much of the P is absorbed during that time for robust root development (PDA, 2008) among other metabolic functions. The role of P in robust root development likely enhances uptake not only of P but uptake of other essential plant nutrient elements as well as moisture (Wasonga *et al.*, 2008). P uptake in maize and utilization, varies across varieties and soil types (Machado *et al.*, 1999).

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Evidence indicates that rotation of maize with annual grain legumes, such as soybean (*Glycine max*) or groundnut, increased maize yields by 10–78%, although on-farm gains largely, do not conform to this trend (Waddington and Karigwindi, 2001; Snapp *et al.*, 2002), largely due to management, climatic and environmental factors. The pigeon pea-groundnut intercrop maize rotation cropping system, is being touted to have high potential of registering positive on-station as well as on-farm gains (Kanyama-Phiri *et al.*, 2008), based on research work conducted both in central and northern Malawi under the legume best bets project. The pigeon pea groundnut intercropping system generates ample biomass which when incorporated into the soil contributes substancial amount of N upon decomposition and mineralization (Phiri *et al.*, 2013). This might impact positively on maize yields. An indepth study of this cropping system therefore, was conducted at Chitedze Agricultural Research Station in Malawi from 2011-2013. The following were the study objectives: (i) assess nutrient uptake by the crops during the legume and cereal cropping phase (ii) quantifying the partitioning of nutrients to harvestable grain and plant biomass returned to soil during the legume and cereal cropping phase.

1.1 MATERIALS AND METHODS

1.1.1 Study site

The study was conducted on station at Chitedze Agricultural Research Station (13º 59’ 23.2 S”, 033º 38’ 36.8 E”) in Lilongwe, Malawi. The site falls within the Lilongwe plain and receives an average annual rainfall of 875 mm and the rainy season starts in November and ends in April (Phiri *et al.*, 2013). The site has a moderate (pH=5.5) soil reaction, low N (<0.12) and low (≤19 mg P kg^{-1}) to marginally adequate P (≥19 mg P kg^{-1}) (Wendt,1996), with a sandy clay loam to sandy clay texture (Phiri *et al.*, 2013).

1.1.2 Characterization of the soils at study site

Characterization of soil at the study site

The soils’ physical and chemical properties at the study site were as presented in Table 1.0.

Vol. 2, No. 05; 2017

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Table 1.0: The soils' physical and chemical properties at the study site before the experiment

Parameter	Depth					
	0-20 cm	**Rating**	**20-40 cm**	**Rating**	**Range**	**Reference**
% Sand	56.9	-	57.5	-	-	-
% Clay	35	-	34.3	-	-	-
% Silt	8.1	-	8.2	-	-	-
Texture class	SC/SCL	-	SC/SCL	-	-	SSSA, (2003)
pH_{H2O}	5.5	Low	5.5	Low	≤ 6.0	Wendt, (1996)
Soil reaction	-	Moderately acid	-	Moderately acid	5.5-5.7	"
% OC	1.4	Medium	1.4	Medium	0.88-1.5%	"
Total N (%)	0.12	Low	0.12	Low	≤ 0.12%	"
P mg kg^{-1}	22.1	Marginally Adequate	20.5	Marginally Adequate	19-25 mg P kg^{-1}	"
Ex. K cmol kg^{-1}	0.20	Adequate	0.20	Adequate	>0.11-4.0 cmol kg^{-1}	"
Ex. Mg cmol kg^{-1}	0.40	Low	0.30	Low	0.2-0.5.cmol kg^{-1}	"
Ex. Ca cmol kg^{-1}	3.3	Marginally adequate	3.4	Marginally adequate	2.04-3.5 cmol kg^{-1}	"
Total Mo mg kg^{-1}	10.8	High	16.8	High	>5 mg kg^{-1}	Hodges, 2010

1.1.3 Field experiment

In the first season the experiment was laid out in a RCBD 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 (biomass not incorporated); and 8) Long duration pigeon pea + groundnut (biomass not incorporated). 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) was ploughed into the soil. This was done inorder to 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. All the treatment plots except for treatment 1 were treated with P as TSP at the rate of 25 kg P ha^{-1}. At harvest (June and September, 2012) for the first season, the biomass in all the plots with the legumes, except plots with treatments 7, 8 and 1 (sole maize) were incorporated into the soil, allowing for comparison of the effect of biomass incorporation on selected soil parameters and the effect this may have on the performance of the succeeding maize crop. All the plots were then planted with maize. A parallel experiment laid in RCBD and replicated 3 times alongside the main experiment 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 + 25 kg P ha^{-1}; 5) Medium duration pigeon pea + 25 kg P ha^{-1}; 6) Long duration pigeon pea + 25 kg P ha^{-1}; 7) Long duration pigeon pea + groundnut; 8) Long duration pigeon pea + groundnut + 25 kg P ha^{-1}; 9) Medium duration pigeon pea + groundnut; and 10) Medium duration pigeon pea + groundnut + 25 kg P ha^{-1}. P was applied in form of TSP in treatments 4, 5, 6 and 8 to enhance N fixation and hence yield by the legumes, for subsequent comparison with non P treated plots. The experimental fields were kept weed free through regular weeding. In season two in the main experiment, the experimental design was transformed into a split plot design by dividing each main plot into four subplots in each replicate. This was done to accommodate the application of N as urea ($CO(NH_2)_2$) to the succeeding maize crop. The rates of mineral N were, 0, 50, 100, 150 kg of N ha^{-1}. All the plots were then planted with maize.

1.1.3 Application of triple super phosphate and urea

At planting in season one (2011/2012) in the main experiment, all the treatment plots except where maize was planted were treated with triple super phosphate (TSP), $Ca(H_2PO_4)_2.H_2O$, at the rate of 25 kg P ha^{-1} to offset soil P deficiency. 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.

For season two (2012/2013), the parallel experiment had TSP applied to plots according to the treatment structure. 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 25.2 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. In the main experiment, in all the sub plots maize was basal dressed with 50 kg P ha^{-1}. Top dressing with urea ($CO(NH_2)_2$), was done three weeks from emergence according to the treatment structure at the rate of 0, 50, 100 and 150 kg N ha^{-1}.

1.2 DATA COLLECTION AND ANALYSIS

1.2.1 Soil sample collection

Before the experiment in season one, a composite soil sample made from twenty four randomly collected soil samples was gathered from the experimental site as described by Okalebo *et al.*, (2000). The sample was air dried and then passed through a 2 mm sieve in preparation for soil physical and chemical analysis.

1.2.2 Biomass and grain yields 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 in the first season for the main experiment and second season for the parallel experiment. These were shelled and weighed (seeds, grains and husks) in the first season (September, 2012) and in the second season (August, 2013). In both seasons, assessment of the amount of litter for each treatment plot was done by collecting all defoliated leaves from the ground on one planting station (90 cm x 75 cm). This was done in October, 2012 in season one and August in the second season. Fresh leaves and twigs for both experiments were also weighed from the 2 m x 2 m net plot. Roots from pigeon pea plants were dug and weighed in season two up to a depth of 30 cm by 30 cm diameter. These were oven dried for 72 hours at 70 ^{o}C to constant weights.

1.2.3 Biomass and grain yields assessment for the groundnut and maize

Grain yield assessment was conducted at physiological maturity of the groundnut in June, 2012 for the main experiment and in May, 2013 for the parallel experiment. Pods were dug from a 2 m x 2 m net plot. The pods were shelled and the grains and the husks weighed. These were later oven dried for 72 hours at 70 ^{o}C to constant weights. 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 weights measured after oven drying for 72 hours at 70^{o}C to constant weights. Agronomic data was collected for the maize plant which include maize grain and stover yields in year one and grain, stover, cob length (mean of five cobs) and rachids in year two. Maize yield data was collected from a 2 m x 3 m net plot within each subplot.

1.2.4 Evaluation of the productivity of the intercropping systems

The Land Equivalent Ratio (LER) (Andrews and Kassam, 1976) 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 Land Equivalent Ratio (LER) is used to evaluate the productivity of intercrops against the monocultures. 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 and 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.

1.2.5 Soil analysis and plant sample analysis

Laboratory soil analysis of the composite soil sample was done in order to characterize the soil. Soil samples were analyzed for OC, total N, available P, exchangeable K, Mg, Ca and soil pH (H_2O). Soil pH was measured in water (1:2.5) using pH meter (Okalebo *et al.*, 2000). Soil analysis for available P, K, Mg and Ca was done by Mehlich 3 extraction procedures (Mehlich, 1984) while OC was determined using the Walkely-Black chromic acid wet oxidation method (Schumacher, 2002) and total N was determined by Kjeldahl method (Amin and Flowers, 2004). Total molybdenum (Mo) was analyzed using the hand held XRF machine (Baranowski *et al.*, 2002). Bulk density was determined using the core sample method (Rowell, 1994). Biomass yields for the legumes were assessed as described by Phiri *et al.*, (2013). This was done at the end of the first season before incorporation into the soil. Maize, pigeon pea and groundnut materials were wet digested using nitric and perchloric acids (Oyewole *et al.*, 2012). P in the digests were determined colomerically using the vanado-molybdate method, K was quantified using flame photometer while Ca was determined using AAS (Oyewole *et al.*, 2012). Total N was determined by the Kjeldahl method (Amin and Flowers, 2004).

1.2.6 Nutrient yields

Nutrient yields were calculated by multiplying the nitrogen, phosphorus, potassium, and calcium content of maize, pigeon pea and groundnut biomass with their respective yields.

1.2.7 Statistical analysis

All the soil, biomass and grain yields data were analyzed using Genstat statistical package and were subjected to analysis of variance at 95% level of confidence.

The general satistical model used for the RCBD was (Gomez and Gomez, 1984):

$Y_{hi} = \mu + \theta_h + \tau_i + \varepsilon_{hi}$

where

Y_{hi} is the random variable representing the response for treatment i observed in block h,

μ is a constant (or the overall mean)

θ_h is the (additive) effect of the h^{th} block (h = 1, 2, 3)

τ_i is the (additive) effect of the i^{th} treatment (i = 1, 2, … , v)

ε_{hi} is the random error for the i^{th} treatment in the h^{th} block (Gomez and Gomez, 1984).

Whilst the statistical model used for the split plot design was:

$X_{ijk} = \bar{X}_{\cdots} + M_i + B_j + d_{ij} + S_k + (MS)_{ik} + e_{ijk}$

X_{ijk} = an observation

$\bar{X}_{\cdots}$ = the experiment mean

M_i = the main plot treatment effect

B_j = the block effect

d_{ij} = the main plot error (error a)

S_k = the subplot treatment effect

$(MS)_{ik}$ = the main plot and subplot treatment interaction effect

e_{ijk} = the subplot error (error b)

i = a particular main plot treatment

j = a particular block

k = a particular subplot treatment (Gomez and Gomez, 1984).

Means were separated by the least significant difference (P<0.05).

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1.3 RESULTS

1.3.2 Nutrient uptake in the parallel experiment

1.3.2.1 Groundnut

Figure Table 1.1, shows nutrient uptake by groundnut in the parallel experiment in season two at flowering stage. Uptake of N and Mg was similar across treatments. For N, this ranged from 3.6 to 4% while for Mg this ranged from 0.33 to 0.43% . On the other hand, uptake of P and Ca differed across treatment. For P, it was higher in the long duration pigeon pea-groundnut intercrop (1.5%) and the TSP treated medium duration pigeon pea-groundnut intercrop (1.5%). This was lower in the TSP treated groundnut monoculture (1.3%) and the non TSP treated groundnut monoculture (1.3%). For Ca uptake was lower in the TSP treated groundnut monoculture (0.9%) and in the TSP treated long duration pigeon pea-groundnut intercrop (0.9%) compared with the rest of the treatments.

Table 1.1: Nutrient concentrations for the haulms of groundnut plants at flowering in the parallel experiment season two

Treatment	%N	%P	%Ca	%Mg
1.Medium duration pigeon pea + groundnut	4.0	1.4	1.0	0.40
2. Long duration pigeon pea + TSP + 25 kg ha^{-1}	-	-	-	
3.Groundnut + TSP 25 kg ha^{-1}	3.7	1.3	0.9	0.33
4. Medium duration pigeon pea only	-	-	-	
5.Long duration pigeon pea + groundnut	4.0	1.5	1.0	0.40
6. Medium duration pigeon pea + TSP-25 kg ha^{-1}	-	-	-	
7.Long duration pigeon pea + groundnut + TSP 25 kg ha^{-1}	3.9	1.4	0.9	0.43
8.Medium duration pigeon pea + groundnut + TSP 25 kg ha^{-1}	4.3	1.5	1.0	0.35
9.Groundnut only	3.6	1.3	0.9	0.38
10. Long duration pigeon pea only	-	-	-	
Cv (%)	12.0	5.7	7.75	18.1
$LSD_{0.05}$	0.85	0.2	0.1	0.31

Vol. 2, No. 05; 2017

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1.3.2.2 Pigeon pea

Nutrient concentrations in the pigeon pea plant at flowering stage in season two indicated no significant differences ($p>0.05$) in tissue concentration of N, P, Ca and Mg across treatments. For N, this ranged from 2.9 to 3.5%, P was at 0.3% in all the treatments, Ca ranged from 0.23 to 0.29%, while Mg ranged from 0.58 to 0.82%.

1.3.2.3 Maize

The N and P uptake by the maize plants for the main experiment at silking stage in season two in the subplots of the eight main treatment plots for season one were as presented in Table 2.0. N uptake for the subplots of the main treatment that had sole maize during season one without incorporating of stover into the soil at harvest was in the order; 150 kg N ha^{-1} (2.6%) > 100 kg N ha^{-1} (2.3%) > 50 kg N ha^{-1} , 0 kg N ha^{-1} (2.0%). Uptake of P was at 0.3% across the subplots.

N uptake by the maize plants for the subplots of the main treatment that had the medium duration pigeon pea monoculture during season one with biomass incorporated into the soil at harvest was in the order; 150 kg N ha^{-1} (2.9%) >100 kg N ha^{-1} (2.5%) > 50 kg N ha^{-1} , 0 kg N ha^{-1}(1.6%), while P uptake was in this order 100 kg N ha^{-1}, 50 kg N ha^{-1}, 0 kg N ha^{-1} (0.3%) > 150 kg N ha^{-1} (0.2%). N uptake by the maize plants for the subplots of the main treatment that had the long duration pigeon pea monoculture during season one with biomass incorporated into the soil at harvest were in the order; 150 kg N ha^{-1} (2.9%) > 100 kg N ha^{-1} (2.2%) > 50 kg N ha^{-1} (1.8%), 0 kg N ha^{-1} (1.4%), while P uptake was in this order; 100 kg N ha^{-1}, 50 kg N ha^{-1}, 0 kg N ha^{-1} (0.3%) > 150 kg N ha^{-1} (0.2%).

N uptake by the maize plants for the subplots of the main treatment that had the groundnut monoculture during season one with biomass incorporated into the soil at harvest was the order; 150 kg N ha^{-1} (2.5%) >100 kg N ha^{-1} > 0 kg N ha^{-1}(1.7%) > 50 kg N ha^{-1} (2.2 %), while P uptake was in the order ; 150 kg N ha^{-1} (0.3%) >100 kg N ha^{-1}, 50 kg N ha^{-1} (0.2 %) > 0 kg N ha^{-1}(0.1%).

N uptake by the maize plants for the subplots of the main treatment that had the medium duration pigeon pea-groundnut intercrop during season one with biomass incorporated into the soil at harvest was in the order; 150 kg N ha^{-1} (2.7%) >100 kg N ha^{-1} (2.4%) > 50 kg N ha^{-1} (2.0 %) > 0 kg N ha^{-1}(1.3%), while P uptake was in the order; 150 kg N ha^{-1},100 kg ha^{-1}(0.3%) > 50 kg N ha^{-1}, 0 kg N ha^{-1}(0.2%).

N uptake by the maize plants for the subplots of the main treatment that had the long duration pigeon pea-groundnut intercrop during season one with biomass incorporated into the soil at harvest was in the order; 150 kg N ha^{-1}, 100 kg N ha^{-1} (2.4%) > 50 kg N ha^{-1} (2.2 %) > 0 kg N ha^{-1}(2.1%), while for P the was at 0.3% in all the treatments for the subplots.

N uptake by the maize plants for the subplots of the main treatment that had the medium duration pigeon pea-groundnut intercrop during season one with no biomass incorporated into the soil at harvest was in the order 150 kg N ha^{-1} (2.7%) > 100 kg ha^{-1} (1.9%) > 50 kg N ha^{-1} (1.8%) > 0 kg N ha^{-1}(1.5%), while uptake of P was at 0.2% across treatments in the sub plots.

N uptake by the maize plants for the subplots of the main treatment that had the long duration pigeon pea-groundnut intercrop during season one with no biomass incorporated into the soil at harvest was in the order; 150 kg N ha^{-1} (2.7%) > 100 kg ha^{-1}(2.3%) > 50 kg N ha^{-1} (1.9%) > 0 kg N ha^{-1}(1.6%), while P uptake was in the order; 150 kg N ha^{-1}, 50 kg ha^{-1}(0.3%) > 100 kg N ha^{-1}, 0 kg N ha^{-1}(0.2%).

Table 2.0: N and P contents in the maize plant (earleaf) at silking in the main experiment (season two)

Treatments: Main and sub plots		
1.	%N	%P
a.Sole Maize-No biomass	2.0	0.3
b.Sole Maize-No biomass + 100 kg N ha^{-1}	2.3	0.3
c.Sole Maize-No biomass + 150 kg N ha^{-1}	2.6	0.3
d.Sole Maize-No biomass + 50 kg N ha^{-1}	2.0	0.3
2.		
a.Medium duration pigeon pea-biomass	1.6	0.3
b.Medium duration pigeon pea-biomass + 100 kg N ha^{-1}	2.5	0.3
c.Medium duration pigeon pea-biomass + 150 kg N ha^{-1}	2.9	0.2
d.Medium duration pigeon pea-biomass + 50 kg N ha^{-1}	1.6	0.3
3.		
a.Long duration pigeon pea-biomass	1.4	0.3
b.Long duration pigeon pea-biomass + 100 kg N ha^{-1}	2.2	0.3
c..Long duration pigeon pea-biomass + 150 kg N ha^{-1}	2.9	0.2
d.Long duration pigeon pea-biomass + 50 kg N ha^{-1}	1.8	0.3
4.		
a..Sole groundnut-biomass	1.7	0.1
b.Sole groundnut-biomass + 100 kg N ha^{-1}	2.2	0.2
c.Sole groundnut-biomass + 150 kg N ha^{-1}	2.5	0.3

d.Sole groundnut-biomass + 50 kg N ha^{-1}	1.2	0.2
5.		
a.Medium duration pigeon pea + groundnut-biomass	1.3	0.2
b.Medium duration pigeon pea + groundnut-biomass + 100 kg N ha^{-1}	2.4	0.3
c.Medium duration pigeon pea + groundnut-biomass + 150 kg N ha^{-1}	2.7	0.3
d.Medium duration pigeon Pea + groundnut-biomass + 50 kg N ha^{-1}	2.0	0.2
6.		
a.Long duration pigeon pea + groundnut-biomass	2.1	0.3
b.Long duration pigeon pea + groundnut-biomass + 100 kg N ha^{-1}	2.4	0.3
c.Long duration pigeon pea + groundnut-biomass + 150 kg N ha^{-1}	2.4	0.3
d.Long duration pigeon pea + groundnut-biomass + 50 kg N ha^{-1}	2.2	0.3
	%N	%P
a.Medium duration pigeon pea + groundnut-no biomass	1.5	0.2
b.Medium duration pigeon pea + groundnut-no biomass + 100 kg N ha^{-1}	1.9	0.2
c.Medium duration pigeon pea + groundnut-no biomass + 150 kg N ha^{-1}	2.7	0.2
d.Medium duration pigeon pea + groundnut-no biomass + 50 kg N ha^{-1}	1.8	0.2
7.	%N	%P
a.Long duration pigeon pea + groundnut-no biomass	1.6	0.2
b.Long duration pigeon pea + groundnut-no biomass + 100 kg N ha^{-1}	2.3	0.2
c.Long duration pigeon pea + groundnut-no biomass + 150 kg N ha^{-1}	2.7	0.3
d.Long duration pigeon pea + groundnut-no biomass + 50 kg N ha^{-1}	1.9	0.3
General Mean	2.1	0.3
CV (%)	15.9	18.3
$LSD_{0.05}$	0.50	-

Table 2.1 shows groundnut shell, grain, weight of 100 grains and haulms yields for the parallel experiment in season two. No significant differences ($p>0.05$) were observed in these yields parameters across treatments. The yields of shells ranged from 846 to 1,985 kg ha^{-1}, for grain this ranged from 1,654 to 3,025 kg ha^{-1}, while for haulms this ranged from 1,396 to 2,463 kg ha^{-1}. The weight of 100 groundnut grains ranged from 102 grams to 133 grams. Significant differences ($p<0.05$) were observed in the average number of pods per plant across treatments and in the weight of 100 pods. Average number of pods per plant was significantly higher for the

groundnut monoculture (22 pods per plant) compared to the medium duration pigeon pea-groundnut (19 pods per plant) and the long duration pigeon pea-groundnut (19 pods per plant) intercrop. The weight of 100 pods was significantly higher for the groundnut monoculture (167g) than for the TSP treated medium duration pigeon pea-groundnut intercrop (147g).

Table 2.1: Groundnut pods, grain and haulm's yields in the parallel experiment

Treatment	Average number of pods plant^{-1}	Grain Wt 100 grains g	Pod Wt 100 g	Shells yield kg ha^{-1}	Grain yield kg ha^{-1}	Haulms yield kg ha^{-1}
1. Medium duration pigeon pea + groundnut	19	1.26	162	1,461	1,835	1,516
3.Groundnut + 25 kg P ha^{-1}	28	1.02	161	1,985	3,025	2,463
5. Long duration pigeon pea + groundnut	19	1.19	155	1,135	1,513	1,396
7. Long duration pigeon pea + groundnut + 25 kg P ha^{-1}	24	1.24	158	1,681	1,719	1,727
8. Medium duration pigeon pea + groundnut + 25 kg P ha^{-1}	19	1.22	147	846	1,654	1,412
9.Sole groundnut	22	1.33	167	1,679	1,875	1,752
GM	21.8	1.2	158	1,464	1,936	1,711
CV (%)	27.5	0.14	5.7	37.1	39.9	41.7
$LSD_{0.05}$	14.0	-	20	-	-	-

1.3.3 Yields of pigeon pea in the parallel experiment in the second cropping season

1.3.3.1 Pigeon pea yields

Yields components of pigeon pea for the parallel experiment for season two were as presented in Table 2.2. No significant differences ($p>0.05$) were observed in the yield of pods, stems and roots across treatments. This ranged from 19 to 24 kg ha^{-1}. No grain yields were recorded as poor grain filling in the pods was witnessed. Stem yields ranged from 597 to 950 kg ha^{-1} while root yields ranged from 507 to 605 kg ha^{-1}.

Significant differences ($p<0.05$) were observed for the yield of pigeon pea litter, fresh leaves and twigs across treatments. For the litter this was significantly higher for the litter from the TSP

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treated medium duration pigeon pea monoculture (824 kg ha^{-1}) and significantly lower for the long duration pigeon pea-groundnut intercrop (518 kg ha^{-1}). For fresh leaves, the yields were significantly higher in fresh leaves for both the TSP treated and non TSP treated medium duration pigeon pea-groundnut intercrop (944 kg ha^{-1}), and were significantly lower in fresh leaves for pigeon pea from the TSP treated long duration pigeon pea monoculture (791 kg ha^{-1}). In twigs the yields were significantly higher for the twigs from the TSP treated medium duration pigeon pea monoculture (882 kg ha^{-1}) and significantly lower for the twigs from the long duration pigeon pea-groundnut intercrop (655 kg ha^{-1}) and the TSP treated long duration pigeon pea monoculture (665 kg ha^{-1}). Computed total biomass yields indicate significant differences ($p<0.05$) across treatment plots. Significantly higher total pigeon pea biomass yields were registered by the TSP treated medium duration pigeon pea monoculture (4,149 kg ha^{-1}). The yields were significantly lower in the non TSP treated long duration pigeon pea groundnut intercrop(3,145.kg.ha^{-1})

ISSN: 2456-8643

Table 2.2: Pigeon pea pod and biomass yields in the parallel experiment

Treatment	Pods	Litter	Fresh Leaves	Twigs	Stems	Roots	Total biomass yield
				kg ha^{-1}			
1. Medium duration pigeon pea + groundnut	21	661	944	808	792	571	3,796
2. Long duration pigeon pea + 25 kg P ha^{-1}	20	597	791	665	757	507	3,337
4. Medium duration pigeon pea only	21	686	909	793	723	596	3,727
5. Long duration pigeon pea + groundnut	21	518	830	655	589	531	3,145
6. Medium duration pigeon pea + 25 kg P ha^{-1}	23	824	899	882	915	605	4,149
7. Long duration pigeon pea + groundnut + 25 kg P ha^{-1}	19	652	914	699	718	601	3,603
8. Medium duration pigeon pea + groundnut + 25 kg P ha^{-1}	21	671	944	764	950	512	3,861
10. Long duration pigeon pea only	24	611	809	767	597	524	3,332
GM	21	653	880	754	755	556	3,619
CV (%)	17.0	19.0	8.0	14.0	26.0	12.0	10.2
$LSD_{0.05}$	-	230	122	198	-	-	681

ISSN: 2456-8643

Maize grain, stover and rachids yields and for the main experiment

Yields trends for maize grain, stover, rachids and the average cob length in season two for treatments of the subplots in the main treatment plots for season one, were as presented in figure 2.0 to 2.7.

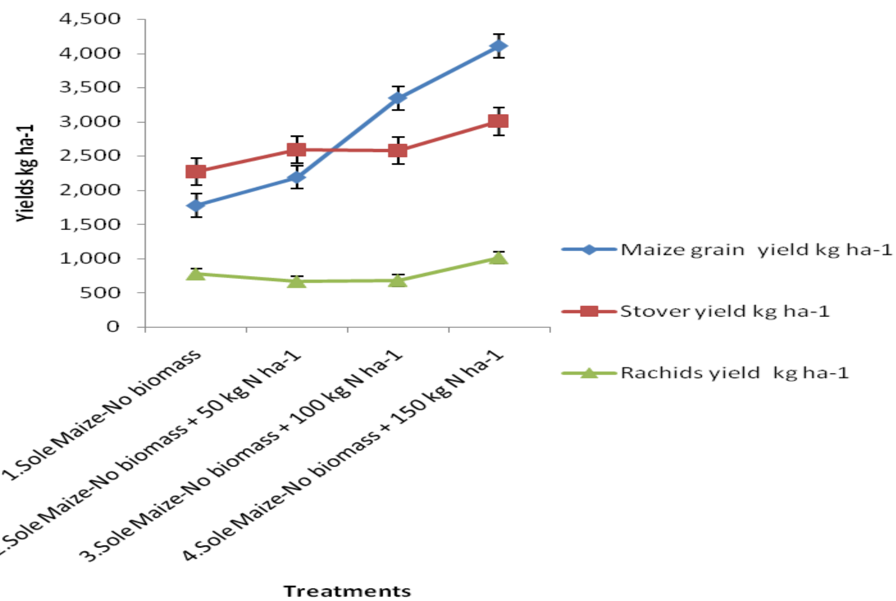


Fig 2.0: Maize yields response to N application without biomass incorporation to the soil after maize monoculture

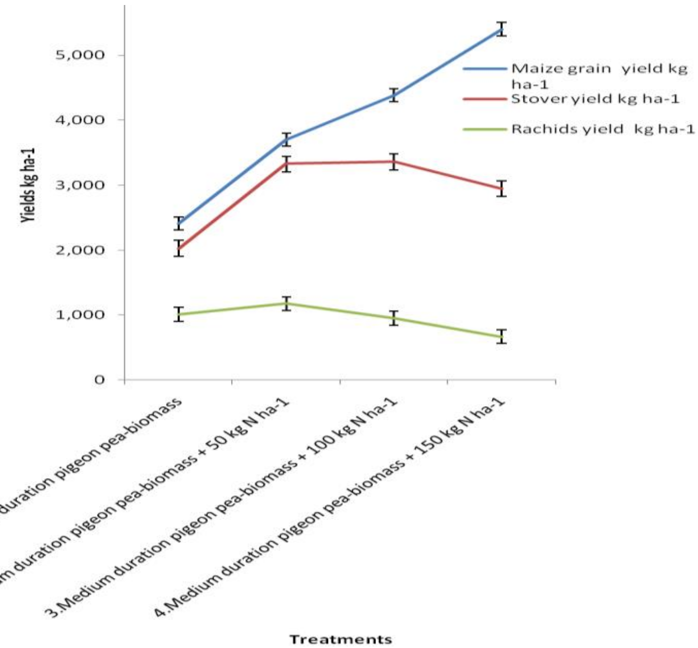


Fig 2.1: Maize yields response to N application with biomass incorporation to the soil under medium duration pigeon pea monoculture

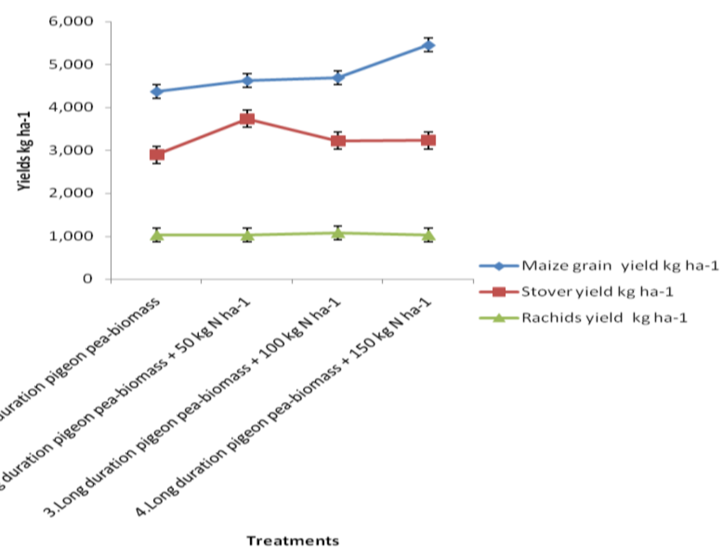


Fig 2.2: Maize yields response to N application with biomass incorporation to the soil after Long duration pigeon pea monoculture

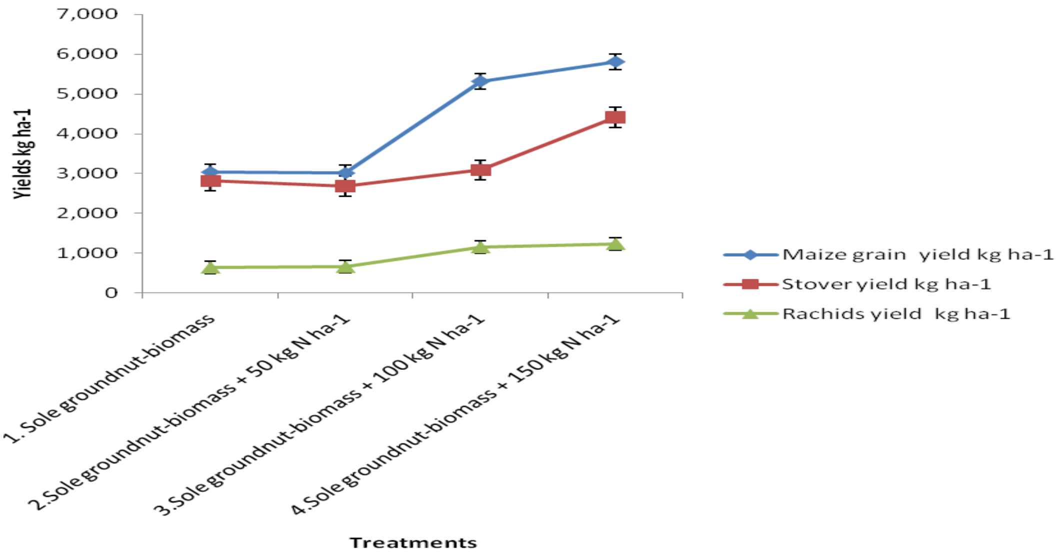
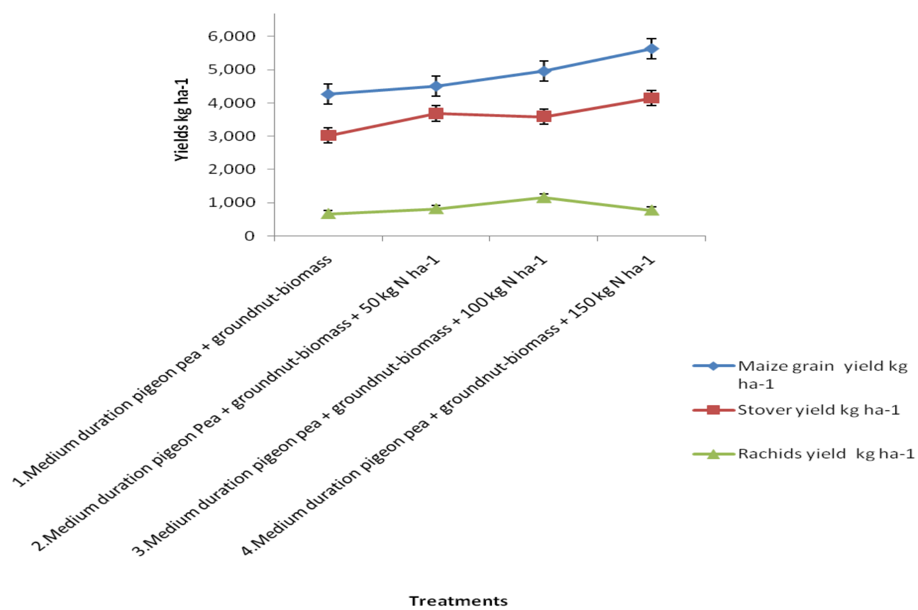


Fig 2.3: Maize yields response to N application with biomass incorporation to the soil after groundnut monoculture



Vol. 2, No. 05; 2017

ISSN: 2456-8643

Fig 2.4: Maize yields response to N application with biomass incorporation to the soil after the intercrop of medium duration pigeon pea and groundnut

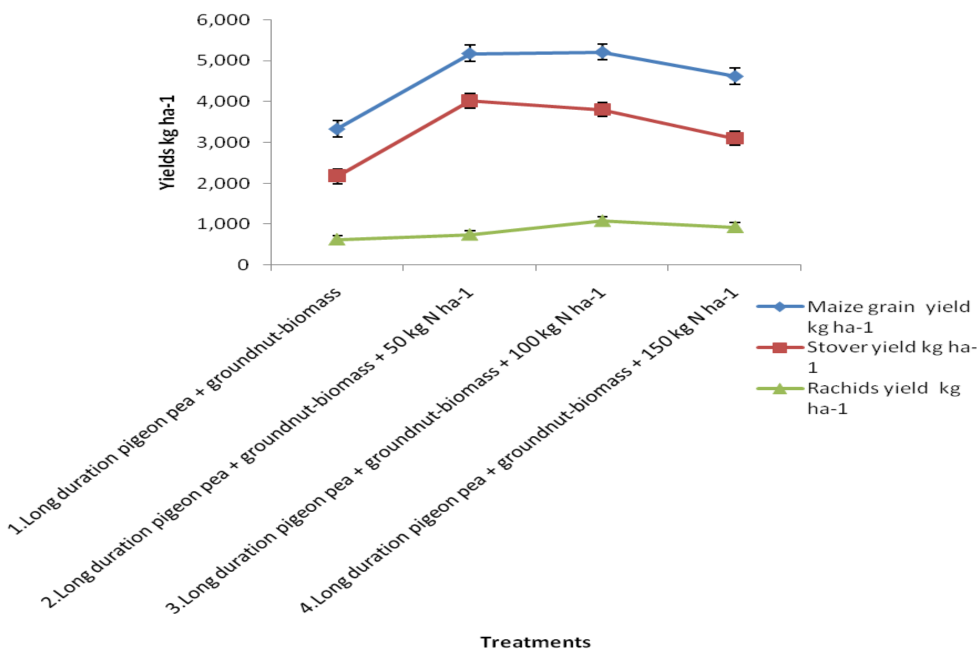


Fig 2.5: Maize yields response to N application with biomass incorporation to the soil after the intercrop of long duration pigeon pea and groundnut

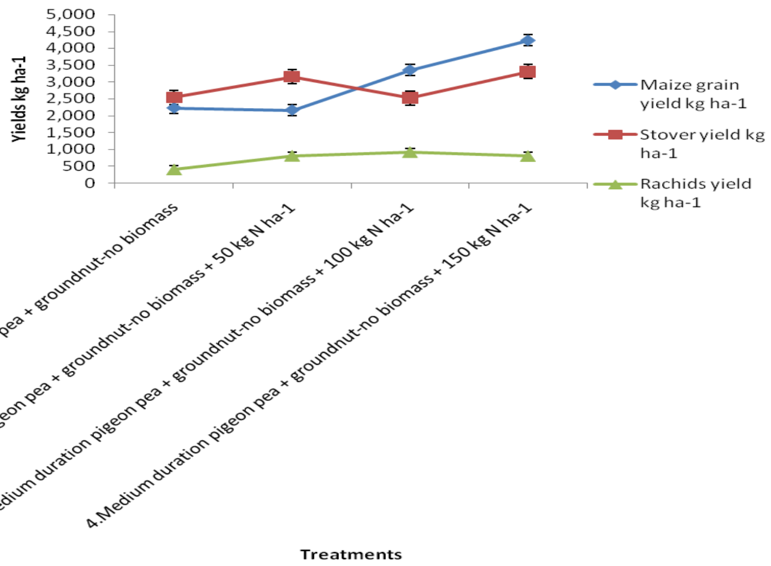


Fig 2.6: Maize yields response to N application without biomass incorporation to the soil after the intercrop of medium duration pigeon pea and groundnut

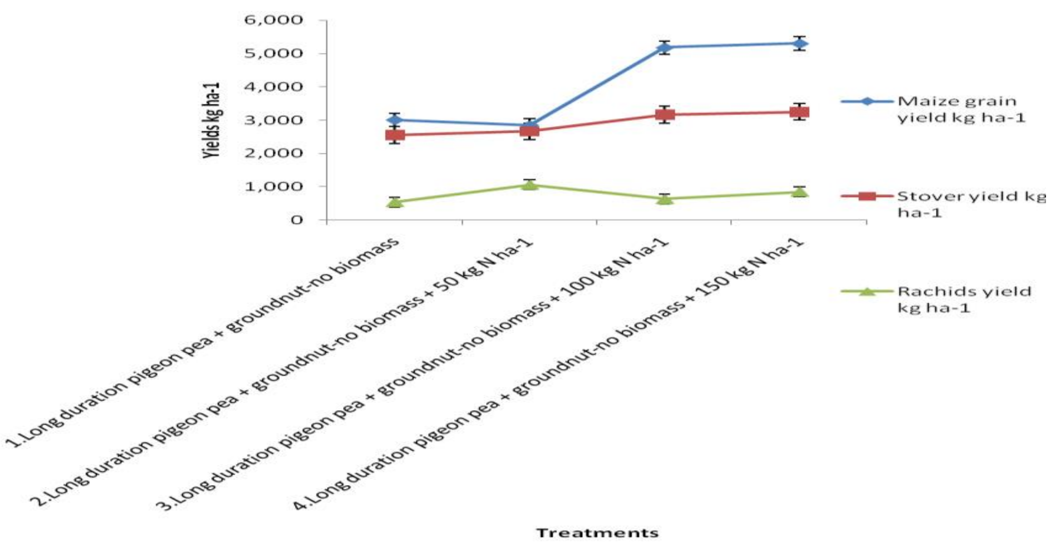


Fig 2.7: Maize yields response to N application without biomass incorporation to the soil after the intercrop of long duration pigeon pea and groundnut

ISSN: 2456-8643

1.3.4 Evaluation of the productivity of the cropping systems

Table 2.3 below shows the evaluation of the productivity of the intercrops using the LER on biomass production basis. Generally, 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 2.3 : Evaluation of the productivity of the cropping systems

Treatment	Groundnut haulms yield ha^{-1}	Pigeon pea biomass-pod yield ha^{-1}	Partial LER= ∑ (Ypi/Ymi)-Pigeon pea	Partial LER= ∑ (Ypi/Ymi) Groundnut	LER= ∑ (Ypi/Ymi)
1. Medium duration pigeon pea + groundnut	1,516	3,775	1.02	0.87	1.88
2. Long duration pigeon pea + 25 kg P ha^{-1}	-	3,317	-	-	-
3.Groundnut + 25 kg P ha^{-1}	2,463	-	-	-	-
4. Medium duration pigeon pea only	-	3,706	-	-	-
5. Long duration pigeon pea + groundnut	1,396	3,124	0.94	0.80	1.74
6. Medium duration pigeon pea + 25 kg P ha^{-1}	-	4,126	-	-	-
7. Long duration pigeon pea + groundnut + 25 kg P ha^{-1}	1,727	3,584	1.08	0.70	1.78
8. Medium duration pigeon pea + groundnut + 25 kg P ha^{-1}	1,412	3,840	0.93	0.57	1.50
9.Sole groundnut	1,752	-	-	-	-
10. Long duration pigeon pea only	-	3,308	-	-	-
GM	1,711	3,598	-	-	-
CV (%)	41.7	10.2	-	-	-
$LSD_{0.05}$	1,524	674	-	-	-

Vol. 2, No. 05; 2017

ISSN: 2456-8643

1.4 DISCUSSION

1.4.1 Groundnut pods, grain and haulm's yields for the parallel trial

The data on nutrient concentration in the groundnut at flowering stage indicate optimal nutrient uptake of N (Table 1.1) as the nutrient concentrations were within the proposed range of sufficiency (Jones, 1974; Campbell, 2000), suggesting possible high yields at harvest time. This was reflected at harvest in the yield parameters. For instance, the yields of grain ranged from 1,654 to 3,025 kg ha^{-1} while the yields of shells ranged from 846 to 1,985 kg ha^{-1} and the yields of haulms ranged from 1,396 to 2,463 kg ha^{-1}. Evidentially in the 2012/2013 cropping season, groundnut was not hyper-stressed nutritionally or by other environmental factors like moisture. Nutrient uptake was optimal as indicated by the concentration of nutrients in plant tissues. The yields parameters contrast sharply with what was generated in the 2011/2012 cropping season in the same environment. Low yields were registered and this was attributed chiefly to dry spells that marked the cropping season (Phiri *et al.*, 2013). Moisture stress reduces nutrient uptake leading into low concentrations of mineral nutrients in crop plants (Gunes *et al.*, 2006), hence resultant retarded growth and yields.

1.4.2 Nutrient uptake for pigeon pea and yields

Under the conditions of this study, nutrient uptake by the pigeon pea was high (Section 1.3.2.2). The concentrations were in a similar range of values reported in literature (Snapp *et al.*, 2003; Dasbak and Asiegbu, 2012). However, though this was the case no grain yields were recorded as poor grain filling in the pods was witnessed. This was a similar phenomenon as observed during the 2011/2012 cropping season (Phiri *et al.*, 2013). For the 2011/2012 cropping season environmental stresses in the form of erratic rainfall pattern were cited as being behind the poor grain filling. On the contrary, for the 2012/2013 cropping season such stresses were absent. Other factors ought to be examined to establish the root cause of the poor grain filling. Probable aspects worth investigating could be the effect of time of planting, temperature and photoperiod on podding and grain filling. Noteworthy is the fact that pigeon pea is a short-day plant that requires a daylight length of 12.5 hours to initiate flowering and seed production (Cook *et al.*, 2005). Mligo and Craufurd, (2005) indicated that for pigeon pea flowering is delayed under long days and under cooler growing conditions. In Malawi, day length and temperature changes along the year. After the first season pigeon pea plants were ratooned with the intention of investigating the effect of ratooning on grain yield. However, during biomass incorporation into the soil the roots of most of the plants were injured leading to drying up. A few plants survived, which podded profusely in the second season and had their pods filled with grain. Therefore, under this environment, it could be worthwhile to investigate the effect of ratooning and ratooning time on pigeon pea podding and grain filling for the pigeon pea during season two.

There was no significant biomass yields difference between medium duration pigeon pea and medium duration pigeon pea that was treated with TSP. The same trend applied to long duration pigeon pea and long duration pigeon pea that was treated with TSP (Table 2.3). However, significantly higher biomass yields, were generated by the medium duration pigeon pea monoculture (4,149 kg ha^{-1}), compared to significantly lower biomass yields registered by the non TSP treated long duration pigeon pea groundnut intercrop (3,145 kg ha^{-1}). The results seem to suggest that medium duration pigeon utilizes P more efficiently than the long duration pigeon pea. Other authors indicate that pigeon pea dry matter increase with increased doses of phosphorus (Kumar and Kumar, 2013; Parihar *et al.* (2005), Kumar and Kushwaha (2006) and Kumar *et al.* (2007). There is need therefore to test different levels of P on both varieties in order to crystallize the noted biomass yield trends within and between the varities. The inclusion of stem and root biomass yields increased the total biomass yields substantially above yields recorded during the previous cropping season (Phiri *et al.*, 2013). The biomass yields obtained under this study falls within the range of values reported by other workers. For instance, from on farm studies conducted in southern Malawi, Snapp, (1998) reported that pigeon pea can produce over 2 t ha^{-1} of biomass which when incorporated into the soil can help alleviate some of the soil fertility limitations under smallholder farms. Some of the limitations include inherent low N and P supply capacity of Malawi's soils (Phiri *et al.*, 2010)

1.4.3 Nitrogen uptake and yields for maize

For optimal growth and production maize must be supplied with enough nitrogen (N) among other nutritional and growth factors (Alley *et al.*, 2009). The nutrient is a major yields determining factor in crop production (Onasanya *et al.*, 2009). Under the conditions of this study, basing on grain yields, uptake of nitrogen and subsequent utilization seem to have been enhanced by the incorporation of pigeon pea and groundnut biomass or the combination of both (Fig 2.0 to 2.7)). Optimal yields were registered under the combination of legume biomass with 150 kg N ha^{-1} and 100 kg N ha^{-1} with grain yields nearing the potential yield (6 t ha^{-1}) of the variety that was used (SC 403). Sole biomass incorporation from either the pigeon pea or groundnut or the combination of both without addition of mineral N appears to have had impact on nutrient uptake and utilization as high maize grain yields which were above grain yields from the control plots were registered (Fig 2.0 to 2.7). Notwithstanding the aforementioned maize responded well to sole application of mineral N at the rate of 150 kg N ha^{-1} and 100 kg N ha^{-1}, though the grain yields were consistently below those obtained from plots treated with the combination of legume biomass with 150 kg N ha^{-1} and 100 kg N ha^{-1} (Fig 2.0 to 2.7). The observed difference in grain yields might be attributed to increased N supply and uptake by maize from the decomposing and mineralizing pigeon pea and groundnut biomass for the latter plots and possible enhance moisture retention and availability. This is in tandem with similar work by Harawa *et al.* (2006) who indicated an increased N uptake by maize in plots treated with biomass combined with inorganic fertilizers. Under such treatment combinations there is better synchrony of N release and N demand by maize (Munthali *et al.*, 2014). Implicitly, adequate N was available not only during the first two to six weeks after planting, which is the time where N deficit reduces yield potential (Jones, 1985), but also was available at the time when N is highly demanded by crop (Alley *et al.*, 2009). This is the time of maximum growth which occurs a month prior to teaselling and silking (Alley *et al.*, 2009). This culminated into the observed high grain yields. It is important to note that pigeon pea biomass is of high quality and decompose very fast to release nutrients to the soil, N in particular, attributable to a narrow C:N ratio (Oke, 2001). The rapid decomposition and mineralization of the biomass to release N coincide with the period of optimum nutrient absorption for vigorous vegetative development in maize plants (Olujobi *et al.*, 2013). N supply to the maize crop therefore was not limiting. Furthermore, on top of the release of N and other nutrients, the decomposition of pigeon pea biomass performs other functions (Olujobi *et al.*, 2013), like the supply of energy through nutrient availability to soil organism thereby enhancing nutrient cycling in the soil, reduction in phosphorus (P) sorption capacity of the soil and stimulation of root growth (Oke, 2001).

It was observed that in treatment plots where legume biomass was not incorporated (treatment 7 & 8), yields comparable with those obtained in plots where biomass was incorporated were recorded. It is highly likely that the supply of N in these treatment plots was boosted not only by mineralized N from decaying roots of pigeon pea but also from residual N (Ferguson *et al.*, 2002; Fan and Hao, 2003; Phiri *et al.*, 2014). Residual NO_3^-–N in soil is an important N source for crops, and its amount correlates with crop yields (Ferguson *et al.*, 2002; Fan and Hao, 2003).

1.5 CONCLUSION

In groundnut the observed yields level for the different yields parameters indicates that the crop was not hyper-stressed nutritionally or by other environmental factors. Nutrient uptake was optimal as indicated by the concentration of nutrients in plant tissues. The yields parameters contrast sharply with what was generated last season in the same environment. Low yields were registered and this was attributed chiefly to dry spells that marked the cropping season. For the pigeon pea, no grain yields were recorded due to poor grain filling in the pods. This was a similar phenomenon as observed during the first cropping. Environmental stresses in form of erratic rainfall pattern were cited as being behind the poor grain filling, however in the second season such stresses were absent. Other factors ought to be examined to establish the root cause of the poor grain filling.

A potential solution to the observed poor grain filling appears to be ratooning the crop. Computed total biomass yields indicate increased biomass yields above yields registered in the first season due to the inclusion of stem and root biomass yields. In general, N uptake and yields for maize was significantly higher in subplots top dressed with 150 kg N ha^{-1} and 100 kg N ha^{-1} with legume residues buried with treatments treated with 50 kg N ha^{-1} and biomass giving reasonably high yields. This could be due to increased and sustained N supply. Under low input conditions like those of Malawian smallholder farmers the latter treatment might not compromise yields when employed.

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