IMPROVING NITROGEN USE EFFICIENCY BY MAIZE THROUGH THE PIGEON PEA-GROUNDNUT INTERCROP-MAIZE ROTATION CROPPING SYSTEM IN MALAWI

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EXTENDED ABSTRACT

A study was initiated in the 2011/12 cropping season with a parallel experiment mounted along side in the second season to investigate the possibility of improving nitrogen use efficiency (NUE) by the maize crop in a pigeon pea groundnut intercrop-maize rotation cropping system at Chitedze Agricultural Research Station in Malawi. The parallel experiment was conducted to compare the performance of legumes over two cropping seasons. The experiments involved the planting of two pigeon pea varieties, namely; long (ICEAP 04000) and medium duration (ICEAP 00557) and groundnut (CG 7) as monocultures or as intercrops. The main experiment had eight treatments; 1) Sole maize (control); 2) Medium duration pigeon pea; 3) Long duration pigeon pea; 4) Sole groundnut; 5) Medium duration pigeon pea + groundnut; 6) Long duration pigeon pea + groundnut; 7) Medium duration pigeon pea + groundnut (biomass not incorporated in season two); and 8) Long duration pigeon pea + groundnut (biomass not incorporated in season two). All the treatment plots except treatment plot number one were treated with 25 kg P ha^{-1}. The parallel experiment had ten 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}. Both experiments were laid in a randomized complete block design replicated three times. Key parametres assessed during the experiment included; legume biomass and grain yield, soil nitrate nitrogen (NO_3^-–N), maize stover, and rachids yields; nitrogen and phosphorus partitioning both for the legumes and maize NUE.

Soil characterization was conducted before treatment application in the first and second year. Generally, the soil chemical characteristics for soil samples collected in all the treatment plots both in the main and parallel experiment indicated that the soil was of low fertility. The %OC and total N (%) was low, and was at 1.4 %, 0.12%, respectively, while plant available phosphorus (Mehlich 3) was marginally adequate (19 mg P kg^{-1} to 25 mg P kg^{-1}). The soil texture which was predominantly sandy clay loam to sandy clay suggest potential high leacheability of mobile nutrient ions more especially nitrogen as nitrate. Inevitably, if the soil is not properly managed crop yield could be reduced drastically.

Total biomass yield assessment for the pigeon pea was conducted in the parallel experiment in season two. Partial biomass yield assessment was done in season one in the main experiment. In season two this involved assessment of litter, twigs, stems, fresh leaves and roots for each treatment plot. The litter was collected from the ground on one planting station (90 cm x 75 cm). This was done in September, 2013. Fresh leaves, twigs and stems were also weighed from the 2 m x 2 m net plot. These were oven dried for 72 hours at 70 ^{o}C to constant weights. The assessment of the above ground groundnut biomass indicate a low yield range of 479-656 kg ha^{-1} while the assessment of the total above ground biomass yield of the pigeon pea varieties indicate a high yield range of 3,124-3,840 kg ha^{-1}. Nitrogen yield assessment indicate that the monoculture for groundnut treated with P yielded more N (52.0 kg N ha^{-1}) compared to the non treated groundnut monoculture (40.0 kg N ha^{-1}) while the P treated monoculture for the long duration pigeon pea yielded higher soil returnable N (87.2 kg N ha^{-1}) compared to the non P treated counterpart (79.7 kg N ha^{-1}). For the medium duration pigeon pea monoculture higher soil returnable N was harvested in the P treated monoculture (95.6 kg N ha^{-1}) than the non P treated monoculture (87.0 kg N ha^{-1}). Similar soil returnable yield of N was observed in the P (128.3 kg N ha^{-1}) and non P treated (128.8 kg N ha^{-1}) intercrop of medium duration pigeon pea and groundnut. Higher soil returnable yield of N was observed in the P (128.4 kg N ha^{-1}) and non P treated (103.9 kg N ha^{-1}) intercrop of long duration pigeon pea and groundnut. Generally, the monocultures and intercrops treated with P gave higher N yield when compared to the non P treated counterparts. This was attributed to enhanced biological N fixation in the P treated treatments due to the increased level of available P. Poor grain filling for the pigeon pea varieties was observed both in the main and parallel experiment. For the groundnut shells' yield ranged from 846 kg ha^{-1} to 1,985 kg ha^{-1} while grain yield ranged from 1,513 kg ha^{-1} to 3,025 kg ha^{-1} and haulms' yield ranged from 1,396 kg ha^{-1} to 2,463 kg ha^{-1}. N concentration in the shells ranged from 0.9% to 1.5% while in the grain ranged from 2.9% to 3.2% while for haulms ranged from 1.9% to 2.3%. N yield in the groundnut shells ranged from 10.2 kg N ha^{-1} to 25.2 kg N ha^{-1} while for grain ranged from 46.9 kg N ha^{-1} to 98.8 kg N ha^{-1} and for haulms ranged from 29 kg N ha^{-1} to 52 kg N ha^{-1}. The concentration of N in the maize grain ranged from 1.1% to 2.1% while maize grain yield ranged from 1,775 kg ha^{-1} to 5, 806 kg ha^{-1} and the N yield ranged from 23 kg N ha^{-1} to 115 kg N ha^{-1}. The concentration of N in the maize stover ranged from 0.1% to 1.0% while stover yield ranged from 2,029 kg ha^{-1} to 4,413 kg ha^{-1} and the N yield ranged from 2.3 kg N ha^{-1} to 33.2 kg N ha^{-1}. The concentration of N in the maize rachids ranged from 0.1% to 0.5% while the rachids yield ranged from 405 kg ha^{-1} to 1,235 kg ha^{-1} and the N yield ranged from 0.7 kg ha^{-1} to 5.1 kg N ha^{-1}. 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 which might lead to depletion of N in the soils.

Assessment of soil NO_3^-–N was conducted in the main experiment in the 2012/2013 cropping season, after the emergence of the succeeding maize crop. This was done in order to establish the effect of incorporating legume residues on soil NO_3^-–N and the implication this might have on nitrogen management and crop yield. Data was collected over a period of three weeks. This was done before top dressing with urea. Over the study period high levels (100 > mg L^{-1}) of soil NO_3^-–N were observed that were in most cases statistically the same ($p>0.05$) across the treatment plots. In general, mean soil NO_3^-–N was higher between 20 cm to 40 cm than 0 to 20 cm, attributable to the soil texture which is predominantly sandy clay loam both between 0 to 20 cm and 20 cm to 40 cm hence high leaching of NO_3^-. Most likely, the level of soil NO_3^-–N, into the season, in treatment plots in which no biomass was incorporated declined faster than in treatment plots where no incorporation was done, as a result of uptake by the maize crop and leaching losses. The high levels of soil NO_3^-–N probably, lasted longer into the season for the latter treatment plots, but might not have endured until the end of the cropping cycle due to limited supply of N from the incorporated biomass. Therefore, supplementation of N from mineral sources is requisite for the attainment of optimal maize grain yield. In general the KCl method gave higher readings of NO_3^-–N (0-20 cm=90.3 mg L^{-1} and 20 cm to 40 cm =108.5 mg L^{-1}) compared to the nitrate meter (0 to 20 cm=68.1 mg L^{-1} and 20 cm to 40 cm=65.9 mg L^{-1}). This could be attributed to the differences in the extraction procedure for the two methods, a cause of the different results generated by each procedure.

Assessment of NUE for the maize crop was conducted in order to determine how efficient the crop utilized applied N from urea. NUE was determined using the recovery efficiency (RE), agronomic efficiency (AE) and partial factor productivity (PFP) indices. Under the conditions of this study RE ranged between 20% and 88%, AE ranged between 7 and 32 kg yield increase per kg of nitrogen applied and PFP ranged from 27 to 104 kg grain yield per kg nutrient applied. RE values of 50% to 80% , AE values of 10–30 kg kg^{-1} and PFP values of 40–80 kg kg^{-1} are often encountered with values >25 kg kg^{-1} for AE and >60 kg kg^{-1} for PFP being common in well-managed systems or at low levels of N use, or at low soil N supply. The linear increase in grain yield with application of N and the presence of a diminishing-return relationship between maize grain yields (grain yield was near the yield potential of the maize variety at high N input) and increasing nitrogen supply, suggest that the RE, AE and PFP values emerging from this study might apply both to low and high levels of N use, or at low and high soil N supply.

From the study, the following conclusions were made; the soils on which the experiments were conducted were of low fertility status evidenced by the low nitrogen and phosphorus. A situation that calls for soil N and P management for increased crop productivity. Furthermore, the study confirmed the viability of the pigeon pea-groundnut intercropping system. The nitrogen yields for the cropping system were deemed to be reasonably high. Employing this system in rotation with maize can reduce to an extent the amounts and hence the costs of mineral fertilizers required for maize production. On the effect of incorporating legume biomass into the soil on soil NO_3^-–N, it was noted that apparently the soil had high NO_3^-–N in the soil solution attributable to residual N from N-fertilization and legume cropping over years. Soil NO_3^-–N was higher between 20 cm to 40 cm than between 0 to 20 cm in the soil. This was attributable to the soil texture which is predominantly sandy clay loam with low to medium level of SOM. Leaching of NO_3^- is high under such soil conditions. It is likely that soil NO_3^-–N levels in all the treatment plots would decline in all the treatment plots along the season principally due to crop uptake of N and leaching losses. This for the Malawian smallholder farmers implies that in this cropping system N supplementation from mineral fertilizer is not optional if reasonably high maize yield is to be realized. Additionaly, comparative analysis of two soil NO_3^-–N analysis procedures indicated that the KCl method gave higher readings of NO_3^-–N compared to the nitrate meter. This accrued from the differences in the extraction procedure for the two methods.

The study served to confirm that more N yield in groundnut is exported from the field in form of shells and grain and less is returned to the soil upon incorporation of the haulms. Over and above, it was observed that in the pigeon pea much of the N contribution to the soil N pool comes from the above ground biomass as compared to the below ground biomass. Additionally, supply of P to legumes increases N accumulation and yield through enhanced biological N fixation. The legumes, however, do not yield enough P for the correction of soil P deffiencies that are prevalent across Malawi. The PFP (27 to 104 kg grain yield kg^{-1} N applied) values obtained under the conditions of this study, which are higher than that (20 kg grain yield kg^{-1} N applied) reported under smallholder farms in Malawi, seem to suggest that legume biomass incorporation into the soil does improve NUE of the suceeding maize crop. The NUE values generated fall within the range of values that are often encountered in well-managed systems or at low levels of N use, or at low soil N supply.

Ratooning of the pigeon pea in this environment appears to be the solution to the observed poor grain filling for the pigeon pea. Furthermore, the low P yields from the legumes indicate the need to supply P using mineral fertilizer sources in addition to N for optimal maize grain yield. Further studies in this cropping system should focus on understanding the decomposition and mineralization pattern of the incorporated legume biomass for the assertion of the time and amount of N release. This is critical inorder to establish if this is in syncrony with nutrient demand by the maize crop.

DECLARATION

I, AUSTIN T. PHIRI, do hereby declare to the Senate of Sokoine University of Agriculture that this Thesis is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

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DEDICATION

"Through my Lord and Saviour Jesus Christ, to God Almighty the Father of Glory, architect and redeemer of the destiny of men...thank you!...to my late Father, Stanslas Esau Velentino Phiri, our guide and cover on life's journey...gratitude... and to my son, Divine Austin Phiri; "carry our dreams, hopes and aspirations into the future"...YO PHIRI!"

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LIST OF ABBREVIATIONS AND SYMBOLS

AGRA:	Alliance for a Green Revolution in Africa
AE:	Agronomic Efficiency
BD:	Bulk Density
BNF:	Biological Nitrogen Fixation
GoM:	Government of Malawi
FARA:	Forum for Agricultural Research in Africa
FISP:	Fertilizer and Inputs Subsidy Program
LER:	Land Equivalent Ratio
NUE:	Nutrient Use Efficiency
NSO:	National Statistical Office
OM:	Organic Matter
PFP:	Partial Factor Productivity
RE:	Recovery Efficiency
SSA:	Sub Saharan Africa
SOM:	Soil Organic Matter
TSP:	Triple Super Phosphate
XRF:	X-ray fluorescence

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1.0 Soil fertility and soil fertility status

Soil fertility has been defined as the soil's ability to provide nutrients, in adequate amounts and in proper balance, for the growth of plants when other growth factors are favourable (Johnson *et al.,* 2000). For optimal crop production a soil that allows for deep rooting, provides aeration, has good water holding capacity, and contains adequate and balanced supply of plant nutrients is considered a productive and fertile soil (Millar and Turk, 2002). Soils on arable lands in sub Saharan Africa (SSA) in general and Malawi in particular are highly degraded, principally due to inappropriate soil management practices (Phiri *et al.,* 2010; Ahaneku, 2010). Some of these practices include; mono-cropping, sole dependence on mineral fertilizers as soil amendments, non incorporation of crop residues into the soil after harvest and limited attention to soil and water conservation practices like soil erosion control practices, mulching and use of contour bunds, among other practices.

1.1.1 Soil fertility management

Maintenance of soil organic matter (SOM) at levels (0.85-3.4%) (Musinguzi *et al.,* 2013) that sustain optimal supply of soil nutrients for uptake by crops and enhance efficiency of applied mineral fertilizers is a major challenge for smallholder farming systems of southern Africa (Mapfumo *et al.,* 2007). Many reports have shown that use of inorganic fertilizers alone may lead to defficiency of nutrients not supplied by the chemical fertilizers and may also lead to chemical soil degradation (Mafongoya *et al.,* 2006), like loss of the soil's natural buffering capacity. Chemical fertilizers are also too costly for farmers to apply the recommended rates. On the other hand, there are demonstrated benefits of the use of organic sources of plant nutrients on soil properties like soil pH, water holding capacity, hydraulic conductivity and infiltration and decreased bulk density (Mafongoya *et al.,* 2006). SOM is a key factor in soil aggregation that leads to improved soil porosity hence increasing the infiltration, storage and drainage of water, improving soil aeration, and the ease of penetration of plant roots (Verhulst *et al.,* 2010). However, sole application of organic sources of plant nutrients is constrained by their low contents and availability of the essential nutrients, N in particular, to the current crop (Nyamagara *et al.,* 2009), imbalanced nutrient contents, unfavorable quality and high labor demands for transporting the bulky organic materials (Palm *et al.,* 1997).

Many researchers have suggested that the alternative is to use the integrated approach to soil fertility management (ISFM), which among other things involves the combined application of organic and inorganic fertilizers for the improvement of crop yields and maintenance of soil fertility (Bationo *et al.,* 2005). Vanlauwe *et al.* (2010) suggested an operational definition of ISFM as 'the set of soil fertility management practices that necessarily include the use of fertilizers, organic inputs, and improved germ plasm, combined with knowledge on how to adapt these practices to local conditions, aiming at maximizing agronomic use efficiencies of the applied inputs and improving crop productivity. However, Musinguzi *et al.* (2013) propose to define ISFM as a practice of improving and restoring soil fertility while optimizing yields using a set of soil fertility management practices that necessarily includes organic and mineral fertilizers, improved germ plasm; and using a set of knowledge to adapt them to a given environment, while targeting maximizing production and recovery efficiencies of applied nutrients for sustainable land use intensification. Abera (2005) reported that half the number of smallholder farmers in SSA may reduce N fertilizer rates if high quality green manure rich in N is used in legume-cereal rotation cropping systems, while Kumwenda *et al.* (1995) was of the idea that comprehesion by farmers on the positive effects of OM application on NUE could increase the number of inorganic fertilizer users by reducing the amount of mineral fertilizer that farmers would purchase for application in their fields.

1.1.2 Consequences of declining soil fertility on soil and crop productivity

The chief consequence of soil degradation has been declining soil fertility and resultant low soil productivity (Amede, 2003). For instance, the average maize grain yield in Africa is estimated to be at 1.7 tons ha^{-1} compared with the global average of about 5 tons ha^{-1} (FARA, 2009). In Malawi, the national yields of maize have averaged 1.3 t ha^{-1} during the last 20 years (FAO, 2008) against a yield potential range of 6 to 10 t ha^{-1} of many maize hybrid varieties currently grown by some progressive Malawian farmers. In the 2005/06 season, the national average maize yield was estimated to be at 1.6 t ha^{-1}. A strong Government-led Farm Input Subsidy Program (FISP) with special emphasis on the use of inorganic fertilizer, increased the national average maize yield to over 2 t ha^{-1} in the 2006/07 season (WFP, 2009). The low productivity is attributed largely to low plant nutrient availability and nutrient use efficiency (Sakala, 2004).

Prevailing economic conditions in Malawi have limited the use of mineral fertilizers by smallholder farmers, due to their low purchasing power. At the same time, annual estimates indicate an increase in nutrient losses under various farming systems through different pathways (Kanyama-Phiri, 2005), for example; through soil erosion, leaching and denitrification. Total national estimates for annual nutrient losses of around 160,000 metric tons, lost mainly through nutrient mining by crops have been reported, with annual estimates of inorganic fertilizer nutrient inputs into the farming systems pegged at 70,000 metric tons thus leaving a net deficit of 90,000 metric tons (Kanyama-Phiri, 2005). About 52.4% of Malawi's 13 million people live below the poverty line, of 1US$/day (GoM, 2006), yet the delivery price for a metric ton of urea from the ocean ports of East African countries is $770 (Cornway and Waage, 2010), translating to $38.5/50 kg bag. Certainly, this is beyond the smallholder farmers' purchasing power, hence the low use of the mineral fertilizers by the farmers. Conscious of the smallholder farmers' resource limitations, the Government of Malawi (GoM) introduced the targeted fertilizer subsidy program. This program is tailored to reach out to resource poor smallholder farmers with the aim of boosting agricultural production at village and national levels. However, many smallholder farmers are not able to access the facility. This is due to the fact that the quantity of the fertilizers purchased by the Government for the program usually is not enough (Phiri *et al.,* 2010).

1.1.3 Challanges affecting agricultural productivity in Malawi

Socially, the HIV/AIDS pandemic and related chronic ailments are paralyzing the most productive age group of Malawi's society rendering them agriculturally ineffective. By 2013 the prevalence rate among adults aged 15 to 49 years was estimated to be at 10.3% (UNAIDS, 2013). This, coupled with the highlighted biophysical and economical impediments to sustainable and increased agricultural productivity, has kept the populace within the confines of an unyielding poverty trap. Furthermore, on farm maize grain yield response to the application of N from inorganic fertilizers

(PFP_N) is low as a result of declining levels of soil organic matter (SOM), deficiencies of macro and micronutrients and reduced soil buffering capacity (Kumwenda *et al.,* 1995). According to Waddington *et al.* (2004), PFP_N is usually below 20 kg maize grain kg^{-1} nitrogen applied.

1.1.4 Strategies for improving soil and crop productivity

Not with standing the above, ample evidence is available attesting to the fact that gains in crop productivity are realizable from nutrient additions through the combination of organic and inorganic sources of plant nutrients compared with each input applied alone (Swift *et al.,* 1994). Bationo *et al.* (2006) stated that a combination of mineral and organic soil amendments is necessary to sustain and improve crop production on depleted soils. Combination of mineral fertilizers and organic nutrient sources often results in synergistic effects on crop yields (Opala, 2010). Studies by Murwira and Kirchmann (1993), showed that synchrony between N release and crop uptake was best achieved by applying combinations of manure and mineral N and having it in such a way that the N is applied as top dressing or side dressing. It was observed that late application of mineral N reduced the amount of N lost through leaching. Similar results were also reported in biomass transfer systems using manures and inorganic fertilizers on vegetables (Kuntashula *et al.,* 2004) and improved fallows when combined with small amounts of inorganic fertilizers. This could be attributed to P additions from inorganic fertilizers or K or N which may not be supplied in sufficient amounts by organic inputs alone leading to better synchrony of nutrient release and uptake.

1.1.5 Crop residue management for soil organic matter and fertility improvement

The Soil Science Society of America (SSSA) (2001) defines SOM as the total organic fraction of the soil exclusive of undecayed plant and animal residues. OM in the soil balances various chemical and biological processes and helps to maintain soil quality parameters at desirable level (Weil and Magdoff, 2004). It improves water infiltration rate, water retention capacity, serves as a reservoir of nutrients and water and supplies them to crops when needed (Weil and Magdoff, 2004). Soils that are rich in OM also have a high cation exchange capacity (CEC) (Weil and Magdoff, 2004). SOM contains many negatively charged surfaces with a high affinity for organics and metals that might otherwise cause pollution (Allen *et al.*, 2011). SOM has a high pH buffering capacity to resist drastic changes in soil pH (Weil and Magdoff, 2004). With a high level of SOM soil tilth is improved, and aggregate size tends to be large with good soil structure (Allen *et al.*, 2011). Soil microbial diversity and quantity generally improve as SOM increases. Microbes are major players of the OM decomposition process. With a high level of SOM, beneficial microorganisms reproduce and grow in the soil, which hastens the decomposition process (Allen *et al.,* 2011).

SOM is highly sensitive to management practices (Wander, 2004). An increase SOM content helps reversing land degradation and often increases soil fertility and crop production (Weil and Magdoff, 2004). Crop residue refers to any organic material including stubble, that remains after an economic crop is harvested from a field (Idaho, 2014). There are several ways of managing residue for adding OM to the soil particularly if C:N ratio is very high. Residue can be chopped, incorporated (with or without chopping), or can be left to decompose on the surface. Removing crop residues from fields reduces the amount of biomass available for conversion to SOM (Gelderman *et al.,* 2011). SOM levels are determined by the relative rates of production and decomposition of both the above and below ground plant biomass material (Gelderman *et al.,* 2011). Residue removal from crop fields coupled to sole use of mineral fertilizer can lead to a decrease of SOM through increased SOM mineralization rates (Termorshuizen *et al.,* 2005). A decrease of 6% SOM over five years for continuous no-till maize when approximately 50% of the crop residue was removed each year has been reported (Varvel *et al.,* 2008). The nutrients removed can be replaced through the use of inorganic fertilizers, but at the expense of other vital functions of SOM like buffering soil pH and increasing the soil's water holding capacity (Gelderman *et al.,* 2011). The amounts of crop residues required to maintain SOM vary with soil types and management options (Gelderman *et al.,* 2011). Crop residues removal in excess of SOM maintenance levels will ultimately result in the deterioration of the soil resource and lead to declining yields (Gelderman *et al.,* 2011). Since SOM levels in cultivated fields are already much reduced from native levels, it is prudent to manage crop residues in a bid to limit the deterioration of the soil resource.

1.1.6 Nutrient use efficiency

Nutrient use efficiency in a cropping system is frequently defined as the proportion of all nutrient inputs that are removed in harvested crop biomass, contained in recycled crop residues, and incorporated into soil organic matter and inorganic nutrient pools (Cassman *et al.,* 2002). According to Mikkelsen (2005), for N, this value frequently varies between 40 and 60%. Another common definition of NUE is the nutrients recovered by plants within the entire soil-crop-root system. For N, this value may be in the range of 65 to 85% (Mikkelsen, 2005). Mosier *et al.* (2004) described 4 agronomic indices commonly used to describe nutrient use efficiency namely; partial factor productivity (PFP, kg crop yield per kg nutrient applied), which is the most widely used; agronomic efficiency (AE, kg crop yield increase per kg nutrient applied); apparent recovery efficiency (RE, kg nutrient taken up per kg nutrient applied); and physiological efficiency (PE, kg yield increase per kg nutrient taken up). For N, Hirel *et al.* (2011) indicated that use efficiency is the product of absorption efficiency, that is the amount of absorbed N (quantity of available N)$^{-1}$ and the utilization efficiency that is the yield (absorbed N)$^{-1}$. Hirel *et al.* (2007) indicated that among crops, there exists genetic variability for both N absorption efficiency and for N utilization efficiency.

1.1.7 Improving crops' nutrient use efficiency for increased productivity

Limited research in Malawi has shown that the low maize grain yield response can be increased through the combined use of organic and inorganic nutrient sources. For example, Sakala *et al.* (2004) reported that applying a combination of organic (*Mucuna puriens* at 2.7 tons, *Crotalaria juncea* 3 tons and *Lab lab purpureus* 2.7 tons) and inorganic fertilizer (35 and 69 kg N ha^{-1}) to maize, increased nutrient use efficiency of the crop above 20 kg grain yield kg^{-1} N applied. Unfortunately, these findings have remained in grey literature primarily because the green manure crops used by the researchers were not the traditional crops grown by Malawian farmers due to either their relative edibility like the *Mucuna* grains have a special preparation recipe or inedibility as is the case with *Crotalaria juncea.* As such, efforts to out scale the technologies have proved to be futile. Further research on NUE therefore, is required but this time using edible legumes grown by farmers that have a high biological N fixing capacity, for example, the pigeon pea and groundnut.

Globally, improvement of crop N use efficiency is still a challenge (Snyder and Fixen, 2012) due to inappropriate nutrient management practice. Randall *et al.* (2008) reported that the apparent above-ground, growing season recovery of applied N by maize (*Zea mays* L.), ranges below 40 to 50%. Dobermann and Cassman (2002) argues that apparent N recoveries above 70% are achievable for many cereal crops through intensive site specific nutrient management. This is attainable upon the use of principles of 4R nutrient stewardship (right source at the right rate, right time, and on the right place) (Bruulsema *et al.,* 2008), deployed concurrently with optimum management of other cropping system resources and inputs (Snyder and Fixen, 2012). A 25% increase in crop N use efficiency above current reported levels is being advocated by the government of the United States of America through the Environmental Protection Agency (Dobermann 2007) through more intensive, skilled nutrient and cropping system management (Snyder and Fixen, 2012). David *et al.* (2010) observed that poorly managed, imbalanced, and inefficient agricultural N use impairs the ability to provide food, feed, fiber and biofuel; raises the risks for N loss to groundwater and surface water resources; and increases the potential for direct and indirect emissions of the potent green house gas, N_2O.

1.1.8 Nutrient management for improved nutrient use efficiency

It is worthwhile to note that nutrient management plays an important role in helping optimize crop response to inputs (Bruulsema *et al.,* 2009), necessitating its inclusion in the overall cropping system management under smallholder farms (Snyder and Fixen, 2012). Nutrient management aims at the maintenance and possible improvement of soil fertility for sustained crop productivity on long term-basis and also to reduce inorganic fertilizer input costs (Praharaj *et al.,* 2007). Aspects embraced in this approach includes appropriate soil and water conservation practices (Delgado and Bausch, 2005), integrated pest management, and the use of adapted crop varieties and hybrids, which are input-efficient and responsive to management (Cassman, 1999) at optimum densities (Ping *et al.,* 2008). In practical terms, NUE for crops can be enhanced through the adoption of appropriate sustainable agricultural practices, judicious use of fertilizers, crop rotation, establishment of ground cover and incorporation of the crop residues into the soil (Hirel *et al.,* (2011). Judicious use of soil amendments entails the application of both organic and inorganic sources of plant nutrients in correct amounts at appropriate growth stages of the crops and under appropriate conditions to prevent runoff or leaching of the applied nutrients (Hirel *et al.,* 2007), hence increased use efficiency by the crops. Alternatively, cropping systems employing carefully designed species mixtures (Malézieux *et al.,* 2009) like for example, intercropping legumes with legumes and rotating with maize, may be a route towards lower N fertilizer input, while maintaining economic profitability (Malézieux *et al.,* 2009) other plant growth factors being optimal.

The recovery of applied mineral N from agricultural production systems globally is about 50% (Krupnik *et al.,* 2004). The surplus may accumulate in soils, lost to air, ground and surface water through various pathways (Eickhout *et al.,* 2006). Losses from the soil-plant system are due to denitrification in the form of gaseous dinitrogen (N_2), nitrous oxide (N_2O) and nitric oxide (NO), volatilization of ammonia (NH_3), leaching of nitrate (NO_3^-), runoff and erosion (FAO/IFA, 2002). Cassman *et al.* (2002) observed that N use efficiencies from experimental plots do not accurately represent the efficiencies obtainable in farmers' fields. The disconnect in the results mainly arises from differences in the scale of farming operations and differences in N management practices (Cassman *et al.,* 2002). According to Cassman *et al.* (2002) the effect of scale influences both N fertilizer application and other management operations like tillage, seeding, weed and pest management, and harvest, which also affect efficiency. Consequentially, NUE in well managed research experiments is generally greater (50-

80%) than the efficiency of the same practices applied by farmers in production fields (Cassman *et al.,* 2002). For instance the RE_N, achieved by rice farmers in four major rice producing Asian countries is 31% of applied N (Dobermann *et al.,* 2002). This differs markedly with RE_N for rice in well managed field experiments which range from 50–80% (Cassman *et al.,* 2002). It is on record that from the early 1980s in the USA PFP_N has increased (Frink *et al.,* 1999) by 36% in the last 21 years, from 42 kg kg^{-1} in 1980 to 57 kg kg^{-1} in 2000 (Cassman *et al.,* 2002) attributable to improved soil fertility management. Edmonds *et al.* (2009) reported that in sub Saharan Africa (SSA), for cereal production on smallholder's farms, generally, NUEs usually exceed 100%. The high NUEs for SSA are a direct result of applying low amounts of mineral N (Edmonds *et al.*, 2009) with resultant nutrient mining by crops from soils and low yields.

1.1.9 Strategies for enhanced and sustainable agricultural production

Sustainable agriculture involves the successful management of agricultural resources to satisfy human needs while maintaining or enhancing environmental quality and conserving natural resources for future generations (FAO, 2002). Improvement in agricultural sustainability requires, alongside effective water and crop management, the optimal use and management of soil fertility and soil physical properties. Both rely on soil biodiversity and soil biological processes. This requires the widespread adoption of management practices that enhance soil biological activity and thereby build up long-term soil productivity and health (FAO, 2002). At farming system level the concept of sustainable agriculture focuses on types of technology and strategies that reduce reliance on non-renewable or environmentally harmful inputs. These include ecoagriculture, organic, ecological, low-input, biodynamic, environmentally-sensitive, community-based, farm-fresh and extensive strategies.

1.1.10 Intercropping

Intercropping is the practice of cultivating two or more crops in the same field at the same time (Machado, 2009). The goal of intercropping is to achieve increased crop yields on a piece of land through maximized crop growth resource use efficiency (Machado, 2009). Crops grown in this system may not be sown or harvested at the same time, but are grown simultaneously during their respective cropping cycle (Lithourgidis *et al.,* 2011). Intercropping can include: annual plants with annual plants intercrop; annual plants with perennial plants intercrop; and perennial plants with perennial plants intercrop (Eskandari *et al.,* 2009).

Legumes through their symbiotic relationship with nodule dwelling bacteria fix atmospheric N through biologically changing it from the inorganic form to forms that are available for uptake by plants (Lithourgidis *et al.,* 2011). Legumes grown on soils with low N derive their N requirements entirely from the process of BNF while cereals grown in rotation with maize may partially satisfy their N requirements from N fixed by the previous legume if residues are incorporated into the soil, which is alternative and sustainable way of introducing N into low input cropping systems (Fustec *et al.,* 2010). In addition, roots of the legumes decompose and release N into the soil thereby increasing soil N reserves for uptake by subsequent crops (Lithourgidis *et al.,* 2011).

Compared to monocropping, intercropping provides increased diversity, which facilitates better biological control of pests and reduced soil erosion (Machado, 2009). Legumes intercropped with cereals can also provide soil cover, as they also smother weeds, provide habitat for pest predators and increase microbial diversity such as vesicular arbuscular mycorrhizae (VAM) (Machado, 2009). On weed suppression, intercropping of cereals and cowpea has been observed to reduce striga infestation (Khan *et al.*, 2002). This was attributed to the soil cover by the cowpea that created an unfavorable conditions for striga germination (Mbwaga *et al.*, 2001). In Zimbabwe, Mashingaidze (2004) found that maize-bean intercropping reduced weed biomass through supression by 50-66% when established at a density of 222,000 plants ha^{-1} for beans equivalent to 33% of the maize density (37,000 plants ha^{-1}) due to more surface cover. Machado (2009) observes the need for more research in intercropping systems before up and out scaling of this technology for potential adoption by farmers. This is the case since choice and management of intercrops requires good planning, that includes selection of appropriate cultivars and application of proper spacing or plant density among other factors (Machado, 2009). For instance, Morgado and Willey (2003) reported that dry matter yield accumulation of individual maize plant decreased with increase in bean plant population. Muoneke *et al.* (2007) found that increasing maize planting density reduced soybean seed yield by 21 and 23% at maize planting density of 44,440 and 53,330 plants ha^{-1}, respectively compared with intercropping at 38,000 maize plants ha^{-1}, attributable to increased competition for growth resources in the cropping system. A clear indication of the need for adequate agronomic research on a variety of crop production aspects inorder to derive suitable recommendations for yield optimization is mandatory.

Machado (2009) further observed that the success of an intercrop system rests on understanding the physiology of the species involved, their growth habits, canopy and root architecture, water and nutrient use. Plants compete for light above ground and for water and nutrients below ground, so competition involves a combination of climatic and soil factors in space and time. What begins as nutrient competition may culminate into a shade issue, as different species compete for various resources at differing times in their growth cycle (Machado, 2009). This spells the need to establish crop compatibility under intercropping systems. In general, intercropping systems are useful in terms of increasing productivity and profitability per unit area, water and radiation use efficiency, control of weeds, pests and diseases (Matusso *et al.,* 2012). Other advantages of intercropping include potential for increased profitability and low fixed costs for land as a result of a second crop in the same field (Thobatsi, 2009). Additionally, intercropping system provides higher financial returns to smallholder farmers than monocropping (Seran and Brintha, 2010).

1.1.11 Legume-legume intercropping

The main goal of legume-legume intercropping is to increase N yields by the N fixing legumes and hence the amount of N returnable to the soil upon incorporation of the biomass into the soil. Compared to short duration legumes like groundnut, long duration legumes like the pigeon pea fix more N biologically, enhance P availability and yields of subsequent cereal crops (Bezner Kerr *et al.,* 2007). However, it has been observed that short duration legumes usually have the higher grain yield potential than long duration legumes, while contributing low amounts of nutrients to the soil if their residues are incorporated due to low biomass yields (Hardarson and Atkins, 2003). Hence intercropping two legumes with differing duration for maturation would yield multiple benefits interms of soil fertility improvement and increased economic yields. Short duration genotypes like the groundnut largely, are grown for commercial purposes, while the long duration counterparts like the pigeon pea are adaptable into relay intercrops and subsistence production systems (Rego and Nageswara, 2000). Integration of legumes requires consideration of the competitive effect intercropping on water and nutrient availability to the crops (Bezner Kerr *et al.,* 2007).

Soil fertility benefits of legume integration into cropping systems depend on the amounts of biomass produced and residue management (Bezner Kerr *et al.,* 2007). Edible legumes apart from the grain, usually their leaves are harvested and cooked for relish or used as fodder for livestock thereby reducing nutrient input to the soil (Bezner Kerr *et al.,* 2007). It is on record that regular and proper addition of organic materials (crop residues) maintains good soil tilth, improves fertility and productivity of agriculture, controls wind and water erosion, and prevents nutrients losses by run-off and leaching (Bukert *et al.,* 2000).

1.1.12 Evaluation of the productivity of intercropping systems

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

1.1.13 Crop rotation

Bruns (2012) defined crop rotation as the production of different economically important plant species in recurrent succession on a particular field or group of fields. Rotational systems reduce the presence of parasitic weeds and soil-borne pests (Kabambe and Mloza-Banda, 2000). Bruns (2012) noted that one main benefit of crop rotation is the breaking of crop pest cycles. It is on record that crop rotations help in the control of crop disease problems such as gray leaf spot in maize (*Cercospora zeae-maydis*), take-all in wheat (*Gaeumannomyces graminis var. tritici*), and sclerotina in soybean (*Sclerotinia sclerotiorum*) (Roth, 1996), through prevention of the buildup of large populations of pathogens (Krupinsky *et al.,* 2002). Appropriate crop rotation increases OM in the soil, improves soil structure, reduces soil nutrient depletion and can result in higher yields and greater farm profitability in the long-term (Overstreet, 2009). Crop rotations may influence the rate of N mineralization hence availability for plant uptake through modification of soil moisture, soil temperature and pH (Al-Kaisi, 2001). Increased levels of SOM through biomass incorporation into the soil enhances water and nutrient retention, the result being increased nutrient uptake by crops and use efficiency (Overstreet, 2009). Crop rotation involving nitrogen-fixing crops, can reduce the input of mineral fertilizers to the succeeding crop through N addition via incorporation of crop residues into the soil. Dias, *et al.* (2014) outlines the potential benefits of crop rotation one of them being breaking the dominance of weeds. The system is recommended as a management strategy against herbicide-resistant weeds;

improving soil structure hence the development of different plant rooting systems that can effectively exploit the soil; resulting in less soil compaction leading to improved plant nutrition with increased carbon sequestration; enhanced soil quality as a result of the various crop residues that improve the quality of SOM, particularly when leguminous plants are used; reducing soil erosion by at least 30% compared with intensive single-culture systems; preventing groundwater pollution; and contributing to landscape diversity, thereby promoting biodiversity.

Many crops can be included into different crop rotations, making the number of possible combinations very high. It follows therefore, that designing crop rotations must follow certain principles. (Dias *et al.,* 2014). Four basic principles are used in choosing crops to be included in a rotation system. This includes: the crop's ability to reduce soil erosion, maintain or improve SOM content, manage plant nutrition and control of pests (Dias *et al.,* 2014). Dias *et al.* (2014) stipulated that additionally, as novel scientific advances become available, other important criteria for choice of crop to be included in a rotation system that currently are not widely used can, and should, be tested. For instance, the influence of plant–soil microbe interactions and soil biota feedbacks on plant health and plant performance which are well established for natural ecosystems (Dias *et al.,* 2014) should be given due consideration. For example mean yield benefits of up to 20% or more can be obtained in rotation systems involving wheat and break crops like *Brassica* (Kirkegaard *et al.,* 2008). Working on groundnut–maize crop rotation experiments on station and on farm in Zimbabwe, Waddington *et al.* (2007) reported that three rotational cycles generated evidence for the substantial improvement in the productivity and sustainability of maize. Clear large benefits were registered from rotations both with and without fertilizer applied to the succeeding maize crop. The additive benefits of the rotation and mineral fertilizer application almost doubled maize grain yields up to 8 t ha^{-1} on station (Waddington *et al.* (2007). The approximate doubling of maize grain yield after groundnut was similar to that reported by Mukurumbira (1985). Benefits from the rotation on farm were smaller, with unfertilized maize production in rotation still increasing yield by about 15% compared with continuous maize cropping, with some groundnut produced along side as a bonus (Waddington *et al.* (2007). Work conducted in Malawi for a period of three years (1997/98-1999/2000) on farm and on station showed that maize grain yields obtained after a *Mucuna*-maize rotation (one year improved fallow of *Mucuna*) were significantly higher than maize yields obtained under continuous maize without added fertilizer inputs (3.5 t ha^{-1} versus 1.0 t ha^{-1}) (Sakala *et al.,* 2003)

1.1.14 Pigeon pea

Pigeon pea (*Cajanus cajan* (L.) Millsp.) is an erect perennial legume shrub often grown as an annual, reaching 1–4 meters in height (Valenzuela and Smith, 2002). The leaves have three leaflets that are green and pubescent above and silvery grayish-green with longer hairs on the under side (Valenzuela and Smith, 2002). The flowers are yellow with red to reddish-brown lines or a red outside (Valenzuela and Smith, 2002). Pigeon pea seedlings emerge 2–3 weeks after sowing. Vegetative growth begins slowly but accelerates at 2–3 months (Valenzuela and Smith, 2002). Pigeon pea roots are thin with a deep-rooting taproot reaching up to 2 m in depth (Valenzuela and Smith, 2002).

1.1.15 Environmental requirements

Pigeon pea can be grown in a wide range of soil textures, from sandy soils to heavy clays. It grows best at a soil pH of 5.0–7.0 but tolerates a wider pH range (pH 4.5–8.4).

It does well in low fertility soils, making it a favorite among subsistence farmers (Valenzuela and Smith, 2002). As with most legumes, it does not tolerate water logged or flooded conditions for very long periods. Pigeon pea is heat-tolerant and grows well in hot, humid climates and thrives under annual rainfall between 600–1000 mm (Valenzuela and Smith, 2002). It is generally grown where the temperatures are in the range of 18–30°C, but under moist soil conditions it can withstand temperatures of 35°C or more (Valenzuela and Smith, 2002). Once established, it is one of the most drought tolerant of the legumes, and it can be grown in rainfed conditions or with minimal irrigation (Valenzuela and Smith, 2002) as the tap root accesses moisture from deeper soil horizons. Pigeon pea is grown in a variety of agro-ecological zones, and are well adapted to semi-arid climate conditions (Mutegi and Zingore, 2014**)**.

In SSA pigeon pea is widely grown in Kenya, Uganda, Tanzania, Malawi and Mozambique for subsistence and for domestic and international markets. Despite potential yields of about 5 t ha^{-1} (Kimani, 2001), pigeon pea yield less than 1 t ha^{-1} in the farmers fields (FAOSTAT, 2008) due to poor management. With global climate change, pigeon pea will become more important for managing food security and nutritional situation in Africa due to the fact that pigeon pea usually yields some grain under moisture stress during dry spells compared to other grain legumes (Mutegi and Zingore, 2014**)**. Pigeon pea can fix 150-200 kg ha^{-1} of atmospheric N biologically in the soil especially when supplied with P (ICRISAT, 2003).

1.1.16 Groundnut

Groundnut (*Arachis hypogaea* L.) is one of the world's most popular oil seed crops which is grown as an annual plant but perennial growth is possible in climates which are warm until harvest (Farag and Zahran, 2014). It is best cultivated in well drained sandy or sandy loam soils with pH ranging from 5.5 to 6.5 (Farag and Zahran, 2014). Groundnut is the most widely cultivated legume in Malawi, which accounts for 25 percent of household's agricultural income (Diop *et al.,* 2003). The crop provides a number of benefits to smallholder farmers, for instance improvement of soil fertility through BNF and saves fertilizer costs for subsequent crops; forms an important component of both rural and urban diets like a source of valuable protein, edible oil, fats, energy, minerals, and vitamins (Longwe-Ngwira, 2012). Groundnut is consumed or processed into oil. In livestock-farming communities, groundnut can be used as a source of livestock feed and increases livestock productivity (Longwe-Ngwira, 2012). Groundnut yields are still very low in Africa, averaging about 800 kg ha^{-1}, compared to the potential yield of 3,000 kg ha^{-1} (Longwe-Ngwira, 2012). The wide gap between actual and potential yields is attributable to several factors, including non-availability of seed of improved varieties, low soil fertility, inappropriate crop management practices, as well as pests and diseases (Longwe-Ngwira, 2012). Groundnut has the capacity to biologically fix up to 235 kg N ha^{-1} (Peoples *et al.*, 1995).

1.1.17 Legume based soil fertility rejuvenating technology

In practical terms soil fertility restoration and improvement could involve utilization of legume based soil fertility improving technologies like the double legume intercropping system. In this approach, the main line of action is to restock SOM on smallholder farms, achievable through incorporation of nitrogen rich biomass from legumes into the soil. This would boost levels of nutrients in the soils, increase the soil's ability to retain nutrients, buffer soil pH and increase the soil's water holding capacity. Legume biomass incorporation into the soil has to be coupled with modest supplementation of nutrients like nitrogen and phosphorus from mineral sources since their concentrations in the biomass are low. The biomass should be generated on farmers' fields, achievable through large scale integration of both edible and non edible legumes in various cropping systems (Bezner-Kerr, 2007). Priority though, has to be given to edible legumes which generate ample biomass. Candidate edible legumes and a cropping system have been proposed (Kanyama-Phiri *et al.,* 2008), which include; pigeon pea, groundnut and soybean among others grown in the double legume intercrop-maize rotation cropping system (Kanyama-Phiri *et al.,* 2008). Incorporating residue of legumes in this cropping system might lead to increased N and OM levels in the soil thereby increasing nutrient use efficiency (NUE) and crop productivity. On this foundation, an indepth study was conducted at Chitedze Agricultural Research Station in Malawi to investigate this proposition. The overall objective of the study was to improve soil productivity through enhancement of nitrogen stocks and N use efficiency of maize using the pigeon pea-groundnut intercrop in rotation with maize for increased and sustainable maize production. The specific objectives were to:

i) characterize the soils at the trial site in terms of their chemical and physical properties and hence the fertility status.

ii) assess the effect of intercropping medium and long duration pigeon pea with groundnut on pigeon pea growth rates and yields.

iii) assess the effect of the biomass incorporation on soil NO_3^-–N in the pigeon pea-groundnut intercropping-maize rotation system.

iv) correlate the nitrate meter and KCl method for soil NO_3^-–N measurement.

v) investigate the partitioning of plant N to harvestable grain and plant biomass returned to soil and

vi) determine N use efficiency of maize in rotation with the legumes as influenced by the incorporation of pigeon pea biomass and groundnut haulms into the soil.

1.2 Expected output

The following was the expected output: Soil fertility and nutrient use efficiency improved for increased crop productivity.

1.3 Hypotheses

The following were the study hypotheses:

i) the pigeon pea-groundnut intercrop maize rotation cropping system does not improve soil fertility status.

ii) intercropping medium and long duration pigeon pea with groundnut does not affect pigeon pea growth rates and yields.

iii) legume biomass incorporation to the soil does not affect soil NO_3^-–N levels in the pigeon pea-groundnut intercropping-maize rotation cropping system.

vi) using the nitrate meter and KCl method for soil NO_3^-–N measurement does not generate different values of soil NO_3^-–N.

v) legume biomass incorporation to the soil does not affect N uptake a the partitioning of plant N to harvestable grain and plant biomass returned to soil and

vi) N use efficiency of maize in rotation with the legumes is not influenced by the incorporation of pigeon pea biomass and groundnut haulms to the soil.

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CHAPTER 2:

EFFECT OF PIGEON PEA-GROUNDNUT INTERCROPPING SYSTEM ON SELECTED SOIL PROPERTIES

ABSTRACT

A study was conducted to investigate on the efffect of the pigeon pea-groundnut intercropping system on selected soil properties, namely organic carbon, nitrogen, phosphorus and calcium. The study was conducted from the 2011/12 cropping season with a parallel experiment set along side in the second season at Chitedze Agricultural Research Station (13^0 59' 23.2 S", 033^0 38' 36.8 E") in Malawi. The main experiment had eight treatments while the parallel experiment had ten treatments. Both were laid in a randomized complete block design (RCBD) replicated three times. The experiments involved planting of pigeon pea and groundnut as monocultures or as intercrops. Soil characterization was conducted before treatment application in the first and second year. After the first season, legume biomass in some plots of the main experiment was incorporated into the soil. Laboratory analytical results indicated that soil texture was predominantly sandy clay loam to sandy clay, organic carbon was marginally adequate ($\geq$ 0.88%), % total N was low ($\leq$ 0.12%), while plant available phosphorus was marginally adequate both between 0-20 cm and 20-40 cm (19 mg P kg^{-1} and 25 mg P kg^{-1}). The soil texture which was predominantly sandy clay loam to sandy clay suggest potential high leacheability of the mobile nutrient ions more especially NO^-_3-N. After harvest, before the commencement of the second season, soil data indicated that soil organic carbon and P remained largely in the medium range while plant total soil N levels stood within the marginally adequate range. The soil reaction was not impacted

by biomass incorporation suggesting that the soils' buffer capacity was not affected with biomass incorporation. The status of OC was not affected with the incorporation of the biomass. Building OC in the soil through biomass incorporation to the soil takes time.

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

2.0 INTRODUCTION

Malawian smallholder farms' productivity is constrained by a myriad of limitations that include biophysico-chemical, economic and social in nature. One of the outstanding biophysico-chemical constraints is the inherent low fertility status of the soils which is being aggravated by the continuous loss of nutrients like nitrogen (N) and phosphorus (P) from the soils. The loss of nutrients is principally through soil erosion, nutrient export from the field and leaching losses. On average Malawi is losing about 40 kg N ha^{-1} and 6.6 kg P ha^{-1} annually (Smaling *et al.,* 1997) principally due to nutrient mining by crops and export from the fields. Additionally, nutrient use efficiency (NUE) is low (Sakala *et al.,* 2004) as a result of declining levels of soil organic matter (SOM) and associated deficiencies of macro and micronutrients and inappropriate soil management/agronomic practices. This results into low uptake and utilization of the nutrients by crops, attributed to a variety of soil properties like low water holding capacity. The NUE is usually below 20 kg maize grain kg^{-1} of nutrients applied (Waddington *et al.,* 2004), which is categorized as being low.

For the past 20 years, national yields of maize have averaged 1.3 t ha^{-1} (FAO, 2008) against a yield potential range of 6 to 10 t ha^{-1} of many maize hybrid varieties currently grown by Malawian farmers (Saka *et al.,* 2006) largely due to the low fertility status of the soils. In the 2005/06 season, the national average maize yield was estimated to be at 1.6 t ha^{-1} (Denning *et al.,*2009) compared to the 1.3 t ha^{-1} (FAO, 2008) attributed to increased mineral fertilizer use through the Government-led Farm Input Subsidy Program (FISP). The program increased the nation average maize grain yield to over 2.5 t ha^{-1} in the 2006/07 season (WFP, 2009). The sustainability of the program has been questioned due to its high dependence on donor funding and the sole use of inorganic fertilizers without addition of organic matter to the soil. It has been argued that this approach will continue to biologically and chemically degrade the soils due to continued decline of SOM (Ogbomo, 2011. Overtime, crop response to applied mineral fertilizer will continue to diminish due to low nutrient availability and uptake by the crops. Sole use of mineral fertilizers can promote microbial C utilization in the soil thereby depleting soil organic N content (Mulvaney *et al.,* 2009). A proposition has been made that one way out of this quandary is the large scale integration of legumes like the pigeon pea in the maize based production systems (Kanyama-Phiri *et al.,* 2009; Bezner-Kerr *et al.,* 2007). Recently, intercropping pigeon pea with groundnut with subsequent incorporation of their residues to the soil has been touted to be a viable soil fertility improving technology (Kanyama-Phiri *et al.,* 2008). This has been attributed to increased N and organic carbon (OC) input by the legumes into the soil. However, the below ground processes and interactions that might enhance N fixation, hence yield and NUE in this system are yet to be well understood. Such processes may include P uptake by legumes along side with biological N fixation and nitrate-N dynamics in the soil during the cereal cropping phase. There is need, therefore, to further investigate for the development of sustainable soil fertility management technologies in the drive to increase crop production and hence food security. To investigate on the possibility of improving soil fertility and NUE through the pigeon pea-groundnut intercrop maize rotation cropping system, a study was initiated in the 2011/12 cropping season, which lasted for two seasons. The objectives were: i) to characterize the soil at the experimental site in terms of the chemical and physical characteristics and hence the fertility status, and ii) to assess changes of key soil fertility parameters namely, %OC, total N (%), pH and exchangeable Ca, as a result of legume biomass incorporation.

2.1 MATERIALS AND METHODS

2.1.1 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).

2.1.2 Materials

Materials used during the study included the following; A photo and thermo insensitive medium duration pigeon pea variety (ICEAP 00557, with a potential yield of up to 2.5 t ha^{-1}) which matures in 5-6 months, a long-duration pigeon pea variety (ICEAP 04000, potential yield of 1.6-2 t ha^{-1}) maturing in 8-9 months, groundnut (CG 7, potential yield of 3 t ha^{-1}), early maturing maize variety (SC 403 potential yield of 6 t ha^{-1}) and triple super phosphate ($Ca(H_2PO_4)_2.H_2O$) as a source of P.

2.1.3 Characterization of the soil at the study site

2.1.3.1 Soil sampling and preparation for laboratory analysis

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.

2.1.3.2 Preparation of the seed bed

The field was then demarcated into three blocks, with each block divided into eight plots that were 20 m x 10 m for planting of the main experiment. Before commencement of the second season, on the same field next to the main experiment a portion of land was demarcated into three blocks, with each block divided into ten plots that were 3 m x 4.5 m for planting of the parallel experiment. In both experiments, ridges were made and spaced at 75 cm apart. All the experiments were laid in a Randomised Complete Block Design (RCBD). For the main experiment legumes (pigeon pea and groundnut) were planted in season one either as monocultures or intercrops, with one plot planted with maize. Legume biomass was incorporated into the soil in some plots (section 2.1.4) in June and September, 2012, before commencement of the second season in December, 2012. All the plots were planted with maize in season two. The legumes were also planted in the parallel experiment in season two like in season one in the main trial. Treatment and agronomic details were as presented under section 2.1.4.

2.1.3.3 Collection of soil sample from each plot after harvest and after biomass incorporation into the soil

In the main experiment, after harvest at the end of season one, soil samples (4 borings from each plot in all the blocks) were taken and a composite sample was made for each plot. Two weeks into the second season, before fertilizer application, soil samples (4 borings from each plot in the blocks) were taken and 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.

2.1.3.4 Laboratory soil 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 P, exchangeable K, Mg and Ca was done by Mehlich 3 extraction procedures (Mehlich, 1984) while OC was determined using the colorimetric method (Schumacher, 2002) and total N was determined by Kjeldahl method (Amin and Flowers, 2004). 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.

2.1.4 The field experiments

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. The amount of biomass produced and incorporated into the soil for each cropping system is presented in Figure 2.0 of this Chapter and Table 4.1, section 4.3.2 under Chapter 4, Appendix 2.5. All the plots were then planted with maize. A parallel experiment laid in RCBD and replicated 3 times along side 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.

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).

2.1.4.1 Effect of cropping system on selected soil properties

In the main experiment effect of cropping system on selected soil properties was assessed by changes observed in selected soil properties after incorporation of biomass into the soil. The selected soil properties were; OC, total N, available P, soil pH and exchangeable Ca.

2.1.4.2 Statistical analysis

All the soil and biomass data were analyzed using Genstat statistical package and were subjected to analysis of variance at 95% level of confidence. Means were separated by the least significant difference ($P<0.05$).

2.2 RESULTS

2.2.1 Characterization of the soils at the study site

The soils' physical and chemical properties at the study site were as presented in Table 2.0.

Table 2.0: 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

2.2.2 Characteristics of the soils at the study site after the first season

Tables 2.1a to 2.2b and Appendices 2.1a to 2.2b, summarize the physical and chemical properties of soils for the main experiment after season one at harvest. The bulk density value both between 0-20 cm and 20-40 cm in all treatment plots was less than 1.6 g cm^3 while soil texture was predominantly sandy clay loam to sandy clay between the two depths. The soil reaction was strongly acid to moderately acid both between 0-20 cm (pH=5.4-5.7) and 20-40 cm (pH=5.4-5.6) (Wendt, 1996) in all the treatment plots (Table 2.1a) (Wendt, 1996). The total nitrogen content was largely low ($\leq$ 0.12%) to marginally adequate ($\geq$ 0.12%) (Wendt, 1996) both between 0-20 cm (0.08-0.14%) and 20-40 cm (0.09-0.13%). The level of soil organic carbon content was medium ($\geq$ 0.88%) (Wendt, 1996) between 0-20 cm (1.1-1.6%) and 20-40 cm (0.9-1.6%) across the treatment plots. Plant available phosphorus was marginally adequate ($\geq$ 19 mg P kg^{-1}) between 0-20 cm (20.6-25.6 mg P kg^{-1}) and marginally adequate between 20-40 cm (16.8-26.6 mg P kg^{-1}). Molybdenum (Mo) content in the soil was high and ranged from 5.4 to 26.4 mg Mo kg^{-1} between 0-20 cm in the soil while between 20-40 cm this ranged from 11.5 to 25.4 mg Mo kg^{-1} (Table 2.1b). The field had adequate (> 0.105 cmol kg^{-1}) exchangeable potassium (K) between 0-20 cm (0.10-0.29 cmol kg^{-1}, 0.30-0.48 cmol kg^{-1}) and between 20-40 cm (0.13-0.35 cmol kg^{-1}, 0.16-0.37 cmol kg^{-1}) while calcium was marginally adequate ($\geq$ 2.04 cmol kg^{-1}) (Wendt, 1996) for crop production.

Figure 2.0 and Appendix 2.5, shows the yield of biomass for the pigeon pea and groundnut. Pigeon pea biomass yields in all the treatments and across the varieties were statistically the same (p>0.05). For groundnut, higher biomass yield was registered in the pure stand and in the medium duration pigeon pea-groundnut intercrop. Overall, the intercrops gave about 21% total biomass yield above the monocultures of pigeon pea and groundnut (Figure 2.0 and Appendix 2.5).

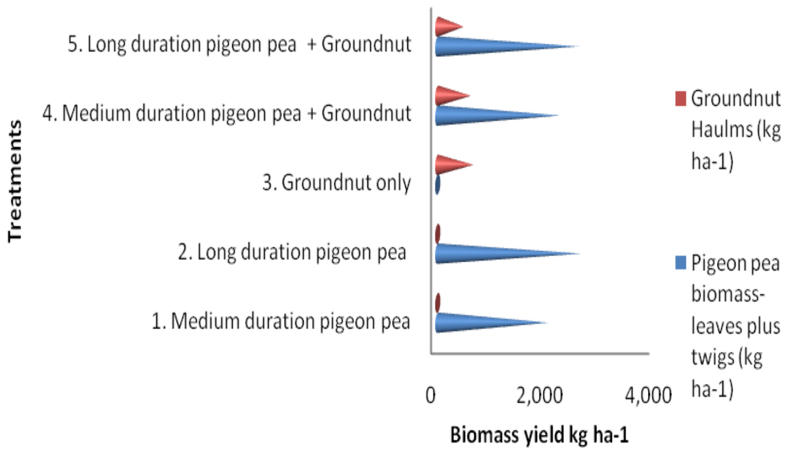

Figure 2.0: Pigeon pea and groundnut biomass yield

Table 2.2 a and b, Appendix 2.1b, show some of the soil chemical properties for the main experiment in the second season after the incorporation of legume biomass. Notably, an increase in the mean level of soil exchangeable Ca was observed in plots where legume biomass was incorporated.

Table 2.1a: Soil physical and chemical parameters for the main experiment after the first season

Treatment	BD g/cc 0-20 cm	BD g/cc 20-40 cm	pH_{H2O} 0-20 cm	pH_{H2O} 20-40 cm	%OC 0-20 cm	%OC 20-40 cm	Total %N 0-20 cm	Total %N 20-40 cm	Total Mo mg kg^{-1} 0-20 cm	Total Mo mg kg^{-1} 20-40 cm
1.Sole maize	1.2	1.2	5.5	5.4	1.4	1.2	0.12	0.12	10.7	16.4
2.Medium duration pigeon pea	1.2	1.3	5.4	5.5	1.3	1.0	0.10	0.12	26.4	22.1
3.Long duration pigeon pea	1.1	1.2	5.6	5.5	1.1	0.9	0.08	0.10	5.4	12.5
4.Sole groundnut	1.2	1.2	5.5	5.4	1.6	1.5	0.14	0.13	22.4	11.5
5.Medium duration pigeon pea + groundnut	1.3	1.3	5.4	5.4	1.4	1.1	0.12	0.09	11.6	14.8
6.Long duration pigeon pea + groundnut	1.2	1.1	5.7	5.5	1.4	1.2	0.12	0.12	9.9	18.4
7.Medium duration pigeon pea + groundnut	1.3	1.2	5.6	5.6	1.4	0.9	0.12	0.12	Trace	25.4
8.Long duration pigeon pea + groundnut	1.2	1.2	5.6	5.5	1.6	1.3	0.14	0.13	Trace	13.1
GM	1.2	1.2	5.5	5.5	1.4	1.4	0.12	0.12	10.8	16.8
CV (%)	11.7	14.2	4.40	3.70	25.5	26.9	25.5	26.9	27.8	32.8
$LSD_{0.05}$	-	-	-	-	-	-	-	-	13.8	12.8

Table 2.1b: Soil chemical parameters for the main experiment after the first season

Treatment	P mg kg^{-1} 0-20 cm	P mg kg^{-1} 20-40 cm	K cmol kg^{-1} 0-20 cm	K cmol kg^{-1} 20-40 cm	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
1.Sole maize	20.6	22.7	0.26	0.17	0.32	0.34	3.30	3.2
2.Medium duration pigeon pea	20.9	18.8	0.13	0.16	0.38	0.36	3.10	4.4
3.Long duration pigeon pea	20.8	16.8	0.16	0.17	0.35	0.28	3.20	3.0
4.Sole groundnut	23.4	17.6	0.10	0.21	0.48	0.52	3.04	3.4
5.Medium duration pigeon pea + groundnut	21.3	18.9	0.25	0.13	0.30	0.31	3.13	2.8
6.Long duration pigeon pea + groundnut	22.1	20.4	0.13	0.35	0.34	0.34	3.52	3.3
7.Medium duration pigeon pea + groundnut	21.4	26.6	0.29	0.20	0.42	0.37	3.87	3.1
8.Long duration pigeon pea + groundnut	25.6	23.4	0.26	0.20	0.42	0.16	3.32	3.8
GM	22.9	20.7	0.20	0.20	0.38	0.34	3.31	3.38
CV (%)	18.2	18.7	47.1	38.3	35.4	35.5	22	20.6
$LSD_{0.05}$	-	7.02	-	-	-	0.21	-	1.2

Table 2.2 a: Selected soil chemical properties for the main experiment after biomass incorporation, second season

Treatment	pH_{H2O} 0-20 cm	pH_{H2O} 20-40 cm	OC(%) 0-20 cm	OC(%) 20-40 cm	Total N(%) 0-20 cm	Total N(%) 20-40 cm
1.Sole maize	5.0	5.1	1.4	1.1	0.09	0.12
2.Medium duration pigeon pea	5.2	5.4	1.5	1.4	0.13	0.12
3.Long duration pigeon pea	5.1	5.0	1.4	1.1	0.07	0.10
4.Sole groundnut	5.3	5.5	1.3	1.3	0.11	0.11
5.Medium duration pigeon pea + groundnut	5.1	5.2	1.3	1.3	0.11	0.11
6.Long duration pigeon pea + groundnut	5.3	5.4	1.7	1.6	0.14	0.11
7.Medium duration pigeon pea + groundnut (biomass not incorporated)	5.1	5.0	1.3	1.3	0.12	0.14
8.Long duration pigeon pea + groundnut (biomass not incorporated)	5.3	5.0	1.6	1.4	0.14	0.12
GM	5.2	5.2	1.4	1.3	0.1	0.1
CV (%)	7.8	8.5	19.0	17.5	19.7	18.53
$LSD_{0.05}$	-	-	0.4	0.4	0.04	0.04

Table 2.2b: Selected soil chemical properties for the main experimemt after biomass incorporation, second season

Treatment	P mg kg^{-1} 0-20 cm	P mg kg^{-1} 20-40 cm	K cmol kg^{-1} 0-20 cm	K cmol kg^{-1} 20-40 cm	Ca cmol kg^{-1} 0-20 cm	Ca cmol kg^{-1}
1.Sole maize	18.34	19.3	0.29	0.26	5.5	4.6
2.Medium duration pigeon pea	19.75	12.9	0.52	0.19	6.6	5.5
3.Long duration pigeon pea	18.63	12.4	0.47	0.17	9.1	8.3
4.Sole groundnut	19.74	13.4	0.39	0.39	9.4	8.0
5.Medium duration pigeon pea + groundnut	18.95	15.6	0.47	0.34	5.8	6.1
6.Long duration pigeon pea + groundnut	19.98	14.7	0.46	0.30	8.9	7.4
7.Medium duration pigeon pea + groundnut (biomass not incorporated)	17.87	14.3	0.42	0.26	5.4	5.3
8.Long duration pigeon pea + groundnut (biomass not incorporated)	19.44	15.5	0.29	0.26	4.9	4.4
GM	19.1	13.5	0.41	0.27	8.63	9.33
CV (%)	27.26	18.2	20.3	36.8	20.7	21.1
$LSD_{0.05}$	-	4.3	0.15	0.18	5.9	8.2

2.3 DISCUSSION

2.3.1 Soil fertility status at the study site

On the experimental site, the soil reaction was moderately acid both between 0-20 cm and 20-40 cm (pH=5.5) in all the treatment plots (Table 2.0). This is attributable to leaching of exchangeable bases, explainable by the soil texure class that was sandy clay loam to sandy clay. The soil reaction suggests that macronutrients like P were likely less available to an extent compared to the micronutrients (Akinrinde, 2006). Low soil pH fixes P as phosphate (s) through the formation of insoluble aluminum and iron phosphates (Sharma *et al.,* 2011). On the other hand, potential for the concentration of soluble metals, especially manganese to toxic level was high, coupled to a high likelihood of a decrease in the populations and the activity of soil micro-fauna that are responsible for the transformation of N, S, and P to plant-available forms (Fernández and Hoeft, 2009), hence the projected low availability.

Furthermore, the total nitrogen content was low ($\leq$0.12%) (Wendt, 1996), both between 0-20 cm and 20-40 cm in the soil. N is inherently low in most soil in Malawi (Phiri *et al.,* 2010) as most soil are highly weathered. This calls for N supplimentation from either inorganic or organic sources for increased crop yields. The level of soil organic carbon content was medium ($\geq$1.4%) both between 0-20 cm and 20-40 cm in the soil, partly due proper crop residues management which abates the rate of SOM turn over in the soil through microbial activities and oxidation of exposed OM. The soil texture which was sandy clay loam to sandy clay a high potential of leaching of mobile nutrient ions like nitrate (NO_3^-), Ammonium (NH_4^+), potassium (K) and magnesium (Mg) (Hodges, 2010) through washing away of the ions beyond the crop root zone by infiltrating and percorating rainfall water. Plant available phosphorus was marginally adequate ($\geq$ 19 mg P kg^{-1}) (Wendt, 1996) at both soil depths, suggesting the need for P supply from mineral sources for increased soil and crop productivity. Total Mo content was around the range (3–15 mg kg^{-1}) reported for surface soils in other parts of the world (Hodges, 2010). However, going by the soil reaction potential for inavailability of Mo for uptake by legumes was high. Mo availability is decreased with increasing soil acidity (Fernández and Hoeft, 2009), due to increasing levels of aluminium and iron oxides which strongly adsorbed the nutrient element (Das, 2014). N deficiency caused by inadequancy of Mo in legumes dependant on BNF is common, more especially on acid mineral soils of the humid and subhumid tropics (Weisany *et al.,* 2013). Molybdenum is a micronutrient specifically for nodulating legumes that form a symbiotic relationship with N fixing bacteria (Weisany *et al.,* 2013). Its essentiality to BNF is very pronounced since the element is part of the 'FeMoCo' cofactor and is at the center of the nitrogen reduction process for most nitrogenases (Weisany *et al.,* 2013). Soil exchangeable K was adequate ($\geq$ 0.105 cmol kg^{-1}) on the site with low (< 0.5 cmol kg^{-1}) Mg content (Wendt, 1996) while calcium was marginally adequate ($\geq$ 2.0-3.5 cmol kg^{-1}) (Wendt, 1996) for crop production.

2.3.2 Effects of biomass incorporation to the soil on selected soil properties

After harvest, before the commencement of the second season, soil data indicated that soil organic carbon and P remained largely in the medium range while plant total soil nitrogen levels stood within the marginally adequate range (Table 2.1a and b). For plant available P in some cases the levels in the soil might have been sustained due to the application of P as TSP. The soil reaction was not impacted by biomass incorporation suggesting that the soils' buffer capacity was not affected with biomass incorporation.

In the short term, liming is recommended for effecting significant changes to soil reaction. The status of OC was not affected with the incorporation of the biomass. Building OC in the soil through biomass incorporation to the soil takes time (Snapp, personal communication). However, after biomass incorporation in season two (Table 2.2a and b), it was noticed that exchangeable calcium levels increased substantially. This could be as a result of the corresponding high Ca yields of the biomass that was returned to the soil.

2.4 CONCLUSION

Generally, the soil chemical characteristics for soil at the experimental site indicate that the soil is of low fertility status. The soil pH which moderately acid suggest possible low availability of the macro plant nutrients for uptake by crops. The largely soil texture which is predominantly sand clay loam to sandy clay suggest potential high leacheability of mobile nutrient ions especially nitrogen as nitrate. Inevitably, if the soil is not properly managed crop yields will be drastically reduced at harvest. Furthermore, NUE of crops cultivated on this soil will be low as the applied nutrients will be rendered unavailable for uptake either due to fixation, soil acidity or leaching. This challenge potentially can be circumvented through incorporation into the soil of high quality organic residues. In the short term to change the soil reaction significantly, liming should be considered. Additionally, for OC to be built sustained biomass incorporation to the soil over time is required.

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CHAPTER 3:

ASSESSMENT OF BIOMASS AND NUTRIENT YIELDS OF MEDIUM AND LONG DURATION PIGEON PEA IN A PIGEON PEA-GROUNDNUT INTERCROPPING SYSTEM

ABSTRACT

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 (13^0 59' 23.2 S", 033^0 38' 36.8 E") 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. Yields were assessed at harvest that included grain and biomass yields. Nutrient accumulation in the grain and biomass was quantified after determination of nutrient concentrations in the respective plant parts. Data were subjected to Analysis of Variance in GENSTAT and means were separated using the least significant difference (LSD). Productivity of intercrops was evaluated using the land equivalent ratio (LER). The assessment of the above ground groundnut biomass ranged from 479-656 kg ha^{-1}, while the leafy biomass yields of the pigeon pea varieties indicates a yields range of 2,034-2,593 kg ha^{-1}. For the nitrogen (N) yields returnable to the soil, 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 significantly ($p<0.05$) higher yields than the monocultures of long duration pigeon pea (41.1 kg N ha^{-1}) and medium duration pigeon pea (41.0 kg N ha^{-1}). Statistically ($p<0.05$), the

lowest N yields were generated by the groundnut sole crop (12.8 kg N ha^{-1}). Overall, the intercrops showed yield advantage (total LER >1.0) compared with the monoculture on equal land area. This is attributable to efficient utilization of growth resources by crops grown in the intercrops.

Key words: Groundnut, double legume intercrop, maize, pigeon pea and rotation

3.0 INTRODUCTION

The smallholder agricultural sector in Malawi is characterized by low productivity and land constraint (Phiri *et al.,* 2012). The latter constraint has been aggravated by increased population growth from 9,933,868 in 1998 to 13,066,320 in 2008, representing an increase of 32% (NSO, 2008). This has exerted 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 and minimal application of soil fertility amendments resulting into decline in soil fertility and productivity in most of the farmers' fields (Phiri *et al.,* 2012). The trend necessitates the generation of agricultural technologies, that would allow for the optimal use of the limited arable land for increased and sustainable 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 more stable in terms of soil fertility, yield and financial returns than monocropping. The stability under intercropping can be attributed to the partial restoration of plant 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. Furthermore, intercropping accords greater financial stability to farmers, making it appropriate for the Malawian labor-intensive smallholder farms. In the event that a crop fails because of unfavourable weather conditions farmers reduce risks for total crop failure by growing more than one crop on their fields (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, which were positionally unavailable. On the otherhand 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).

Annual crop legumes grown in rotation with cereal crops can contribute to the total soil N pool and improve yields of the cereals. Reported annual cereal yield responses to previous legume crops are in the range of 50-80% over yields in cereal-cereal sequences (Hayat, 2005). The yield increase is attributable chiefly to enhanced supply of N to the succeeding cereal crop. Benefits of legumes have also been attributed to improvements in soil structure, reduced insect pests and cereal diseases like yellow spot (*Pyrenophora tritici-repentis*) in wheat (Delane *et al.,* 1996).

A study was conducted at Chitedze Agricultural Research Station in Malawi 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 the contribution by the legumes of the biologically fixed N to the soil N pools in the pigeon pea-groundnut for the subsequent maize.

3.1 MATERIALS AND METHODS

3.1.1 Study site

Details for the study site were as presented in Chapter 2 under section 2.1.1.

3.1.2 Materials

Details of the materials used in the study were as presented in Chapter 2 under section 2.1.2.

3.1.3 Field experiment

Details of the main experiment and the satistical model used for the RCBD were as presented in Chapter 2 under section 2.1.4.

3.1.4 Experimental layout for each treatment plot

The gross plot size was 20 m x 10 m. Open 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 stations 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 one seed at 25 cm per planting station. This was done in January 2012.

3.1.5 Application of triple super phosphate ($Ca(H_2PO_4)_2 . H_2O$)

At planting, 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 boost N fixation by the legumes due to marginally adequate plant available 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 in the groove made on each ridge. While in the sole pigeon pea treatment 8.4 g of TSP was applied per planting station equivalent to 25 kg P ha^{-1}.

3.2 DATA COLLECTION AND ANALYSIS

3.2.1 Soil sample collection

Details on soil sample collection and preparation were as presented in Chapter 2 under section 2.1.3.1.

3.2.2 Rainfall data

It was observed that the study area received moderate amount of rainfall (875 mm) and that dry spells are a common phenomenon. Over the thirteen year period data indicate that the area received more rainfall in the months of December, January and February. The mean annual rainfall (875 mm) is adequate for the production of maize, pigeon pea and groundnut.

3.2.3 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 seedling emergence (Hussain, 2005).

3.2.4 Biomass and grain yields assessment for the pigeon pea

Grain yields assessment was done at physiological maturity of the two pigeon pea varieties. Pods were harvested from a 2 m x 2 m net plot. Shelling was done, then grains and the husks were weighed. The litter was collected from the ground on one planting station (90 cm x 75 cm). This was done in October, 2012 when most leaves had defoliated. Fresh leaves and twigs were also weighed from the 2 m x 2 m net plot. These were oven dried for 72 hours at 70 ^{o}C to constant weights.

3.2.5 Biomass and grain yields assessment for the groundnut

Grain yields assessment was conducted at physiological maturity of the groundnut in June, 2012. Pods were dug from a 2 m x 2 m net plot. Shelling was done, then grains and the husks were 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 weight measured after oven drying at 70^{o}C for 72 hours to constant weights. Agronomic data were collected for the maize plant which include maize grain, stover and rachids yield.

3.2.6 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 formula used was as presented in Chapter 1 under section 1.1.12.

3.2.7 Plant sample analysis

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).

3.2.8 Nutrient yields

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

3.2.9 Statistical analysis

All the data were analyzed using Genstat statistical package and were subjected to analysis of variance at 95% level of confidence. Means were separated by the least significant difference ($P<0.05$).

3.3 RESULTS

3.3.1 Growth rates for the long duration and medium duration pigeon pea

Figure 3.0 and Appendices 3.0 a and b, show the growth rates of the long and medium duration pigeon pea for both intercrops and pure stands. For the first 40 days after planting, medium duration pigeon pea intercropped with groundnut had the highest 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.

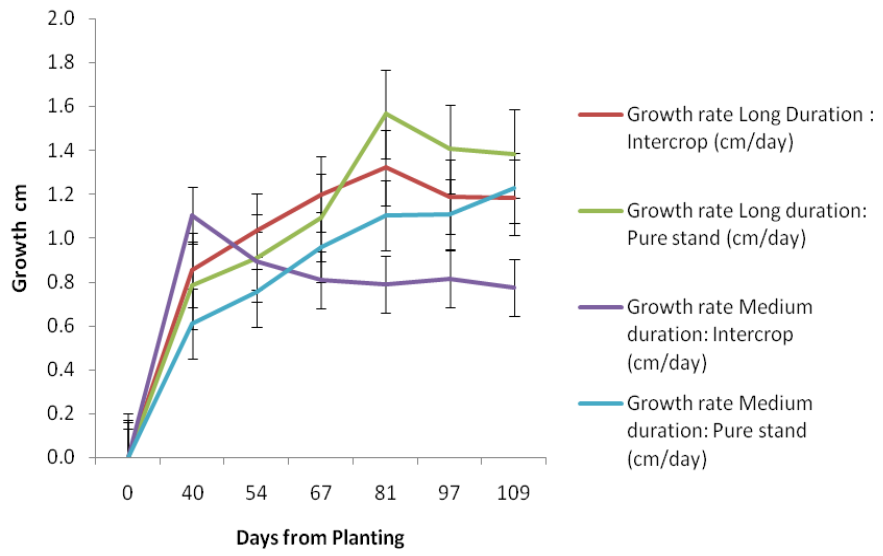

Figure 3.0: Growth rate of long and medium duration pigeon pea in intercrops and pure stands.

Nutrient concentrations in the litter, leaves and twigs for the pigeon pea in the long and medium duration pigeon pea were as presented in Table 3.0a and Appendices 3.2 a-c. No significant differences ($p>0.05$) were observed in the 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, it ranged from 2.4 to 3.4%. In the twigs, the concentration of N ranged from 2.0 to 2.6%.

For P in the same treatments, the 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 concentration of P ranged from 0.14 to 0.19%, for K this ranged from 0.25 to 0.31% in the litter, while for the fresh leaves and twigs, the concentration ranged from 0.78 to 1.51%. For calcium (Ca) no significant differences were observed in the 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 Ca concentration in the fresh leaves were recorded. The highest was registered by the medium duration pigeon pea grown in the pure stand (2.9%) while the lowest concentration of Ca (2.0%) was observed in the long duration pigeon pea-groundnut intercrop.

Table 3.0a: Nutrient concentrations in pigeon pea biomass: Litter (L), Fresh leave (L) and Twigs (T)

Treatment	N(%)			P(%)			K(%)			Ca(%)			
	(L)	(F)	(T)	(L)	(F)	(T)	(L)	(F)	(T)	(L)	(F)	(T)	(L)
1.Sole maize	na	na	na	na	na	na	na	na	na	na	na	na	na
2. Medium duration pigeon pea	0.65	2.4	2.4	0.20	0.33	0.15	0.25	1.51	1.04	1.2	2.6	1.3	0.35
3. Long duration pigeon pea	0.69	2.9	2.0	0.18	0.15	0.17	0.31	1.04	0.78	1.4	2.7	1.9	0.31
5. Medium duration pigeon pea + groundnut	0.59	3.1	2.6	0.30	0.19	0.14	0.28	0.87	0.93	1.6	2.9	1.5	0.36
6. Long duration pigeon pea + groundnut	0.72	3.4	2.3	0.18	0.25	0.19	0.29	0.78	1.51	1.6	2.0	1.8	0.35
7. Medium duration pigeon pea + groundnut (Biomass not incorporated)	0.78	2.9	3.2	0.17	0.16	0.15	0.29	0.69	0.87	1.3	2.0	2.0	0.35
8. Long duration pigeon pea + groundnut (Biomass not incorporated)	0.71	2.4	2.4	0.17	0.26	0.21	0.28	0.93	0.69	1.5	2.6	1.7	0.34
GM	0.69	2.85	2.48	0.20	0.22	0.17	0.28	0.97	0.97	1.5	2.5	1.7	0.34
CV (%)	26.2	15.5	25.7	20.9	27.7	24.1	29.4	20.5	25.5	18	9.4	28.8	9.33
$LSD_{0.05}$	-	0.81	1.2	-	-	-	-	-	-	-	0.4	-	-

na= not applicable

3.3.2 Pigeon pea biomass and nutrient yields: litter, fresh leaves and twigs

Pigeon pea biomass and nutrient yields for the litter, fresh leaves and the twigs on a hectare basis was as presented in Table 3.0b and Appendices 3.2 a-c. 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 ($p>0.05$) were observed in the biomass yield for the litter and fresh leaves across the treatments. For the litter, yields ranged from 1,047 to 1,753 kg ha^{-1} in the treatments where biomass was incorporated into the soil. For the twigs the yield ranged from 332 to 553 kg ha^{-1}. Significant differences ($p<0.05$) were observed in the yields of twigs with the sole crop of long (861 kg ha^{-1}) and medium duration pigeon pea (654 kg ha^{-1}) registering the highest yield. The long duration pigeon pea-groundnut intercrop (494 kg ha^{-1}) and the medium duration pigeon pea-groundnut intercrop (370 kg ha^{-1}) gave the lowest yield.

For the long duration pigeon pea-groundnut intercrop and the medium duration pigeon pea-groundnut intercrop, no significant differences were observed in the N yields for the litter and fresh leaves across the treatments. This ranged from 7.7 to 11.6 kg N ha^{-1} for the litter, while for the fresh leaves this ranged from 11.7 to 16.1 kg N ha^{-1}. For the twigs, significant yields 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 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 P yields, no significant differences were observed across the treatments in the litter, fresh leaves and twigs. This ranged from 2.2 to 3.2 kg P ha^{-1} for the litter, while for the fresh leaves, this ranged from 0.77 to 0.97 kg P ha^{-1}. In the twigs, the yields of P ranged from 0.91 to 1.7 kg P ha^{-1}. For the yields of K, no significant differences were observed across the treatments in the litter and fresh leaves (Table 3.0b). This ranged from 9.7 to 12.3 kg K ha^{-1} for the litter, while for the fresh leaves, this ranged from 3.8 to 6.5 kg K ha^{-1}. Significant differences in the yields of K in the twigs were observed. The highest yields of K were 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 Ca yields, no significant differences were observed across the treatments in the litter, fresh leaves and twigs. Calcium yields in the litter ranged from 20.1 to 26.5 kg Ca ha^{-1}. While in the fresh leaves this was 6.9 to 12.3 kg Ca ha^{-1}. For the twigs this ranged from 7.0 to 11.5 kg Ca ha^{-1}.

Table 3.0b: Pigeon pea biomass and nutrient yields: Litter (L), fresh leaves (FL) and twigs (T)

Treatment	Yield kg ha^{-1}			N kg ha^{-1}			P kg ha^{-1}			K kg ha^{-1}			Ca kg ha^{-1}		
	L	F	T	L	F	T	L	F	T	L	F	T	L	F	T
1.Sole maize	na	na	na	na	na	na	na	Na	na	na	na	na	na	na	na
2. Medium duration pigeon pea	1,047	531	654	7.7	13.5	19.8	2.4	0.97	1.5	9.7	5.8	4.5	23.5	10.6	9.8
3. Long duration pigeon pea	1,235	479	861	8.0	15.6	17.5	2.2	0.82	1.7	11.7	3.8	5.2	26.5	12.3	11.5
5. Medium duration pigeon pea + groundnut	1,753	460	370	8.9	16.1	11.6	3.2	0.80	1.06	10.7	4.8	2.4	20.1	12.0	7.0
6. Long duration pigeon pea + groundnut	1,620	332	494	11.6	11.7	12.7	2.9	0.77	0.91	12.3	6.5	3.6	26.4	6.9	8.7
7. Medium duration pigeon pea + groundnut	1,467	217	275	10.7	6.5	10.6	2.6	0.42	1.06	9.0	2.1	1.9	16.3	5.2	11.2
8. Long duration pigeon pea + groundnut	2,114	123	760	12.0	6.2	25.4	3.6	0.35	3.9	9.5	3.0	2.8	17.4	4.7	13.5
GM	1,319	306	487	8.4	9.9	13.9	2.4	0.6	1.4	9.0	3.7	2.9	18.6	7.4	8.8
CV (%)	48.9	37.1	30	32.7	35.4	23.8	43.1	38.3	35.8	22.1	33.2	44.1	37.7	33.7	20.0
$LSD_{0.05}$	-	255	327	-	9.3	8.5	-	0.61	1.30	-	-	0.5	-	6.6	-

3.3.3 Concentration of nutrients in groundnut pods, haulms and grain

Nutrient concentration in the pods, haulms and grains for the groundnut in different treatments was as presented in Table 3.1a and Appendices 3.3 d and e. No significant differences ($p>0.05$) were observed in the 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, ranged from 2.4 to 3.2%. In the grain, the concentration of N ranged from 4.6 to 6.5%. For P in the same treatments, the concentration in the haulms and grains was statistically the same, but statistically different in the pods (Table 3.1a). Higher 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 P concentrations for the pods were noted in the groundnut intercropped with long duration pigeon pea (0.09%) in treatment six.

For the haulms P concentrations 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 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 K concentration ranged from 0.84 to 1.02%. For calcium (Ca) no significant differences were observed in the 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 ($p<0.05$) for Ca concentrations in the grain were recorded. The highest concentrations were registered by the sole groundnut treatment (0.84%) while the other treatments had statistically similar mean concentrations of Ca.

Table 3.1a: Concentration of nutrients in groundnut pods (Ps), haulms (H) and grain (G)

Treatment	N(%)			P(%)			K(%)			Ca(%)		
	Ps	H	G	Ps	H	G	Ps	H	G	Ps	H	G
4. Sole groundnut	0.93	2.4	4.6	0.10	0.30	0.82	1.30	0.33	0.87	0.44	0.86	0.84
5. Medium duration pigeon pea + groundnut	0.84	3.2	6.1	0.12	0.24	0.87	1.47	0.43	0.91	0.47	0.81	0.45
6. Long duration pigeon pea + groundnut	0.61	2.4	5.5	0.09	0.17	0.81	0.99	0.59	0.86	0.52	1.08	0.44
7. Medium duration pigeon pea + groundnut	0.86	2.9	6.5	0.12	0.17	0.92	1.16	0.42	1.02	0.57	0.93	0.47
8. Long duration pigeon pea + groundnut	1.04	2.7	5.0	0.10	0.15	0.85	1.12	0.48	0.84	0.66	0.74	0.44
GM	0.93	2.4	4.6	0.10	0.30	0.82	1.30	0.33	0.87	0.44	0.86	0.84
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
$LSD_{0.05}$	-	-	-	0.03	-	-	-	-	-	-	-	0.08

3.3.4 Groundnut pods, haulms, grain and nutrient yields

Groundnut biomass and nutrient yields for the pods, haulms and the grain on a hectare basis were as presented in Table 3.1b and Appendices 3.3 e and 4.0. No significant differences were observed in the biomass yields for the pods, haulms and grain across the treatments. For the pods, this ranged from 136 to 619 kg ha^{-1}. While for the haulms this ranged from 413 to 656 kg ha^{-1}. The grain yields ranged from 549 to 873 kg ha^{-1}.

For the N yields, significant differences were observed for the pods across the treatments in which biomass was incorporated. Higher N yields were observed for 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 P yields, no significant differences were observed across the treatments in the pods, haulms and grains. This ranged from 0.15 to 0.20 kg P ha^{-1} for the pods. For the haulms statistically higher 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 yields ranged from 4.7 to 6.7 kg P ha^{-1}.

For K yields, no significant differences were observed across the treatments in the pods, haulms and grain. This ranged from 1.9 to 2.8 kg K ha^{-1} for the pods, while for the haulms, this ranged from 2.0 to 3.5 kg K ha^{-1}. In the grain this ranged from 4.3 to 7.1 kg K ha^{-1}. Significant differences in the yield of K in the twigs, was observed. The highest yields of K were 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 Ca yields, no significant differences were observed across the treatments in the pods. The calcium yields in the litter ranged from 20.1 to 26.5 kg Ca ha^{-1}. While in the fresh leaves this was 6.9 to 12.3 kg Ca ha^{-1}. For the twigs this ranged from 7.0 to 11.5 kg Ca ha^{-1}.

Table 3.1b: Groundnut pods (Ps), haulms (H), grain (G) and nutrient yields

Treatment	Yields			N			P			K			Ca		
	kg ha^{-1}														
	Pods	Haulms	Grain	(Ps)	(H)	(G)	(Ps)	(H)	(G)	(Ps)	(H)	G)	(Ps)	(H)	(G)
4. Sole groundnut	188	656	647	2.4	12.8	29	0.17	1.87	5.3	2.8	3.5	4.3	1.1	5.7	9.7
5. Medium duration pigeon pea + groundnut	619	612	569	1.8	13.6	28	0.15	1.41	4.7	2.1	2.8	5.7	0.7	1.4	11
6. Long duration pigeon pea + groundnut	182	479	691	1.0	11.5	38	0.16	0.81	6.1	2.1	2.0	7.1	1.1	4.0	7.7
7. Medium duration pigeon pea + groundnut	136	498	549	1.3	14.0	30	0.19	0.86	4.7	1.9	2.7	5.3	0.6	4.7	9.7
8. Long duration pigeon pea + groundnut	240	413	873	2.5	10.9	40	0.20	0.60	6.7	2.0	2.2	6.6	1.1	3.1	13
GM	273	532	666	1.8	12.6	33	0.2	1.1	5.5	2.2	2.6	5.8	0.9	3.8	10
CV (%)	61.0	9.9	50.7	30	22.0	30	45	56	36	28	32	37	32	20.0	22
$LSD_{0.05}$	-	-	-	1.0	-	-	-	1.18	-	-	-	-	-	1.7	-

3.3.5 Nitrogen and phosphorus yields returned to the soil

Table 3.2 shows the calculated sum total of nitrogen and phosphorus yields returned to the soil after biomass incorporation in each treatment that had the biomass incorporated into the soil. Estimated yields for N and P returned to the soil for the intercrops were 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 yields 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 N yield was generated by the groundnut sole crop (12.8 kg N ha^{-1}). Significant differences were obtained in the yields of P across the treatments. For the treatments that had the biomass incorporated 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 3.2: Calculated nitrogen and phosphorus yields returned to the soil by the legumes where biomass was incorporated to the soil

	N			N			N returned to soil	P			P			P returned to soil
	PPL	PPF	PPT	GNP	GNH	GNG		PPL	PPF	PPT	GNP	GNH	GNG	
							kg ha^{-1}							
2. Medium duration pigeon pea	7.7	13.5	19.8	-	-	-	41.0	2.4	0.97	1.5	-	-	-	4.9
3. Long duration pigeon pea	8.0	15.6	17.5	-	-	-	41.1	2.2	0.82	1.7	-	-	-	4.7
4. Sole groundnut	-	-	-	2.4	12.8	29.0	12.8	-	-	-	0.17	1.9	5.3	1.9
5. Medium duration pigeon pea + Groundnut	8.9	16.1	11.6	1.8	14.0	27.7	50.6	3.2	0.80	1.1	0.15	1.41	4.7	6.5
6. Long duration pigeon pea + Groundnut	11.6	11.7	12.7	0.98	13.6	38.1	49.6	2.9	0.77	0.91	0.16	0.81	6.1	5.4
GM	9.1	14.2	15.4	1.7	13.4	31.6	39.0	2.7	0.84	1.3	0.16	1.37	5.7	4.7
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
$LSD_{0.05}$	-	9.3	8.5	1.02	-	-	2.0	-	0.61	1.28	-	-	-	0.2

PPL= Pigeon pea litter, PPF= Pigeon pea fresh leaves. PPT= Pigeon pea twigs. GNP= Groundnut pods, GNH= Groundnut haulms, GNG= Groundnut grain

Table 3.3 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 3.3: Evaluation of the productivity of the intercrop against the monocultures: biomass

Treatment	Pigeon pea biomass-leaves plus twigs (kg ha^{-1})	Ground nut Haulms (kg ha^{-1})	Partial LER= ∑ (Ypi/Ymi) -Pigeon pea	Partial LER= ∑ (Ypi/Ymi) Groundnut	LER = ∑ (Ypi/ Ymi)
2. Medium duration pigeon pea	2,034	-	-	-	-
3. Long duration pigeon pea	2,636	-	-	-	-
4. Sole groundnut	-	656	-	-	-
5. Medium duration pigeon pea + groundnut	2,245	612	1.10	0.93	2.03
6. Long duration pigeon pea + groundnut	2,593	479	0.98	0.73	1.71
GM	2,377	582.3	-	-	-
CV (%)	29.2	9.9	-	-	-
$LSD_{0.05}$	-	98.9	-	-	-

LER=Land equivalent ratio

3.4 DISCUSSION

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

Pigeon pea has a slow initial growth rate (Sharma *et al.,* 2010). Under this study, height measurements commenced at three weeks from emergence of the pigeon pea. At this point in time potentially the growth rate for the crop had increased. In general, for the first forty days after planting, the medium duration pigeon pea intercropped with groundnut had the highest growth rate than the rest of the treatments. 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 with the observation made in the medium duration pure stand in which a gradual slowing down of the growth rate was noticed. The observed trends could be attributed to increased competition for growth factors i.e. solar radiation, nutrients and moisture, in the intercrop between the pigeon pea and groundnut (Olujobi *et al.,* 2013). In the pure stand, the competition effect might have been less pronounced in the sole medium duration pigeon pea due to the absence of the groundnut crop (Olujobi *et al.,* 2013), hence the gradual decrease 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. This trend could not be explained. After this phase growth rate increased sharply in the pure stand and eventually slowed down, while in the intercrop growth rate decreased slowly.

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

In general, high variability in the yields data was observed for the crops, attributable to competition for growth factors across the cropping systems that impacted on yields. The evaluation of the intercrops against the monocultures (Table 3.3) 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 and Gibbons, 2002; Lingaraju *et al.,* 2008; 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 3.1b and 3.2). The advantage of the pigeon pea-groundnut double legume intercropping system over the monocultures of either of the legumes was fortified further by the calculated yields of nitrogen obtain from the system. Both the medium duration and long duration pigeon pea-groundnut intercrop gave statistically similar nitrogen yields (Table 3.3) as N concentrations and biomass yields that were the basis for quantification were similar (Tables 3.0b and 3.3). This was higher than the yields of nitrogen that were generated by the monocultures of the two legumes with the groundnut sole crop generating the lowest yields of nitrogen. It is worthwhile to note that the nitrogen yields for the pigeon pea monocultures and the pigeon pea-groundnut intercrop could have been slightly higher given the fact that quantification of nitrogen yields in the roots and stems of the legume erroneously was not conducted hence this was not included in the assessment. Sanginga and Woomer (2009) indicated that intercropping systems use more efficiently growth factors since they capture more radiation and utilize better the available water and nutrients, reduce pests, diseases and suppress weeds. The legume biomass was incorporated into the soil. Going by the yields 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 for enhanced crop yields. 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 yields while reducing the cost accrued by purchasing the external source of nitrogen.

The biomass yields for P across the treatments were very low rendering the biomass a poor source of P for uptake by the suceeding maize crop. The result resonates with the report by Smithson and Giller, (2002) who indicated that biomass P content is largely too low to provide enough P for annual crops. As such supply of phosphorus requirements to the succeeding maize crop using the legume biomass alone was virtually not possible. This was further aggravated by the prevailing soil reaction which tends to increase fixation of the nutrient (Smithson and Giller, 2002). Use of external mineral source of phosphorus on the subsequent maize crop is therefore indispensable. For increased soil productivity, phosphorus must be added at higher rates than is removed by crops inorder to offset the deficit of plant available P due to conversion of the element to plant-unavailable forms, or P fixation (Smithson and Giller, 2002).

3.5 CONCLUSION

The study revealed that the soil on which the experiment was conducted was predominantly sandy clay loam, with variable pH. The soil reaction was moderately acid (5.5) (Wendt, 1996). The soil reaction might have reduced the availability of the macronutrients for crop uptake. This was further compounded by the inherently low soil N, marginally adequate soil P, Ca and low Mg content. Though P was externally supplied through TSP to make up for the shortfall, the rate used might not have been enough to offset a possible high P 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 yields of the groundnut and extremely low grain yields 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.

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CHAPTER 4:

INSITU ASSESSMENT OF SOIL NITRATE-NITROGEN IN THE PIGEON PEA-GROUNDNUT INTERCROPPING-MAIZE ROTATION SYSTEM: IMPLICATIONS ON NITROGEN MANAGEMENT FOR INCREASED MAIZE PRODUCTIVITY

ABSTRACT

A study on the assessment of the effect of biomass incorporation in the soil on the level of soil nitrate nitrogen (NO_3^-–N), was conducted in a pigeon pea-groundnut intercrop-maize rotation cropping system at Chitedze Agricultural Research Station (13^o 59' 23.2" S, 033^{o}38' 36.8" E) in the 2012/2013 cropping season. In the 2011/2012 cropping season, eight treatments replicated three times laid in a randomized complete block design, with monocultures and intercrops of either long (ICEAP 04000) and medium duration (ICEAP 00557) pigeon pea with groundnut (CG 7) planted. At harvest, legume biomass was incorporated to the soil in some of the plots. Maize was planted in the 2012/2013 cropping season and NO_3^- data collected insitu from emergence at 0-20 cm and 20-40 cm depth over a period of three weeks. This was done before top dressing with urea. This was conducted at an interval of four days over a period of three weeks and six days. The assessment was done using a Horiba NO_3^- meter for soil (B-342). Means for NO_3^- level from the four points for each soil depth in each plot were computed. The corrected data was transformed into NO_3^-–N by multiplying by a factor of 0.23. The data were subjected to the analysis of variance using GENSTAT. Means were separated using the least significant difference (LSD). The results from the study suggest that there was high (> 100 mg L^{-1}) NO_3^-–N in the soil solution in all plots over the study period (106.4 mg L^{-1} to 463.1 mg L^{-1}). In general, soil NO_3^-–N was higher between 20-40 cm than between 0-20 cm, a result of leaching. This was attributable to the sandy clay loam texture of the soil and the low to medium level of SOM. Potentially, the high levels of soil NO_3^-–N in the plots declined over the season due to uptake by the maize crop and leaching losses, justifying the need for N supplementation from mineral fertilizer into this system for the realization of reasonably high maize yields.

Key Words: Groundnut biomass, Intercropping, nitrate-nitrogen, pigeon pea biomass

4.0 INTRODUCTION

In Malawi maize yields are limited principally by nitrogen (N) defficiencies in soils under cultivation (Phiri *et al.,* 2010). To circumvert this impedement, use of mineral N fertilizer for increased yields has been advocated for decades. However, with escalation of the fertilizer prices on the market, this option has proved to be beyond reach of the resource poor smallholder farmers (Phiri *et al.,* 2010). Furthermore, the sole use of mineral fertilizers on many smallholder farms has led to general physical and chemical degradation of the soil (Maida, 2005). This has severely undermined the productivity of the soils in Malawi. To address the challenge, an array of soil rejuvinating technologies have been proposed. The premier method appears to be the large scale integration of legumes like the pigeon pea and groundnut in the maize production systems and the incorporation of their biomass into the soils (Bezner-Kerr, 2007). A systematic integrating of legumes into the predominantly maize production system has been proposed which is the pigeon pea-groundnut intercropping system in rotation with maize (Kanyama-Phiri *et al.,* 2008). Phiri *et al.* (2013), reported that the system can generate substantial amounts of nitrogen rich biomass which upon incorporation into the soil, in a legume-cereal rotation system, the biomass can improve soil fertility thereby leading to increased maize yields. The improvement in soil fertility is attributable to increase in the soil's ability to retain nutrients, buffer soil pH, increase the soil's water holding capacity and the nutrients released upon the decomposition and mineralization of the biomass (Krull *et al.,* 2004) particularly N.

In this system, the prime nutrient element, released by the incorporated, decomposing and mineralizing pigeon pea and groundnut residues, is the organically bound N. The soil microbe mediated process of decomposition and N mineralization, converts the organically bound N into plant available forms namely ammonium nitrogen (NH_4^+–N), and nitrate nitrogen (NO_3^-–N) (Deenik, 2006). Uwah *et al.* (2009) reported that NO_3^- or NO_3^-–N is the major form of N absorbed by plants. Currently, in Malawi, little is known on the impact of the incorporation of pigeon pea and groundnut biomass on soil NO_3^-–N and the implication of this effect on maize production. A study therefore, was conducted, to assess the effect of the biomass incorporation on soil NO_3^-–N in the pigeon pea-groundnut intercropping-maize rotation system. It was hypothesized that the assessment would help in the assertion of the implication of this effect on soil N management and maize production. Estimates of mineral fertilizer N required for maize production are functions of expected yields, the amount of residual soil NO_3^-–N, SOM and other sources of N, timing of application and price of mineral fertilizer (Shapiro *et al.,* 2008). Residual NO_3^-–N in soil is an important N source for crops, and correlates with crop yields (Ferguson *et al.,* 2002; Fan and Hao, 2003).

4.1 MATERIALS AND METHODS

4.1.1 Study site

Details on the location of the study site are as presented in Chapter 2 section 2.1.1.

4.1.2 Materials

Materials used during the study included the following; biomass of a photo and thermo insensitive medium duration pigeon pea variety (ICEAP 00557, whose potential yield is up to 2.5 t ha^{-1}) and matures in 5-6 months; biomass of a long-duration pigeon pea variety (ICEAP 04000, potential yield is 1.6-2 t ha^{-1}) maturing in 8-9 months; biomass of groundnut (CG 7 whose potential yield is 3 t ha^{-1}); early maturing maize variety (SC

403 with a potential yield of 6 t ha^{-1}) and triple super phosphate (TSP), $Ca(H_2PO_4)_2$. H_2O. To generate data the following were used; Horiba NO_3^- meter for NO_3^- soil, a digital pH meter, Hygrothermo, distilled water; plastic bottles, beakers, centrifuge tubes, soil auger, and a wash bottle.

4.1.2 Experimental design

Details on expelimental design and layout are as presented in Chapter 2 under section 2.1.4.

4.2 DATA COLLECTION AND ANALYSIS

4.2.1 Soil sample collection after biomass incorporation to the soil preparation and laboratory analysis

Details of soil sample collection after biomass incorporation to the soil, preparation and laboratory analysis were as described in Chapter 2 under section 2.1.3.3.

4.2.2 Insitu measurement of soil pH, soil temperature and soil humidity

Soil pH_{H_2O}, was measured insitu using a digital pH meter. This was calibrated before making the measurements. Soil temperature and humidity were measured using a hygrothermo. The assessment of these parameters was done at the depth of 0-20 cm and 20-40 cm in the soil. Measurement was done at four positions within each plot for the respective soil depths. Means of the measurements for each parameter in the respective plots were computed thereafter.

4.2.3 Soil nitrate-nitrogen

Soil NO_3^- level was assessed after every three days over a period of four weeks for seven times from the emergence of maize using Horiba NO_3^- meter for soil (B-342).

Data was collected after every three days within the stated time frame. The assessment was conducted from 16 December, 2012 to 10 January, 2013. Soil NO_3^- was measured on 16, 20, 24, 29 December 2012 and 1, 6, and 10 January, 2013. The assessment was done on four different points in each treatment plot for the soil depths of 0-20 cm and 20-40 cm. Soil nitrate was measured according to the procedure by Hall and Lockhart. Calibration of the NO_3^- meter was done on each day before making measurements. Means of the NO_3^- level from the four points for the respective depth in each plot were computed. The corrected data was then transformed into NO_3^-–N by multiplying by a factor of 0.23.

In the parallel experiment after harvest, the legume biomass was incorporated (one ridge in each treatment plot) in May, 2013 for one month. The ridges were watered at an interval of three days for a fortnight as a way of simulating wet soil conditions that prevail during the rainy season and also to facilitate decomposition and mineralization of the biomass. Composite soil samples from 0-20 cm and 20-40 cm were collected from all the plots. The composite samples were made from soil collected on five points on the ridge. Soil NO_3^- measurements using the meter, transformed to NO_3^-–N, were done on the samples. Measurement of NO_3^-–N was also performed on the samples using the KCl method (Miller and Sonon) for the correlation of the KCl and the digital nitrate meter method for soil NO_3^-–N measurement.

4.2.4 Daily rainfall and temperature reading during the data collection period

The study was conducted in the months of December, 2012, January, May and June, 2013. Daily rainfall and temperature data for these months were obtained from Chitedze Meteorogical Station (Appendices 4.0a to 4.2d).

4.2.5 Statistical analysis

All the data were analyzed using Genstat statistical package and were subjected to analysis of variance at 95% level of confidence. Means were separated by the least significant difference ($P<0.05$)

4.3 RESULTS

4.3.1 Soil pH, soil temperature, humidity, total nitrogen and organic carbon content

Table 4.0 and Appendinces 4.1-4.4, summarizes the soil pH, soil temperature and humidity as recorded on the first day of the assessment. Also included is second season data after biomass incorporation to the soil, for total nitrogen and organic carbon content in the soil. The results indicate that the mean soil reaction was acid to moderately acid both between 0-20 cm (pH=5.4-5.7) and between 20-40 cm (pH=5.4-5.6) (Wendt, 1996) in all the treatment plots. Total nitrogen was low (<0.12%) both between 0-20 cm (0.09%) and 20-40 cm (0.11%) to marginally adequate (≥ 0.12%) (0.12-0.14%) in the sampled levels. It is worth while to note that total N between 0-20 cm was low in treatment plots 1 and 3. This was high in other treatment plots for this sampled depth. Organic carbon was marginally adequate (≥ 0.88%) (Wendt, 1996) both between 0-20 cm (1.08-1.63%) and 20-40 cm (1.17-1.55%). Soil temperature ranged from 25.9 to 27.2 ^{o}C between 0-20 cm and 25.9 to 27.1 ^{o}C between 20-40 cm.

Table 4.0: Soil pH, soil temperature, humidity, total nitrogen and organic carbon content

Treatment	pH_{H2O} 0-20 cm	pH_{H2O} 20-40 cm	OC (%) 0-20 cm	OC (%) 20-40 cm	Total N(%) 0-20 cm	Total N(%) 20-40 cm	Soil Temperature (^oC) 0-20 cm	Soil Temperature (^oC) 20-40 cm	Soil Humidity (%) 0-20 cm	Soil Humidity (%) 20-40 cm
1.Sole maize	5.5	5.4	1.08	1.42	0.09	0.12	26.2	26.2	75.7	77.8
2.Medium duration pigeon pea	5.4	5.5	1.50	1.36	0.13	0.12	26.9	26.7	73.6	75.0
3.Long duration pigeon pea	5.6	5.5	1.10	1.17	0.07	0.11	25.9	25.9	75.2	77.2
4.Sole groundnut	5.5	5.4	1.28	1.34	0.11	0.11	26.3	26.2	77.5	79.8
5.Medium duration pigeon pea + groundnut	5.4	5.4	1.29	1.32	0.11	0.11	26.1	25.9	77.6	80.9
6.Long duration pigeon pea + groundnut	5.7	5.5	1.63	1.35	0.14	0.11	27.2	26.9	73.5	74.7
7.Medium duration pigeon pea + groundnut biomass not incorporated	5.6	5.6	1.31	1.55	0.12	0.13	25.7	25.7	79.9	81.0
8.Long duration pigeon pea + groundnut biomass not incorporated	5.6	5.5	1.58	1.39	0.14	0.12	27.1	27.1	76.8	77.6
GM	5.5	5.5	1.35	1.36	0.11	0.12	26.4	26.3	76.2	78.0
CV (%)	4.4	3.70	33.6	17.2	19.72	17.75	3.8	3.6	3.6	4.0
$LSD_{0.05}$	-	-	-	-	0.04	-	-	-	-	-

4.3.2 The amount of biomass produced by the legumes and incorporated into the soil

The biomass yields for the legume monocultures and legume intecrops were as presented in Table 4.1, Appendix 2.5. All the biomass were ploughed under in treatment plot 2 to 6. The weighed leafy biomass ploughed under was as shown below. Stems for pigeon pea were also ploughed under but these were not weighed, erroneously.

Table 4.1: The amount of biomass produced by the legumes and incorporated into the soil

Treatment	**Total pigeon pea biomass (leaves plus twigs) (kg ha^{-1})**	**Groundnut Haulms (kg ha^{-1})**	**Total biomass Incorporated (kg ha^{-1})**
2. Medium duration pigeon pea	2,034	na	2,034
3. Long duration pigeon pea	2,636	na	2,636
4. Groundnut only	na	656	656
5. Medium duration pigeon pea + groundnut	2,245	612	2,857
6. Long duration pigeon pea + groundnut	2,593	479	3,072
GM	2,377	582	1,876
CV (%)	29.2	9.9	30.0
$LSD_{0.05}$	-	98.9	932

na= not applicable

4.3.3 Level of soil nitrate-nitrogen measured over the four week period

Table 4.2 and Appendices 4.5 to 4.17, shows the level of soil nitrate-nitrogen measured over the period of three weeks and five days in the month of December, 2012 and January, 2013.

On the first, day the amount of soil NO_3^-–N between 0-20 cm ranged from 243.7 to 456.4 mg L^{-1}. Significant differences ($p<0.05$) were observed in the amount of soil NO_3^-–N across the treatment plots at this depth. A statistically higher ($p<0.05$) amount of soil NO_3^-–N was recorded in treatment plot 8 (456.4 mg L^{-1}) compared with the rest of the treatment plots. In the soil between 20-40 cm there was no significant difference ($p>0.05$) in the level of NO_3^-–N across treatment plots. This ranged from 249.6 to 444.9 mg L^{-1}. Except in treatment plot 3, 5 and 8, soil NO_3^-–N was higher between 20-40 cm than between 0-20 cm.

For the second day measurements, no statistical differences were observed in the level of soil NO_3^-–N across treatment plots both between 0-20 cm and 20-40 cm in the soil. This ranged from 161.7 to 369.2 mg L^{-1} between 0-20 cm and 252.3 to 409.5 mg L^{-1} between 20-40 cm in the soil. All treatment plots apart from treatment plot 2 had higher NO_3^-–N between 20-40 cm than between 0-20 cm in the soil.

On the third day of data collection, the amount of soil NO_3^-–N between 0-20 cm ranged from 149.6 to 300.3 mg L^{-1}. A Significantly higher ($p<0.05$) amount of soil NO_3^-–N was recorded in treatment plot 6 (300.3 mg L^{-1}) compared with the rest of the treatment plots. Between 20-40 cm in soil there were no differences in the level of NO_3^-–N across treatment plots. This ranged from 198.8 to 410.4 mg L^{-1}. On this day, across all the treatment plots, soil NO_3^-–N was higher between 20-40 cm than between 0-20 cm.

On the fourth day of measurement, no statistical differences were observed in the level of soil NO_3^-–N across treatment plots both between 0-20 cm and 20-40 cm in the soil. This ranged from 278.5 to 444.9 mg L^{-1} between 0-20 cm and 276.9 to 443.3 mg L^{-1} between 20-40 cm. All treatment plots except treatment plot 1, 2 and 3 had higher NO_3^-–N between 20-40 cm than between 0-20 cm.

On day number five, the amount of NO_3^-–N ranged from 265.7 to 463.1 mg L^{-1} between 0-20 cm and 294.5 to 452.6 mg L^{-1} between 20-40 cm in the soil. A significantly higher ($p<0.05$) amount of soil NO_3^-–N was recorded in treatment plot 8 both between 0-20 cm (463.1 mg L^{-1}) and 20-40 cm (452.6 mg L^{-1}) in the soil, compared with the rest of the treatment plots. Except for treatment plot 1, 2, 4 and 8 soil NO_3^-–N was higher in the latter than former depth level.

On the sixth day of data collection, amount of NO_3^-–N ranged from 106.6 to 324.0 mg L^{-1} between 0-20 cm and 139.9 to 375.0 mg L^{-1} between 20-40 cm. Statistical differences ($p<0.05$) were observed in the mean amount of soil NO_3^-–N between 0-20 cm. This was significantly higher in treatment plot 4 (328.0 mg L^{-1}) and treatment plot 8 (324 mg L^{-1}). The lowest amount was recorded in treatment plot 1 (106.4 mg L^{-1}) and treatment plot 2 (150.1 mg L^{-1}). Except for treatment plot 2 soil NO_3^-–N was higher between 20-40 cm than between 0-20 cm.

On the seventh day, no significance differences were observed in the amount of NO_3^-–N across treatment plots between 0-20 cm in the soil. This ranged from 130.9 to 226.4

mg L^{-1}, while between 20-40 cm it ranged from 144.0 to 233.1 mg L^{-1}. A significantly higher ($p<0.05$) amount of soil NO_3^-–N was recorded in treatment plot 3 (233.1 mg L^{-1}) and treatment plot 5 (227.4 mg L^{-1}). The lowest amount of NO_3^-–N was registered in treatment plot 7 (144.0 mg L^{-1}). Minus treatment plot 1, 4, and 8, soil NO_3^-–N was higher between 20-40 cm than between 0-20 cm.

Table 4.2: Soil nitrate-nitrogen in level in plots three weeks from the emergence of maize, second season

	Day 1		Day 2		Day 3		Day 4		Day 5		Day 6		Day 7	
	0-20cm	**20-40 cm**	**0-20 cm**	**20-40 cm**	**0-20 Cm**	**20-40 cm**	**0-20 cm**	**20-40 cm**	**0-20 cm**	**20-40 cm**	**0-20 cm**	**20-40 cm**	**0-20 cm**	**20-40 cm**
Treatments	**mg/L**													
1.Sole maize	356.8	366.4	161.7	263.1	214.3	276.6	390.0	388.4	406.6	378.2	106.4	130.9	179.0	175.3
2.Medium duration pigeon pea	356.8	376.9	296.6	252.3	211.6	299.3	394.1	392.5	420.0	383.6	150.1	144.1	186.4	211.4
3.Long duration pigeon pea	300.2	249.6	369.2	409.5	149.6	198.8	331.9	330.3	323.2	354.9	283.0	328.0	219.2	233.1
4.Sole groundnut	335.7	367.3	299.6	322.4	151.3	260.9	429.0	427.4	330.9	294.5	328.0	375.0	165.5	151.9
5.Medium duration pigeon pea + groundnut	382.6	303.5	244.2	342.4	184.3	252.2	392.2	390.6	331.9	368.3	311.7	316.2	226.4	227.4
6.Long duration pigeon pea + groundnut	251.4	285.9	282.0	398.5	300.3	410.4	444.9	443.3	337.6	389.4	198.2	213.2	152.0	166.2
7.Medium duration pigeon pea + groundnut biomass not incorporated	243.7	309.8	254.2	264.7	191.6	287.8	278.5	276.9	265.7	355.8	279.5	307.5	130.8	144.0
8.Long duration pigeon pea + groundnut biomass not incorporated	456.4	444.9	184.3	270.6	255.3	394.1	350.1	361.2	463.1	452.6	324.0	325.1	224.5	212.7
GM	335.5	338.0	261.5	315.4	207.3	297.5	376.3	376.3	359.9	372.2	247.6	267.5	185.5	190.3
CV%	24.6	24.4	22.2	26.8	23.9	24.4	25.4	25.4	19.3	22.9	51.3	26.1	22.2	24.4
$LSD_{0.05}$	144.2	-	-	-	122.9	-	-	-	121.3	149.4	127.1	-	-	81.2

4.3.4 Nitrate nitrogen data from the meter and KCl method

Figure 4.0 and 4.1 Appendix 4.6, show the comparison of NO_3^-–N data generated from the parallel experiment using the nitrate meter as well as the KCl method. In general, the amount of NO_3^-–N recorded was lower than data from the main experiment (Table 4.2). Analysis indicate that there was no linear correlation (Figure 4.2 and 4.3) of the data obtained using the nitrate meter and data generated by the KCl method both between 0-20 cm (R Sq.=0.009) and 20-40 cm (R Sq. 0.071) with wide variation noted within the data sets. In general the KCl method gave higher readings of NO_3^-–N (0-20 cm μ=90.3 mg L^{-1} and 20-40 cm μ=108.5 mg L^{-1}) compared to the nitrate meter (0-20 cm μ=68.1 mg L^{-1} and 20-40 cm μ=65.9 mg L^{-1}). This could be attributed to the differences in the extraction procedure for the two methods, a cause of the different results by each procedure.

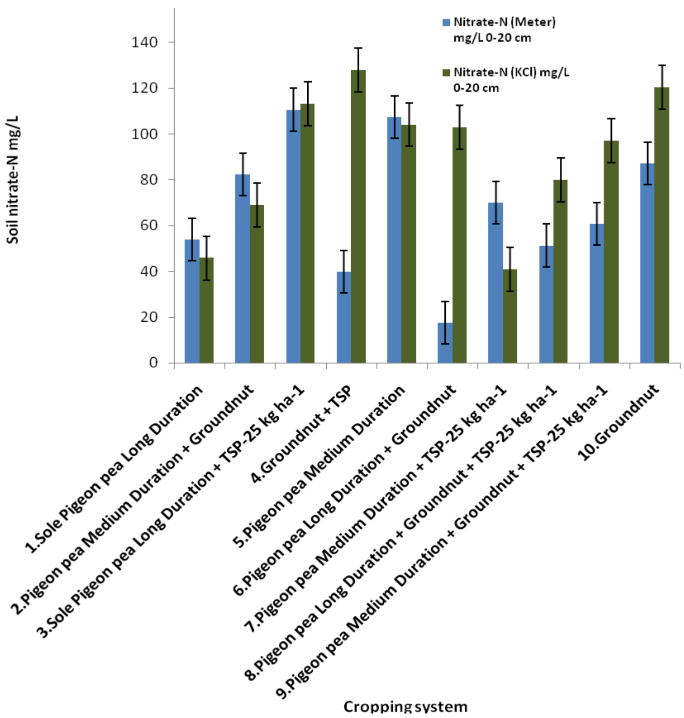

Figure 4.0: Comparison of NO_3^-–N data (Meter) and NO_3^-–N data (KCl): 0-20 cm.

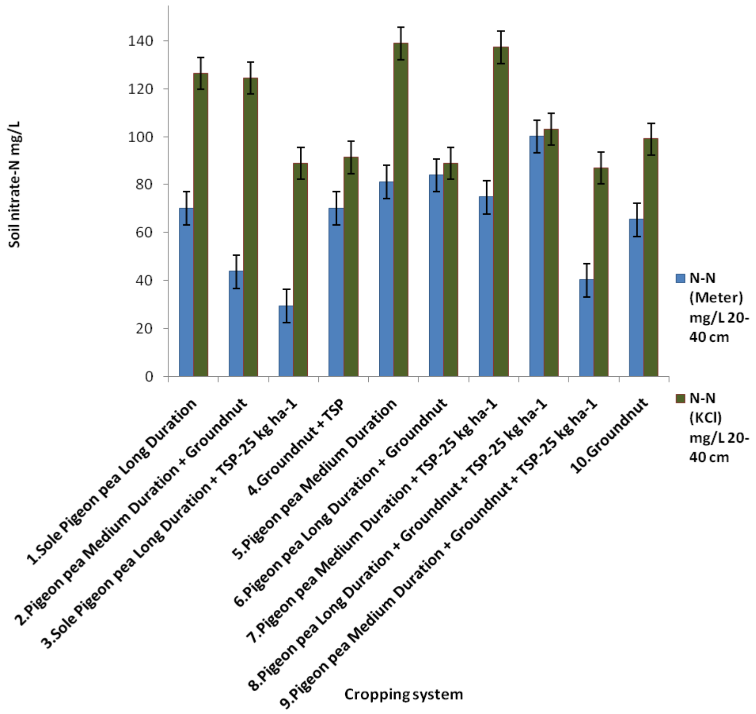

Figure 4.1: Comparison of NO_3^-–N data (Meter) and NO_3^-–N data (KCl): 20-40 cm.

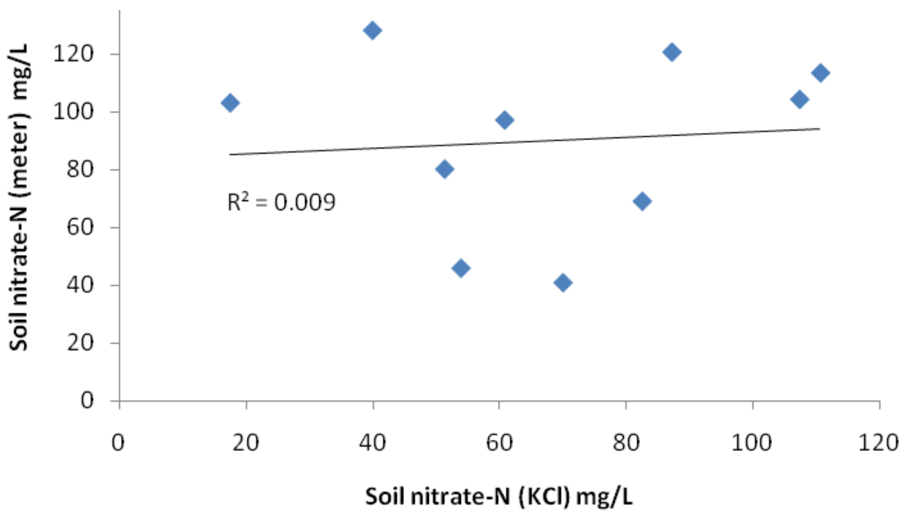

Figure 4.2: Correlation of NO_3^-–N data (Meter) and NO_3^-–N data (KCl): 0-20 cm

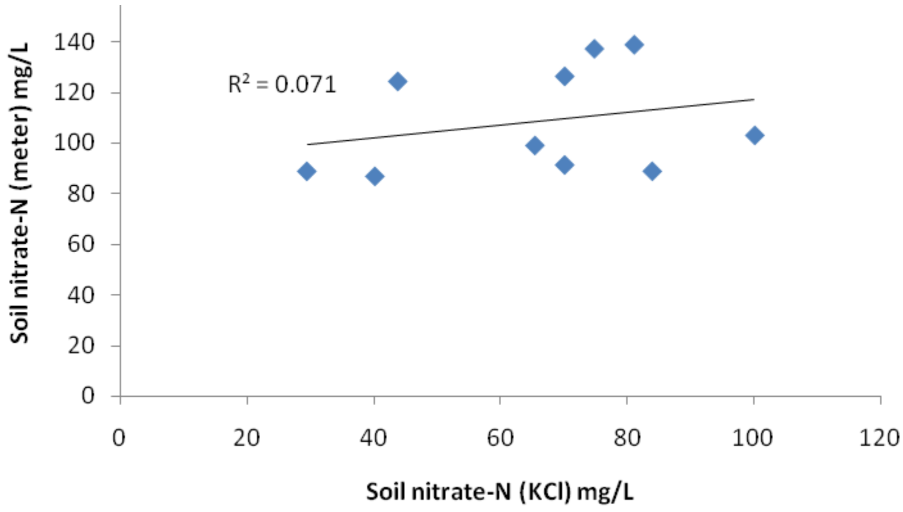

Figure 4.3: Correlation of NO_3^-–N (Meter) and NO_3^-–N data (KCl): 20-40 cm.

4.4 DISCUSSION

The results of the study seem to suggest that the soil generally has high NO_3^-–N in the soil solution (≥100 mg/L) (Ray Weil, personal communication). The values obtained during the cropping season were higher than values reported by Uwah *et al.,* (2009). However, the results obtained off season in the parallel experiment using both the meter and the KCl method fall within the same range of values reported by Uwah *et al.,* (2009) that is 40.0 to 107 mg L^{-1}.

In general, the amount of NO_3^-–N recorded off season was lower than data from the cropping season (Figure 4.0-4.1 and Table 4.2). This is explainable mainly interms of the prevailing temperature conditions at the time the measurements were done. It was warmer in January, 2013 (Appendix 4.0b) and cooler in June, 2013 (Appendix 4.0c) when data was collected from the main experiment and parallel experiment, respectively. Most likely higher microbiological activity was present in January than in June, resulting into a higher rate of decomposition and mineralization of N from the incorporated biomass (Davidson *et al.,* 2006). This released more NO_3^- into the soil system culminating into higher NO_3^-–N readings. The opposite scenario held for the parallel experiment. The lower temperature possibly reduced microbial activity and hence the rate of decomposition of the biomass and mineralization of N (Davidson *et al.,* 2006). The result of this is mirrored by the lower NO_3^-–N values that were recorded. In general the KCl method gave higher readings of NO_3^-–N compared with the nitrate meter. This could be attributed to the differences in the extraction procedure for the two methods, a cause of the different results by each procedure.

It was further observed, that the level of soil NO_3^-–N in most cases was statistically the same ($p>0.05$) in treatment plots that had the legume biomass ploughed under and in treatment plots that did not have plant biomass ploughed under. This could be due to two reasons. Firstly, the soil on which the experiment was mounted though not having high indigenous nitrogen content has been subjected to N fertilization and legume cropping over years. As such, potential for having residual soil NO_3^-–N in soil solution is high (Shapiro *et al.,* 2008). This could possibly be the reason why the values of the parameter were consistently statistically the same ($p>0.05$) in treatment plots with biomass incorporated and treatment plots that did not have the biomass incorporated into the soil. Secondly, it is highly likely that the process of biomass decomposition and mineralization of the organically bound N from the incorporated legume biomass was gradual, due to warm soil conditions, thus, this could not lead to spontenous increament in the level of soil NO_3^-–N in these treatment plots. From work conducted in southern Malawi, Phiri *et al.,* (1999) reported that the incorporation of biomass for *Sesbania sesban* into the soil increased soil nitrate level. It was also observed that largely, soil NO_3^-–N was higher between 20-40 cm than between 0-20 cm in the soil. This was attributable to the soil texture which is predominantly sandy clay loam. Leaching of

NO_3^- is high in soils with such texture class (Fan *et al.,* 2010). It is likely that the level of soil NO_3^-–N in the treatment plots which had no biomass incorporated would decline faster as the season advanced, than in the treatment plots where biomass was incorporated. This would have come about mostly due to uptake by the maize crop, leaching losses and denitrification (Ju *et al.,* 2009). However, it is worth while to note that though the high level of NO_3^-–N might have endure longer into the season, for the latter treatment plots, this may not have lasted until the end of the cropping cycle due to the limited amount of organically bound N in the biomass.

4.5 CONCLUSION

Under the conditions of the study, the results of the suggest that the soil in general has high NO_3^-–N in the soil solution attributable to residual N from fertilization and legume cropping over years. The soil NO_3^-–N was higher between 20-40 cm than between 0-20 cm in the soil. This was attributable to the soil texture which is predominantly sandy clay loam with low to medium level of SOM. Leaching of NO_3^- is high under such soil conditions. It was projected that soil NO_3^-–N levels in all the treatment plots will decline in all the treatment plots along the season. This for the Malawian smallholder farmers implies that in this cropping system N supplementation from mineral fertilizer is not optional if reasonably high maize yield is to be realized. This principally is due to the limited amount of tissue N in the biomass.

Comparative analysis of two nitrate analysis procedures indicated that the KCl method gave higher readings of NO_3^-–N compared with the nitrate meter. This was accrued to the differences in the extraction procedure for the two methods. From the study, both methods are recommended for the analysis of soil NO_3^-–N.

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CHAPTER 5:

PIGEON PEA ROOT NITROGEN YIELDS FOR THE PIGEON PEA-GROUNDNUT INTERCROP SYSTEM

ABSTRACT

A study aimed at the assessment of the contribution of pigeon pea roots to N yield for the pigeon pea was conducted at Chitedze Agricultural Research Station (13° 59' 23.2" S, 033°38' 36.8" E), Malawi in the 2012/2013 cropping season. Ten treatments, replicated three times were laid in a randomized complete block design. 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. Some of the plots were treated with triple super phosphate (TSP) at the rate of 25 kg P ha^{-1} for subsequent comparison of N yields between the P treated plots and non P treated plots. At harvest, roots for pigeon pea from three plants in each plot were dug out up to the 30 cm depth by 30 cm diameter. The root biomass was oven dried for 72 hours at 70°C to costant weights. The roots were then ground and laboratory analysis performed to determine concentrations of N, which ranged from 1.0-1.6%. Pigeon pea root biomass yields which were statistically the same ($P>0.05$) ranged from 507-605 kg ha^{-1}. This translated to N yields of 5.7 to 7.7 kg N ha^{-1}. Though it is a modest contribution to the soil it cannot be overlooked since the nutrient even after immobilization, a temporally state, largely is available for uptake by succeeding crops in a rotation system as it does not get complexed in the soil as is the case with phosphorus.

Key words: Biomass, groundnut, Intercrop, maize, nitrogen, pigeon pea and roots

5.0 INTRODUCTION

The role of legumes in soil fertility rejuvenation is globally reckoned and remains a vital link towards sustainable agricultural production. The role played by legumes, nitrogen (N) fixation and high quality biomass production are chorused as the main reasons why legumes hold a key to sustainable agriculture. Other equally important unique traits of legumes have also been spelt out and these include; the capacity to excrete root compounds that solubilizes complexed phosphorus (P) that otherwise remain unavailable (Drinkwater and Snapp, 2007). For example, the roots of pigeon pea (*Cajanus cajan*), produce an exudate (piscidic acid-$C_{11}H_{12}O_7$) which releases P from the Fe-P complexes through solubilization, thereby increasing available P (Ae *et al.,* 1990). The deep penetrating and laterally spreading root system confers drought tolerance through optimal use of soil moisture (Sharma, 2009). Furthermore, the deep roots absorb nutrients from deeper soil horizons, thereby recycling nutrients translocated to deep horizons (Masson *et al.,* 1986). On the otherhand, the highly prized annual edible legume, groundnut (*Arachis hypogaea*), possess a unique ability of utilizing soil nutrients that relatively are unavailable to other crops (Ikisan, 2000). The crop is also billed as very effective in extracting nutrients from soils of low nutrient supply, possibly as a result of the mycorrhizal association between roots and soil fungi or because of phosphobacteria found in the rhizosphere (Ikisan, 2000). Mycorrhizal association between roots and soil fungi, effectively extends roots beyond the nutrient depletion zone that is found around roots and increases the surface area thereby enabling plant roots to exploit a greater volume of undepleted soil and increase the specific surface area for P absorption (Lambers, 2008; Lambers *et al.,* 2011). Plants whose roots form mycorrhizal with soil fungi absorb more nutrients, particularly P even at low concentration from the soil solution compared with other plants that do not form such associations (Lynch and Brown 2001). Zhu *et al.* (2010) reported that mycorrhizal hyphae have a higher affinity for P than roots. Over and above the aforementioned, around the hyphae, the P concentration gradient is limited, thus there exists a minimal depletion zone (Barber, 1984). Principally, this is because the radius of hyphae (0.005 mm) is much smaller than that of roots plus root hairs (0.15 mm) (Rai *et al.,* 2013). This results into perpetually higher P concentration in soil solution around the hyphae than in the P depletion zone around roots (Rai *et al.,* 2013). Consequencially, the hyphae absorbs more P under conditions of low soil P even in the absence of a higher affinity for the nutrient (Rai *et al.,* 2013). It has been documented that mycorrhiza releases organic anions such as citrate, malate and oxalate, which can occupy P ($H_2PO_4^-$, HPO_4^{2-} and PO_4^{3-}) sorption sites thereby enhancing availability of P into the soil for plant uptake (Richardson *et al.,* 2011).

A less emphasized dimension on the role of legumes in recharging soil fertility is their contribution to the soil nutrient pool by decayed roots especially for leguminous plants like pigeon pea (Guretzky *et al.,* 2004; Cherr *et al.,* 2006). Crops and trees root residues contribute substancially to nutrient dynamics and pools and carbon turnover in agricultural ecosystems (Egbe *et al.,* 2013). Roots of plants also accord pathways for channeling of carbon and energy from the canopies to the soil (Egbe *et al.,* 2013). Implicitly therefore, root production and turnover directly impact the biogeochemical cycles of carbon and nutrients in terrestrial ecosystems (McGroddy *et al.,* 2004; Majdi *et al.,* 2005; Espeleta and Clark, 2007). Decomposition and mineralization of the organically bound nutrients from roots might have a positive influence on the growth of succeeding crops in rotational cropping systems such as the pigeon pea-groundnut intercrop maize rotational cropping system. Nnadi and Haque, (1986), reported that under intercropping, legume roots can contribute between 5 and 15 kg N ha^{-1} to soil N pool. In a study conducted by Phiri *et al.,* (2013b), the root component and the accompaning nutrient yields for two pigeon pea varieties used in the study were not assessed, thus under estimating the amount of nutrients returnable to the soil. Not with standing this however, their study indicate that this cropping system returns significant amount of nutrients which can benefit the succeeding maize crop. It was necessary therefore, to reassess biomass and nutrient yields, including that for roots of the pigeon pea inorder to quantify the total amount of nutrient yields in this system. In gross terms, the amount of nutrients added to a legume-cereal rotation cropping system depends on the total legume biomass yields (Giller, 2001). The following were the study objectives: (i) assess biomass and nutrient yields for the legumes (ii) Quantify N yields returned to the soil for the monoculture of groundnut and pigeon pea and the intercrop of the groundnut (iii) Quantify the contribution of root biomass to the soil N pool.

5.1 MATERIALS AND METHODS

5.1.1 Study site

Details on the location of the study site are as presented in Chapter 2 section 2.1.1.

5.1.2 Field Experiments

Details of the field experiments were as presented in Chapter 2 section 2.1.4.

5.1.3 Plot description and application of triple super phosphate ($Ca(H_2PO_4)_2.H_2O$) and urea ($CO(NH_2)_2$)

Details for the plots and application of triple super phosphate for the main experiment in season one (2011/2012), were as presented in Chapter 3 under section 3.1.4 and 3.1.5 respectively.

In season two (2012/2013), for the parallel experiment the plot size was 3 m x 4.5 m. While for the main experiment the size for the main plot size remained 20 m x 10 m. The subplots had 6 ridges each. The ridges were spaced at 75 cm apart both in the main and parallel experiment. In the parallel experiment planting of the legumes was as for the main experiment in season one (Chapter 3, section 3.1.4). For the main experiment planting of maize was as presented in Chapter 3, section 3.1.4. This was done in December, 2012.

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 defficiency. 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}.

5.2 DATA COLLECTION AND ANALYSIS

5.2.1 Soil sample collection

Details on soil sample collection and preparation were as presented in Chapter 2 under section 2.1.3.1 and 2.1.3.3.

5.2.2 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 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.

5.2.3 Biomass and grain yield 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.

5.2.4 Evaluation of the productivity of the intercropping systems

The Land Equivalent Ratio (LER) (Mazaheri and Oveysi, 2004) was used to evaluate the productivity of the doubled up legume intercrops against the monocultures. The formula used was as presented in Chapter 1 under section 1.1.12.

5.2.5 Soil analysis and plant sample analysis

Laboratory soil analysis was conducted as presented in Chapter 2 under section 2.1.3.4. The plant materials were analysed in the laboratory as described in Chapter 3 under section 3.2.7.

5.2.6 Nutrient yields

Nutrient yields were calculated as described in Chapter 3 under section 3.2.9.

5.2.7 Statistical analysis

Statistical analysis on the soil, biomass, plant nutrient concentrations and yields data was performed as presented in Chapter 2 under section 2.1.4.2.

5.3 RESULTS

5.3.1 Characterization of soil at the study site

Soil laboratory analytical results for the site were as presented in Chapter 2, Tables 2.0, 2.1a and 2.1b, sections 2.2.1 and 2.2.2, Appendices 2.0-2.1b.

5.3.2 N, P, Ca and Mg content and yield for groundnut and pigeon pea

5.3.2.1 Groundnut

Yields of groundnut haulms, nutrient concentrations for the haulms and yields at harvest in season two were as presented in Table 5.0 and Appendix 5.0a. No significant differences were observed ($p>0.05$) for the yields of haulms across the treatments. This ranged from 1,396 to 2,463 kg ha^{-1}. On nutrient concentrations no significant differences ($p>0.05$) were observed for the concentration of N, P and Ca across treatment plots. For N this ranged from 1.9 to 2.3%, for P this ranged from 0.18 to 0.22% while for Ca this ranged from 0.19 to 0.25%. However, significant differences ($p<0.05$) were observed for the concentrations of Mg across treatment plots with haulms from the sole groundnut plots treated with TSP having the lowest concentrations (0.13%) compared with the rest of the treatments which had a concentration of 0.14%. On nutrient yields no significant differences were observed across treatments ($p>0.05$) for the yields of N, P, Ca and Mg. For N this ranged from 29 to 52 kg ha^{-1}; the yields of P ranged from 3 to 5 kg ha^{-1}; the yields of Ca ranged from 2.7 to 4.9 kg ha^{-1} while the yields of Mg ranged from 2.0-3.2 kg ha^{-1}.

Table 5.0: N, P, Ca and Mg concentrations and yields for groundnut haulms at harvest, parallel experiment, second season

Treatment	Haulms yield kg ha^{-1}	N(%)	P(%)	Ca(%)	Mg(%)	N yield kg ha^{-1}	P yield kg ha^{-1}	Ca yield kg ha^{-1}	Mg yield kg ha^{-1}
1. Medium duration pigeon pea + groundnut	1,516	2.0	0.18	0.25	0.14	30	3	3.8	2.1
3.Groundnut + 25 kg P ha^{-1}	2,463	2.1	0.19	0.20	0.13	52	5	4.9	3.2
5. Long duration pigeon pea + groundnut	1,396	2.1	0.18	0.21	0.14	29	3	2.9	2.0
7. Long duration pigeon pea + groundnut + 25 kg P ha^{-1}	1,727	1.9	0.19	0.24	0.14	33	3	4.1	2.4
8. Medium duration pigeon pea + groundnut + 25 kg P ha^{-1}	1,412	2.2	0.20	0.19	0.14	31	3	2.7	2.0
9.Sole groundnut	1,752	2.3	0.22	0.19	0.14	40	4	3.3	2.5
GM	1,711	2.10	0.19	0.21	0.14	35.83	3.50	3.62	2.37
CV (%)	41.7	14.4	16.7	11.2	18.1	38.3	17.0	32.1	19.2
$LSD_{0.05}$	-	-	-	-	0.01	-	-	-	-

Yields of groundnut shells, nutrient concentrations and yields at harvest were as presented in Table 5.1 and Appendix 5.0b. No significant differences ($p>0.05$) were observed in the yields of groundnut shells across treatments. This ranged from 846 to 1,992 kg ha^{-1}. Significant differences in the concentrations of N, P and Ca were observed across treatments. N concentrations were lowest for groundnut shells from the long duration pigeon pea-groundnut intercrop (0.9%) and highest in the groundnut shells from the sole groundnut treatment (1.5%) and the TSP treated groundnut (1.4%).

For P, concentrations were highest for groundnut shells from the sole groundnut treatment (0.16%) and the TSP treated groundnut (0.15%). Thes were lowest for the TSP treated intercrops of groundnut with long and medium duration pigeon pea and the non TSP treated long duration pigeon pea-groundnut intercrop (0.12%). For Ca, concentrations were highest for groundnut shells from sole groundnut (0.4%) and the TSP treated long duration pigeon pea-groundnut intercrop (0.4%). These were lowest for the non TSP treated long duration pigeon pea- groundnut intercrop (0.2%). This ranged from 2.1 to 4.1%.

On nutrient yields, except for P which had non signficant different ($p>0.05$) nutrient yields for the shells across the treatments (1.0 kg ha^{-1} to 3.0 kg ha^{-1}), significant yields differences ($p<0.05$) were recorded for the yields of N and Ca. Significantly higher N yields were obtained for groundnut shells from the TSP treated groundnut (27.8 kg ha^{-1}) and the sole groundnut treatment (25.2 kg ha^{-1}). N yields were lowest for the shells TSP treated medium duration pigeon pea-groundnut intercrop (10.2 kg ha^{-1}) and the long duration pigeon pea-groundnut intercrop (10.2 kg ha^{-1}). Calcium yields were significantly higher for the shells from the TSP treated long duration-groundnut intercrop (6.9 kg ha^{-1}) and sole groundnut treatment (6.2 kg ha^{-1}). Significantly low Ca yields were generated for groundnut shells from the long duration pigeon pea-groundnut intercrop (2.7 kg ha^{-1}) and the TSP treated medium duration pigeon pea-groundnut intercrop (2.5 kg ha^{-1}).

Table 5.1: N, P and Ca concentrations and nutrient yields for groundnut shell at harvest, parallel experiment, second season

Treatments	Shells yield	N	P	Ca	N yield	P yield	Ca yield
	$kg\ ha^{-1}$		(%)			$kg\ ha^{-1}$	
1. Medium duration pigeon pea + groundnut	1,468	1.1	0.13	0.3	16.1	1.9	4.7
3.Groundnut + 25 kg P ha^{-1}	1,992	1.4	0.15	0.3	27.8	3.0	5.0
5. Long duration pigeon pea + groundnut	1,162	0.9	0.12	0.2	10.2	1.4	2.7
7. Long duration pigeon pea + groundnut + 25 kg P ha^{-1}	1,403	1.1	0.12	0.4	18.5	2.0	6.9
8. Medium duration pigeon pea + groundnut + 25 kg P ha^{-1}	846	1.2	0.12	0.3	10.2	1.0	2.5
9.Sole groundnut	1,686	1.5	0.16	0.4	25.2	2.7	6.2
GM	1,426	1.2	0.13	0.32	18.0	2.0	4.7
CV (%)	39.6	15	16.1	17.3	41.2	45.2	31.8
$LSD_{0.05}$	-	0.3	0.04	0.10	14.8	-	2.9

Groundnut grain yields, nutrient concentrations for the groundnut grain and nutrient yields were as presented in Table 5.2 and Appendix 5.0c. Non significantly different ($p>0.05$) groundnut grain yields were registered across the treatments. This ranged from 1,513 to 3,025 kg ha^{-1}.

Significant differences ($p<0.05$) were observed for N and Ca concentrations for the groundnut grain across treatments. For N this was significantly higher for the groundnut grain from the TSP treated medium duration pigeon pea-groundnut intercrop (3.2%) than for the groundnut grain from the TSP treated long duration pigeon pea-groundnut intercrop (2.9%). Calcium concentration was significantly higher for the groundnut grain from the sole groundnut treatment (0.18%) than for the groundnut grain from the medium duration pigeon pea-groundnut intercrop (0.07%). No significant differences ($p>0.05$) were observed for the concentrations of P in the groundnut grains across treatments. This ranged from 0.42% to 0.46%.

On nutrient yields, significant differences ($p<0.05$) were observed for groundnut grain yields of N and P across treatments. N yields were significantly higher in the TSP treated groundnut (98.8 kg ha^{-1}) compared with the rest of the treatments (46.9 to 58.1 kg ha^{-1}). Phosphorus yields were significantly higher for the groundnut grain from the TSP treated groundnut (13.0 kg ha^{-1}) than in the groundnut grain from the long duration pigeon pea-groundnut intercrop (6.7 kg ha^{-1}) and the TSP treated medium duration pigeon pea-groundnut intercrop. Non significant yields differences ($p>0.05$) for the groundnut grain were observed for Ca across treatments. This ranged from 1.3 to 4.5 kg ha^{-1}.

Table 5.2: N, P and Ca concentrations for the grains of groundnut at harvest in the parallel experiment

Treatments	Grain yield	N	P	Ca	N yield	P yield	Ca yield
	$kg\ ha^{-1}$			%		$kg\ ha^{-1}$	
1. Medium duration pigeon pea + groundnut	1,835	3.0	0.42	0.07	55.1	7.7	1.3
3.Groundnut + 25 kg P ha^{-1}	3,025	3.1	0.43	0.15	98.8	13.0	4.5
5. Long duration pigeon pea + groundnut	1,513	3.1	0.44	0.14	46.9	6.7	2.1
7. Long duration pigeon pea + groundnut + 25 kg P ha^{-1}	1,719	2.9	0.43	0.12	49.9	7.4	2.1
8. Medium duration pigeon pea + groundnut + 25 kg P ha^{-1}	1,654	3.2	0.42	0.09	52.9	6.9	1.5
9.Sole groundnut	1,875	3.1	0.46	0.18	58.1	8.6	3.4
GM	1,936	3.1	0.43	0.13	60.3	8.4	2.5
CV (%)	39.9	5.3	7.19	47.6	34.3	38.1	48.2
$LSD_{0.05}$	-	0.3	-	0.11	38.1	6.1	-

5.3.3 Biomass yields, nutrient concentrations and nutrient yields for fresh leaves of pigeon pea

Biomass yields, nutrient concentrations and nutrient yields for fresh leaves of pigeon pea were as presented in Table 5.3 and Appendix 5.1a. Nutrient concentrations were significantly ($p<0.05$) higher for fresh leaves for pigeon pea 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}). N concentrations were significantly higher in fresh leaves for the crop from the medium duration pigeon pea-groundnut intercrop (3.7%) than for the long duration pigeon pea-groundnut intercrop (3.1%). No significant differences ($p>0.05$) were observed in the concentrations of P in the fresh leaves of the pigeon pea across treatments. This ranged from 0.2 to 0.4%. For Ca, significant differences ($p<0.05$) in concentrations for the fresh leaves were observed across treatments. The concentrations were significantly higher in the TSP treated medium duration pigeon pea-groundnut intercrop (0.99%) than in the monoculture for medium duration (0.68%) and long duration (0.72%) pigeon pea. On yields no significant differences ($p>0.05$) were observed in the yields of N and P for the fresh leaves. For N this ranged from 25.7 to 32.6 kg N ha^{-1} while for P this ranged from 1.7 to 3.3 kg P ha^{-1}. For Ca significant yields differences ($p<0.05$) were observed across treatments. The yields were significantly higher in the fresh leaves from the TSP treated medium duration pigeon pea-groundnut intercrop (9.4 kg ha^{-1}) than in the fresh leaves from the monoculture for long duration (5.8 kg ha^{-1}) and medium duration 6.0 kg ha^{-1}) pigeon pea.

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Table 5.3: N, P and Ca concentrations in the fresh leaves for pigeon pea and yields at harvest, parallel experiment, second season

Treatment	Fresh leaves	N	P	Ca	N yield	P yield	Ca yield
	$kg\ ha^{-1}$		%			$kg\ ha^{-1}$	
1. Medium duration pigeon pea + groundnut	944	3.7	0.20	0.68	34.7	1.9	6.4
2. Long duration pigeon pea + 25 kg P ha^{-1}	791	3.5	0.40	0.96	28.0	3.1	7.6
4. Medium duration pigeon pea only	909	3.5	0.30	0.66	31.9	2.7	6.0
5. Long duration pigeon pea + groundnut	830	3.1	0.20	0.87	25.7	1.7	7.2
6. Medium duration pigeon pea + 25 kg P ha^{-1}	899	3.4	0.35	0.94	30.7	3.2	8.5
7. Long duration pigeon pea + groundnut + 25 kg P ha^{-1}	914	3.5	0.29	0.84	31.8	2.7	7.7
8. Medium duration pigeon pea + groundnut + 25 kg P ha^{-1}	944	3.5	0.35	0.99	32.6	3.3	9.4
10. Long duration pigeon pea only	809	3.4	0.25	0.72	27.6	2.0	5.8
GM	880	3.5	0.29	0.83	30.38	2.58	7.33
CV (%)	8.0	9.0	44.0	11.4	14.6	44.8	17.3
$LSD_{0.05}$	122	0.5	-	0.10	-	-	2.2

Biomass yields, nutrient concentrations and nutrient yields for pigeon pea litter were as presented in Table 5.4 and Appendix 5.1b. Significant differences ($p<0.05$) were observed in the yields of pigeon pea litter across treatments. The yields were significantly higher for pigeon pea litter from the TSP treated medium duration pigeon pea monoculture (824 kg ha^{-1}) than for the long duration pigeon pea-groundnut intercrop (518 kg ha^{-1}). N concentrations were significantly in the litter from the TSP treated long duration pigeon pea-groundnut intercrop (2.6%) than in the litter from long duration pigeon pea-groundnut intercrop (2.1%) and the litter from the TSP treated medium duration pigeon pea monoculture (2.1%). Significant differences ($p<0.05$) were observed in the concentrations of P in the pigeon pea litter across treatments. The concentrations were significantly higher in the litter from; the medium duration pigeon pea-groundnut intercrop, TSP treated long duration pigeon pea monoculture, long duration pigeon pea-groundnut intercrop and the long duration pigeon pea monoculture. In all these treatments P concentrations were at 0.08%. Significantly lower P concentrations were observed in the monoculture for medium duration pigeon pea treated TSP (0.06%).

For Ca, significant differences ($p<0.05$) for concentrations in the pigeon pea litter were observed across treatments. The concentrations were significantly higher for the litter from the long duration pigeon pea-grounut intercrop (3.4%) and the TSP treated medium duration pigeon pea-groundnut intercrop (3.3%) than for the litter from the monoculture for medium duration (0.21%) and long duration (0.21%) pigeon pea, the TSP treated medium duration (0.22%) and long duration (0.22%) pigeon pea monoculture and the medium duration pigeon pea-groundnut intercrop (2.5%).

On yields no significant differences ($p>0.05$) were observed for the yields of N and P for litter. For N this ranged from 11.0 to 17.4 kg ha^{-1} while for P this ranged from 0.4 to 0.5 kg ha^{-1}. For Ca significant yields differences ($p<0.05$) were observed across treatments. The yields were significantly higher for litter from; the medium duration pigeon pea-groundnut intercrop (6.4 kg ha^{-1}), the monoculture of medium duration pigeon pea (6.0 kg ha^{-1}), the TSP treated long duration pigeon pea monoculture (5.9 kg ha^{-1}), long duration pigeon pea monoculture (5.6 kg ha^{-1}), the TSP treated long duration pigeon pea-groundnut intercrop (5.3 kg ha^{-1}). Significantly lower Ca concentrations were observed in the litter from the long duration pigeon pea-groundnut intercrop (2.3 kg ha^{-1}).

Table 5.4: N, P and Ca concentrations and nutrient yields for dry leaves for pigeon pea plants at harvest, parallel experiment, second season

Treatment	Dry leaves	N	P	Ca	N yield	P yield	Ca yield
	$kg\ ha^{-1}$		%			$kg\ ha^{-1}$	
1. Medium duration pigeon pea + groundnut	661	2.2	0.08	2.5	14.4	0.5	6.4
2. Long duration pigeon pea + 25 kg P ha^{-1}	597	2.2	0.08	2.2	13.3	0.5	5.9
4. Medium duration pigeon pea only	686	2.3	0.06	2.1	15.8	0.4	4.7
5. Long duration pigeon pea + groundnut	518	2.1	0.08	3.4	11.0	0.4	2.3
6. Medium duration pigeon pea + 25 kg P ha^{-1}	824	2.1	0.06	2.2	17.4	0.5	6.0
7. Long duration pigeon pea + groundnut + 25 kg P ha^{-1}	652	2.6	0.07	2.1	16.9	0.5	5.3
8. Medium duration pigeon pea + groundnut + 25 kg P ha^{-1}	671	2.4	0.07	3.3	16.1	0.5	4.8
10. Long duration pigeon pea only	611	2.3	0.08	2.1	14.2	0.5	5.6
GM	652	2.3	0.07	2.5	14.9	0.5	5.1
CV (%)	19	13	16.12	14.8	25.6	26.4	32.7
$LSD_{0.05}$	230	0.5	0.02	0.7	-	-	3.04

Biomass yields, nutrient concentrations and nutrient yields for pigeon pea twigs were as presented in Table 5.5 and Appendix 5.1c. Significant differences ($p<0.05$) were observed in the yield of twigs for pigeon pea across treatments. 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 in the long duration pigeon pea-groundnut intercrop (655 kg ha^{-1}) and the TSP treated long duration pigeon pea monoculture (665 kg ha^{-1}). No significant differences ($p>0.05$) were observed in N concentration for the twigs across the treatments. This ranged from 2.1 to 3.3%.

Significant differences ($p<0.05$) were observed for the concentrations of P for the pigeon pea twigs across treatments. The concentrations were significantly higher for the twigs from the TSP treated long duration pigeon pea monoculture (0.3%), the medium duration pigeon pea monoculture (0.3%) and the TSP treated medium duration pigeon pea monoculture (0.3%). Significantly lower P concentrations were observed for the twigs from the long duration pigeon pea-groundnut intercrop (0.1%) and long duration pigeon pea monoculture (0.1%). For Ca, significant differences ($p<0.05$) for concentrations in the twigs were observed across treatments. The concentration were significantly higher for the twigs from the TSP treated medium duration pigeon pea (3.2%) and significantly lower for the twigs from the medium duration pigeon pea-groundnut intercrop (2.1%) and the long duration pigeon pea monoculture treated with TSP (2.2%).

Significant differences ($p<0.05$) in Mg concentration for the pigeon pea twigs were observed across treatments. The concentrations were significantly higher in the medium duration pigeon pea-ground nut intercrop (0.96%) but significantly lower for the twigs for the TSP treated long duration pigeon pea-groundnut intercrop (0.61%), the TSP treated medium duration pigeon pea monoculture (0.62%) and the TSP treated medium duration pigeon pea-groundnut intercrop (0.63%). The concentrations were significantly lower for the litter from the non TSP treated long duration pigeon pea-groundnut intercrop (0.44%).

On yields significant differences ($p<0.05$) were observed for the yields of N, P, Ca and Mg for the twigs. For N significantly higher yields were observed in the twigs from the medium duration pigeon pea-groundnut intercrop (26.3 kg ha^{-1}) and the TSP treated medium duration pigeon pea monoculture (23.7 kg ha^{-1}). Significantly low N yields were observed for the twigs for the long duration pigeon pea monoculture (16.3 kg ha^{-1}). Phosphorus yields were significantly higher for the twigs from the TSP treated medium duration pigeon pea monoculture (2.3 kg ha^{-1}) and were significantly lower in the twigs from; the medium duration pigeon pea-groundnut intercrop (1.0 kg ha^{-1}), long duration pigeon pea-groundnut intercrop (1.0 kg ha^{-1}), the long duration pigeon pea monoculture (1.1 kg ha^{-1}) and the TSP treated long duration pigeon pea-groundnut intercrop (1.2 kg ha^{-1}). For Ca the yields were significantly higher for twigs from the TSP treated medium duration pigeon pea monoculture (28.5 kg ha^{-1}). Significantly lower Ca concentrations were observed for the twigs from the long duration pigeon pea-groundnut intercrop (13.4 kg ha^{-1}). For Mg the yields were significantly higher for twigs from the medium duration-groundnut intercrop (7.8 kg ha^{-1}) but significantly lower for twigs from the rest of the treatments except Mg yields for twig from the monoculture of long duration pigeon pea and medium duration pigeon pea (6.0 kg ha^{-1}) that had intermediary yields.

Table 5.5: N, P, Ca and Mg concentrations and nutrient yields for twigs of the pigeon pea plants at harvest, parallel experiment, second season

Treatment	Twigs	N	P	Ca	Mg	N yield	P yield	Ca yield	Mg yield
1. Medium duration pigeon pea + groundnut	808	3.3	0.1	2.1	0.96	26.3	1.0	17.2	7.8
2. Long duration pigeon pea + 25 kg P ha^{-1}	665	3.1	0.3	2.2	0.81	20.4	2.0	14.6	5.4
4. Medium duration pigeon pea only	793	2.6	0.3	2.4	0.76	20.5	2.2	19.3	6.0
5. Long duration pigeon pea + groundnut	655	3.3	0.1	2.0	0.78	21.6	1.0	13.4	5.1
6. Medium duration pigeon pea + 25 kg P ha^{-1}	882	2.7	0.3	3.2	0.62	23.7	2.3	28.5	5.4
7. Long duration pigeon pea + groundnut + 25 kg P ha^{-1}	699	3.2	0.2	2.5	0.61	22.7	1.2	17.8	4.2
8. Medium duration pigeon pea + groundnut + 25 kg P ha^{-1}	764	2.7	0.2	2.4	0.63	20.8	1.6	18.1	4.8
10. Long duration pigeon pea only	767	2.1	0.1	2.3	0.78	16.3	1.1	17.6	6.0
GM	754	2.9	0.2	2.4	0.7	21.5	1.6	18.3	5.6
CV (%)	14.0	18	41.2	15.3	16.7	17.7	39.4	12.4	21.7
$LSD_{0.05}$	198	-	0.2	0.93	0.31	6.8	1.1	4.0	2.1

Biomass yields, nutrient concentrations and nutrient yields for pigeon pea stems were as presented in Table 5.6 and Appendix 5.1d. No significant differences ($p>0.05$) were observed for the yields of stems for pigeon pea across treatments. This ranged from 597 to 950 kg ha^{-1}.

Significant differences ($p<0.05$) were observed in N concentrations for the stems across the treatments. Significantly lower stem N concentrations were observed in the long duration pigeon pea-groundnut intercrop (1.6%) and the medium duration pigeon pea monoculture (1.8%) compared to the rest of the treatments except for the TSP treated medium duration pigeon pea monocrop (1.9%) which had an intermediary concentrations of N in the stems. Significant differences ($p<0.05$) were observed in the concentrations of P for the pigeon pea stems across treatments. The concentrations were significantly higher in the stems from the TSP treated long duration pigeon pea monoculture (0.16%) compared with the rest of the treatments except for the TSP treated medium duration pigeon pea monoculture (0.15%) and the non TSP treated medium duration pigeon pea monoculture (0.13%) that had intermediate concentration of N in the stems.

For Ca, significant differences ($p<0.05$) in concentrations for stems were observed across treatments. The concentrations were significantly higher for stems from the TSP treated long duration pigeon pea monocrop (2.5%) and significantly lower for stems from the medium duration pigeon pea-groundnut intercrop (2.1%), the medium duration pigeon pea monoculture treated with TSP (2.1%) and the TSP treated medium duration pigeon pea-groundnut intercrop. Significant differences ($p<0.05$) in Mg concentration for pigeon pea stems were observed across treatments.

The concentrations were significantly higher in the TSP treated medium duration pigeon pea-groundnut intercrop (0.7%), long duration pigeon pea monoculture (0.7%) and the TSP treated medium duration pigeon pea monocrop (0.6%) but was significantly lower in stems for the TSP treated long duration pigeon pea-groundnut intercrop (0.4%) and medium duration pigeon pea monoculture (0.4%). On yields significant differences ($p<0.05$) were observed in the yield of N, P, and Mg for the stems. For N significantly higher yields were observed for stems from the TSP treated medium duration pigeon pea-groundnut intercrop (20.7 kg N ha^{-1}) and the TSP treated long duration pigeon pea monoculture (19.3 kg N ha^{-1}). Significantly low N yields were observed for the stems for the long duration pigeon pea-groundnut intercrop (16.3 kg N ha^{-1}). Phosphorus yields were significantly higher for stems from the TSP treated medium duration pigeon pea monoculture (1.4 kg P ha^{-1}) and were significantly lower for stems from the long duration pigeon-groundnut intercrop (0.6 kg P ha^{-1}) and long duration pigeon pea monoculture (0.7 kg P ha^{-1}). For Ca no significant yields differences ($p>0.05$) were observed across treatments. This ranged 13.2 to 20.4 kg Ca ha^{-1}. Significant differences ($p<0.05$) were observed in the yields of Mg for the stems. This was significantly higher for stems from the TSP medium duration-groundnut intercrop (6.8 kg Mg ha^{-1}) but significantly lower for stems the medium duration pigeon pea monoculture (2.6 kg Mg ha^{-1}) and the TSP treated long duration pigeon pea-groundnut intercrop (2.8 kg Mg ha^{-1}).

Table 5.6: N, P, Ca and Mg concentrations in stems for pigeon pea plants at harvest in the parallel experiment

Treatment	Stems kg ha^{-1}	N	P	Ca	Mg	N yield	P yield	Ca yield	Mg yield
		%				kg ha^{-1}			
1. Medium duration pigeon pea + groundnut	792	2.0	0.10	2.1	0.5	15.7	0.8	16.6	4.2
2. Long duration pigeon pea + 25 kg P ha^{-1}	757	2.5	0.16	2.5	0.5	19.3	1.2	18.8	4.0
4. Medium duration pigeon pea only	723	1.8	0.13	2.1	0.4	13.1	1.0	15.3	2.6
5. Long duration pigeon pea + groundnut	589	1.6	0.10	2.2	0.5	9.3	0.6	13.2	3.1
6. Medium duration pigeon pea + 25 kg P ha^{-1}	915	1.9	0.15	2.2	0.6	17.5	1.4	20.4	5.6
7. Long duration pigeon pea + groundnut + 25 kg P ha^{-1}	718	2.4	0.12	2.2	0.4	17.1	0.9	16.0	2.8
8. Medium duration pigeon pea + groundnut + 25 kg P ha^{-1}	950	2.2	0.12	2.0	0.7	20.7	1.1	19.3	6.8
10. Long duration pigeon pea only	597	2.3	0.12	2.2	0.7	13.4	0.7	13.3	4.1
GM	755	2.1	0.13	2.2	0.5	15.8	0.96	16.6	4.2
CV (%)	26	13.9	10.7	7.84	21.8	33.02	30.9	24.9	23.3
$LSD_{0.05}$	-	0.6	0.03	0.4	0.3	9.1	0.5	-	1.7

Biomass yields, nutrient concentrations and nutrient yields for pigeon pea roots were as presented in Table 5.7 and Appendix 5.1e. No significant differences ($p>0.05$) were observed in the yields of roots for pigeon pea across treatments. This ranged from 507 to 605 kg ha^{-1}. Significant differences ($p<0.05$) were observed in N concentrations for the roots across treatments. Significantly higher N concentrations were observed for the long duration pigeon pea monoculture (1.6%). The concentrations were significantly lower for roots from medium duration pigeon pea monoculture (1.0%) and for the roots from the TSP treated medium duration pigeon pea monocrop (1.0%). Significant differences ($p<0.05$) were observed for the concentration of P for the pigeon pea roots across treatments. The concentrations were significantly higher for roots from the long duration pigeon pea-groundnut intercrop (0.09%) but were significantly lower for roots from the TSP treated medium duration pigeon pea monoculture (0.06%), the TSP treated medium duration pigeon pea-groundnut intercrop (0.06%) and the non TSP treated medium duration pigeon pea-groundnut intercrop (0.06%).

For Ca, significant differences ($p<0.05$) in concentration for the roots were observed across treatments. The concentrations were significantly higher for roots from the medium duration pigeon pea monocrop (2.5%) and significantly lower for roots from the medium duration pigeon pea-groundnut intercrop (0.9%), the long duration pigeon pea monoculture treated with TSP (1.0%) and the TSP treated medium duration pigeon pea-groundnut intercrop (1.0%). On yields no significant differences ($p>0.05$) were observed for the yields of N and P for the roots. For N this ranged from 5.7 kg ha^{-1} to 8.2 kg ha^{-1}. While for P this ranged from 0.3 kg ha^{-1} to 0.5 kg ha^{-1}. For Ca significantly higher yields were observed for roots from the medium duration pigeon pea monoculture (6.6 kg ha^{-1}). The yield were significantly lower for the long duration pigeon pea monoculture (4.2 kg ha^{-1}) and the long duration pigeon pea-groundnut intercrop (4.2 kg ha^{-1}).

Table 5.7: N, P and Ca concentrations and yields for roots of the pigeon pea plants at harvest, parallel experiment, second season

Treatment	Roots	N	P	Ca	N yield	P yield	Ca yield
	kg ha^{-1}	%			kg ha^{-1}		
1. Medium duration pigeon pea + groundnut	571	1.3	0.06	0.9	7.7	0.3	5.1
2. Long duration pigeon pea + 25 kg P ha^{-1}	507	1.2	0.07	1.0	6.2	0.4	5.1
4. Medium duration pigeon pea only	596	1.0	0.08	1.1	5.7	0.5	6.6
5. Long duration pigeon pea + groundnut	531	1.4	0.09	0.8	7.3	0.5	4.2
6. Medium duration pigeon pea + 25 kg P ha^{-1}	605	1.0	0.06	0.8	6.3	0.4	4.8
7. Long duration pigeon pea + groundnut + 25 kg P ha^{-1}	601	1.1	0.07	0.8	6.9	0.4	4.8
8. Medium duration pigeon pea + groundnut + 25 kg P ha^{-1}	512	1.4	0.06	1.0	7.1	0.3	5.1
10. Long duration pigeon pea only	524	1.6	0.08	0.8	8.2	0.4	4.2
GM	555.9	1.3	0.07	0.90	6.9	0.4	5.0
CV (%)	12	15.8	15.6	19.1	22.2	15.5	22.1
$LSD_{0.05}$	-	0.4	0.02	0.3	-	-	1.9

5.3.4 Summary of nitrogen and phosphorus yields for groundnut in the parallel experiment season two

Figure 5.0 summarizes nutrient total N and P yields for the groundnut in the parallel experiment. For the haulms N yields ranged from 29 to 52 kg ha-1, while yields of P ranged from 3 to 5 kg ha-1; For the shells N yields ranged from 10.2 to 25.2 kg ha-1 while P yields ranged from 2.5 to 6.9 kg ha-1. For the grain N yields ranged from 46.9 to 98.8 kg ha-1, the yields of P ranged from 6.7 to 8.6 kg ha-1. Total N yields ranged from 86.1 to 178.6 kg ha-1 while total P yields ranged from 10.9 to 21.0 kg ha-1.

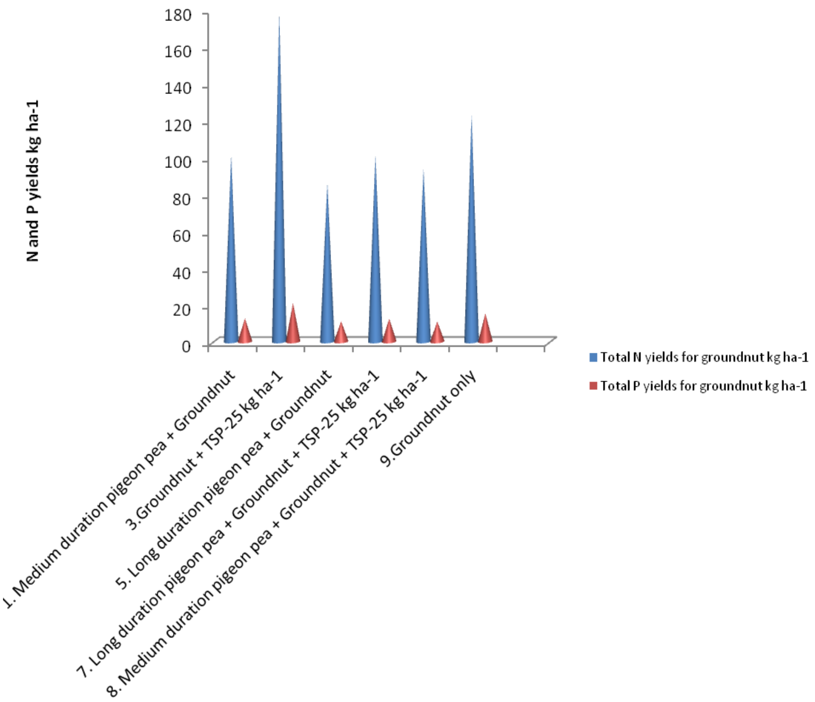

Figure 5.0: Nutrient yields for the groundnut in the parallel experiment in season two

5.3.5 Summary of nitrogen and phosphorus yields for the pigeon pea in the parallel experiment season two

Figure 5.1 summarizes the total yields of N and P for the pigeon pea in the parallel experiment for the pigeon pea in season two. N yields for the fresh leaves of the crop ranged from 27.6 to 34.7 kg ha^{-1} while the yields of P ranged from 1.7 to 3.3 kg ha^{-1}. N yields for dry leaves ranged from 11.0 to 17.4 kg ha^{-1} while the yields of P ranged from 0.4 to 0.5 kg ha^{-1}. N yields in twigs ranged from 16.3 to 26.3 kg ha^{-1} while the yields of P ranged from 1.0 to 2.3 kg ha^{-1}. N yields for stems ranged from 9.3 to 20.7 kg ha^{-1} while the yields of P ranged from 0.7 to 1.4 kg ha^{-1}. N yields for roots ranged from 5.7 to 8.2 kg ha^{-1} while the yields of P ranged from 0.3 to 0.5 kg ha^{-1}. The sum total for N yields for the crop ranged from 74.9 to 98.8 kg ha^{-1} while the yield of P ranged from 3.7 to 6.8 kg ha^{-1}.

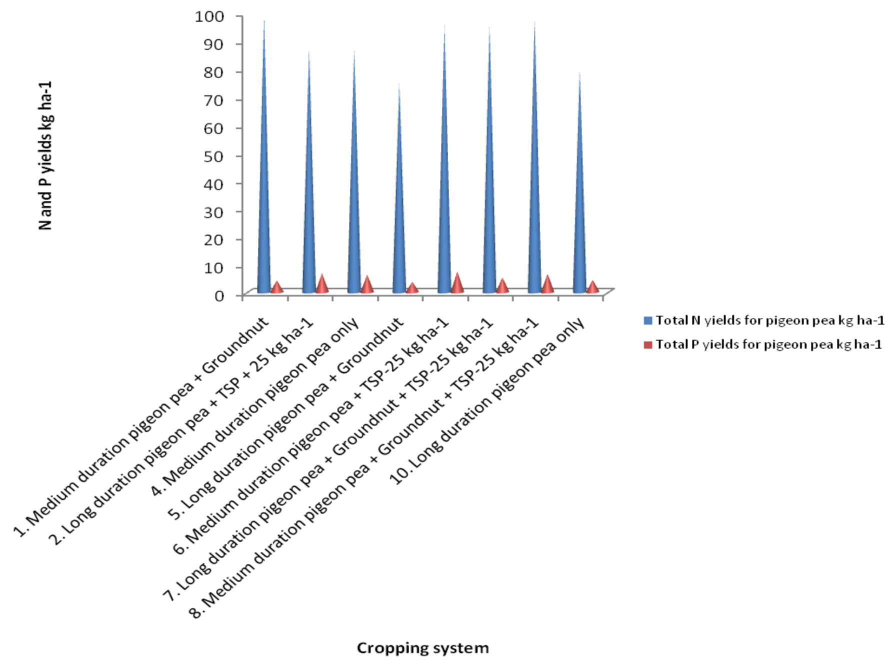

Figure 5.1: Nitrogen and phosphorus yields for the pigeon pea in the parallel experiment season two

5.3.6 Estimated soil returnable N and P yields for the monoculture of groundnut and pigeon pea and the intercrop of the groundnut

Figure 5.2 summarizes the computed soil returnable N and P yields for the monoculture of groundnut and pigeon pea and the intercrop of the groundnut with two varieties of pigeon pea. The monoculture for groundnut treated with TSP yielded more N (52.0 kg N ha^{-1}) compared to the non treated groundnut monoculture (40.0 kg N ha^{-1}). The soil returnable yields of P for the two treatments differed marginally. The TSP treated monoculture for the long duration pigeon pea yielded higher soil returnable N (87.2 kg N ha^{-1}) compared to the non TSP treated counterpart (79.7 kg N ha^{-1}). A marginal difference in the yields of soil returnable P was observed for the two treatments. For the medium duration pigeon pea monoculture higher soil returnable N was harvested in the TSP treated monoculture (95.6 kg N ha^{-1}) compared to the non TSP treated monoculture (87.0 kg N ha^{-1}). A marginal difference for the yields of soil returnable P was observed for the two treatments. Similar soil returnable yields of N were observed in the TSP (128.3 kg N ha^{-1}) and non TSP treated (128.8 kg N ha^{-1}) intercrop of medium duration pigeon pea and groundnut. A marginal difference for the yields of soil returnable P was observed for the two treatments. Higher soil returnable yields of N was observed for the TSP (128.4 kg N ha^{-1}) than for the non TSP treated (103.9 kg N ha^{-1}) intercrop of long duration pigeon pea and groundnut. A marginal difference for the yields of soil returnable P was also observed for the two treatments. The amount of soil returnable P ranged from 4.0 to 9.5 kg P ha^{-1}

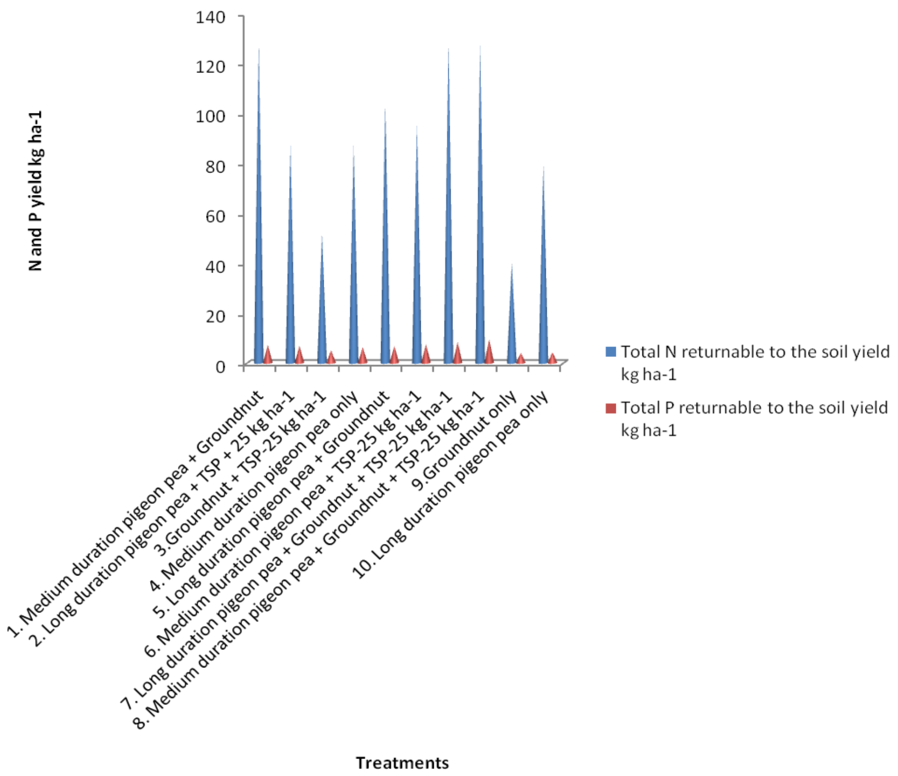

Figure 5.2: Calculated soil returnable N and P yields for the monoculture of groundnut and pigeon pea and the intercrop of the groundnut

5.3.7 Evaluation of the productivity of the cropping systems

Table 5.8 shows the evaluation of the productivity of the intercrops using the LER on biomass production basis. 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 5.8: Evaluation of the productivity of the intercrops

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	1.89
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	-	-	-	-
$LSD_{0.05}$	-	-	-	-	-

LER=Land Equivalent Ratio

5.4 DISCUSSION

5.4.1 Yields, nitrogen and phosphorus partitioning for the legumes

In general, for all the crops high variability in the yields data was observed, attributable to competition for growth resources across the cropping systems that impacted on the yields. Higher groundnut grains and haulms yields were registered in the 2012/2013 cropping season (Tables 5.0, 5.2 and 5.8) than in 2011/2012 cropping season (Phiri *et al.,* 2013). The higher yields in the 2012/2013 cropping season might be attributed to sustained moisture availability over the cropping season and adequate nutrient uptake that promoted vegetative growth, leading to more yields. On the other hand dry spells in the 2011/2012 cropping season reduced the amount of available moisture leading to a significant reduction in biomass and grain yields (Banerjee *et al.,* 2005; Phiri *et al.,* 2013). Potential grain yield (3 t ha^{-1}) was generated in pure stands of groundnut that were treated with TSP (Table 5.2). This implies that in these plots ideal conditions for the growth of the variety were available. The conditions include soil moisture, nutrients, temperature soil pH among others. Groundnut grain yields for intercrops treated with TSP did not reach the yield potential (Table 5.2). It is likely that competition for growth resources i.e. nutrients and moisture, with the pigeon pea prevented the groundnut from fully expressing the potential yield. Though lower yields were generated in the latter treatment plots, the yields were statistically the same ($p>0.05$) to the yields that were obtained in the TSP treated monoculture.

Haulms' N values (Figure 5.0) generated from this study were not consistent with reported values of 60 kg N ha^{-1} (Ghosh *et al.,* 2007) and 54-58 kg N ha^{-1} (Hedge and Dwevidi, 1993). This could be attributed to environmental factors controlling nitrogen concentration in the residues and plant size at maturity that determines the overall haulms' and hence N yields. It is important to note that N yields indicate that more of the plant absorbed and biologically fixed N in the crop is exported from the field in form of shells and grain and less is return to the soil upon the incorporation of the haulms. This spells out the need to manage crop residues to avoid depletion of N from the soil.

For the pigeon pea, the N and P yields (Figure 5.1) were lower for the dry leaves compared with the fresh leaves because some N and P was remobilized to other plant parts during the senescence of defoliating leaves (Fischer, 2007). The N and P content was lower for the stems than the twigs and leaves (Figure 5.1) as the stems contain more lignin and fibre (Norton, 1992). N yields for roots falls within the yields range of 5 and 15 kg N ha^{-1} reported for intercropping systems involving legumes (Nnadi and Haque, 1986). Overall, the results have shown that much of the N contribution to the soil N pool comes from the above ground biomass as compared with the below ground biomass. Though modest the contribution of roots to soil N cannot be overlooked since the nutrient even after immobilization, a temporally state, largely is available for uptake by succeeding crops in a rotation system as it does not get complexed in the soil as is the case with phosphorus.

5.4.2 Estimated soil returnable N yields for the monoculture of groundnut and pigeon pea and the intercrop of the groundnut

The results indicate that the monoculture for groundnut treated with TSP yielded more N (52.0 kg N ha^{-1}) compared with the control (40.0 kg N ha^{-1}). This is attributable to enhanced N fixation and accumulation in plant tissues of groundnut plants for the former treatment plots compared to the latter treatment plots due to increased supply of P. The results agrees with reports that indicate increase in N fixation when P is applied to legumes growing on soils with low P supply (Yakubu *et al.,* 2010). Phosphorus enhances the energy demanding process of biological nitrogen fixation (BNF) in legumes (Somado and Kuehne, 2006), as it is an integral part of the energy containing molecules of ATP and ADP that provide energy for plant biochemical processes (Rai *et al.,* 2013). In legumes nodule number, as well as nitrogenase activity increases with the additions of P, implying more efficient N fixation (Israel, 1987). The soil returnable yields of P for the two treatments differed marginally. The TSP treated monoculture for the long duration pigeon pea yielded higher soil returnable N (87.2 kg N ha^{-1}) compared with the non TSP treated counterpart (79.7 kg N ha^{-1}).

The marginal difference for P uptake between the monoculture for groundnut treated with TSP and the control is explainable interms of the efficiency of groundnut in P uptake under conditions of low P supply (Ikisan, 2000). This largely is accrued to the mycorrhizal association between roots of groundnut and soil fungi or due to phosphobacteria found in the rhizosphere (Ikisan, 2000). Phosphobacterium turns phosphate present in the soil from unavailable to available form (Basu *et al.,* 2006). Due to low P supply by the soil, it is likely that groundnut plants in the control plots, scavenged for P from the soil through the above mechanisms, thereby concentrating P in the biomass.

For the medium duration pigeon pea monoculture higher soil returnable N was harvested from the TSP treated monoculture (95.6 kg N ha^{-1}) compared with the non TSP treated monoculture (87.0 kg N ha^{-1}). The difference was attributable to enhanced

BNF for the former plots compared with the latter plots due to increased supply of P (Somado and Kuehne, 2006). A marginal difference for the yields of soil returnable P was observed for the two treatments. Pigeon pea is a known scavenger of P under soil conditions of low supply of P (Gwata, 2012). The deep tap root extracts moisture and nutrients from deep layers of the soil (Gwata, 2012). Additionally, the roots of pigeon pea produce an exudate (piscidic acid-$C_{11}H_{12}O_7$) which releases P from the Fe-P complexes, thereby increasing available P (Ae *et al.,* 1990; Gwata, 2012). It is likely that the plants in the latter plots concentrate P in their tissues through this mechanism.

Similar soil returnable yields of N were observed for the TSP (128.3 kg N ha^{-1}) and non TSP treated (128.8 kg N ha^{-1}) intercrop of medium duration pigeon pea and groundnut. This suggests that N accumulation in plant tissues due to uptake and BNF did not differ markedly. The observation could be explained by the uptake and yields of P. A marginal difference for the yields of soil returnable P was observed between the two treatments. The mode of TSP application for the former plots and potential resultant competition for uptake of the applied P by the pigeon pea and groundnut might have reduced the potential effects of applying P to the legumes. TSP was evenly spread out in grooves made on the ridges, leading to low concentration on an area basis and hence uptake by the two legumes of the applied P. Consequencially, N accumulation in plant tissues due to uptake and BNF in particular might not have been enhanced for the TSP treated plants leading to the observed similar yields of N by the legumes from the TSP treated and control plots.

Higher soil returnable yields of N were observed for the TSP (128.4 kg N ha^{-1}) than the non TSP treated (103.9 kg N ha^{-1}) intercrop of long duration pigeon pea and groundnut. The difference is accountable since total biomass yields, which is the basis for the N yields were lower for the intercrop of long duration pigeon pea and groundnut compared with the intercrop of long duration pigeon pea and groundnut treated with TSP (Table 5.8).

The evaluation of the productivity of the intercrops using the LER was based on biomass production basis. In general, all intercrops registered a yield advantage above the monocultures of both the pigeon pea and groundnut. This was in agreement with the findings of other researchers like Schilling and Gibbons (2002) Lingaraju, *et al.* (2008) and Phiri *et al.* (2013a). A higher yield advantage over the monocultures was registered by the medium duration pigeon pea-groundnut intercrop.

5.5 CONCLUSION

The study has served to confirm that more N for groundnut is exported from the field in form of shells and grain and less is return to the soil upon the incorporation of the haulms. Furthermore, in the pigeon pea much of the N contribution to the soil N pool comes from the above ground biomass as compared with the below ground biomass. This though still is vital in increasing the level of soil N for increased crop productivity in a rotation system. Additionally, supply of P to legumes increases N yields through enhanced biological fixation. The legumes however do not yield enough P for the correction of soil P deffiencies that are prevalent across Malawi.

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CHAPTER 6:

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

ABSTRACT

An experiment involving eight treatments replicated three times in a randomized complete block design was established at Chitedze Agricultural Research Station (13^{o} 59' 23.2" S, 033^{o} 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 accomodate 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.

Key words: groundnut, intercrop, maize, nutrient, pigeon pea and rotation

6.0 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 defficiencies 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 $\geq$ 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 ti its widespread deffiency, 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 defficiency 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 (NO_3^- and NH_4^+) 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 rejuvination 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 otherhand 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 utilisation,varies across varieties and soil types (Machado *et al.*, 1999).

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.

6.1 MATERIALS AND METHODS

6.1.1 Study site

Details on the location of the study site are as presented in Chapter 2 section 2.1.1.

6.1.2 Field experiment

Details of the field experiments were as presented in Chapter 2 section 2.1.4. 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 accomodate 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.

The statistical model used for the split plot design was:

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

X_{ijk} = an observation

$\bar{X}_{...}$ = 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).

6.1.3 Plot description and application of triple super phosphate and urea

Details for treatment plots and application of triple super phosphate and urea were as presented in Chapter 5 section 5.1.3.

6.2 DATA COLLECTION AND ANALYSIS

6.2.1 Soil sample collection

Details on soil sample collection and preparation were as presented in Chapter 2 under section 2.1.3.1 and 2.1.3.3.

6.2.2 Biomass and grain yields assessment for the pigeon pea

Details for the assessment of grain and biomass yields for the pigeon pea are as presented in Chapter 5 under section 5.2.2.

6.2.3 Biomass and grain yields assessment for the groundnut and maize

Details for the assessment of grain and biomass yields for the groundnut and maize are as presented in Chapter 5 under section 5.2.3.

6.2.4 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 formula used was as presented in Chapter 1 under section 1.1.12.

6.2.5 Soil analysis and plant sample analysis

Laboratory soil analysis was conducted as presented in Chapter 2 under section 2.1.3.4. The plant materials were analysed in the laboratory as described in Chapter 3 under section 3.2.7.

6.2.6 Nutrient yields

Nutrient yields were calculated as presented in Chapter 3 under section 3.2.9.

6.2.7 Statistical analysis

Statistical analysis on the soil, biomass, plant nutrient concentrations and yields data was performed as presented in Chapter 2 under section 2.1.4.2.

6.3 RESULTS

6.3.1 Characterization of the soils at study site

Soil laboratory analytical results for the site were as presented in Chapter 2, Tables 2.0, 2.1a and 2.1b, sections 2.2.1 and 2.2.2, Appendices 2.0-2.1b.

6.3.2 Nutrient uptake in the parallel experiment

6.3.2.1 Groundnut

Figure 6.0 and Appendix 6.0, 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 0.32 to

0.34%. 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.

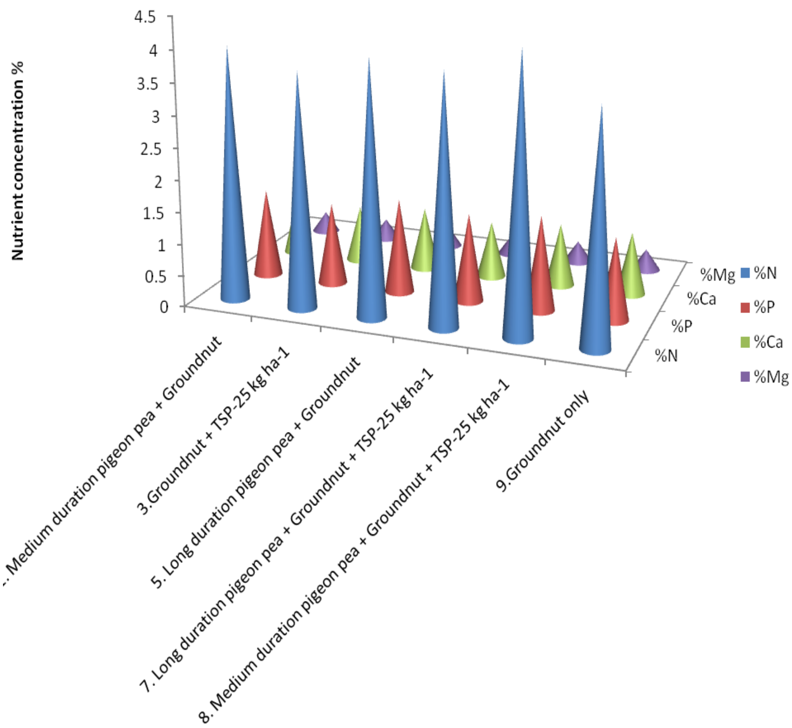

Figure 6.0: Nutrient concentrations for the haulms of groundnut plants at flowering in the parallel experiment season two

6.3.2.2 Pigeon pea

Figure 6.1 and Appendix 6.1, shows the nutrient concentrations in the pigeon pea plant at flowering stage in season two. No significant differences ($p>0.05$) were observed 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%.

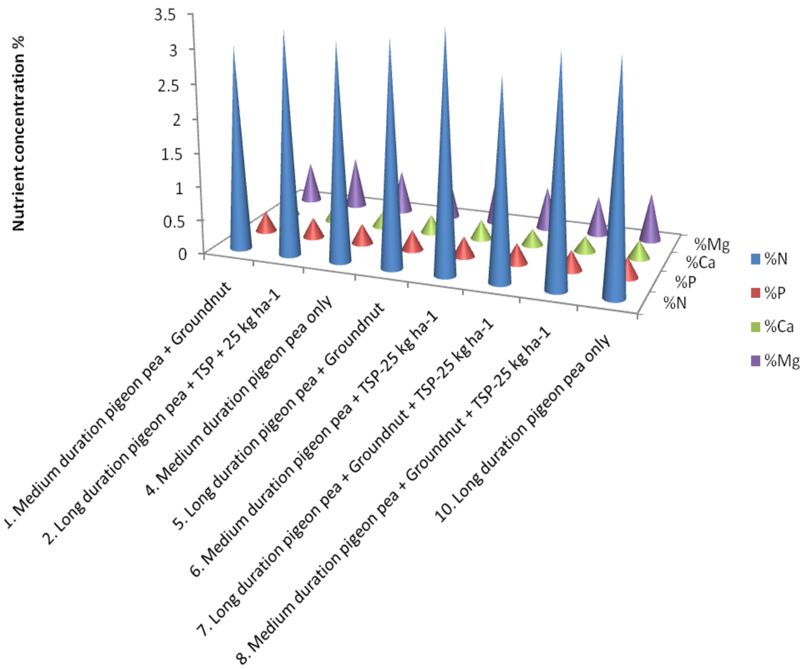

Figure 6.1: Nutrient concentrations for pigeon pea plants at flowering stage in the parallel experiment season two

6.3.2.3 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 6.0, Appendix 6.0a. 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 6.0: N and P contents in the maize plant 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
GM	2.1	0.3
CV (%)	15.9	18.3
$LSD_{0.05}$	0.50	-

Table 6.1, Appendix 5.0d, 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) and significantly lower in the TSP treated medium duration pigeon pea-groundnut intercrop (147g).

Table 6.1: 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.Srole goundnut	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	-	-	-

6.3.3 Yields of pigeon pea and groundnut in the parallel and main experiment in the second cropping season

6.3.3.1 Pigeon pea yields

Yields components of pigeon pea for the parallel experiment for season two were as presented in Table 6.2 and Appendices 5.1a to 5.1e. 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 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}).

Table 6.2: 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

Yields 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 Table 6.3, and Appendices 6.2b to 6.2e. Grain yields for the subplots of the main treatment that had sole maize during season one without incorporation of stover into the soil at harvest were in the order; 150 kg N ha^{-1} (4,106 kg ha^{-1}) > 100 kg N ha^{-1} (3,346 kg ha^{-1}) > 50 kg N ha^{-1} (2,188 kg ha^{-1}) > 0 kg N ha^{-1} (1,775 kg ha^{-1}); Stover yields were in this order; 150 kg N ha^{-1} (3,006 kg ha^{-1}) > 50 kg N ha^{-1} (2,587 kg ha^{-1}) > 100 kg N ha^{-1} (2,579 kg ha^{-1}) > 0 kg N ha^{-1} > (2,272 kg ha^{-1}); rachids yields were in the order; 150 kg N ha^{-1} (1,012 kg ha^{-1}) > 0 kg N ha^{-1} (774 kg ha^{-1}) > 100 kg N ha^{-1} (679 kg ha^{-1}) > 50 kg N ha^{-1} > (661kg ha^{-1});and the average cob lengths were in this order 150 kg N ha^{-1}, 100 kg N ha^{-1} (17cm) > 50 kg N ha^{-1}, 0 kg N ha^{-1} (16cm).

Grain yields for the subplots of the main treatment that had medium duration pigeon pea monoculture during season one with biomass incorporated into the soil at harvest were in the order; 150 kg N ha^{-1} (5, 404kg ha^{-1}) > 100 kg N ha^{-1} (4,391 kg ha^{-1}) > 50 kg N ha^{-1} (3,700 kg ha^{-1}) > 0 kg N ha^{-1} > (2, 410 kg ha^{-1}). While stover yields were in the order; 100 kg N ha^{-1} (3,360 kg ha^{-1}) > 50 kg N ha^{-1} (3,326 kg ha^{-1}) > 150 kg N ha^{-1} (2,944 kg ha^{-1}) > 0 kg N ha^{-1} > (2, 026 kg ha^{-1}); rachids yields were in this order; 50 kg N ha^{-1} (1,178 kg ha^{-1}) > 0 kg N ha^{-1} (1,013 kg ha^{-1}) > 100 kg N ha^{-1} (953 kg ha^{-1}) > 150 kg N ha^{-1} > (669 kg ha^{-1}) and cob lengths were in the order; 150 kg N ha^{-1} (18cm) > 100 kg N ha^{-1}, 50 kg N ha^{-1} (17cm) > 0 kg N ha^{-1} > (15cm).

Grain yields for the subplots of the main treatment that had 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} (5, 453 kg ha^{-1}) > 100 kg N ha^{-1} (4,691 kg ha^{-1}) > 50 kg N ha^{-1} (4,621 kg ha^{-1}) > 0 kg N ha^{-1} > (4,365 kg ha^{-1}). While stover yields were in the order; 50 kg N ha^{-1} (3,731 kg ha^{-1}) > 150 kg N ha^{-1} (3,232 kg ha^{-1}) > 100 kg N ha^{-1} (3,222 kg ha^{-1}) > 0 kg N ha^{-1} > (2, 896 kg ha^{-1}); rachids yields were in the order; 100 kg N ha^{-1} (1,076 kg ha^{-1}) > 150 kg N ha^{-1} (1,027 kg ha^{-1}) > 0 kg N ha^{-1} (1,025 kg ha^{-1}) > 50 kg N ha^{-1} > (1,019 kg ha^{-1}) and cob lengths were in the order; 150 kg N ha^{-1} (18cm) > 100 kg N ha^{-1}, 50 kg N ha^{-1} (17cm) > 0 kg N ha^{-1} > (16cm).

Grain yields for the subplots of the main treatment that had sole groundnut during season one with biomass incorporated into the soil at harvest were in the order; 150 kg N ha^{-1} (5,806 kg ha^{-1}) > 100 kg N ha^{-1} (5,314 kg ha^{-1}) > 0 kg N ha^{-1} > (3,034 kg ha^{-1}) > 50 kg N ha^{-1} (3,010 kg ha^{-1}). While stover yields were in the order; 150 kg N ha^{-1} (4,413 kg ha^{-1}) > 100 kg N ha^{-1} (3,086 kg ha^{-1}) > 0 kg N ha^{-1} > (2,814 kg ha^{-1}) > 50 kg N ha^{-1} (2,684 kg ha^{-1}); rachids yields were in the order; 150 kg N ha^{-1} (1,235 kg ha^{-1}) > 100 kg N ha^{-1} (1,150 kg ha^{-1}) > 50 kg N ha^{-1} (657 kg ha^{-1})> 0 kg N ha^{-1} (641 kg ha^{-1}). Cob lengths were in the order; 150 kg N ha^{-1} (18cm) > 100 kg N ha^{-1} (17cm) > 0 kg N ha^{-1} (16cm) > 50 kg N ha^{-1} > (15cm). Grain yields for the subplots of the main treatment that had medium duration pigeon pea-groundnut intercrop during season one with biomass incorporated into the soil at harvest were in the order; 150 kg N ha^{-1} (5,636 kg ha^{-1}) > 100 kg N ha^{-1} (4,956 kg ha^{-1}) > 50 kg N ha^{-1} > (4,509 kg ha^{-1}) > 0 kg N ha^{-1} (4,266 kg ha^{-1}). While stover yields were in the order; 150 kg N ha^{-1} (4,146 kg ha^{-1}) > 50 kg N ha^{-1} (3,684 kg ha^{-1}) > 100 kg N ha^{-1} > (3,592 kg ha^{-1}) > 0 kg N ha^{-1} (3,023 kg ha^{-1}); rachids yields were in the order; 100 kg N ha^{-1} (1,155 kg ha^{-1}) > 50 kg N ha^{-1} (817 kg ha^{-1}) > 150 kg N ha^{-1} (777 kg ha^{-1})> 0 kg N ha^{-1} (671 kg ha^{-1}). Cob lengths were in the order; 150 kg N ha^{-1}, 100 kg N ha^{-1} (17cm) > 50 kg N ha^{-1}, 0 kg N ha^{-1} (16cm).

Grain yields for the subplots of the main treatment that had long duration pigeon pea-groundnut intercrop during season one with biomass incorporated into the soil at harvest were in the order; 100 kg N ha^{-1} (5, 217 kg ha^{-1}) > 50 kg N ha^{-1} (5,184 kg ha^{-1}) > 150 kg N ha^{-1} (4,625 kg ha^{-1}) > 0 kg N ha^{-1} (3,333 kg ha^{-1}). While stover yields were in the order; 50 kg N ha^{-1} (4,022 kg ha^{-1}) > 100 kg N ha^{-1} (3,810 kg ha^{-1}) > 150 kg N ha^{-1} (3,105 kg ha^{-1}) > 0 kg N ha^{-1} (2,179 kg ha^{-1}); rachids yields were in the order; 100 kg N ha^{-1} (1,088 kg ha^{-1}) > 150 kg N ha^{-1} (936 kg ha^{-1}) > 50 kg N ha^{-1} (749 kg ha^{-1}) > 0 kg N ha^{-1} (631 kg ha^{-1}). Cob lengths were in the order; 100 kg N ha^{-1} (17cm) > 150 kg N ha^{-1}, 50 kg N ha^{-1} (16cm) > 0 kg N ha^{-1} (15cm).

Grain yields for the subplots of the main treatment that had medium duration pigeon pea-groundnut intercrop during season one with no biomass buried into the soil at harvest were in the order; 150 kg N ha^{-1} (4,235 kg ha^{-1}) > 100 kg N ha^{-1} (3,352 kg ha^{-1}) > 0 kg N ha^{-1} (2,226 kg ha^{-1}) > 50 kg N ha^{-1} (2,163 kg ha^{-1}). While stover yields were in the order; 150 kg N ha^{-1} (3,308 kg ha^{-1}) > 50 kg N ha^{-1} (3,157kg ha^{-1}) > 0 kg N ha^{-1} (2,538 kg ha^{-1}) > 100 kg N ha^{-1} (2,520 kg ha^{-1}); rachids yields were in the order; 100 kg N ha^{-1} (918 kg ha^{-1}) > 50 kg N ha^{-1} (810 kg ha^{-1}) > 150 kg N ha^{-1} (803 kg ha^{-1}) > 0 kg N ha^{-1} (405 kg ha^{-1}). Cob lengths were in the order; 150 kg N ha^{-1} (18cm) > 0 kg N ha^{-1}(17cm) > 100 kg N ha^{-1} (16cm) > 50 kg N ha^{-1} (15cm).

Grain yields for the subplots of the main treatment that had long duration pigeon pea-groundnut intercrop during season one with no biomass buried into the soil at harvest were in the order; 150 kg N ha^{-1} (5,308 kg ha^{-1}) > 100 kg N ha^{-1} (5,185 kg ha^{-1}) > 0 kg N ha^{-1} (3,007 kg ha^{-1}) > 50 kg N ha^{-1} (2,845 kg ha^{-1}). While stover yields were in the order; 150 kg N ha^{-1} (3,254 kg ha^{-1}) > 100 kg N ha^{-1} (3,167kg ha^{-1}) > 50 kg N ha^{-1} (2,670 kg ha^{-1}) > 0 kg N ha^{-1} (2,556 kg ha^{-1}); rachids yields were in the order; 50 kg N ha^{-1} (1,070 kg ha^{-1}) > 150 kg N ha^{-1} (856 kg ha^{-1}) > 100 kg N ha^{-1} (635 kg ha^{-1}) > 0 kg N ha^{-1} (541 kg ha^{-1}). Cob lengths were in the order; 150 kg N ha^{-1} (17cm) > 100 kg N ha^{-1}(17cm),50 kg N ha^{-1}, 0 kg N ha^{-1} (16cm).

Table 6.3: Maize grain, stover, rachids yields and average cob length for the main experiment

Treatments: Main and sub plot	Maize grain yield kg ha^{-1}	Stover yield kg ha^{-1}	Rachids yield kg ha^{-1}	Average cob length cm
1.				
a.Sole Maize-No biomass	1,775	2,272	774	16
b.Sole Maize-No biomass + 100 kg N ha^{-1}	3,346	2,579	679	17
c.Sole Maize-No biomass + 150 kg N ha^{-1}	4,106	3,006	1,012	17
d.Sole Maize-No biomass + 50 kg N ha^{-1}	2,188	2,587	661	16
2.				
a.Medium duration pigeon pea-biomass	2,410	2,029	1,013	15
b.Medium duration pigeon pea-biomass + 100 kg N ha^{-1}	4,391	3,360	953	17
c.Medium duration pigeon pea-biomass + 150 kg N ha^{-1}	5,404	2,944	669	18
d.Medium duration pigeon pea-biomass + 50 kg N ha^{-1}	3,700	3,326	1,178	17
3.				
a.Long duration pigeon pea-biomass	4,365	2,896	1,025	16
b.Long duration pigeon pea-biomass + 100 kg N ha^{-1}	4,691	3,222	1,076	17
c.Long duration pigeon pea-biomass + 150 kg N ha^{-1}	5,453	3,232	1,027	18
d.Long duration pigeon pea-biomass + 50 kg N ha^{-1}	4,621	3,731	1,019	17
4.				
a. Sole groundnut-biomass	3,034	2,814	641	16
b.Sole groundnut-biomass + 100 kg N ha^{-1}	5,314	3,089	1,150	17
c.Sole groundnut-biomass + 150 kg N ha^{-1}	5,806	4,413	1,235	18
d.Sole groundnut-biomass + 50 kg N ha^{-1}	3,010	2,684	657	15
5.				
a.Medium duration pigeon pea + groundnut-biomass	4,266	3,023	671	16
b.Medium duration pigeon pea + groundnut-biomass + 100 kg N ha^{-1}	4,956	3,592	1,155	16
c.Medium duration pigeon pea + groundnut-biomass + 150 kg N ha^{-1}	5,636	4,146	777	17
d.Medium duration pigeon Pea + groundnut-biomass + 50 kg N ha^{-1}	4,509	3,684	817	17
6.				
a.Long duration pigeon pea + groundnut-biomass	3,333	2,179	630	15
b.Long duration pigeon pea + groundnut-biomass + 100 kg N ha^{-1}	5,217	3,810	1,088	17
c.Long duration pigeon pea + groundnut-biomass + 150 kg N ha^{-1}	4,625	3,105	936	16
d.Long duration pigeon pea + groundnut-biomass + 50 kg N ha^{-1}	5,184	4,022	749	16

7.	Maize grain yield kg ha^{-1}	Stover yield kg ha^{-1}	Rachids yield kg ha^{-1}	Average cob length cm
a.Medium duration pigeon pea + groundnut-no biomass	2,226	2,538	405	17
b.Medium duration pigeon pea + groundnut-no biomass + 100 kg N ha^{-1}	3,352	2,520	918	16
c.Medium duration pigeon pea + groundnut-no biomass + 150 kg N ha^{-1}	4,235	3,308	803	18
d.Medium duration pigeon pea + groundnut-no biomass + 50 kg N ha^{-1}	2,163	3,157	810	15
8.				
a.Long duration pigeon pea + groundnut-no biomass	3,007	2,556	541	16
b.Long duration pigeon pea + groundnut-no biomass + 100 kg N ha^{-1}	5,185	3,167	635	16
c.Long duration pigeon pea + groundnut-no biomass + 150 kg N ha^{-1}	5,308	3,254	856	17
d.Long duration pigeon pea + groundnut-no biomass + 50 kg N ha^{-1}	2,845	2,670	1,070	16
GM	4,052	3,091	863	16.5
CV (%)	21.6	32.7	41.6	9.2
$LSD_{0.05}$	1,425	1,649	586	3.0

6.3.4 Evaluation of the productivity of the cropping systems

Table 6.4 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 6.4: 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	-	-	-	-
$LSD_{0.05}$	-	-	-	-	-

LER=Land Equivalent Ratio

6.4 DISCUSSION

6.4.1 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 (Figure 6.0) 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}. Evidencially 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 contrasts 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.

6.4.2 Nutrient uptake for pigeon pea and yields

Under the conditions of this study, nutrient uptake by the pigeon pea was high (Figure 6.1). 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 patttern 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.

On biomass yields, pigeon pea seem to have responded well to the application of phosphorus, as reflected by the significant high yields registered by the TSP treated medium duration pigeon pea monoculture (4,149 kg ha^{-1}). Lower biomass yields were registered by the non TSP treated long duration pigeon pea groundnut intercrop (3,145 kg ha^{-1}). The results are in agreement with recent findings by Kumar and Kumar, (2013) who indicated pigeon pea dry matter increase with increased doses of phosphorus. Parihar *et al.* (2005), Kumar and Kushwaha (2006) and Kumar *et al.*

(2007) reported a similar trend of yields increase. The inclusion of stem and root biomass yields increased the total biomass yields substancially 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)

6.4.3 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 (Table 6.3). 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 (Table 6.3). 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} (Table 6.3). 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 tasseling 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).

6.5 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 contrasts 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 patttern 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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CHAPTER 7:

ASSESSMENT OF NITROGEN USE EFFICIENCY IN THE PIGEON PEA-GROUNDNUT INTERCROP MAIZE ROTATION CROPPING SYSTEM IN MALAWI

ABSTRACT

An on station experiment was conducted in two seasons (2012/2012 and 2012/2013 cropping seasons) at Chitedze Agricultural Research Station (13^{o} 59' 23.2" S, 033^{o} 38' 36.8" E) to assess nitrogen use efficiency (NUE) by maize in the pigeon pea-groundnut intercrop maize rotation cropping system where N was applied as urea, $CO(NH_2)_2$. Eight treatments replicated three times in a randomized complete block design were established. Two pigeon pea varieties, long (ICEAP 04000) and medium duration (ICEAP 00557) and groundnut (CG 7) were grown as monocultures and intercrops in the 2011/2012 cropping season. The intercrops involved planting of pigeon pea varieties with groundnut. At harvest legume biomass was incorporated 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}) applied as top dressing to the succeeding maize crop in the 2012/2013 cropping season. During planting the maize crop was basal dressed with 50 kg P ha^{-1}. Top dressing with N was conducted three weeks from emergence. NUE was determined using the recovery efficiency (RE), agronomic efficiency (AE) and partial factor productivity (PFP) indices. Under the conditions of this study, RE ranged from 20% to 88%, AE ranged from 7 to 32 kg yield increase per kg of nitrogen applied and PFP ranged from 27 to 104 kg grain yield per kg N applied. The linear increase in maize grain yield with application of N and the presence of a diminishing-return relationship between maize grain yields (grain yield was near the yield potential of the

maize variety at high N input) and increasing nitrogen supply, suggest that the RE, AE and PFP values obtained from this study might apply both to low and high levels of N use, or at low and high soil N supply for the maize crop. For optimal NUE under low input agriculture, top dressing with 50 kg N ha^{-1} could be ideal while for high input agriculture top dressing with 100 kg N ha^{-1} seem to be reasonable.

Key words: Groundnut, intercrop, maize, nutrient, pigeon pea and rotation

7.0 INTRODUCTION

Nutrient use efficiency (NUE) is one of the most important aspects of cropping systems involving legumes (Makgoga, 2013) since legume biomass incorporation to the soil has the potential to improve NUE. In Malawi, NUE is on the decrease (Sakala, 2004) as a result of declining levels of soil organic matter (SOM) and associated deficiencies of other macro and micronutrients, particulary N, reduced soil buffering and ion retention capacity and soil moisture (Kumwenda *et al.,* 1995). Prevailing economic conditions in Malawi have limited the use of mineral fertilizers by smallholder farmers as farmers have low income. At the same time, annual estimates indicate an increase in nutrient losses from the farming system through different pathways like leaching and soil erosion. Total national estimates for annual nutrient losses of around 160,000 metric tons have been reported, with annual estimates of inorganic fertilizer input into the farming systems pegged at 70,000 metric tons thus leaving a net imbalance of 90,000 metric tons (Kanyama-Phiri, 2005).

About 52.4% of Malawian population (13 million people) live below the poverty line, of 1US$/day (GoM, 2006), yet the delivery price for a metric ton of urea from the ocean ports of East African countries is $770 (Cornway and Waage, 2010), translating to $38.5/50 kg bag which is beyond the smallholder farmers' purchasing power. Conscious of the smallholder farmers' resource limitations, the Government of Malawi introduced the targeted fertilizer subsidy program. This program is tailored to reach out to resource poor smallholder farmers with the aim of boosting agricultural production at village and national levels. However, many smallholder farmers are not able to access the facility. This is due to the fact that the quanties of the fertilizers purchased by the Government for the program are usually not enough (Phiri *et al.,* 2010). Therefore, technologies that can rejuvinate soil fertility under smallholder farms ought to be developed.

In Malawi, on farm maize grain yields response to the application of N and P from inorganic fertilizer is low. According to Waddington *et al.* (2004) this is usually below 20 kg maize grain kg^{-1} nutrient applied. Limited research in Malawi has shown that the low maize grain yields response to the application of mineral fertilizer can be increased through the combined use of organic and inorganic nutrient sources (Sakala *et al.,* 2004). For example, Sakala *et al.* (2004) reported that combined application to maize of organic biomass (*from Mucuna puriens* at 2.7 tons, *Crotalaria juncea at* 3 tons and *Lab lab purpureus at* 2.7 tons) and inorganic fertilizer (35 and 69 kg N ha^{-1}) increased NUE of the maize crop above 20 kg maize grain kg^{-1} nutrient applied. Unfortunately, these findings have remained in grey literature primarily because the green manure crops used by the researchers are not the traditional crops grown by Malawian farmers due to either their relative edibility (i.e. *Mucuna* grains have a special preparation recipe) or inedibility like is the case with *Crotalaria juncea.* As such efforts to out scale the technologies have proved to be futile. Further research on NUE therefore, is required but this time using edible legumes, grown by farmers, that have a high biological N fixing capacity, for example, the pigeon pea.

Cropping system, N source and method of application have been identified as some of the major factors influencing NUE for N (NUE_N) (Raun and Johnson, 1999). It is on record that crop rotation has a profound influence on NUE, as it impacts soil mineral N availability and water use and hence the availability of N for plant growth (López-Bellido and López-Bellido, 2001). Larbi *et al.,* (1993) noted that NUE can be improved through the combined use of inorganic and organic fertilizers. The improvement in NUE comes about due to increased supply of nutrients, improved soil buffer capacity, improved soil water retention and provision of balanced nutrition (Tolessa and Friesen, 2001). Substancial amounts of N from mineralization of decomposed plant biomass enhance inorganic N availability to growing crops (Omokanye *et al.,* 2011). Cassman *et al.* (2002) contended that the overall NUE of a cropping system can be increased by achieving greater uptake efficiency from applied N, reducing the amount of N lost from soil organic and inorganic N pools, or both. Mosier *et al.* (2004) reported four agronomic indices commonly used to describe NUE: partial factor productivity (PFP) expresssed as kg crop yield per kg nutrient applied; agronomic efficiency (AE) expressed as kg crop yield increase per kg nutrient applied); apparent recovery efficiency (RE) expressed as kg nutrient taken up per kg nutrient applied); and physiological efficiency (PE) expressed as kg yield increase per kg nutrient taken up).

Genetically, some plant species (Brennan and Bolland, 2007; Rose *et al.,* 2007) and genotypes within species (Gunes *et al.,* 2006) have the capacity to grow and yield decently on soils with low available nutrients; such species and genotypes are considered tolerant to nutrient deficiency (Rengel, 2005; Rengel and Marschner, 2005). Efficient genotypes have specific physiological mechanisms that allow them to gain access to sufficient quantities of a specific nutrient and/or effectively utilize amounts of the absorbed nutrients (Sattelmacher *et al.* 1994). Nutrient-efficient genotypes are important because they can produce more yields on soils where the effectiveness of inorganic fertilizers may be constrained by chemical and biological processes (Rengel and Marschner, 2005).

Agronomically, in cropping systems involving legumes, choice of crop has been reported to be important for increasing NUE (Thobatsi, 2009). Cropping systems having crop components with different rooting and nutrient uptake patterns result in efficient use of nutrients, particularly of N (Makgoga, 2013). In the pigeon pea-groundnut intercrop-maize rotation cropping system the deep roots of the pigeon pea absorb nutrients from deeper soil layers, thereby recycling leached nutrients and reducing competition (Masson *et al.,* 1986). Simultenously, the groundnut (*Arachis hypogaea*), possess a unique ability of utilizing soil nutrients that relatively are unavailable to other crops (Ikisan, 2000). The highlighted facts might be the reason for the substancial accumulation of nutrients in the biomass of the two legumes in the pigeon pea-groundnut intercrop (Phiri *et al.,* 2013). The nutrients accumulate or are partitioned to different parts of the crops for instance, grain, shells and haulms for groundnut and grain, pods, twigs, leaves (senenced and fresh) stems and roots for the pigeon pea. For the maize crop, nutrients accumulate in the grain, stover, and rachids.

The grains of these crops are taken from the field for either consumption or sale. As such in a legume-cereal rotation system not all of the nutrients are returned to the soil for the succeeding maize crop to benefit and after the maize cropping phase. This includes nutrients that accumulate in the groundnut shells, pigeon pea pods and maize rachids. Quantification of nutrient partitioning and hence accumulation in the different parts of these crops is imperative to bring to light the actual amount of nutrients returned into the system for the assessment of NUE of the maize crop.

An indepth study, therefore, was conducted on station at Chitedze Agricultural Research Station in Malawi on the pigeon pea groundnut intercropping maize rotation cropping system with the following objectives; i) determination of the partitioning of plant N to harvestable grain and plant biomass returned to soil and ii) determination of NUE of maize in rotation with the legumes as influenced by the incorporation of pigeon pea biomass and groundnut haulms into the soil.

7.1 MATERIALS AND METHODS

7.1.1 Study site

Details on the location of the study site are as presented in Chapter 2 section 2.1.1.

7.1.2 Field Experiment

Details of the field experiments were as presented in Chapter 2 section 2.1.4.

7.1.3 Treatment plot description and application of triple super phosphate ($Ca(H_2PO_4)_2.H_2O$) and urea ($CO(NH_2)_2$)

Details for treatment plots and application of triple super phosphate and urea were as presented in Chapter 5 section 5.1.3.

7.2 DATA COLLECTION AND ANALYSIS

7.2.1 Soil sample collection

Details on soil sample collection and preparation were as presented in Chapter 2 under section 2.1.3.1 and 2.1.3.3.

7.2.2 Soil analysis and plant sample analysis

Laboratory soil analysis was conducted as presented in Chapter 2 under section 2.1.3.4. The plant materials were analysed in the laboratory as described in Chapter 3 under section 3.2.7.

7.2.3 Biomass and grain yields assessment for the pigeon pea

Details for the assessment of grain and biomass yields for the pigeon pea are as presented in Chapter 5 under section 5.2.2.

7.2.4 Biomass and grain yields assessment for the groundnut and maize

Details for the assessment of grain and biomass yields for the groundnut and maize are as presented in Chapter 5 under section 5.2.3.

7.2.5 Nitrogen yields

Nitrogen yields were calculated as presented in Chapter 3 under section 3.2.9.

7.2.6 Assessment of nutrient use efficiency by the maize crop

NUE for each treatment was determined using the recovery efficiency (RE), agronomic efficiency (AE) and the partial factor productivity (PFP) indices (Dobermann, 2007). RE (% of applied nutrients) = Nutrient uptake (F)-Nutrient uptake (C)/Quantity of applied nutrients*100; AE=(Y – Yo)/F and FP=Y/F or PFP = (Yo/F) + AE; Where F = amount of (fertilizer) nutrient applied (kg ha^{-1}); Y = Crop yield with applied nutrients (kg ha^{-1}) and Yo = crop yield (kg ha^{-1}) in a control treatment with no nitrogen; C = Nutrient uptake in a control treatment with no nitrogen. A primary assumption was that N uptake is the same across the treatments. This assumption was made cautiously since soil N transformations and root development may differ in the treatment plots (Brye *et al.,* 2002).

7.2.7 Statistical analysis

Statistical analysis on the soil, biomass, plant N concentrations and yields data was performed as presented in Chapter 2 under section 2.1.4.2.

7.3 RESULTS

7.3.1 Characterization of the soils at the site

Soil laboratory analytical results for the site were as presented in Chapter 2, Tables 2.0, 2.1a and 2.1b, sections 2.2.1 and 2.2.2 and Appendices 2.0-2.1b.

7.3.2 Calculated nitrogen yields returnable to the soil

The pigeon pea biomass yields, N yields for pigeon pea biomass, groundnut haulms yields, N yields for groundnut haulms and sum total for N yield for the intercrops were as shown in Table 7.0. 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}). This was significantly lower in the non TSP treated long duration pigeon pea groundnut intercrop (3,145 kg ha^{-1}). No significant differences ($p>0.05$) were observed in the of groundnut haulms this ranged from 1,396 to 2,463 kg ha^{-1}. N yields for pigeon pea biomass ranged from 74.9 to 98.8 kg ha^{-1} while for groundnut haulms it ranged from 29 to 52 kg ha^{-1}. N yields in the intercrops ranged from 103.9 to 128.8 kg N ha^{-1}.

Table 7.0: Calculated amount of biomass and N returned to the soil by the monoculture and intercrop of groundnut and pigeon pea

Treatment	TTBYPP kg ha^{-1}	PP-N yield kg ha^{-1}	Haulms yield kg ha^{-1}	GH-N yield kg ha$^{-1\ H}$	TTC-N yield kg ha^{-1}
1. Medium duration pigeon pea + groundnut	3,796	98.8	1,516	30	128.8
2. Long duration pigeon pea + 25 kg P ha^{-1}	3,337	87.2	-	-	87.2
3.Groundnut + 25 kg P ha^{-1}	-	-	2,463	52	52.0
4. Medium duration pigeon pea only	3,727	87	-	-	87.0
5. Long duration pigeon pea + groundnut	3,145	74.9	1,396	29	103.9
6. Medium duration pigeon pea + 25 kg P ha^{-1}	4,149	95.6	1,173	-	95.6
7. Long duration pigeon pea + groundnut + 25 kg P ha^{-1}	3,603	95.4	1,727	33	128.4
8. Medium duration pigeon pea + groundnut + 25 kg P ha^{-1}	3,861	97.3	1,412	31	128.3
9.Sole groundnut	-	-	1,752	40	40.0
10. Long duration pigeon pea only	3,332	79.7	-	-	79.7
GM	3,619	89.5	1,634	43	93.1
CV (%)	10.2	-	41.7	38.3	-
$LSD_{0.05}$	681	-	-	-	-

TTBYPP=total biomass yield for pigeon pea; PP=pigeon pea; GH=groundnut haulms; TTC=total yield for the cropping system

7.3.3 Maize yields

The maize grain yields, nitrogen concentrations and yields in the grain in season two for treatments of the subplots in the main treatment plots, were as presented in Table 7.1 and Appendix 6.2b.

Grain yields for the subplots of the main treatment that had sole maize during season one without incorporation of stover into the soil at harvest were in the order; 150 kg N ha^{-1} (4,106 kg ha^{-1}) > 100 kg N ha^{-1} (3,346 kg ha^{-1}) > 50 kg N ha^{-1} (2,188 kg ha^{-1}) > 0 kg N ha^{-1} (1,775 kg ha^{-1}); while N concentrations in the grains were in the order; 100 kg N ha^{-1} (1.5%) > 150 kg ha^{-1}, 50 kg N ha^{-1}, 0 kg N ha^{-1}(1.3%) and N yields were in the order; 150 kg N ha^{-1} (55 kg N ha^{-1}) > 100 kg N ha^{-1} (49 kg N ha^{-1}) > 50 kg N ha^{-1} (28 kg N ha^{-1}) > 0 kg N ha^{-1} (23 kg N ha^{-1}). Grain yields for the subplots of the main treatment that had medium duration pigeon pea monoculture during season one with biomass incorporated into the soil at harvest were in the order; 150 kg N ha^{-1} (5, 404kg ha^{-1}) > 100 kg N ha^{-1} (4,391 kg ha^{-1}) > 50 kg N ha^{-1} (3,700 kg ha^{-1}) > 0 kg N ha^{-1} (2, 410 kg ha^{-1}); while N concentrations in the grains were in the order; 150 kg N ha^{-1},100 kg ha^{-1}(2.3%), 0 kg N ha^{-1} (1.2%) > 50 kg N ha^{-1}(1.1%) and N yields were in the order; 150 kg N ha^{-1} (67 kg N ha^{-1}) > 100 kg N ha^{-1} (54 kg N ha^{-1}) > 50 kg N ha^{-1} (41 kg N ha^{-1}) > 0 kg N ha^{-1} (28 kg N ha^{-1}).

Grain yields for the subplots of the main treatment that had 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} (5, 453 kg ha^{-1}) > 100 kg N ha^{-1} (4,691 kg ha^{-1}) > 50 kg N ha^{-1} (4,621 kg ha^{-1}) > 0 kg N ha^{-1} (4,365 kg ha^{-1}); while N concentrations in the grains were in the order; 150 kg N ha^{-1} (1.9%) > 100 kg ha^{-1}(1.7%) > 50 kg N ha^{-1}, 0 kg N ha^{-1}(1.2%) and N yields were in the order; 150 kg N ha^{-1} (104 kg N ha^{-1}) > 100 kg N ha^{-1} (81 kg N ha^{-1}) > 50 kg N ha^{-1} (55 kg N ha^{-1}) > 0 kg N ha^{-1} (54 kg N ha^{-1}). Grain yields for the subplots of the main treatment that had sole groundnut during season one with biomass incorporated into the soil at harvest were in the order; 150 kg N ha^{-1} (5,806 kg ha^{-1}) > 100 kg N ha^{-1} (5,314 kg ha^{-1}) > 0 kg N ha^{-1} > (3,034 kg ha^{-1}) > 50 kg N ha^{-1} (3,010 kg ha^{-1}); while N concentrations in the grains were in the order; 150 kg N ha^{-1} (2.0%) > 100 kg ha^{-1}(1.8%) > 0 kg N ha^{-1} (1.4%) > 50 kg N ha^{-1}(1.3%) and N yields were in the order; 150 kg N ha^{-1} (115 kg N ha^{-1}) > 100 kg N ha^{-1} (98 kg N ha^{-1}) > 0 kg N ha^{-1} (43 kg N ha^{-1}) > 50 kg N ha^{-1} (38 kg N ha^{-1}).

Grain yields for the subplots of the main treatment that had medium duration pigeon pea-groundnut intercrop during season one with biomass incorporated into the soil at harvest were in the order; 150 kg N ha^{-1} (5,636 kg ha^{-1}) > 100 kg N ha^{-1} (4,956 kg ha^{-1}) > 50 kg N ha^{-1} > (4,509 kg ha^{-1}) > 0 kg N ha^{-1} (4,266 kg ha^{-1}); while N concentrations in the grains were in the order; 100 kg N ha^{-1} (1.7%) > 150 kg ha^{-1}, 0 kg N ha^{-1} (1.5%) > 50 kg N ha^{-1}(1.2%) and N yields were in the order; 150 kg N ha^{-1} (85 kg N ha^{-1}) > 100 kg N ha^{-1} (84 kg N ha^{-1}) > 0 kg N ha^{-1} (62 kg N ha^{-1}) > 50 kg N ha^{-1} (55 kg N ha^{-1}). Grain yields for the subplots of the main treatment that had long duration pigeon pea-groundnut intercrop during season one with biomass incorporated into the soil at harvest were in the order; 100 kg N ha^{-1} (5, 217 kg ha^{-1}) > 50 kg N ha^{-1} (5,184 kg ha^{-1}) > 150 kg N ha^{-1} (4,625 kg ha^{-1}) > 0 kg N ha^{-1} (3,333 kg ha^{-1}); while N concentrations in the grains were in the order; 0 kg N ha^{-1} (1.8%) > 150 kg ha^{-1}(1.7%) > 100 kg N ha^{-1}, 50 kg N ha^{-1}(1.6%) and N yields were in the order; 100 kg N ha^{-1} (86 kg N ha^{-1}) > 50 kg N ha^{-1} (84 kg N ha^{-1}) > 150 kg N ha^{-1} (76 kg N ha^{-1}) > 0 kg N ha^{-1} (59 kg N ha^{-1}).

Grain yields for the subplots of the main treatment that had medium duration pigeon pea-groundnut intercrop during season one with no biomass incorporated into the soil at harvest were in the order; 150 kg N ha^{-1} (5,308 kg ha^{-1}) > 100 kg N ha^{-1} (5,185 kg ha^{-1}) > 0 kg N ha^{-1} (3,007 kg ha^{-1}) > 50 kg N ha^{-1} (2,845 kg ha^{-1}); while N concentrations in the grains were in the order; 150 kg N ha^{-1}, 100 kg ha^{-1}(1.7%) > 50 kg N ha^{-1} (1.6%) > 0 kg N ha^{-1}(1.5%) and N yields were in the order; 150 kg N ha^{-1} (71 kg N ha^{-1}) > 100 kg N ha^{-1} (56 kg N ha^{-1}) > 50 kg N ha^{-1} (36 kg N ha^{-1}) > 0 kg N ha^{-1} (34 N kg ha^{-1}).

Grain yields for the subplots of the main treatment that had long duration pigeon pea-groundnut intercrop during season one with no biomass incorporated into the soil at harvest were in the order; 150 kg N ha^{-1} (4,235 kg ha^{-1}) > 100 kg N ha^{-1} (3,352 kg ha^{-1}) > 0 kg N ha^{-1} (2,226 kg ha^{-1}) > 50 kg N ha^{-1} (2,163 kg ha^{-1}); while N concentrations in the grains were in the order; 150 kg N ha^{-1} (2.1%) > 100 kg ha^{-1}(1.8%) > 50 kg N ha^{-1}, 0 kg N ha^{-1}(1.4%) and N yields were in the order; 150 kg N ha^{-1} (110 kg N ha^{-1}) > 100 kg N ha^{-1} (91 kg N ha^{-1}) > 0 kg N ha^{-1} (43 kg N ha^{-1}) > 50 kg N ha^{-1} (40 kg N ha^{-1}).

Table 7.1: Nitrogen concentrations and yields: maize grain, main experiment, second season

Treatments: Main and sub plots

1.	Maize grain yield kg ha^{-1}	N (%)	N yield kg ha^{-1}
a.Sole Maize-No biomass	1,775	1.3	23
b.Sole Maize-No biomass + 100 kg N ha^{-1}	3,346	1.5	49
c.Sole Maize-No biomass + 150 kg N ha^{-1}	4,106	1.3	55
d.Sole Maize-No biomass + 50 kg N ha^{-1}	2,188	1.3	28
2.			
a.Medium duration pigeon pea-biomass	2,410	1.2	28
b.Medium duration pigeon pea-biomass + 100 kg N ha^{-1}	4,391	1.2	54
c.Medium duration pigeon pea-biomass + 150 kg N ha^{-1}	5,404	1.2	67
d.Medium duration pigeon pea-biomass + 50 kg N ha^{-1}	3,700	1.1	41
3.			
a.Long duration pigeon pea-biomass	4,365	1.2	54
b.Long duration pigeon pea-biomass + 100 kg N ha^{-1}	4,691	1.7	81
c.Long duration pigeon pea-biomass + 150 kg N ha^{-1}	5,453	1.9	104
d.Long duration pigeon pea-biomass + 50 kg N ha^{-1}	4,621	1.2	55
4.			
a. Sole groundnut-biomass	3,034	1.4	43
b.Sole groundnut-biomass + 100 kg N ha^{-1}	5,314	1.8	98
c.Sole groundnut-biomass + 150 kg N ha^{-1}	5,806	2.0	115
d.Sole groundnut-biomass + 50 kg N ha^{-1}	3,010	1.3	38
5.			
a.Medium duration pigeon pea + groundnut-biomass	4,266	1.5	62
b.Medium duration pigeon pea + groundnut-biomass + 100 kg N ha^{-1}	4,956	1.7	84
c.Medium duration pigeon pea + groundnut-biomass + 150 kg N ha^{-1}	5,636	1.5	85
d.Medium duration pigeon Pea + groundnut-biomass + 50 kg N ha^{-1}	4,509	1.2	55
6.			
a.Long duration pigeon pea + groundnut-biomass	3,333	1.8	59
b.Long duration pigeon pea + groundnut-biomass + 100 kg N ha^{-1}	5,217	1.6	86
c.Long duration pigeon pea + groundnut-biomass + 150 kg N ha^{-1}	4,625	1.7	76
d.Long duration pigeon pea + groundnut-biomass + 50 kg N ha^{-1}	5,184	1.6	84

7.	Maize grain yield kg ha^{-1}	N (%)	N yield kg ha^{-1}
a.Medium duration pigeon pea + groundnut-no biomass	2,226	1.5	34
b.Medium duration pigeon pea + groundnut-no biomass + 100 kg N ha^{-1}	3,352	1.7	56
c.Medium duration pigeon pea + groundnut-no biomass + 150 kg N ha^{-1}	4,235	1.7	71
d.Medium duration pigeon pea + groundnut-no biomass + 50 kg N ha^{-1}	2,163	1.6	36
8.			
a.Long duration pigeon pea + groundnut-no biomass	3,007	1.4	43
b.Long duration pigeon pea + groundnut-no biomass + 100 kg N ha^{-1}	5,185	1.8	91
c.Long duration pigeon pea + groundnut-no biomass + 150 kg N ha^{-1}	5,308	2.1	110
d.Long duration pigeon pea + groundnut-no biomass + 50 kg N ha^{-1}	2,845	1.4	40
GM	4052	1.5	63
CV (%)	21.6	27.96	38.7
$LSD_{0.05}$	1,425	0.70	52

The yields for maize stover, nitrogen concentrations and yields in season two for treatments of the subplots in the main treatment plots were as presented in Table 7.2 and Appendix 6.2c.

Stover yields for the subplots of the main treatment that had sole maize during season one without incorporating of stover into the soil at harvest were in the order; 150 kg N ha^{-1} (3,006 kg ha^{-1}) > 50 kg N ha^{-1} (2,587 kg ha^{-1}) > 100 kg N ha^{-1} (2,579 kg ha^{-1}) > 0 kg N ha^{-1} (2,272 kg ha^{-1}; while N concentrations in the stover were in the order; 150 kg N ha^{-1} (0.8%) > 50 kg ha^{-1}(0.7%) > 100 kg N ha^{-1} (0.6%) > 0 kg N ha^{-1}(0.1%) and N yields were in the order; 150 kg N ha^{-1} (23.8 kg ha^{-1}) > 50 kg N ha^{-1} (17.5 kg ha^{-1}) > 100 kg N ha^{-1} (14.5 kg ha^{-1}) > 0 kg N ha^{-1} (2.3 kg ha^{-1}). Stover yields for the subplots of the main treatment that had medium duration pigeon pea monoculture during season one with biomass incorporated into the soil at harvest were in the order; 100 kg N ha^{-1}

(3,360 kg ha^{-1}) > 50 kg N ha^{-1} (3,326 kg ha^{-1}) > 150 kg N ha^{-1} (2,944 kg ha^{-1}) > 0 kg N ha^{-1} (2, 026 kg ha^{-1}); while N concentrations in the stover were in the order; 100 kg N ha^{-1}, 0 kg N ha^{-1} (0.8%) > 150 kg ha^{-1}, 50 kg N ha^{-1} and N yields were in the order; 100 kg N ha^{-1} (2.7 kg N ha^{-1}) > 0 kg N ha^{-1} (16.1 kg N ha^{-1}) > 50 kg N ha^{-1} (14.3 kg N ha^{-1}) > 150 kg N ha^{-1} (13.2 kg N ha^{-1}). Stover yields for the subplots of the main treatment that had long duration pigeon pea monoculture during season one with biomass incorporated into the soil at harvest were in the order; 50 kg N ha^{-1} (3,731 kg ha^{-1}) > 150 kg N ha^{-1} (3,232 kg ha^{-1}) > 100 kg N ha^{-1} (3,222 kg ha^{-1}) > 0 kg N ha^{-1} (2, 896 kg ha^{-1}); while N concentrations in the stover were in the order; 150 kg N ha^{-1} (0.6%) > 100 kg ha^{-1}(0.4%) > 50 kg N ha^{-1}, 0 kg N ha^{-1} (0.2%) and N yields were in the order; 150 kg N ha^{-1} (18.2 kg N ha^{-1}) > 100 kg N ha^{-1} (14.4 kg N ha^{-1}) > 50 kg N ha^{-1} (8.1 kg N ha^{-1}) > 0 kg N ha^{-1} (6.3 kg N ha^{-1}).

Stover yields for the subplots of the main treatment that had sole groundnut during season one with biomass incorporated into the soil at harvest were in the order; 150 kg N ha^{-1} (4,413 kg ha^{-1}) > 100 kg N ha^{-1} (3,086 kg ha^{-1}) > 0 kg N ha^{-1} (2,814 kg ha^{-1}) > 50 kg N ha^{-1} (2,684 kg ha^{-1}); while N concentrations in the stover were in the order; 100 kg N ha^{-1} (0.8%) > 150 kg ha^{-1} (0.6%) > 0 kg N ha^{-1} (0.3%) > 50 kg N ha^{-1}(0.2%) and N yields were in the order; 150 kg N ha^{-1} (24.8 kg N ha^{-1}) > 100 kg N ha^{-1} (24.5 kg N ha^{-1}) > 0 kg N ha^{-1} (9.3 N kg ha^{-1}) > 50 kg N ha^{-1} > (5.8 N kg ha^{-1}). Stover yields for the subplots of the main treatment that had medium duration pigeon pea-groundnut intercrop during season one with biomass incorporated into the soil at harvest were in the order; 150 kg N ha^{-1} (4,146 kg ha^{-1}) > 50 kg N ha^{-1} (3,684 kg ha^{-1}) > 100 kg N ha^{-1} > (3,592 kg ha^{-1}) > 0 kg N ha^{-1} (3,023 kg ha^{-1}); while N concentrations in the stover were in the order; 150 kg N ha^{-1}, 100 kg ha^{-1}(0.4%) > 50 kg N ha^{-1}, 0 kg N ha^{-1}(0.3%) and N yields were in the order; 150 kg N ha^{-1} (17.1 kg N ha^{-1}) > 100 kg N ha^{-1} (16.1 N kg ha^{-1}) > 50 kg N ha^{-1} (12.2 kg N ha^{-1}) > 0 kg N ha^{-1} (10 kg N ha^{-1}).

Stover yields for the subplots of the main treatment that had long duration pigeon pea-groundnut intercrop during season one with biomass incorporated into the soil at harvest were in the order; 50 kg N ha^{-1} (4,022 kg ha^{-1}) > 100 kg N ha^{-1} (3,810 kg ha^{-1}) > 150 kg N ha^{-1} (3,105 kg ha^{-1}) > 0 kg N ha^{-1} (2,179 kg ha^{-1}); while N concentrations in the stover were in the order; 100 kg N ha^{-1} (0.8%) > 50 kg ha^{-1}(0.6%) > 150 kg N ha^{-1} (0.4%) > 0 kg N ha^{-1}(0.2%) and N yields were in the order; 100 kg N ha^{-1}(32 kg N ha^{-1}) > 50 kg N ha^{-1} (24.6 kg N ha^{-1}) > 150 kg N ha^{-1}(13.6 kg N ha^{-1}) 0 kg N ha^{-1} (3.3 kg N ha^{-1}).

Stover yields for the subplots of the main treatment that had medium duration pigeon pea-groundnut intercrop during season one with no biomass incorporated into the soil at harvest were in the order; 150 kg N ha^{-1} (3,308 kg ha^{-1}) > 50 kg N ha^{-1} (3,157kg ha^{-1}) > 0 kg N ha^{-1} (2,538 kg ha^{-1}) > 100 kg N ha^{-1} (2,520 kg ha^{-1}); while N concentrations in the stover were in the order; 150 kg N ha^{-1} (1.0%) > 100 kg ha^{-1}, 50 kg N ha^{-1} (0.3%) > 0 kg N ha^{-1}(0.2%) and N yields were in the order; 150 kg N ha^{-1} (33.2 kg N ha^{-1}) > 50 kg N ha^{-1} (9.9 kg N ha^{-1}) > 100 kg N ha^{-1} (79 kg N ha^{-1}) > 0 kg N ha^{-1} (5.1 kg N ha^{-1})

Stover yields for the subplots of the main treatment that had long duration pigeon pea-groundnut intercrop during season one with no biomass incorporated into the soil at harvest were in the order; 150 kg N ha^{-1} (3,254 kg ha^{-1}) > 100 kg N ha^{-1} (3,167kg ha^{-1})

> 50 kg N ha^{-1} (2,670 kg ha^{-1}) > 0 kg N ha^{-1} (2,556 kg ha^{-1}); while N concentrations in the stover were in the order; 100 kg N ha^{-1} (0.9%) > 150 kg ha^{-1}(0.4%) > 50 kg N ha^{-1} (0.3%) > 0 kg N ha^{-1}(0.1%) and N yields were in the order; 100 kg N ha^{-1} (28.4 kg N ha^{-1}) > 150 kg N ha^{-1} (14.3 kg N ha^{-1}) > 50 kg N ha^{-1} (8.9 kg N ha^{-1}) > 0 kg N ha^{-1} (2.6 kg N ha^{-1}).

Table 7.2: Nitrogen concentrations and yields: Maize stover, main experiment, second season

Treatments: Main and sub plots	Stover yield kg ha^{-1}	N (%)	N yield kg ha^{-1}
1.			
a.Sole Maize-No biomass	2,272	0.1	2.3
b.Sole Maize-No biomass + 100 kg N ha^{-1}	2,579	0.6	14.5
c.Sole Maize-No biomass + 150 kg N ha^{-1}	3,006	0.8	23.8
d.Sole Maize-No biomass + 50 kg N ha^{-1}	2,587	0.7	17.5
2.			
a.Medium duration pigeon pea-biomass	2,029	0.8	16.1
b.Medium duration pigeon pea-biomass + 100 kg N ha^{-1}	3,360	0.8	27.0
c.Medium duration pigeon pea-biomass + 150 kg N ha^{-1}	2,944	0.4	13.2
d.Medium duration pigeon pea-biomass + 50 kg N ha^{-1}	3,326	0.4	14.3
3.			
a.Long duration pigeon pea-biomass	2,896	0.2	6.3
b.Long duration pigeon pea-biomass + 100 kg N ha^{-1}	3,222	0.4	14.4
c.Long duration pigeon pea-biomass + 150 kg N ha^{-1}	3,232	0.6	18.2
d.Long duration pigeon pea-biomass + 50 kg N ha^{-1}	3,731	0.2	8.1
4.			
a. Sole groundnut-biomass	2,814	0.3	9.3
b.Sole groundnut-biomass + 100 kg N ha^{-1}	3,089	0.8	24.5
c.Sole groundnut-biomass + 150 kg N ha^{-1}	4,413	0.6	24.8
d.Sole groundnut-biomass + 50 kg N ha^{-1}	2,684	0.2	5.8
5.			
a.Medium duration pigeon pea + groundnut-biomass	3,023	0.3	10.0
b.Medium duration pigeon pea + groundnut-biomass + 100 kg N ha^{-1}	3,592	0.4	16.1
c.Medium duration pigeon pea + groundnut-biomass + 150 kg N ha^{-1}	4,146	0.4	17.1
d.Medium duration pigeon pea + groundnut-biomass + 50 kg N ha^{-1}	3,684	0.3	12.2
6.			
a.Long duration pigeon pea + groundnut-biomass	2,179	0.2	3.3
b.Long duration pigeon pea + groundnut-biomass + 100 kg N ha^{-1}	3,810	0.8	32.0
c.Long duration pigeon pea + groundnut-biomass + 150 kg N ha^{-1}	3,105	0.4	13.6
d.Long duration pigeon pea + groundnut-biomass + 50 kg N ha^{-1}	4,022	0.6	24.6

7.	Stover yield kg ha^{-1}	N (%)	N yield kg ha^{-1}
a.Medium duration pigeon pea + groundnut-no biomass	2,538	0.2	5.1
b.Medium duration pigeon pea + groundnut-no biomass + 100 kg N ha^{-1}	2,520	0.3	7.9
c.Medium duration pigeon pea + groundnut-no biomass + 150 kg N ha^{-1}	3,308	1.0	33.2
d.Medium duration pigeon pea + groundnut-no biomass + 50 kg N ha^{-1}	3,157	0.3	9.9
8.			
a.Long duration pigeon pea + groundnut-no biomass	2,556	0.1	2.6
b.Long duration pigeon pea + groundnut-no biomass + 100 kg N ha^{-1}	3,167	0.9	28.4
c.Long duration pigeon pea + groundnut-no biomass + 150 kg N ha^{-1}	3,254	0.4	14.3
d.Long duration pigeon pea + groundnut-no biomass + 50 kg N ha^{-1}	2,670	0.3	8.9
GM	3,091	0.5	15.0
CV (%)	32.7	28.7	46.1
$LSD_{0.05}$	1,649	0.5	23.3

The yield for maize rachids, nitrogen concentrations and yields in season two for treatments of the subplots in the main treatment plots were as presented in Table 7.3, Appendix 6.2d.

Rachids yields for the subplots of the main treatment that had sole maize during season one without incorporation of stover into the soil at harvest were in the order; 150 kg N ha^{-1} (1,012 kg ha^{-1}) > 0 kg N ha^{-1} (774 kg ha^{-1}) > 100 kg N ha^{-1} (679 kg ha^{-1}) > 50 kg N ha^{-1} > (661kg ha^{-1}); while N concentrations in the rachids were in the order; 50 kg N ha^{-1} (0.5%) > 100 kg ha^{-1}, 0 kg N ha^{-1} (0.2%) > 150 kg N ha^{-1}(0.1%) and N yields were in the order; 50 kg N ha^{-1} (3.0 kg ha^{-1}) > 100 kg N ha^{-1} (1.6 kg N ha^{-1}) > 0 kg N ha^{-1} (1.4 kg N ha^{-1}) > 150 kg N ha^{-1} (1.0 kg N ha^{-1}). Rachids yields for the subplots of the main treatment that had medium duration pigeon pea monoculture during season one with biomass incorporated into the soil at harvest were in the order; 50 kg N ha^{-1} (1,178 kg

ha^{-1}) > 0 kg N ha^{-1} (1,013 kg ha^{-1}) > 100 kg N ha^{-1} (953 kg ha^{-1}) > 150 kg N ha^{-1} > (669 kg ha^{-1}); while N concentration in the rachids was at; 50 kg N ha^{-1} (0.4%) and N yield was at 50 kg N ha^{-1} (5.1 kg N ha^{-1}). N concentrations and yields for other treatments were not determined.

Rachid yields for the subplots of the main treatment that had long duration pigeon pea monoculture during season one with biomass incorporated into the soil at harvest were in the order; 100 kg N ha^{-1} (1,076 kg ha^{-1}) > 150 kg N ha^{-1} (1,027 kg ha^{-1}) > 0 kg N ha^{-1} (1,025 kg ha^{-1}) > 50 kg N ha^{-1} > (1,019 kg ha^{-1}); while N concentrations in the rachids were in the order; 50 kg N ha^{-1} (0.3%) > 0 kg ha^{-1}(0.2%) > 150 kg N ha^{-1}, 100 kg N ha^{-1}(0.1%) and N yields were in this order; 50 kg N ha^{-1} (3.9 kg N ha^{-1}) > 0 kg N ha^{-1} (2.3 kg N ha^{-1}) > 100 kg N ha^{-1} (1.4 kg N ha^{-1}) > 150 kg N ha^{-1} (0.9 kg N ha^{-1}). Rachids yields for the subplots of the main treatment that had sole groundnut during season one with biomass incorporated into the soil at harvest were in the order; 150 kg N ha^{-1} (1,235 kg ha^{-1}) > 100 kg N ha^{-1} (1,150 kg ha^{-1}) > 50 kg N ha^{-1} (657 kg ha^{-1})> 0 kg N ha^{-1} (641 kg ha^{-1}); while N concentrations in the rachids were in the order; 150 kg N ha^{-1}, 50 kg ha^{-1}(0.4%) > 100 kg N ha^{-1}, 0 kg N ha^{-1}(0.3%) and N yields were in the order; 150 kg N ha^{-1} (4.3 kg N ha^{-1}) > 100 kg N ha^{-1} (2.9 kg N ha^{-1}) > 50 kg N ha^{-1} (2.5 kg N ha^{-1}) > 0 kg N ha^{-1} (2.2 kg N ha^{-1}).

Rachids yields for the subplots of the main treatment that had medium duration pigeon pea-groundnut intercrop during season one with biomass incorporated into the soil at harvest were in the order; 100 kg N ha^{-1} (1,155 kg ha^{-1}) > 50 kg N ha^{-1} (817 kg ha^{-1}) > 150 kg N ha^{-1} (777 kg ha^{-1}) > 0 kg N ha^{-1} (671 kg ha^{-1}); while N concentrations in the rachids were in the order; 50 kg N ha^{-1}, 0 kg ha^{-1}(0.4%) > 100 kg N ha^{-1} (0.3%) > 150 kg N ha^{-1}(0.2%) and N yields were in the order; 100 kg N ha^{-1} (3.2 kg N ha^{-1}) > 50 kg N ha^{-1} (3.1 kg N ha^{-1}) > 0 kg N ha^{-1} (3.0 kg N ha^{-1}) > 150 kg N ha^{-1} (1.5 kg N ha^{-1}). Rachid yields for the subplots of the main treatment that had long duration pigeon pea-groundnut intercrop during season one with biomass incorporated into the soil at harvest were in the order; 100 kg N ha^{-1} (1,088 kg ha^{-1}) > 150 kg N ha^{-1} (936 kg ha^{-1}) > 50 kg N ha^{-1} (749 kg ha^{-1}) > 0 kg N ha^{-1} (631 kg ha^{-1}); while N concentrations in the rachids were in the order; 0 kg N ha^{-1} (0.3%) > 100 kg ha^{-1}, 50 kg N ha^{-1} (0.2%) > 0 kg N ha^{-1}(0.1%) and N yields were in the order; 100 kg N ha^{-1} (2.0 kg N ha^{-1}) > 50 kg N ha^{-1} (1.8 kg N ha^{-1}) > 0 kg N ha^{-1} (1.7 kg N ha^{-1}) > 150 kg N ha^{-1} (0.9 kg N ha^{-1}).

Rachids yields for the subplots of the main treatment that had medium duration pigeon pea-groundnut intercrop during season one with no biomass incorporated into the soil at harvest were in the order; 100 kg N ha^{-1} (918 kg ha^{-1}) > 50 kg N ha^{-1} (810 kg ha^{-1}) > 150 kg N ha^{-1} (803 kg ha^{-1}) > 0 kg N ha^{-1} (405 kg ha^{-1}); while N concentrations in the rachids were in the order; 100 kg N ha^{-1} (0.4%) > 50 kg ha^{-1}(0.3%) > 0 kg N ha^{-1} (0.2%) > 150 kg N ha^{-1}(0.1%) and N yields were in the order; 100 kg N ha^{-1} (3.2 kg N ha^{-1}) > 50 kg N ha^{-1} (2.5 kg N ha^{-1}) > 0 kg N ha^{-1} (0.9 kg N ha^{-1}) > 150 kg N ha^{-1} (0.8 kg N ha^{-1}). Rachids yields for the subplots of the main treatment that had long duration pigeon pea-groundnut intercrop during season one with no biomass incorporated into the soil at harvest were in the order; 50 kg N ha^{-1} (1,070 kg ha^{-1}) > 150 kg N ha^{-1} (856 kg ha^{-1}) > 100 kg N ha^{-1} (635 kg ha^{-1}) > 0 kg N ha^{-1} (541 kg ha^{-1}); while N concentrations in the rachids were in the order; 150 kg N ha^{-1}, 100 kg N ha^{-1}, 50 kg N ha^{-1} (0.3%) > 0 kg N ha^{-1}(0.1%) and N yields were in the order; 50 kg N ha^{-1} (2.7 kg N ha^{-1}) > 150 kg N ha^{-1} (2.4 kg ha^{-1}) > 100 kg N ha^{-1} (1.9 kg ha^{-1}) > 0 kg N ha^{-1} (0.7 kg N ha^{-1}).

Table 7.3: Nitrogen concentrations and yields: maize rachids, main experiment, second season

Treatments: Main and sub plots	Rachids yield kg ha^{-1}	N (%)	N yield kg ha^{-1}
1.			
a.Sole Maize-no biomass	774	0.2	1.4
b.Sole Maize-no biomass + 100 kg N ha^{-1}	679	0.2	1.6
c.Sole Maize-no biomass + 150 kg N ha^{-1}	1,012	0.1	1.0
d.Sole Maize-no biomass + 50 kg N ha^{-1}	661	0.5	3.0
2.			
a.Medium duration pigeon pea-biomass	1,013	ND	ND
b.Medium duration pigeon pea-biomass + 100 kg N ha^{-1}	953	ND	ND
c.Medium duration pigeon pea-biomass + 150 kg N ha^{-1}	669	ND	ND
d.Medium duration pigeon pea-biomass + 50 kg N ha^{-1}	1,178	0.4	5.1
3.			
a.Long duration pigeon pea-biomass	1,025	0.2	2.3
b.Long duration pigeon pea-biomass + 100 kg N ha^{-1}	1,076	0.1	1.4
c.Long duration pigeon pea-biomass + 150 kg N ha^{-1}	1,027	0.1	0.9
d.Long duration pigeon pea-biomass + 50 kg N ha^{-1}	1,019	0.3	3.9
4.			
a. Sole groundnut-biomass	641	0.3	2.2
b.Sole groundnut-biomass + 100 kg N ha^{-1}	1,150	0.3	2.9
c.Sole groundnut-biomass + 150 kg N ha^{-1}	1,235	0.4	4.3
d.Sole groundnut-biomass + 50 kg N ha^{-1}	657	0.4	2.5
5.			
a.Medium duration pigeon pea + groundnut-biomass	671	0.4	3.0
b.Medium duration pigeon pea + groundnut-biomass + 100 kg N ha^{-1}	1,155	0.3	3.2
c.Medium duration pigeon pea + groundnut-biomass + 150 kg N ha^{-1}	777	0.2	1.5
d.Medium duration pigeon pea + groundnut-biomass + 50 kg N ha^{-1}	817	0.4	3.1
6.			
a.Long duration pigeon pea + groundnut-biomass	630	0.3	1.7
b.Long duration pigeon pea + groundnut-biomass + 100 kg N ha^{-1}	1,088	0.2	2.0
c.Long duration pigeon pea + groundnut-biomass + 150 kg N ha^{-1}	936	0.1	0.9
d.Long duration pigeon pea + groundnut-biomass + 50 kg N ha^{-1}	749	0.2	1.8

7.	Rachids yield kg ha^{-1}	N (%)	N yield kg ha^{-1}
a.Medium duration pigeon pea + groundnut-no biomass	405	0.2	0.9
b.Medium duration pigeon pea + groundnut-no biomass + 100 kg N ha^{-1}	918	0.4	3.2
c.Medium duration pigeon pea + groundnut-no biomass + 150 kg N ha^{-1}	803	0.1	0.8
d.Medium duration pigeon pea + groundnut-no biomass + 50 kg N ha^{-1}	810	0.3	2.5
8.			
a.Long duration pigeon pea + groundnut-no biomass	541	0.1	0.7
b.Long duration pigeon pea + groundnut-no biomass + 100 kg N ha^{-1}	635	0.3	1.9
c.Long duration pigeon pea + groundnut-no biomass + 150 kg N ha^{-1}	856	0.3	2.4
d.Long duration pigeon pea + groundnut-no biomass + 50 kg N ha^{-1}	1,070	0.3	2.7
GM	863	0.3	2.2
CV (%)	41.6	47.31	39.2
$LSD_{0.05}$	586	0.3	-

ND= not determined

The calculated total N yields in the maize plant, N inputs to the soil by different legume cropping systems, N inputs to the soil through urea, total N inputs, the N recovery and agronomic use efficiencies were as presented in Table 7.4. The amount of N input through urea was as presented in the subplot treatment structure. The sum total of N yields in the maize plant, being a sum of nitrogen yields for grain, stover and rachids has been presented alongside with the computed N recovery (RE) agronomic use efficiency (AE) and the partial productivity factor (PFP).

N inputs to the maize plants for the subplots of the main treatment that had sole maize during season one without incorparation of stover into the soil at harvest were according to the treatment structure. Total N yield for the maize plants were in the order; no biomass + 150 kg N ha^{-1} (79.8 kg N ha^{-1}) > no biomass + 100 kg N ha^{-1} (65.1 kg N ha^{-1}) > no biomass + 50 kg N ha^{-1} (48.5 kg N ha^{-1}) > 0 kg N ha^{-1} (26.7 kg N ha^{-1}); while REs were in this order; no biomass + 50 kg N ha^{-1} (44%) > no biomass + 100 kg

N ha^{-1} (38%) > no biomass + 150 kg N ha^{-1} (35%); AEs were in this order; no biomass + 150 kg N ha^{-1}, 100 kg N ha^{-1} (16 kg G kg^{-1} N) > no biomass + 50 kg N ha^{-1} (8 kg G kg^{-1} N); and PFPs were in the order; no biomass + 50 kg N ha^{-1} (44 kg G kg^{-1} N) > no biomass + 100 kg N ha^{-1} (33 kg G kg^{-1} N) > no biomass + 50 kg N ha^{-1} (27 kg G kg^{-1} N) > 150 kg N ha^{-1} (33 kg G kg^{-1} N).

Total N inputs from mineral fertilizer and biomass to the maize plants for the subplots of the main treatment that had medium duration pigeon pea monoculture during season one with biomass incorporated into the soil at harvest were only computed for the subplots treated with 50 kg N ha^{-1}. This was at 141 kg N ha^{-1} with biomass contributing 91 kg N ha^{-1}. N yields from legume biomass in the other subplots were not calculated due to lack of data on pigeon pea biomass yield. Additionally, total N yield for maize plants was not calculated due to lack of data on N yield for rachids.NUEs for the subplots treated with 50 kg N ha^{-1}were as follows; RE (24%) AE (141 kg G kg^{-1} N) and PFP (74 kg G kg^{-1} N).

Total N inputs from mineral fertilizer and biomass to the maize plants for the subplots of the main treatment that had long duration pigeon pea monoculture during season one with biomass incorporated into the soil at harvest were in the order; biomass + 150 kg N ha^{-1} (233 kg N ha^{-1}) > biomass + 100 kg N ha^{-1} (183 kg N ha^{-1}) > biomass + 50 kg N ha^{-1} (133 kg N ha^{-1}) > biomass only (83 kg N ha^{-1}); while total N yield for the maize plants were in the order; biomass + 150 kg N ha^{-1} (123.1 kg N ha^{-1}) > biomass + 100 kg N ha^{-1} (96 kg N ha^{-1}) > biomass + 50 kg N ha^{-1} (67 kg N ha^{-1}) > biomass only (62.6 kg ha^{-1}); REs were in this order; biomass only (43%) > biomass + 150 kg N ha^{-1} (41%) > biomass + 100 kg N ha^{-1} (38%) > biomass 50 kg N ha^{-1} (30%); AEs were in the order;

biomass only (31 kg G kg^{-1} N) > biomass + 150 kg N ha^{-1}, biomass + 100 kg N ha^{-1} (16 kg G kg^{-1} N) > biomass + 50 kg N ha^{-1} (21 kg G kg^{-1} N); and PFPs were in this order; biomass + 50 kg N ha^{-1} (92 kg G kg^{-1} N) > biomass + 100 kg N ha^{-1} (47 kg G kg^{-1} N) > biomass + 150 kg N ha^{-1} (92 kg G kg^{-1} N).

Total N inputs from mineral fertilizer and biomass to the maize plants for the subplots of the main treatment that had sole groundnut during season one with biomass incorporated into the soil at harvest were in the order; biomass + 150 kg N ha^{-1} (196 kg N ha^{-1}) > biomass + 100 kg N ha^{-1} (146 kg N ha^{-1}) > biomass + 50 kg N ha^{-1} (96 kg N ha^{-1}) > biomass only (46 kg N ha^{-1}); while total N yield for the maize plants were in the order; biomass + 150 kg N ha^{-1} (144.1 kg N ha^{-1}) > biomass + 100 kg N ha^{-1} (125.4 kg N ha^{-1}) > biomass only (54.5 kg N ha^{-1}) > biomass + 50 kg N ha^{-1} (46.3 kg ha^{-1}); REs were in the order; biomass + 100 kg N ha^{-1} (48%) > biomass + 150 kg N ha^{-1}, biomass only (60%) > biomass + 50 kg N ha^{-1} (20%); AEs were in the order; biomass only (27 kg G kg^{-1} N) > biomass + 100 kg N ha^{-1} (24 kg G kg^{-1} N) > biomass + 150 kg N ha^{-1}, (21 kg G kg^{-1} N)> biomass + 50 kg N ha^{-1} (13 kg G kg^{-1} N); and PFPs were in the order; biomass + 50 kg N ha^{-1} (60 kg G kg^{-1} N) > biomass + 100 kg N ha^{-1} (53 kg G kg^{-1} N) > biomass + 150 kg N ha^{-1} (39 kg G kg^{-1} N).

Total N inputs from mineral fertilizer and biomass to the maize plants for the subplots of the main treatment that had medium duration pigeon pea-groundnut intercrop during season one with biomass incorporated into the soil at harvest were in the order; biomass + 150 kg N ha^{-1} (279 kg N ha^{-1}) > biomass + 100 kg N ha^{-1} (229 kg N ha^{-1}) > biomass + 50 kg N ha^{-1} (179 kg N ha^{-1}) > biomass only (129 kg N ha^{-1}); while total N yield for the maize plants were in the order; biomass + 150 kg N ha^{-1} (103.6 kg N ha^{-1}) > biomass + 100 kg N ha^{-1} (103.3 kg N ha^{-1}) > biomass only (75 kg N ha^{-1}) > biomass + 50 kg N ha^{-1} (70.3 kg ha^{-1}); REs were in the order; biomass only (37%) > biomass + 100 kg N ha^{-1} (33%) > biomass + 150 kg N ha^{-1}(28%)> biomass + 50 kg N ha^{-1} (24%); AEs were in the order; biomass only (19 kg G kg^{-1} N) > biomass + 50 kg N ha^{-1} (15 kg G kg^{-1} N) > biomass + 150 kg N ha^{-1}, biomass + 100 kg N ha^{-1} (14 kg G kg^{-1} N); and PFPs were in the order; biomass + 50 kg N ha^{-1} (90 kg G kg^{-1} N) > biomass + 100 kg N ha^{-1} (50 kg G kg^{-1} N) > biomass + 150 kg N ha^{-1} (38 kg G kg^{-1} N).

Total N inputs from mineral fertilizer and biomass to the maize plants for the subplots of the main treatment that had long duration pigeon pea-groundnut intercrop during season one with biomass incorporated into the soil at harvest were in the order; biomass + 150 kg N ha^{-1} (266 kg N ha^{-1}) > biomass + 100 kg N ha^{-1} (216 kg N ha^{-1}) > biomass + 50 kg N ha^{-1} (166 kg N ha^{-1}) > biomass only (116 kg N ha^{-1}); while total N yield for the maize plants were in the order; biomass + 50 kg N ha^{-1} (110.4 kg N ha^{-1}) > biomass + 100 kg N ha^{-1} (120 kg N ha^{-1}) > biomass + 150 kg N ha^{-1} (90.5 kg N ha^{-1}) > biomass only (64 kg N ha^{-1}); REs were in the order; biomass + 50 kg N ha^{-1} (50%) > biomass + 100 kg N ha^{-1} (43%) > biomass only (32%) > biomass + 150 kg N ha^{-1} (24%); AEs were in the order; biomass + 50 kg N ha^{-1} (21 kg G kg^{-1} N) > biomass + 100 kg N ha^{-1} (16 kg G kg^{-1} N) > biomass only (13 kg G kg^{-1} N) > biomass + 150 kg N ha^{-1} (11 kg G kg^{-1} N) >; and PFPs were in the order biomass + 50 kg N ha^{-1} (104 kg G kg^{-1} N) > biomass + 100 kg N ha^{-1} (52 kg G kg^{-1} N) > biomass + 150 kg N ha^{-1} (31 kg G kg^{-1} N).

Total N inputs from mineral fertilizer and root biomass to the maize plants for the subplots of the main treatment that had medium duration pigeon pea-groundnut intercrop during season one with no biomass incorporated into the soil at harvest were in the order; root biomass + 150 kg N ha^{-1} (157.4 kg N ha^{-1}) > root biomass + 100 kg N ha^{-1} (107.4 kg N ha^{-1}) > root biomass + 50 kg N ha^{-1} (57.4 kg N ha^{-1}) > root biomass only (7.4 kg N ha^{-1}); while total N yield for the maize plants were in the order; root biomass + 150 kg N ha^{-1} (105 kg N ha^{-1}) > root biomass + 100 kg N ha^{-1} (67.1 kg N ha^{-1}) > root biomass only (48.4 kg N ha^{-1}) > root biomass + 50 kg N ha^{-1} (40 kg ha^{-1}); REs were in the order; root biomass + 150 kg N ha^{-1} (50%) > root biomass + 100 kg N ha^{-1}, root biomass + 50 kg N ha^{-1} (38%); AEs were in the order; root biomass + 150 kg N ha^{-1} (16 kg G kg^{-1} N) > root biomass + 100 kg N ha^{-1}, (15 kg G kg^{-1} N) > root biomass + 50 kg N ha^{-1} (7 kg G kg^{-1} N); and PFPs were in the order; root biomass + 50 kg N ha^{-1} (43 kg G kg^{-1} N) > root biomass + 100 kg N ha^{-1} (34 kg G kg^{-1} N) > root biomass + 150 kg N ha^{-1} (28 kg G kg^{-1} N).

Total N inputs from mineral fertilizer and root biomass to the maize plants for the subplots of the main treatment that had long duration pigeon pea-groundnut intercrop during season one with no biomass incorporated into the soil at harvest were in the order; root biomass + 150 kg N ha^{-1} (157.1 kg N ha^{-1}) > root biomass + 100 kg N ha^{-1} (107.1 kg N ha^{-1}) > root biomass + 50 kg N ha^{-1} (57.1 kg N ha^{-1}) > root biomass only (7.1 kg N ha^{-1}); while total N yield for the maize plants were in the order; root biomass + 150 kg N ha^{-1} (126.7 kg N ha^{-1}) > root biomass + 100 kg N ha^{-1} (121.3 kg N ha^{-1}) > root biomass + 50 kg N ha^{-1} (51.6 kg ha^{-1}) > root biomass only (46.3 kg N ha^{-1}); REs were in the order; root biomass + 100 kg N ha^{-1} (88%) > root biomass + 50 kg N ha^{-1}

(64%) > root biomass + 100 kg N ha^{-1} (44%); AEs were in the order; root biomass + 100 kg N ha^{-1} (32 kg G kg^{-1} N) > root biomass + 150 kg N ha^{-1}, (22 kg G kg^{-1} N) > root biomass + 50 kg N ha^{-1} (19 kg G kg^{-1} N); and PFPs were in the order; root biomass + 50 kg N ha^{-1} (57 kg G kg^{-1} N) > root biomass + 100 kg N ha^{-1} (52 kg G kg^{-1} N) > root biomass + 150 kg N ha^{-1} (35 kg G kg^{-1} N).

Table 7.4: Summary of total N yields in the maize plant, N input to the soil by legumes, total N input, the N recovery agronomic use efficiency and the partial factor productivity

Treatments: Main and sub plots	N input-biomass kg ha^{-1}	N input-Urea kg ha^{-1}	TT N input	N yield in maize kg ha^{-1TT}	RE (%)	AE kg G kg^{-1} N	PFP_N kg G kg^{-1} N
1.							
a.Sole Maize-No biomass	0	0	0	26.7	-	-	-
b.Sole Maize-No biomass + 100 kg N ha^{-1}	0	100	100	65.1	38	16	33
c.Sole Maize-No biomass + 150 kg N ha^{-1}	0	150	150	79.8	35	16	27
d.Sole Maize-No biomass + 50 kg N ha^{-1}	0	50	50	48.5	44	8	44
2.							
a.Medium duration pigeon pea-biomass	87.0	0	-	-	ND	ND	ND
b.Medium duration pigeon pea-biomass + 100 kg N ha^{-1}	ND	100	ND	ND	ND	ND	ND
c.Medium duration pigeon pea-biomass + 150 kg N ha^{-1}	ND	150	ND	ND	ND	ND	ND
d.Medium duration pigeon pea-biomass + 50 kg N ha^{-1}	91	50	141	60.4	24	14	74
3.							
a.Long duration pigeon pea-biomass	83	0	83	62.6	43	31	-
b.Long duration pigeon pea-biomass + 100 kg N ha^{-1}	83	100	183	96.8	38	16	47
c.Long duration pigeon pea-biomass + 150 kg N ha^{-1}	83	150	233	123.1	41	16	36
d.Long duration pigeon pea-biomass + 50 kg N ha^{-1}	83	50	133	67	30	21	92
4.							
a. Sole groundnut-biomass	46	0	46	54.5	60	27	-
b.Sole groundnut-biomass + 100 kg N ha^{-1}	46	100	146	125.4	68	24	53
c.Sole groundnut-biomass + 150 kg N ha^{-1}	46	150	196	144.1	60	21	39
d.Sole groundnut-biomass + 50 kg N ha^{-1}	46	50	96	46.3	20	13	60
5.							
a.Medium duration pigeon pea + groundnut-biomass	129	0	129	75	37	19	-
b.Medium duration pigeon pea + groundnut-biomass + 100 kg N ha^{-1}	129	100	229	103.3	33	14	50
c.Medium duration pigeon pea + groundnut-biomass + 150 kg N ha^{-1}	129	150	279	103.6	28	14	38
d.Medium duration pigeon Pea + groundnut-biomass + 50 kg N ha^{-1}	129	50	179	70.3	24	15	90

	N input-Biomass kg ha^{-1}	N input-Urea kg ha^{-1}	TT N input	N yield in Maize kg ha^{-1TT}	RE %	AE kg G kg^{-1} N	PFP_N kg G kg^{-1} N
a.Long duration pigeon pea + groundnut-biomass	116	0	116	64	32	13	-
b.Long duration pigeon pea + groundnut-biomass + 100 kg N ha^{-1}	116	100	216	120	43	16	52
c.Long duration pigeon pea + groundnut-biomass + 150 kg N ha^{-1}	116	150	266	90.5	24	11	31
d.Long duration pigeon pea + groundnut-biomass + 50 kg N ha^{-1}	116	50	166	110.4	50	21	104
7.							
a.Medium duration pigeon pea + groundnut-no biomass	7.4	0	7.4	40	-	-	-
b.Medium duration pigeon pea + groundnut-no biomass + 100 kg N ha^{-1}	7.4	100	107.4	67.1	38	15	34
c.Medium duration pigeon pea + groundnut-no biomass + 150 kg N ha^{-1}	7.4	150	157.4	105	50	16	28
d.Medium duration pigeon pea + groundnut-no biomass + 50 kg N ha^{-1}	7.4	50	57.4	48.4	38	7	43
8.							
a.Long duration pigeon pea + groundnut-no biomass	7.1	0	7.1	46.3	-	-	-
b.Long duration pigeon pea + groundnut-no biomass + 100 kg N ha^{-1}	7.1	100	107.1	121.3	88	32	52
c.Long duration pigeon pea + groundnut-no biomass + 150 kg N ha^{-1}	7.1	150	157.1	126.7	64	22	35
d.Long duration pigeon pea + groundnut-no biomass + 50 kg N ha^{-1}	7.1	50	57.1	51.6	44	19	57
GM	-	-	-	80.8	-	-	-
CV (%)	-	-	-	33.5	-	-	-
$LSD_{0.05}$	-	-	-	58	-	-	-

ND= not determined

7.4 DISCUSSION

7.4.1 Nitrogen partitioning in the maize crop

In general, data on nitrogen yields for the maize grains, stover and rachids presented in Tables 7.1, 7.2 and 7.3 indicate that more N was partitioned to grains, followed by stover and rachids. This being the result of N remobilization during grain filling from the stover to cobs for grain formation (Yazdani, 2013). In all grain crops, the supply of assimilates for grain filling emanates both from current assimilation channelled directly to the developing grains and from the remobilization of assimilates stored in vegetative plant parts (Arduini *et al,* 2006; Yang *et al*, 2007). Remobilization of assimilates arises from plant senescence, a process that involves translocation of stored reserves from stems and sheaths to grains (Masoni *et al,* 2004). Remobilizable nitrogen stored in plant parts occurs in the form of amino acids and proteins (Yazdani, 2013). In this study, plants in treatment plots that were treated with a combination of 150 kg N ha^{-1}, 100 kg N ha^{-1} with groundnut biomass and plants in the long duration pigeon pea groundnut intercrop that did not have biomass buried into the soil, had more N partitioned to the grains compared to N partitioned to the grains of maize in other treatment plots (Table 7.1). The reason for the trend is not so clear as lower N yields were observed in plots with similar treatment combination. The control plots had the least amount of N partitioned to the grains largely due to low N supply and uptake during the reproductive stage. A similar trend of N partitioning was reflected in stover and rachids (Tables 7.2 and 7.3). Overall, the combination of mineral N and legume biomass seem not to have affected N partitioning to the grains, stover and rachids. In maize, grain yields and partitioning of dry matter increases with increasing plant uptake and use of nitrogen at proper growth stages (Amanulluh, 2007). The trend of N partitioning reflected by the N yields which is a function of the amount of dry matter of plant parts (grain, stover and rachids), seem to suggest that N uptake was not constrained at any stage of plant growth across the treatments except the control plots. This resulted into high N accumulation in the grains. Binder *et al.* (2000) indicated that limitation on plant growth due to inadequate N is a function of N deficiency during the initial growth stages. The basic reason for the limitation is reduced leaf expansion rate and leaf area (Wolfe *et al.,* 1988) resulting into reduced interception of solar radiation (Uhart and Andrade, 1995). The stated trend culminates into reduce rates of photosynthesis and hence assimilation of photosynthetic products into plant biomass. Chen *et al.* (2003) indicated that crop biomass production especially grain yields are directly associated with current rates of assimilation of photosynthetic products and translocation during the reproductive stage. Furthermore, inadequate N at the flowering stage of maize reduces the dry matter partitioning to reproductive sinks (Uhart and Andrade, 1995). Under this study, the high N and grain yields suggest that there was no deficit of N during the flowering stage.

7.4.2 Maize yields and nitrogen use efficiency by the maize crop

Evidencially, external N supply to plants under the conditions of this study was requisite as the control plots had significantly less grain ($p < 0.05$) compared with treament plots supplied with mineral N alone, pigeon pea and groundnut biomass, a combination of mineral N with either pigeon pea and groundnut biomass, and a combination of mineral N with a combination of pigeon pea and groundnut biomass. The subplots under treatment plots (treatment 7 and 8) that had pigeon pea intercropped with groundnut in year one without incorporating biomass in year two but supplied with mineral N had high yields as well (Table 7.1), which were comparable to yields obtained in treatments which had biomass incorporated into the soil and treated with mineral N. Under treatments 7 and 8 the subplots which were not supplied with mineral N had higher yields compared to the control. This could have come about because in the former plots roots of pigeon pea might have increased the supply of N to the plants upon decay and subsequent mineralization.

Overall, linear increase in grain yield with either sole application of mineral N or a combination of mineral N and biomass incorporation over the control was observed. The grain yields increase above yields from the control plots ranged from 21% to 227.1%. The grain yields increase above the yields generated by control plots was in conformity with what was reported by other researchers. For example Munthali *et al.,* (2014) working on N rich tephrosia biomass incorporation from tephrosia fallows plus inorganic fertilizer amendment to maize reported 518% grain yields increase over the control for maize grown where tephrosia biomass was incorporated and treated with lower rates of N ($45\,\text{kg N ha}^{-1}$) and P ($20\,\text{kg P ha}^{-1}$). On the other hand tephrosia biomass alone without inorganic fertilizer input increased maize yields by 400% over the control. The maize grain yields increase over the control plots in systems involving the incorporation of legume biomass into the soil is usually attributed to increased and sustained supply of N to maize plants emanating from decomposition and subsequent mineralization of N from the biomass (Harawa *et al.,* 2006).

Under this study, platueing of grain yields below the yield potential (6 t ha^{-1}) of the early maturing variety used (SC 403) was observed with increasing supply of mineral N (Table 7.1). This suggested a diminishing-return relationship between maize grain yields and increasing nitrogen supply, an indication of possible presence of other factors that constrained the full expression of the yield potential. Such factors might include defficiencies in other macro and micro nutrients, temperature regime and the amount of intercepted solar radiation during the cropping season (van Wart *et al.,* 2013). The platueing of grain yields was noticed at the fertilizer rate of 150 kg N ha^{-1} plus mineralized N from legume biomass.

Recovery efficiency (RE) expressed by relative increase in above-ground crop uptake per unit of N applied, Agronomic efficiency (AE) expressed by relative yield increase per unit of N applied and partial factor productivity (PFP) expressed as crop yield per unit of N applied (Roberts, 2008) indicate the extent of economic and environmental efficiency in use of nutrient inputs. Under this study RE ranged between 20% and 88%, AE ranged between 7 and 32 kg yield increase per kg of nitrogen applied and the PFP ranges from 27 to 104 kg grain yield per kg nutrient applied. The PFP values are above the value reported by Waddington *et al.* (2004) for Malawian smallholder agriculture. This indicates that under the conditions of this study the pigeon pea-groundnut intercrop maize rotation cropping system improved NUE. RE values of 50% to 80% , AE values of 10–30 kg kg^{-1} and PFP values of 40–80 kg kg^{-1} are often encountered with values >25 kg kg^{-1} for AE and >60 kg kg^{-1} for PFP being common in well-managed systems or at low levels of N use, or at low soil N supply (Doberman, 2007).

7.5 CONCLUSION

The linear increase in grain yield with application of N and the presence of a diminishing-return relationship between maize grain yields (grain yield was near the yield potential of the maize variety at high N input) and increasing nitrogen supply, suggest that the RE, AE and PFP values emerging from this study might apply both to low and high levels of N use, or at low and high soil N supply. In the pigeon pea groundnut intercrop-maize rotation cropping system, for optimal NUE under low input agriculture, basal dressing the maize crop with 50 kg P ha^{-1} and top dressing with 50 kg N ha^{-1} could be ideal while for high input agriculture basal dressing the maize crop with 50 kg P ha^{-1} and top dressing with 100 kg N ha^{-1} seem to be reasonable. Under the conditions of this study the lack of expression of the full yield potential by the variety used at a high rate of N supply suggests the presence of other factors that constrained the full expression of the yield potential. This requires further investigation inorder to unravel the constraints.

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CHAPTER 8

8.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

From the study the following general conclusions can be made:

- Generally, the soil chemical characteristics for soil samples collected in all the treatment plots both in the main and parallel experiment indicate that the soil is of low low fertility status. The soil fertility limitations being low pH (<6.0), Low N (<0.88%) and marginally adequate P (19 mg P kg^{-1} to 25 mg P kg^{-1})

- The study confirmed the viability of the pigeon pea-groundnut intercropping system. The nitrogen yields for the cropping system were deemed to be reasonably high.

- High soil NO_3^-–N was observed in plots where legume biomass was not incorporated attributable to residual N from fertilization and legume cropping over years. Residual N accumulates in the soil solution.

- N supplement from mineral fertilizer is requiste for the attainment of high maize grain yields as the soils have a lowN supplying capacity and are prone to leaching due to the sandy clay loam texture.

- Differences in the extraction procedures for the two nitrate analysis methods (KCl method and the nitrate meter) seem to be the source of the observed differences of nitrate readings generated by the methods.

- Furthermore, in the pigeon pea plant, upon incorporation to the soil, much of the N contribution to the soil's N pool comes from the above ground biomass as compared to the below ground biomass.

- Additionally, supply of P to legumes increases N yield through enhanced biological fixation. The legumes however do not yield enough P for the correction of soil P deffiencies that are prevalent across Malawi.

- The linear increase in grain yield with application of N and the presence of a diminishing-return relationship between maize grain yields and increasing nitrogen supply, suggest that the RE, AE and PFP values emerging from this study might apply both to low and high levels of N use, or at low and high soil N supply.

- For optimal NUE under low input agriculture, top dressing with 50 kg N ha^{-1} could be ideal while for high input agriculture top dressing with 100 kg N ha^{-1} seem to be reasonable.

- Under the conditions of this study the pigeon pea-groundnut maize rotation cropping system improved NUE through increased N supply and subsequent uptake by the maize crop.

8.2 Recommendations

- Further studies in this cropping system should focus on understanding the decomposition and mineralization pattern of the incorporated legume biomass for the assertion of the time and amount of N release. This is critical inorder to establish empirically if this is in syncrony with N demand by the maize crop.

- Studies to answer the question on the amount of mineral nitrogen required to suppliment to N added to the soil by the incorporated legume biomass for the optimization of yield while reducing the cost accrued by purchasing mineral nitrogen should be conducted and investigation on the effect of ratooning and ratooning time on pigeon pea podding and grain filling in the second season should be undertaken.

9.0 APPENDICES

Appendix 2.0a: Soils data for the main experiment at harvest (First season)

Treatment	Depth cm	Plot	Rep	pH_{H2O}	OC(%)	N(%)	P mg kg^{-1}
1.Sole maize	0-20	3	"	5.01	1.35	0.12	16.7
1.Sole maize	20-40	"	"	4.96	1.23	0.11	16.2
2.Medium duration pigeon pea	0-20	2	"	5.26	1.20	0.10	19.4
2.Medium duration pigeon pea	20-40	"	"	5.05	1.26	0.11	24.1
3.Long duration pigeon pea	0-20	4	"	5.06	1.26	0.11	21.8
3.Long duration pigeon pea	20-40	"	"	5.03	1.35	0.12	16.9
4.Sole groundnut	0-20	5	"	5.13	1.26	0.11	23.6
4.Sole groundnut	20-40	"	"	5.22	1.44	0.12	20.1
5.Medium duration pigeon pea + groundnut	0-20	1	1	5.65	1.35	0.12	23.4
5.Medium duration pigeon pea + groundnut	20-40	"	"	5.37	1.44	0.12	19.2
6.Long duration pigeon pea + groundnut	0-20	7	"	5.17	1.38	0.12	11.7
6.Long duration pigeon pea + groundnut	20-40	"	"	5.28	1.41	0.12	15.3
7.Medium duration pigeon pea + groundnut	0-20	6	"	5.15	1.56	0.13	36.6
7.Medium duration pigeon pea + groundnut	20-40	"	"	5.14	1.44	0.12	23.4
8.Long duration pigeon pea + groundnut	0-20	8	"	5.28	1.62	0.14	29.2
8.Long duration pigeon pea + groundnut	20-40	"	"	5.28	1.53	0.13	28.8
1.Sole maize	0-20	2	"	5.40	1.53	0.13	29.2
1.Sole maize	20-40	"	"	5.36	1.62	0.14	22.6

Treatment	Depth cm	Plot	Rep	pH_{H2O}	OC(%)	N(%)	P mg kg^{-1}
2.Medium duration pigeon pea	0-20	3	"	5.34	1.65	0.14	21.9
2.Medium duration pigeon pea	20-40	"	"	5.21	1.65	0.14	20.7
3.Long duration pigeon pea	0-20	6	"	5.46	1.35	0.12	23.9
3.Long duration pigeon pea	20-40	"	"	5.35	1.47	0.13	17.1
4.Sole groundnut	0-20	5	"	5.43	1.17	0.10	26.7
4.Sole groundnut	20-40	"	"	5.40	1.44	0.12	16.5
5.Medium duration pigeon pea + groundnut	0-20	8	"	5.45	1.44	0.12	17.6
5.Medium duration pigeon pea + groundnut	20-40	"	"	5.46	1.59	0.14	15.7
6.Long duration pigeon pea + groundnut	0-20	4	"	5.34	1.68	0.14	18.9
6.Long duration pigeon pea + groundnut	20-40	"	"	5.35	1.74	0.15	20.1
7.Medium duration pigeon pea + groundnut	0-20	7	"	5.29	1.59	0.14	20.5
7.Medium duration pigeon pea + groundnut	20-40	"	"	5.30	1.71	0.15	17.9
8.Long duration pigeon pea + groundnut	0-20	1	2	5.26	1.65	0.14	21.2
8.Long duration pigeon pea + groundnut	20-40	"	"	5.43	1.92	0.17	23.9
1.Sole maize	0-20	5	"	5.43	1.77	0.15	26.3
1.Sole maize	20-40	"	"	5.31	1.74	0.15	18.1
2.Medium duration pigeon pea	0-20	4	"	5.50	1.59	0.14	27.5
2.Medium duration pigeon pea	20-40	"	"	5.36	1.65	0.14	27.6
3.Long duration pigeon pea	0-20	2	"	6.25	1.35	0.12	16.7
3.Long duration pigeon pea	20-40	"	"	5.90	1.59	0.14	16.5
4.Sole groundnut	0-20	3	"	5.65	1.56	0.13	19.9

Treatment	Depth cm	Plot	Rep	pH_{H2O}	OC(%)	N(%)	P mg kg^{-1}
4.Sole groundnut	20-40	"	"	5.46	1.74	0.15	16.2
5.Medium duration pigeon pea + groundnut	0-20	7	"	5.43	1.83	0.16	19.6
5.Medium duration pigeon pea + groundnut	20-40	"	"	5.32	1.92	0.17	25.2
6.Long duration pigeon pea + groundnut	0-20	1	3	5.41	1.38	0.12	32.3
6.Long duration pigeon pea + groundnut	20-40	"	"	5.38	1.59	0.14	29.4
7.Medium duration pigeon pea + groundnut	0-20	8	"	5.09	1.65	0.14	22.8
7.Medium duration pigeon pea + groundnut	20-40	"	"	5.14	1.71	0.15	22.8
8.Long duration pigeon pea + groundnut	0-20	6	"	5.45	1.68	0.14	19.8
8.Long duration pigeon pea + groundnut	20-40	"	"	5.37	1.77	0.15	24.1

Appendix 2.0b: Soils data for the main experiment after biomass incorporation to the soil (second season)

Rep.	Treatments	Depth (cm)	pH_{H2O}	OC(%)	N(%)	P mg kg^{-1}
1	1.Sole maize	0-20	5.6	0.81	0.07	9.29
1	1.Sole maize	20-40	5.7	1.20	0.10	18.27
1	2.Medium duration pigeon pea	0-20	5.7	1.26	0.11	12.89
1	2.Medium duration pigeon pea	20-40	5.6	1.06	0.09	19.62
1	3.Long duration pigeon pea	0-20	5.3	1.15	0.01	12.37
1	3.Long duration pigeon pea	20-40	5.0	1.09	0.09	18.59
1	4.Sole groundnut	0-20	5.6	1.29	0.11	13.51
1	4.Sole groundnut	20-40	5.7	1.04	0.09	19.76
1	5.Medium duration pigeon pea + Groundnut	0-20	5.5	1.09	0.09	15.64
1	5.Medium duration pigeon pea + Groundnut	20-40	5.5	1.20	0.10	18.89
1	6.Long duration pigeon pea + Groundnut	0-20	5.2	1.54	0.13	14.55
1	6.Long duration pigeon pea + Groundnut	20-40	5.2	1.54	0.13	20.10
1	7.Medium duration pigeon pea + Groundnut	0-20	5.8	0.78	0.07	14.29
1	7.Medium duration pigeon pea + Groundnut	20-40	5.8	1.34	0.12	17.67

Rep.	**Treatments**	**Depth (cm)**	**pH_{H2O}**	**OC(%)**	**N(%)**	**P mg kg^{-1}**
1	8.Long duration pigeon pea + Groundnut		5.8	1.34	0.12	15.49
1	8.Long duration pigeon pea + Groundnut	20-40	5.6	1.37	0.12	19.54
2	1.Sole maize	0-20	5.2	1.23	0.11	8.96
2	1.Sole maize	20-40	5.1	1.76	0.15	19.34
2	2.Medium duration pigeon pea	0-20	5.8	1.26	0.11	13.14
2	2.Medium duration pigeon pea	20-40	5.6	1.43	0.12	19.81
2	3.Long duration pigeon pea	0-20	5.7	1.88	0.16	12.42
2	3.Long duration pigeon pea	20-40	5.6	1.54	0.13	18.71
2	4.Sole groundnut	0-20	5.1	1.04	0.09	13.52
2	4.Sole groundnut	20-40	5.0	1.29	0.11	18.81
2	5.Medium duration pigeon pea + Groundnut	0-20	5.4	1.46	0.13	14.73
2	5.Medium duration pigeon pea + Groundnut	20-40	5.5	1.40	0.12	19.91
2	6.Long duration pigeon pea + Groundnut	0-20	5.9	1.46	0.13	15.68
2	6.Long duration pigeon pea + Groundnut	20-40	5.8	1.54	0.13	22.10
2	7.Medium duration pigeon pea + Groundnut	0-20	5.1	1.43	0.12	16.30

Rep.	Treatments	Depth (cm)	pH_{H2O}	OC(%)	N(%)	P mg kg^{-1}
2	7.Medium duration pigeon pea + Groundnut	20-40	5.1	1.57	0.14	19.87
2	8.Long duration pigeon pea + Groundnut	0-20	6.0	1.12	0.10	14.54
2	8.Long duration pigeon pea + Groundnut	20-40	6.0	1.20	0.10	17.44
3	1.Sole maize	0-20	5.2	1.51	0.13	10.41
3	1.Sole maize	20-40	5.1	1.68	0.14	18.55
3	2.Medium duration pigeon pea	0-20	5.9	1.04	0.09	16.87
3	2.Medium duration pigeon pea	20-40	5.4	1.31	0.11	22.75
3	3.Long duration pigeon pea	0-20	5.9	2.02	0.17	15.59
3	3.Long duration pigeon pea	20-40	6.0	1.26	0.11	19.63
3	4.Sole groundnut	0-20	5.7	1.18	0.10	13.78
3	4.Sole groundnut	20-40	5.6	1.62	0.14	21.74
3	5.Medium duration pigeon pea + Groundnut	0-20	5.2	1.46	0.13	14.63
3	5.Medium duration pigeon pea + Groundnut	20-40	5.1	0.98	0.08	17.86
3	6.Long duration pigeon pea + Groundnut	0-20	6.0	1.71	0.15	14.68
	6.Long duration pigeon pea + Groundnut	20-40	6.0	1.76	0.15	19.98

Appendix 2.5: Yield parameter in the main experiment (season one)

Treatments	BLOCK	G/nut leaves (kg ha^{-1})	PP litter (kg ha^{-1})	PP fresh leaves (kg ha^{-1})	Twigs (kg ha^{-1})	Total PP biomass (kg ha^{-1})	G/nut wt (kg ha^{-1})	Grain wt (kg)	Shells wt (kg ha^{-1})	Number of g/nut pods plant^{-1}	Maize Stover	Maize Grain (kg ha^{-1})
1	1	-	-	-	-	-	-	-	-	-	280	516.75
1	2	-	-	-	-	-	-	-	-	-	293	558.5
1	3	-	-	-	-	-	-	-	-	-	409	864.0
2	1	-	2133.3	550	710	3393.3	-	-	-	-	-	-
2	2	-	844.4	277.5	772.5	1894.4	-	-	-	-	-	-
2	3	-	163.0	170	480	813.0	-	-	-	-	-	-
3	1	-	933.3	760	1292.5	2985.8	-	-	-	-	-	-
3	2	-	1600	335	562.5	2497.5	-	-	-	-	-	-
3	3	-	1170.4	497.5	727.5	2395.4	-	-	-	-	-	-
4	1	592.5	-	-	-	-	1962.5	1220	324.5	36	-	-
4	2	682.5	-	-	-	-	2250	587	190	26	-	-
4	3	692.5	-	-	-	-	187.5	135	50.25	25	-	-
5	1	540	785.2	287.5	557.5	1630.2	1000	711.75	196	29	-	-
5	2	682.5	1837.0	292.5	337.5	2467.0	1875	533.75	1593	28	-	-
5	3	612.5	2637.0			2637.0	875	461	68.75	28	-	-
6	1	335	1585.2	665	597.5	2847.7	1250	287.75	84.75	34	-	-
6	2	572.5	1837.0	535	550	2922.0	1237.5	855.5	228.5	37	-	-
6	3	530	1437.0	237.5	335	2009.5	1252.5	929	232.8	35	-	-

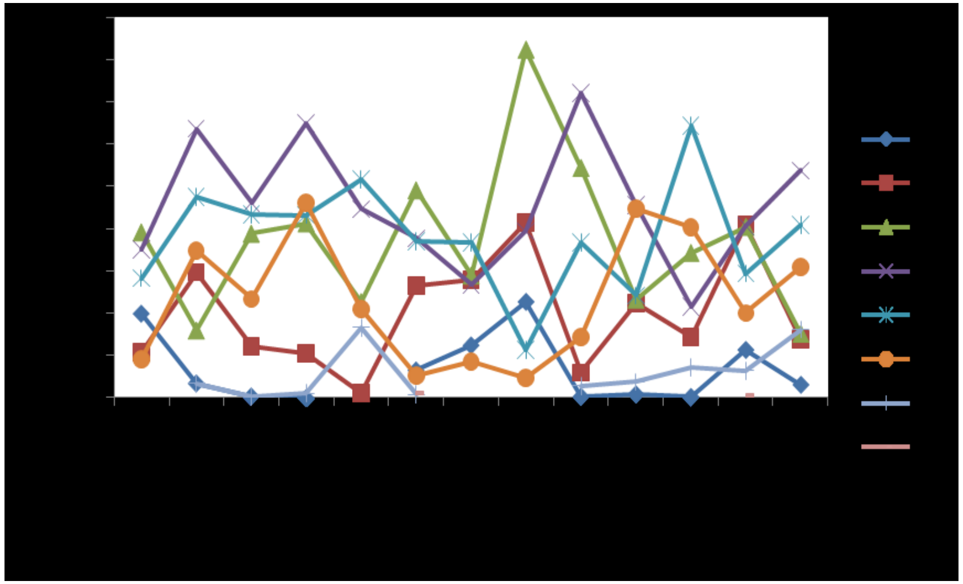
Treatments	BLOCK	G/nut leaves (kg ha^{-1})	PP litter (kg ha^{-1})	PP fresh leaves (kg ha^{-1})	Twigs (kg ha^{-1})	Total PP biomass (kg ha^{-1})	G/nut wt (kg ha^{-1})	Grain wt (kg)	Shells wt (kg ha^{-1})	Number of g/nut pods plant^{-1}	Maize Stover	Maize Grain (kg ha^{-1})
7	1	332.5	1363.0	245	477.5	2085.5	1250	690.75	102.5	35	-	-
7	2	585	918.5	147.5	227.5	1293.5	1312.5	366.25	112.8	36	-	-
7	3	577.5	2118.5	-	-	2118.5	1000	591.25	193.5	26	-	-
8	1	385	2874.1	482.5	860	4216.6	1250	840.25	243.8	24	-	-
8	2	442.5	1437.0	582.5	815	2834.5	1000	756.5	200.8	25	-	-
8	3	412.5	2029.6	-	-	-	1500	1023.5	274.5	18	-	-

1=Sole maize, 2=Medium duration pigeon pea, 3= Long duration pigeon pea, 5=Medium duration pigeon pea + pigeon pea, 6= Long duration pigeon pea + groundnut, 7=Medium duration pigeon pea + groundnut, 8= Long duration pigeon pea + groundnut.

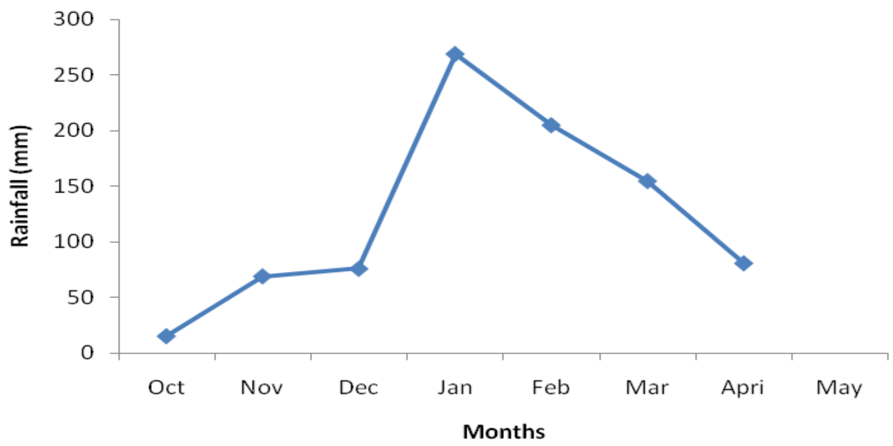
Appendix 3.0a: Thirteen year rainfall data for the area

Year/ Month	**1999/ 2000**	**2000 /2001**	**2001 /2002**	**2002 /2003**	**2003 /2004**	**2004 /2005**	**2005 /2006**	**2006 /2007**	**2007 /2008**	**2008 /2009**	**2009 /2010**	**2010 /2011**	**2011 /2012**	**Means**
							Rainfall amount in mm							
Oct	99.2	17.3	2	0.1	-	32.5	61.9	113.1	1.7	4.5	1.4	56.6	15.6	31.2
Nov	53.7	148.4	60.9	53	5.4	132.7	139.6	207.6	29.7	112.3	71.7	205.4	69.2	99.2
Dec	195.8	79.8	194.3	206.5	113.6	245.6	144.9	411.8	272	116.4	171.6	202.4	76	187.0
Jan	174.9	318	230.5	324.7	222.9	188.6	134	196.7	360.5	227.8	107.3	202.9	268.5	227.5
Feb	141.6	237.5	217.2	216.2	258.8	185.4	183.6	56.5	183.6	121	322.4	147.2	204.7	190.
Mar	46	174.4	116.9	230.8	105	26.3	43.2	23.5	72.3	223.7	201.3	100.3	154.6	116.8
Apri	-	16.5	0.6	5	83.2	3.7	-	-	13.6	18.1	35.3	31.7	80.9	22.2
May	-	-	-	-	-	5.8	-	-	-	-	-	2.6	-	0.65
														875.0

Appendix 3.0b: Rainfall (mm) distribution in the study area, for thirteen years (1999/00 to 2011/12 cropping season)



Appendix 3.0c: Rainfall (mm) distribution in the study area for the 2011/12 cropping season



Appendix 3.1a: Pigeon pea height data in the main experiment season 1

Date of Measurement	PLOT I-TRT 8 Height of tagged plant cm					PLOT III-TRT 2 Height of tagged plant cm					PLOT IV-TRT 6 Height of tagged plant cm				
	1	**2**	**3**	**4**	**Mean**	**5**	**6**	**7**	**8**	**Mean**	**9**	**10**	**11**	**12**	**Mean**
13.2.12	25	30	24	44	30.75	24	22	21	18	21.25	28	21	28	20	24.5
27.2.12	66	42	41	47	49	42	37	34	29	35.5	49	35	47	33	42
12.3.12	74	72	62	87	73.75	66	56	50	42	53.5	80	52	72	59	66
26.3.12	109	88	80	74	87.75	63	105	74	97	84.75	90	108	120	99	99
12.4.12	122	120	110	138	122.5	-	107	104	94	101.7	-	119		120	59.5
24.4.12	136	137	119	155	136.8	-	125	120	109	118	-	134		137	67

Appendix 3.1b: Pigeon pea height data in the main experiment season 1

Date of Measurement	PLOT VI-TRT 3 Height of tagged plant cm					PLOT VII-TRT 5 Height of tagged plant cm					PLOT VIII-TRT 7 Height of tagged plant cm				
	13	**14**	**15**	**16**	**Mean**	**17**	**18**	**19**	**20**	**Mean**	**21**	**22**	**23**	**24**	**Mean**
13.2.12	45	45	40	49	44.75	37	43	56	47	45.75	49	40	39	44	43
27.2.12	70	72	55	74	67.75	55	73	86	83	74.25	77	65	62	72	69
12.3.12	91	92	78	100	90.25	95	94	106	113	102	108	90	85	105	97
26.3.12	121	125	117	142	126.25	139	129	110	129	126.8	130	105	138	133	126.5
12.4.12	149	147	127	146	142.25	157	129	150	139	143.8	152	115	149	140	139
24.4.12	164	165	140	164	158.25	175	147	173	150	161.3	171	127	160	160	154.5

TRT=Treatment; 2=Medium duration pigeon pea; 3= Long duration pigeon pea; 5=Medium duration pigeon pea + pigeon pea; 6= Long duration pigeon pea + groundnut; 7=Medium duration pigeon pea + groundnut; 8= Long duration pigeon pea + groundnut

Appendix 3.2a: Nutrient concentration and yields, fresh leaves pigeon pea main experiment season one

REP.	Treatments	Leaves kg ha^{-1}	N(%)	P(%)	Ca(%)	N Yield kg ha^{-1}	P Yield kg ha^{-1}	Ca Yield kg ha^{-1}
1	2.Medium duration pigeon pea	550	2.84	0.17	1.63	15.6	0.9	9.0
2	2.Medium duration pigeon pea	277.5	3.79	0.30	2.19	10.5	0.8	6.1
3	2.Medium duration pigeon pea	170	3.49	0.29	2.40	5.9	0.5	5.0
1	3.Long duration pigeon pea	760	2.39	0.12	2.60	18.2	0.9	9.1
2	3.Long duration pigeon pea	335	2.39	0.19	2.48	8.0	0.6	8.3
3	3.Long duration pigeon pea	497.5	2.29	0.26	2.73	11.4	1.3	13.6
1	5.Medium duration pigeon pea + Groundnut	287.5	2.79	0.20	1.75	8.0	0.6	5.0
2	5.Medium duration pigeon pea + Groundnut	292.5	2.69	0.11	2.10	7.9	0.3	6.1
1	6.Long duration pigeon pea + Groundnut	665	3.14	0.16	2.60	20.9	1.1	15.0
2	6.Long duration pigeon pea + Groundnut	535	3.19	0.17	2.73	17.1	0.9	14.6
3	6.Long duration pigeon pea + Groundnut	237.5	2.49	0.18	2.73	5.9	0.4	6.5
1	7.Medium duration pigeon pea + Groundnut	245	2.99	0.21	1.87	7.3	0.5	5.1
2	7.Medium duration pigeon pea + Groundnut	147.5	2.59	0.17	3.00	8.0	0.3	5.0
1	8.Long duration pigeon pea + Groundnut	482.5	2.94	0.15	2.60	14.2	0.7	12.5
2	8.Long duration pigeon pea + Groundnut	582.5	3.59	0.16	3.00	20.9	0.9	12.3

Appendix 3.2b: Nutrient concentration and yields, twigs pigeon pea main experiment season one

REP.	Treatments	Twigs kg ha^{-1}	N(%)	P(%)	Ca(%)	N Yield kg ha^{-1}	P Yield kg ha^{-1}	Ca Yield kg ha^{-1}
1	2.Medium duration pigeon pea	710	3.04	0.07	0.99	21.6	1.0	7.0
2	2.Medium duration pigeon pea	772.5	3.19	0.08	1.63	24.6	1.2	12.6
3	2.Medium duration pigeon pea	480	1.99	0.55	1.98	10.2	2.6	9.5
1	3.Long duration pigeon pea	1292.5	1.84	0.12	1.30	23.8	1.6	13.0
2	3.Long duration pigeon pea	562.5	2.39	0.07	1.63	13.4	0.9	9.2
3	3.Long duration pigeon pea	727.5	1.69	0.60	2.87	12.3	3.2	12.0
1	5.Medium duration pigeon pea + Groundnut	557.5	2.44	0.09	1.30	13.6	0.9	7.2
2	5.Medium duration pigeon pea + Groundnut	337.5	2.69	0.05	1.87	11.4	0.8	6.9
1	6.Long duration pigeon pea + Groundnut	597.5	2.04	0.17	1.52	12.2	1.0	9.1
2	6.Long duration pigeon pea + Groundnut	550	2.29	0.24	1.75	12.6	1.3	9.6
3	6.Long duration pigeon pea + Groundnut	335	1.99	0.19	2.10	10.0	0.8	7.0

Appendix 3.2c: Nutrient concentration and yields, litter pigeon pea main experiment season one

Rep.	Treatments	Litter kg ha^{-1}	N(%)	P(%)	Ca(%)	N Yield kg ha^{-1}	P Yield kg ha^{-1}	Ca Yield kg ha^{-1}
1	2.Medium duration pigeon pea	2133.3	0.76	0.17	1.22	12.0	3.6	26.0
2	2.Medium duration pigeon pea	844.4	0.30	0.26	1.39	5.0	2.2	11.7
3	2.Medium duration pigeon pea	163.0	0.89	0.18	1.02	6.0	1.5	11.0
1	3.Long duration pigeon pea	933.3	0.54	0.17	1.25	5.0	1.6	11.7
2	3.Long duration pigeon pea	1600	0.60	0.19	1.29	9.6	3.0	20.6
3	3.Long duration pigeon pea	1170.4	0.92	0.17	1.69	10.8	2.0	19.8
1	5.Medium duration pigeon pea + Groundnut	785.2	0.84	0.19	1.32	6.6	1.5	10.4
2	5.Medium duration pigeon pea + Groundnut	1837.0	0.24	0.40	1.64	7.0	4.0	30.1
3	5.Medium duration pigeon pea + Groundnut	2637.0	0.69	0.30	1.97	13.0	4.0	30.0
1	6.Long duration pigeon pea + Groundnut	1585.2	0.49	0.19	1.32	7.8	3.0	20.9
2	6.Long duration pigeon pea + Groundnut	1837.0	0.69	0.20	1.64	12.7	3.7	30.1
3	6.Long duration pigeon pea + Groundnut	1437.0	0.99	0.14	1.97	14.2	2.0	28.3
1	7.Medium duration pigeon pea + Groundnut	1363.0	0.79	0.15	1.64	10.8	2.0	22.4

Appendix 3.3a: Nutrient concentration and yields, groundnut pods main experiment season one

REP.	Treatments	Pods kg ha^{-1}	N(%)	P(%)	Ca(%)	N Yield kg ha^{-1}	P Yield kg ha^{-1}	Ca Yield kg ha^{-1}
1	4.Groundnut	324.5	0.94	0.09	0.35	3.1	0.2	1.1
2	4.Groundnut	190	1.34	0.11	0.70	2.5	0.2	1.3
3	4.Groundnut	50.25	0.69	0.09	0.50	1.5	0.1	0.8
1	5.Medium duration pigeon pea + Groundnut	196	0.84	0.10	0.35	1.6	0.2	0.7
2	5.Medium duration pigeon pea + Groundnut	1592.5	0.88	0.10	0.58	2.8	0.2	0.9
3	5.Medium duration pigeon pea + Groundnut	68.75	0.74	0.09	0.82	1.0	0.1	0.6
1	6.Long duration pigeon pea + Groundnut	84.75	1.49	0.11	0.58	1.3	0.1	0.5
2	6.Long duration pigeon pea + Groundnut	228.5	0.44	0.08	0.58	1.0	0.2	1.3
3	6.Long duration pigeon pea + Groundnut	232.75	0.29	0.13	0.58	0.7	0.2	1.3
1	7.Medium duration pigeon pea + Groundnut	102.5	0.69	0.09	0.47	1.4	0.2	0.5
2	7.Medium duration pigeon pea + Groundnut	112.75	0.99	0.09	0.47	1.1	0.1	0.5
3	7.Medium duration pigeon pea + Groundnut	193.5	0.34	0.14	0.47	1.4	0.3	0.9
1	8.Long duration pigeon pea + Groundnut	243.75	0.89	0.10	0.35	2.2	0.2	0.9
2	8.Long duration pigeon pea + Groundnut	200.75	1.29	0.13	0.47	2.6	0.3	0.9
3	8.Long duration pigeon pea + Groundnut	274.5	0.95	0.12	0.50	2.6	0.1	1.4

Appendix 3.3b: Nutrient concentration and yields, groundnut haulms main experiment season one

REP.	Treatments	G/nut haulms kg ha^{-1}	N(%)	P(%)	Ca(%)	N Yield kg ha^{-1}	P Yield kg ha^{-1}	Ca Yield kg ha^{-1}
1	4.Groundnut	592.5	2.39	0.55	0.80	14.2	3.3	4.7
2	4.Groundnut	682.5	1.34	0.19	0.80	9.1	1.3	5.5
3	4.Groundnut	692.5	3.44	0.15	0.99	15.0	1.0	6.9
1	5.Medium duration pigeon pea + Groundnut	540	2.94	0.35	0.63	15.9	1.9	3.4
2	5.Medium duration pigeon pea + Groundnut	682.5	3.54	0.18	0.80	13.0	1.2	5.5
3	5.Medium duration pigeon pea + Groundnut	612.5	3.14	0.18	0.99	12.0	1.1	6.1
1	6.Long duration pigeon pea + Groundnut	335	2.59	0.15	0.63	8.7	0.5	2.1
2	6.Long duration pigeon pea + Groundnut	572.5	1.79	0.17	1.80	10.2	1.0	5.6
3	6.Long duration pigeon pea + Groundnut	530	2.94	0.18	0.80	15.6	1.0	4.2
1	7.Medium duration pigeon pea + Groundnut	332.5	3.29	0.15	0.80	10.9	0.5	2.7

Appendix 4.0a: Daily temperature at the time of nitrate nitrogen measurement

		Dec-12		
Day	**Max Temp ^oC**	**Min Temp ^oC**	**Day**	**Ave. Temp ^oC**
1	31.3	18.1	1	24.7
2	29.7	18.9	2	24.3
3	31.3	17.7	3	24.5
4	31.3	18.4	4	24.9
5	32.1	19.8	5	26.0
6	30.3	20.1	6	25.2
7	30.9	19.4	7	25.2
8	31.7	18.9	8	25.3
9	30.4	20.4	9	25.4
10	21.3	18.7	10	20.0
11	25.4	18.3	11	21.9
12	23.7	18.9	12	21.3
13	25.1	18.2	13	21.7
14	24.9	17.9	14	21.4
15	26.9	18.6	15	22.8
16	28.9	18.4	16	23.7
17	27.4	19.8	17	23.6
18	28.4	18.8	18	23.6
19	27.4	19.3	19	23.4
20	28.2	19.6	20	23.9
21	27.9	18.4	21	23.2
22	27.9	16.6	22	22.3
23	28.2	18.9	23	23.6
24	27.9	18.3	24	23.1
25	29.4	18.6	25	24.0
26	28.4	18.6	26	23.5
27	29.7	18.6	27	24.2
28	27.6	19.8	28	23.7
29	27.4	17.9	29	22.7
30	28.7	18.3	30	23.5
31	29.2	19.4	31	24.3

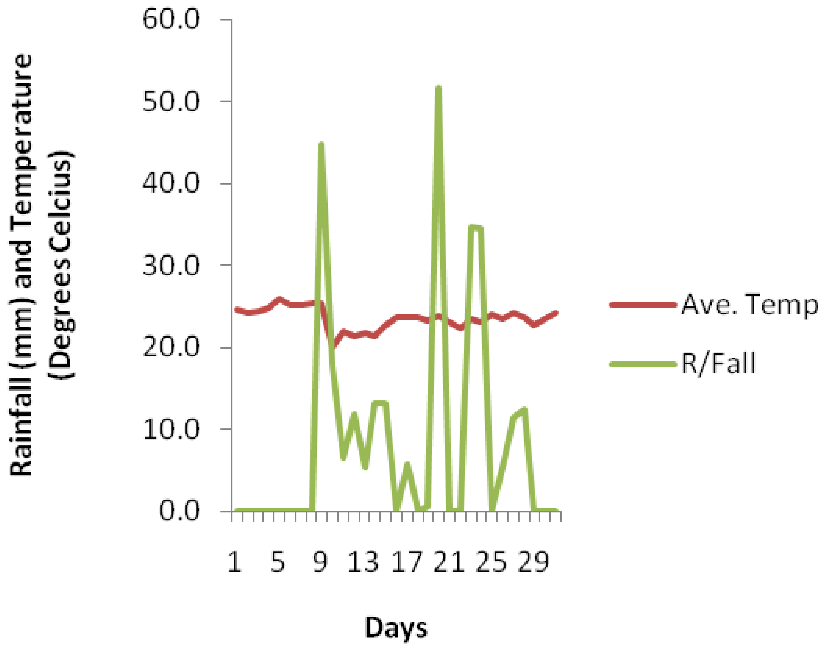
Appendix 4.0b: Daily temperature at the time of nitrate nitrogen measurement

Dec-13		Jan-13				
	R/Fall		Max Temp	Min Temp	Ave. Temp	R/Fall
Day	(mm)	Day	°C	°C	°C	(mm)
1	-	1	30.6	19.4	25.0	-
2	-	2	29.7	19.7	24.7	4.3
3	-	3	26.9	19.9	23.4	-
4	-	4	28.9	20.5	24.7	5.9
5	-	5	22.8	19.6	21.2	8.4
6	-	6	26.8	19.1	23.0	12.3
7	-	7	26.4	19.1	22.8	46.3
8	-	8	25.1	18.1	21.6	1.9
9	44.8	9	21.2	19.7	20.5	25.1
10	17.8	10	25.7	18.7	22.2	20.7
11	6.4	11	27.4	18.8	23.1	124.9
12	11.8	12	26.9	19.5	23.2	-
13	5.4	13	25.4	18.2	21.8	0.2
14	13.2	14	26.7	18.8	22.8	23.7
15	13.1	15	26.8	19.2	23.0	12.1
16	-	16	28.6	17.9	23.3	1.7
17	5.8	17	28.2	19.4	23.8	1.6
18	-	18	29.6	19.1	24.4	-
19	0.6	19	30.7	18.8	24.8	-
20	51.6	20	29.4	20.1	24.8	1.3
21	-	21	28.6	19.9	24.3	4.3
22	-	22	28.2	19.6	23.9	4.7
23	34.7	23	26.6	19.2	22.9	49.6
24	34.4	24	27.6	19.7	23.7	-
25	-	25	26.4	20.4	23.4	1.4
26	5.3	26	27.4	17.8	22.6	4.4
27	11.4	27	27.9	16.9	22.4	0.2
28	12.3	28	26.9	16.9	21.9	2.5

Appendix 4.0c: Off season daily temperature at the time of nitrate nitrogen measurement

DATE			Mean Temp °C	DATE			Mean Temp °C
1	22.7	14.9	18.8	1	27.4	12.2	19.8
2	25.4	12.9	19.2	2	25.7	8.9	17.3
3	25.9	11.3	18.6	3	25.8	7.7	16.75
4	26.3	12.4	19.4	4	25.2	8.8	17
5	27.4	14.3	20.9	5	25.7	9.9	17.8
6	23.8	15.5	19.7	6	27.6	9.6	18.6
7	23.3	9.7	16.5	7	25.2	9.2	17.2
8	24.7	12.1	18.4	8	25.3	8.6	16.95
9	27.7	10.6	19.2	9	25.2	9.7	17.45
10	28.3	11.9	20.1	10	26.7	9.4	18.05
11	26.8	13.7	20.3	11	22.1	10.9	16.5
12	28.1	14.3	21.2	12	21.7	13.4	17.55
13	26.3	10.7	18.5	13	24.4	9.4	16.9
14	25.6	11.6	18.6	14	25.3	10.3	17.8
15	26.2	10.7	18.5	15	25.8	11.3	18.55
16	25.7	11.6	18.7	16	23.4	9.4	16.4
17	27.2	11.9	19.6	17	19.2	9.4	14.3
18	26.6	12.5	19.6	18	22.1	10.9	16.5
19	24.9	13.2	19.1	19	19.9	10.7	15.3
20	25.2	12.8	19.0	20	22.4	10.3	16.35
21	24.4	11.9	18.2	21	22.3	8.8	15.55
22	25.6	12.7	19.2	22	24.6	7.4	16
23	25.8	13.2	19.5	23	22.5	8.9	15.7
24	26	14.4	20.2	24	23	9.9	16.45
25	25.7	13.7	19.7	25	22.8	8.4	15.6
26	26.4	10.6	18.5	26	25.7	8.4	17.05
27	27.7	10.4	19.1	27	25.7	8.8	17.25
28	27.4	11.7	19.6	28	24.7	9.6	17.15
29	27.4	12.3	19.9	29	25.4	8.9	17.15
30	27.4	12.3	19.9	30	25.6	9.8	17.7
31	28.4	12.1	20.3				

Appendix 4.0d: Rainfall and mean daily temperature December, 2012



Appendix 4.0e: Rainfall and mean daily temperature readings for the month of January, 2013

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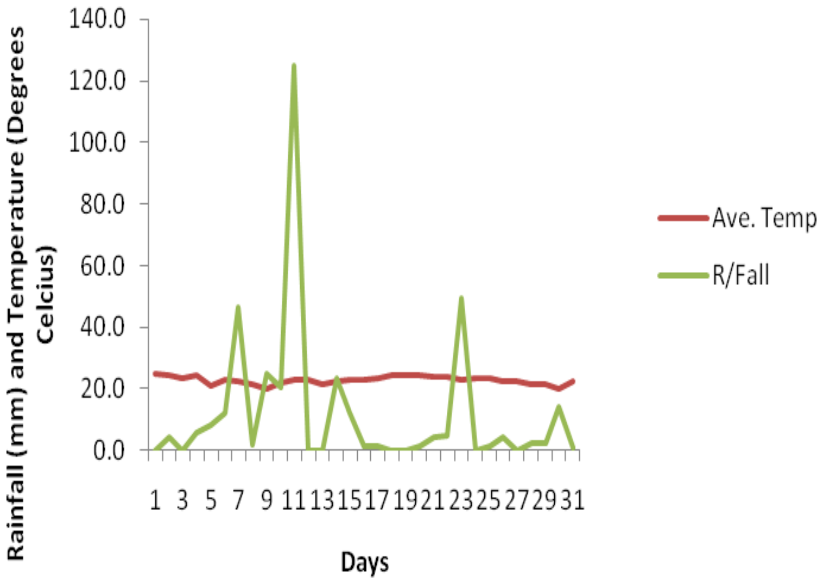
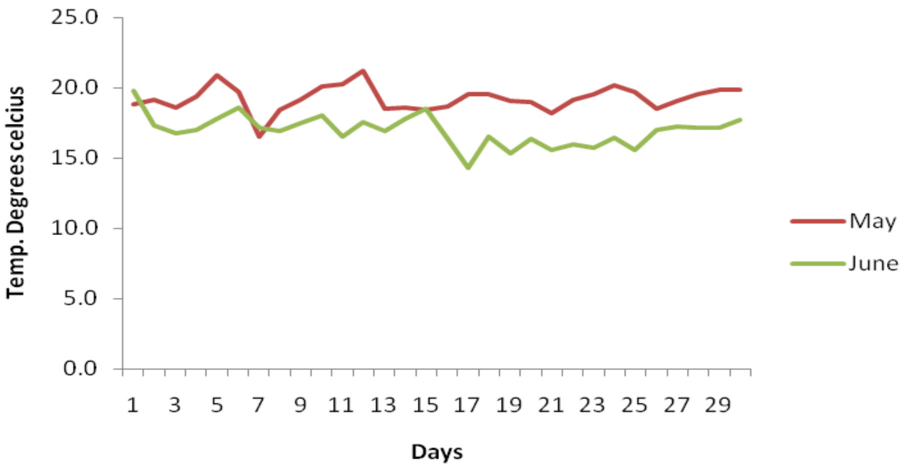


Appendix 4.0f: Mean daily temperature readings for the month of May and June, 2013.



Appendix 4.1: Soil pH at the time of nitrate nitrogen measurement

Rep.	Treatment pH_{H2O}	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean
1	1.Sole maize	0-20	5.47	5.68	5.70	-	5.62
1	1.Sole maize	0-20	5.93	5.54	5.87	5.34	5.67
1	1.Sole maize	0-20	5.22	5.26	5.13	5.42	5.26
1	2.Medium duration pigeon pea	0-20	5.46	5.70	5.74	5.66	5.64
1	2.Medium duration pigeon pea	0-20	5.64	5.48	5.44	5.31	5.47
1	2.Medium duration pigeon pea	0-20	5.28	5.13	5.16	5.08	5.16
1	3.Long duration pigeon pea	0-20	5.75	5.76	5.79	5.85	5.79
1	3.Long duration pigeon pea	0-20	5.80	5.92	5.73	5.62	5.77
2	3.Long duration pigeon pea	0-20	5.09	5.36	5.09	5.14	5.17
2	4.Sole groundnut	0-20	5.78	5.80	5.79	5.84	5.80
2	4.Sole groundnut	0-20	5.73	5.85	5.72	5.38	5.67
2	4.Sole groundnut	0-20	5.26	5.07	4.86	-	5.06
2	5.Medium duration pigeon pea + groundnut	0-20	5.45	5.07	5.01	5.90	5.36
2	5.Medium duration pigeon pea + groundnut	0-20	5.68	5.93	5.97	5.84	5.86
2	5.Medium duration pigeon pea + groundnut	0-20	4.76	4.99	5.45	5.23	5.11
2	6.Long duration pigeon pea + groundnut	0-20	6.02	5.94	5.98	6.01	5.99
3	6.Long duration pigeon pea + groundnut	0-20	5.26	4.92	5.42	5.35	5.24
3	6.Long duration pigeon pea + groundnut	0-20	6.57	5.88	5.71	5.29	5.86

Rep.	Treatment pH_{H2O}	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean
3	7.Medium duration pigeon pea + groundnut	0-20	5.94	5.92	5.72	5.99	5.89
3	7.Medium duration pigeon pea + groundnut	0-20	5.72	5.53	5.76	5.87	5.72
3	7.Medium duration pigeon pea + groundnut	0-20	4.94	5.45	5.31	-	5.23
3	8.Long duration pigeon pea + groundnut	0-20	5.96	5.94	5.87	6.01	5.95
3	8.Long duration pigeon pea + groundnut	0-20	5.61	5.53	5.68	5.49	5.58
3	8.Long duration pigeon pea + groundnut	0-20	5.10	5.09	5.71	5.02	5.23

Appendix 4.1: Soil pH at the time of nitrate nitrogen measurement

Rep.	Treatment pH_{H2O}	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean
1	1.Sole maize	20-40	5.62	5.71	5.68	-	5.67
1	1.Sole maize	20-40	5.80	5.54	5.76	5.37	5.62
1	1.Sole maize	20-40	4.99	5.07	5.07	4.97	5.03
1	2.Medium duration pigeon pea	20-40	5.68	5.79	5.70	5.60	5.69
1	2.Medium duration pigeon pea	20-40	5.80	5.78	5.31	5.18	5.52
1	2.Medium duration pigeon pea	20-40	5.17	5.20	5.17	5.24	5.20
1	3.Long duration pigeon pea	20-40	5.74	5.70	5.80	5.84	5.77
1	3.Long duration pigeon pea	20-40	5.81	5.95	5.30	5.43	5.62
2	3.Long duration pigeon pea	20-40	4.92	5.33	5.18	5.08	5.13
2	4.Sole groundnut	20-40	5.79	5.77	4.82	5.87	5.56
2	4.Sole groundnut	20-40	5.84	5.72	5.42	5.36	5.59
2	4.Sole groundnut	20-40	5.07	4.92	5.00	-	5.00
2	5.Medium duration pigeon pea + groundnut	20-40	5.20	5.05	5.97	5.76	5.50
2	5.Medium duration pigeon pea + groundnut	20-40	5.73	5.88	5.88	5.50	5.75
2	5.Medium duration pigeon pea + groundnut	20-40	4.97	4.92	5.42	5.10	5.10
2	6.Long duration pigeon pea + groundnut	20-40	5.95	5.97	6.10	5.92	5.99
3	6.Long duration pigeon pea + groundnut	20-40	5.08	4.98	5.15	5.28	5.12
3	6.Long duration pigeon pea + groundnut	20-40	5.66	5.44	5.53	4.95	5.40

Rep.	Treatment pH_{H2O}	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean
3	7.Medium duration pigeon pea + groundnut	20-40	6.02	5.96	5.90	5.96	5.96
3	7.Medium duration pigeon pea + groundnut	20-40	5.40	5.60	5.62	5.83	5.61
3	7.Medium duration pigeon pea + groundnut	20-40	5.10	5.26	5.05	-	5.14
3	8.Long duration pigeon pea + groundnut	20-40	5.93	5.95	6.03	6.04	5.99
3	8.Long duration pigeon pea + groundnut	20-40	5.44	5.55	5.43	5.52	5.49
3	8.Long duration pigeon pea + groundnut	20-40	4.86	4.95	5.18	4.82	4.95

Appendix 4.2: Soil temperature at the time of soil nitrate nitrogen measurement

Rep No.	Treatment	Depth (cm)	Temp °C 1	2	3	4	Mean Temp °C
1	1.Sole maize	0-20	25.90	26.00	25.80	25.10	25.70
1	1.Sole maize	0-20	29.60	27.50	29.00	28.60	28.68
1	1.Sole maize	0-20	24.00	24.10	24.10	24.10	24.08
1	2.Medium duration pigeon pea	0-20	28.50	26.60	26.00	26.00	26.78
1	2.Medium duration pigeon pea	0-20	29.40	29.30	30.10	29.60	29.60
1	2.Medium duration pigeon pea	0-20	24.30	24.10	24.00	24.30	24.18
1	3.Long duration pigeon pea	0-20	25.60	25.20	25.40	25.00	25.30
1	3.Long duration pigeon pea	0-20	27.30	27.00	27.10	27.10	27.13
2	3.Long duration pigeon pea	0-20	25.30	25.20	25.00	25.70	25.30
2	4.Sole groundnut	0-20	26.10	26.40	26.90	28.40	26.95
2	4.Sole groundnut	0-20	27.80	27.80	27.30	26.70	27.40
2	4.Sole groundnut	0-20	24.90	24.40	24.50	-	24.60
2	5.Medium duration pigeon pea + groundnut	0-20	27.40	27.80	28.20	27.90	27.83
2	5.Medium duration pigeon pea + groundnut	0-20	27.00	26.40	26.40	26.60	26.60
2	5.Medium duration pigeon pea + groundnut	0-20	24.10	23.80	23.60	23.70	23.80
2	6.Long duration pigeon pea + groundnut	0-20	27.90	27.30	26.70	28.40	27.58
3	6.Long duration pigeon pea + groundnut	0-20	28.80	27.50	30.30	26.90	28.38

Rep.	Treatment	Depth (cm)	Temp ^oC 1	2	3	4	Mean Temp ^oC
3	6.Long duration pigeon pea + groundnut	0-20	26.40	25.70	25.40	25.40	25.73
3	7.Medium duration pigeon pea + groundnut	0-20	28.40	26.30	27.00	27.20	27.23
3	7.Medium duration pigeon pea + groundnut	0-20	26.80	26.20	27.20	26.40	26.65
3	7.Medium duration pigeon pea + groundnut	0-20	23.50	23.20	23.30	-	23.33
3	8.Long duration pigeon pea + groundnut	0-20	28.60	28.10	28.60	29.20	28.63
3	8.Long duration pigeon pea + groundnut	0-20	28.80	28.10	28.80	27.90	28.40
3	8.Long duration pigeon pea + groundnut	0-20	24.40	24.20	24.20	24.50	24.33

Appendix 4.3: Soil humidity at the time of soil nitrate nitrogen measurement

Rep.	Treatment	Depth (cm)	Soil humidity (%) 1	2	3	4	Mean (%)
1	1.Sole maize	0-20	78.00	75.00	79.00	83.00	78.75
1	1.Sole maize	0-20	73.60	76.90	70.50	72.70	73.43
1	1.Sole maize	0-20	71.60	77.00	73.90	77.60	75.03
1	2.Medium duration pigeon pea	0-20	72.00	80.00	84.00	80.00	79.00
1	2.Medium duration pigeon pea	0-20	78.10	66.10	63.90	67.50	68.90
1	2.Medium duration pigeon pea	0-20	70.60	73.00	70.30	78.00	72.98
1	3.Long duration pigeon pea	0-20	82.00	81.50	86.00	80.00	82.38
1	3.Long duration pigeon pea	0-20	74.60	72.60	79.40	73.90	75.13
2	3.Long duration pigeon pea	0-20	68.40	66.90	67.10	69.70	68.03
2	4.Sole groundnut	0-20	89.50	83.20	79.50	81.00	83.30
2	4.Sole groundnut	0-20	75.50	74.80	75.00	75.50	75.20
2	4.Sole groundnut	0-20	79.50	69.20	73.70	-	74.13
2	5.Medium duration pigeon pea + groundnut	0-20	76.10	76.30	81.00	76.00	77.35
2	5.Medium duration pigeon pea + groundnut	0-20	73.40	78.60	77.60	80.40	77.50
2	5.Medium duration pigeon pea + groundnut	0-20	76.80	76.60	80.30	78.50	78.05
2	6.Long duration pigeon pea + groundnut	0-20	76.30	78.90	84.30	75.80	78.83
3	6.Long duration pigeon pea + groundnut	0-20	73.60	74.90	67.10	79.30	73.73
3	6.Long duration pigeon pea + groundnut	0-20	67.60	66.30	68.50	69.10	67.88

Rep.	Treatments	Depth (cm)	Soil humidity (%)				Mean (%)
			1	2	3	4	
1	1.Sole maize	0-20	78.00	75.00	79.00	83.00	78.75
3	7.Medium duration pigeon pea + groundnut	0-20	73.90	76.20	78.50	-	76.20
3	8.Long duration pigeon pea + groundnut	0-20	77.20	79.80	85.50	79.80	80.58
3	8.Long duration pigeon pea + groundnut	0-20	76.50	73.20	75.20	75.60	75.13
3	8.Long duration pigeon pea + groundnut	0-20	76.90	74.90	70.90	75.80	74.63

Appendix 4.3: Soil temperature at the time of soil nitrate nitrogen measurement

Rep No.	Treatment	Depth (cm)	Temperature ^{o}C				Mean ^{o}C
1	1.Sole maize	20-40	25.80	26.00	25.80	25.80	25.85
1	1.Sole maize	20-40	29.50	27.60	28.70	28.30	28.53
1	1.Sole maize	20-40	24.00	24.10	24.20	24.30	24.15
1	2.Medium duration pigeon pea	20-40	27.80	26.20	26.00	26.00	26.50
1	2.Medium duration pigeon pea	20-40	29.20	29.40	30.00	29.40	29.50
1	2.Medium duration pigeon pea	20-40	24.20	24.20	24.10	24.30	24.20
1	3.Long duration pigeon pea	20-40	25.60	25.30	25.30	25.00	25.30
1	3.Long duration pigeon pea	20-40	27.20	27.00	27.00	26.90	27.03
2	3.Long duration pigeon pea	20-40	25.30	25.90	26.10	24.40	25.43
2	4.Sole groundnut	20-40	25.80	26.40	27.30	27.70	26.80
2	4.Sole groundnut	20-40	27.40	27.40	27.00	26.60	27.10
2	4.Sole groundnut	20-40	24.90	25.00	24.40	-	24.77
2	5.Medium duration pigeon pea + groundnut	20-40	25.90	28.40	26.10	27.50	26.98
2	5.Medium duration pigeon pea + groundnut	20-40	26.90	27.00	26.60	26.50	26.75
2	5.Medium duration pigeon pea + groundnut	20-40	24.30	23.90	23.90	23.80	23.98
2	6.Long duration pigeon pea + groundnut	20-40	27.40	27.10	26.40	27.80	27.18
3	6.Long duration pigeon pea + groundnut	20-40	28.40	27.30	28.00	26.80	27.63
3	6.Long duration pigeon pea + groundnut	20-40	26.80	26.10	25.20	25.90	26.00

Rep.	Treatment	Depth (cm)		Temperature ^{o}C			Mean ^{o}C
3	7.Medium duration pigeon pea + groundnut	20-40	27.20	26.40	26.60	27.50	26.93
3	7.Medium duration pigeon pea + groundnut	20-40	26.40	27.00	27.10	26.60	26.78
3	7.Medium duration pigeon pea + groundnut	20-40	23.80	23.30	23.40	-	23.50
3	8.Long duration pigeon pea + groundnut	20-40	28.30	27.50	29.40	29.20	28.60
3	8.Long duration pigeon pea + groundnut	20-40	28.80	28.00	28.10	27.60	28.13
3	8.Long duration pigeon pea + groundnut	20-40	24.40	24.30	24.40	24.60	24.43

Appendix 4.4: Soil humidity at the time of soil nitrate nitrogen measurement

Rep.	Treatment	Depth (cm)	Soil humidity (%)				Mean (%)
1	1.Sole maize	20-40	81.00	80.00	82.00	84.00	81.75
1	1.Sole maize	20-40	71.30	76.20	70.20	73.60	72.83
1	1.Sole maize	20-40	75.50	77.90	79.80	82.00	78.80
1	2.Medium duration pigeon pea	20-40	76.00	82.00	84.00	81.00	80.75
1	2.Medium duration pigeon pea	20-40	73.60	67.40	64.90	68.60	68.63
1	2.Medium duration pigeon pea	20-40	73.10	75.80	73.60	79.50	75.50
1	3.Long duration pigeon pea	20-40	84.70	86.00	86.40	81.00	84.53
1	3.Long duration pigeon pea	20-40	75.70	78.00	79.90	76.50	77.53
2	3.Long duration pigeon pea	20-40	70.40	69.00	70.40	68.60	69.60
2	4.Sole groundnut	20-40	87.90	81.10	83.30	77.80	82.53
2	4.Sole groundnut	20-40	76.20	75.70	77.80	79.50	77.30
2	4.Sole groundnut	20-40	80.90	83.80	74.10	-	79.60
2	5.Medium duration pigeon pea + groundnut	20-40	81.20	84.00	86.20	82.00	83.35
2	5.Medium duration pigeon pea + groundnut	20-40	77.30	77.60	80.30	77.60	78.20
2	5.Medium duration pigeon pea + groundnut	20-40	80.90	83.50	80.60	80.10	81.28
2	6.Long duration pigeon pea + groundnut	20-40	77.90	78.50	84.40	74.60	78.85
3	6.Long duration pigeon pea + groundnut	20-40	73.10	74.90	74.70	79.70	75.60
3	6.Long duration pigeon pea + groundnut	20-40	70.10	68.00	69.20	71.40	69.68

Rep.	Treatment	Depth (cm)	Soil humidity (%)				Mean (%)
			1	2	3	4	
3	7.Medium duration pigeon pea + groundnut	20-40	81.80	88.10	84.40	87.30	85.40
3	7.Medium duration pigeon pea + groundnut	20-40	76.90	77.40	78.60	79.20	78.03
3	7.Medium duration pigeon pea + groundnut	20-40	81.10	77.80	80.10	-	79.67
3	8.Long duration pigeon pea + groundnut	20-40	74.50	77.90	84.80	80.10	79.33
3	8.Long duration pigeon pea + groundnut	20-40	73.20	73.70	77.50	77.20	75.40
3	8.Long duration pigeon pea + groundnut	20-40	76.40	78.60	77.70	79.90	78.15

Appendix 4.5: Soil nitrate nitrogen, day 1

Readings in mg L^{-1}

Rep No.	Treatment	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N(Adj. Meanx0.23)
1	1.Sole maize	0-20	220	360	240	240	265.0	1325.0	1297.0	298.3
1	1.Sole maize	0-20	230	220	440	410	325.0	1625.0	1597.0	367.3
1	1.Sole maize	0-20	420	330	370	310	357.5	1787.5	1759.5	404.7
1	2.Medium duration pigeon pea	0-20	110	200	210	220	185.0	925.0	897.0	206.3
1	2.Medium duration pigeon pea	0-20	490	290	450	430	415.0	2075.0	2047.0	470.8
1	2.Medium duration pigeon pea	0-20	260	310	330	490	347.5	1737.5	1709.5	393.2
1	3.Long duration pigeon pea	0-20	70	380	280	190	230.0	1150.0	1122.0	258.1
1	3.Long duration pigeon pea	0-20	100	360	220	300	245.0	1225.0	1197.0	275.3
2	3.Long duration pigeon pea	0-20	390	240	270	400	325.0	1625.0	1597.0	367.3
2	4.Sole groundnut	0-20	310	480	330	300	355.0	1775.0	1747.0	401.8
2	4.Sole groundnut	0-20	410	270	320	220	305.0	1525.0	1497.0	344.3
2	4.Sole groundnut	0-20	230	350	350	-	232.5	1162.5	1134.5	260.9
2	5.Medium duration pigeon pea + groundnut	0-20	470	210	130	110	230.0	1150.0	1122.0	258.1
2	5.Medium duration pigeon pea + groundnut	0-20	450	290	310	290	335.0	1675.0	1647.0	378.8
2	5.Medium duration pigeon pea + groundnut	0-20	430	540	420	410	450.0	2250.0	2222.0	511.1

Rep No.	Treatments	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N(Adj. Meanx0.23)
3	6.Long duration pigeon pea + groundnut	0-20	420	190	220	230	265.0	1325.0	1297.0	298.3
3	6.Long duration pigeon pea + groundnut	0-20	200	90	120	210	155.0	775.0	747.0	171.8
3	7.Medium duration pigeon pea + groundnut	0-20	210	280	140	150	195.0	975.0	947.0	217.8
3	7.Medium duration pigeon pea + groundnut	0-20	230	260	180	230	225.0	1125.0	1097.0	252.3
3	7.Medium duration pigeon pea + groundnut	0-20	200	310	420	-	232.5	1162.5	1134.5	260.9
3	8.Long duration pigeon pea + groundnut	0-20	330	560	400	470	440.0	2200.0	2172.0	499.6
3	8.Long duration pigeon pea + groundnut	0-20	240	390	370	410	352.5	1762.5	1734.5	398.9
3	8.Long duration pigeon pea + groundnut	0-20	370	350	530	410	415.0	2075.0	2047.0	470.8

Appendix 4.6: Soil nitrate nitrogen, day 2

Readings in mg L^{-1}

Rep.	Treatments	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N(Adj. Meanx0.23)
1	1.Sole maize	0-20	350	220	300	-	217.5	1087.5	1059.5	243.7
1	1.Sole maize	0-20	46	190	82	210	132.0	660.0	632.0	145.4
1	1.Sole maize	0-20	74	58	74	150	89.0	445.0	417.0	95.9
1	2.Medium duration pigeon pea	0-20	56	300	290	290	234.0	1170.0	1142.0	262.7
1	2.Medium duration pigeon pea	0-20	260	190	180	100	182.5	912.5	884.5	203.4
1	2.Medium duration pigeon pea	0-20	370	570	480	76	374.0	1870.0	1842.0	423.7
1	3.Long duration pigeon pea	0-20	290	240	300	70	225.0	1125.0	1097.0	252.3
1	3.Long duration pigeon pea	0-20	230	300	350	130	252.5	1262.5	1234.5	283.9
2	3.Long duration pigeon pea	0-20	550	690	770	-	502.5	2512.5	2484.5	571.4
2	4.Sole groundnut	0-20	290	210	33	190	180.8	903.8	875.8	201.4
2	4.Sole groundnut	0-20	110	160	610	140	255.0	1275.0	1247.0	286.8
2	4.Sole groundnut	0-20	170	340	590	350	362.5	1812.5	1784.5	410.4
2	5.Medium duration pigeon pea + groundnut	0-20	310	330	260	290	297.5	1487.5	1459.5	335.7
2	5.Medium duration pigeon pea + groundnut	0-20	280	150	230	110	192.5	962.5	934.5	214.9

Rep.	Treatments	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N(Adj. Meanx0.23)
3	6.Long duration pigeon pea + groundnut	0-20	430	150	160	150	222.5	1112.5	1084.5	249.4
3	6.Long duration pigeon pea + groundnut	0-20	390	140	420	200	287.5	1437.5	1409.5	324.2
3	7.Medium duration pigeon pea + groundnut	0-20	290	190	100	190	192.5	962.5	934.5	214.9
3	7.Medium duration pigeon pea + groundnut	0-20	130	250	280	690	337.5	1687.5	1659.5	381.7
3	7.Medium duration pigeon pea + groundnut	0-20	270	190	140	-	150.0	750.0	722.0	166.1
3	8.Long duration pigeon pea + groundnut	0-20	240	300	250	270	265.0	1325.0	1297.0	298.3
3	8.Long duration pigeon pea + groundnut	0-20	150	100	88	57	98.8	493.8	465.8	107.1
3	8.Long duration pigeon pea + groundnut	0-20	75	130	150	180	133.8	668.8	640.8	147.4

Appendix 4.7: Soil nitrate nitrogen, day 3

Readings in mg L^{-1}

Rep.	Treatments	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N(Adj. Meanx0.23)
1	1.Sole maize	0-20	360	170	180	-	177.5	887.5	859.5	197.7
1	1.Sole maize	0-20	320	300	290	220	282.5	1412.5	1384.5	318.4
1	1.Sole maize	0-20	160	78	170	55	115.8	578.8	550.8	126.7
1	2.Medium duration pigeon pea	0-20	160	180	180	200	180.0	900.0	872.0	200.6
1	2.Medium duration pigeon pea	0-20	300	250	340	200	272.5	1362.5	1334.5	306.9
1	2.Medium duration pigeon pea	0-20	94	91	180	100	116.3	581.3	553.3	127.2
1	3.Long duration pigeon pea	0-20	170	170	180	290	202.5	1012.5	984.5	226.4
1	3.Long duration pigeon pea	0-20	87	130	130	130	119.3	596.3	568.3	130.7
2	3.Long duration pigeon pea	0-20	83	100	95	63	85.3	426.3	398.3	91.6
2	4.Sole groundnut	0-20	140	270	220	170	200.0	1000.0	972.0	223.6
2	4.Sole groundnut	0-20	140	93	79	64	94.0	470.0	442.0	101.7
2	4.Sole groundnut	0-20	120	200	150	-	117.5	587.5	559.5	128.7
2	5.Medium duration pigeon pea + groundnut	0-20	140	160	190	140	157.5	787.5	759.5	174.7
2	5.Medium duration pigeon pea + groundnut	0-20	110	150	170	130	140.0	700.0	672.0	154.6

Rep.	Treatments	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N(Adj. Meanx0.23)
2	5.Medium duration pigeon pea + groundnut	0-20	170	350	150	130	200.0	1000.0	972.0	223.6
2	6.Long duration pigeon pea + groundnut	0-20	440	320	270	260	322.5	1612.5	1584.5	364.4
3	6.Long duration pigeon pea + groundnut	0-20	530	510	120	96	314.0	1570.0	1542.0	354.7
3	6.Long duration pigeon pea + groundnut	0-20	110	310	160	75	163.8	818.8	790.8	181.9
3	7.Medium duration pigeon pea + groundnut	0-20	210	270	300	260	260.0	1300.0	1272.0	292.6
3	7.Medium duration pigeon pea + groundnut	0-20	200	86	110	130	131.5	657.5	629.5	144.8
3	7.Medium duration pigeon pea + groundnut	0-20	160	200	140	-	125.0	625.0	597.0	137.3
3	8.Long duration pigeon pea + groundnut	0-20	220	250	200	260	232.5	1162.5	1134.5	260.9
3	8.Long duration pigeon pea + groundnut	0-20	330	440	260	250	320.0	1600.0	1572.0	361.6
3	8.Long duration pigeon pea + groundnut	0-20	100	180	81	160	130.3	651.3	623.3	143.3

Appendix 4.8: Soil nitrate nitrogen, day 4

			Readings in mg L^{-1}							
Rep No.	Treatment	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N(Adj. Meanx0.23)
1	1.Sole maize	0-20	300	210	170	-	226.7	1133.3	1105.3	254.2
1	1.Sole maize	0-20	310	310	150	260	257.5	1287.5	1259.5	289.7
1	1.Sole maize	0-20	680	740	560	220	550.0	2750.0	2722.0	626.1
1	2.Medium duration pigeon pea	0-20	190	230	270	180	217.5	1087.5	1059.5	243.7
1	2.Medium duration pigeon pea	0-20	210	260	430	390	322.5	1612.5	1584.5	364.4
1	2.Medium duration pigeon pea	0-20	240	670	640	470	505.0	2525.0	2497.0	574.3
1	3.Long duration pigeon pea	0-20	230	320	400	200	287.5	1437.5	1409.5	324.2
1	3.Long duration pigeon pea	0-20	150	360	230	430	292.5	1462.5	1434.5	329.9
2	3.Long duration pigeon pea	0-20	490	220	290	210	302.5	1512.5	1484.5	341.4
2	4.Sole groundnut	0-20	300	350	230	280	290.0	1450.0	1422.0	327.1
2	4.Sole groundnut	0-20	220	310	490	230	312.5	1562.5	1534.5	352.9
2	4.Sole groundnut	0-20	560	460	580	-	533.3	2666.7	2638.7	606.9
2	5.Medium duration pigeon pea + groundnut	0-20	660	200	130	390	345.0	1725.0	1697.0	390.3

2	5.Medium duration pigeon pea + groundnut	0-20	230	430	450	490	400.0	2000.0	1972.0	453.6
2	5.Medium duration pigeon pea + groundnut	0-20	320	370	180	310	295.0	1475.0	1447.0	332.8
2	6.Long duration pigeon pea + groundnut	0-20	290	350	360	310	327.5	1637.5	1609.5	370.2
3	6.Long duration pigeon pea + groundnut	0-20	370	380	440	380	392.5	1962.5	1934.5	444.9
3	6.Long duration pigeon pea + groundnut	0-20	480	460	460	430	457.5	2287.5	2259.5	519.7
3	7.Medium duration pigeon pea + groundnut	0-20	310	290	260	280	285.0	1425.0	1397.0	321.3
3	7.Medium duration pigeon pea + groundnut	0-20	240	210	190	260	225.0	1125.0	1097.0	252.3
3	7.Medium duration pigeon pea + groundnut	0-20	240	280	180	-	233.3	1166.7	1138.7	261.9
3	8.Long duration pigeon pea + groundnut	0-20	300	240	180	270	247.5	1237.5	1209.5	278.2
3	8.Long duration pigeon pea + groundnut	0-20	360	260	240	240	275.0	1375.0	1347.0	309.8
3	8.Long duration pigeon pea + groundnut	0-20	700	380	320	230	407.5	2037.5	2009.5	462.2

Appendix 4.9: Soil nitrate nitrogen, day 5

Readings in mg L^{-1}

Rep No.	Treatment	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N(Adj. Meanx0.23)
1	1.Sole maize	0-20	340	290	300	-	310.0	1550.0	1522.0	350.1
1	1.Sole maize	0-20	410	760	260	300	432.5	2162.5	2134.5	490.9
1	1.Sole maize	0-20	370	400	280	290	335.0	1675.0	1647.0	378.8
1	2.Medium duration pigeon pea	0-20	260	350	400	340	337.5	1687.5	1659.5	381.7
1	2.Medium duration pigeon pea	0-20	330	510	440	440	430.0	2150.0	2122.0	488.1
1	2.Medium duration pigeon pea	0-20	220	340	380	440	345.0	1725.0	1697.0	390.3
1	3.Long duration pigeon pea	0-20	370	250	440	350	352.5	1762.5	1734.5	398.9
1	3.Long duration pigeon pea	0-20	260	210	340	180	247.5	1237.5	1209.5	278.2
2	3.Long duration pigeon pea	0-20	250	220	370	200	260.0	1300.0	1272.0	292.6
2	4.Sole groundnut	0-20	200	390	330	450	342.5	1712.5	1684.5	387.4
2	4.Sole groundnut	0-20	220	390	130	280	255.0	1275.0	1247.0	286.8
2	4.Sole groundnut	0-20	370	410	350	-	282.5	1412.5	1384.5	318.4
2	5.Medium duration pigeon pea + groundnut	0-20	210	260	210	360	260.0	1300.0	1272.0	292.6
2	5.Medium duration pigeon pea + groundnut	0-20	260	190	270	300	255.0	1275.0	1247.0	286.8
2	5.Medium duration pigeon pea +	0-20	350	250	500	370	367.5	1837.5	1809.5	416.2

	groundnut									
2	6.Long duration pigeon pea + groundnut	0-20	350	340	210	220	280.0	1400.0	1372.0	315.6

Rep No.	**Treatment**	**Depth (cm)**	**Point No. 1**	**Point No. 2**	**Point No. 3**	**Point No. 4**	**Mean**	**Corrected Mean (Meanx5)**	**Adjusted mean (Corr mean-28)**	**Nitrate-N(Adj. Meanx0.23)**
3	6.Long duration pigeon pea + groundnut	0-20	440	650	190	200	370.0	1850.0	1822.0	419.1
3	6.Long duration pigeon pea + groundnut	0-20	270	220	300	200	247.5	1237.5	1209.5	278.2
3	7.Medium duration pigeon pea + groundnut	0-20	250	220	280	180	232.5	1162.5	1134.5	260.9
3	7.Medium duration pigeon pea + groundnut	0-20	210	270	360	270	277.5	1387.5	1359.5	312.7
3	7.Medium duration pigeon pea + groundnut	0-20	180	410	210	-	200.0	1000.0	972.0	223.6
3	8.Long duration pigeon pea + groundnut	0-20	400	340	330	430	375.0	1875.0	1847.0	424.8
3	8.Long duration pigeon pea + groundnut	0-20	420	740	360	550	517.5	2587.5	2559.5	588.7
3	8.Long duration pigeon pea + groundnut	0-20	390	280	280	380	332.5	1662.5	1634.5	375.9

Appendix 4.10: Soil nitrate nitrogen, day 6

Readings in mg L^{-1}

Rep No.	Treatment 6	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N(Adj. Mean x0.23)
1	1.Sole maize	0-20	100	74	130	-	76.0	380	352	81
1	1.Sole maize	0-20	130	90	83	-	75.8	379	351	81
1	1.Sole maize	0-20	210	130	130	100	142.5	713	685	157
1	2.Medium duration pigeon pea	0-20	58	92	110	59	79.8	399	371	85
1	2.Medium duration pigeon pea	0-20	84	470	120	120	198.5	993	965	222
1	2.Medium duration pigeon pea	0-20	100	160	120	140	130.0	650	622	143
1	3.Long duration pigeon pea	0-20	700	350	320	440	452.5	2263	2235	514
1	3.Long duration pigeon pea	0-20	120	130	110	140	125.0	625	597	137
2	3.Long duration pigeon pea	0-20	220	180	130	180	177.5	888	860	198
2	4.Sole groundnut	0-20	530	540	600	720	597.5	2988	2960	681
2	4.Sole groundnut	0-20	110	140	130	150	132.5	663	635	146
2	4.Sole groundnut	0-20	190	160	220	-	142.5	713	685	157
2	5.Medium duration pigeon pea + groundnut	0-20	360	440	520	490	452.5	2263	2235	514

Rep.	Treatments	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N(Adj. Meanx0.23)
2	6.Long duration pigeon pea + groundnut	0-20	420	600	140	80	310.0	1550	1522	350
3	6.Long duration pigeon pea + groundnut	0-20	110	99	97	130	109.0	545	517	119
3	6.Long duration pigeon pea + groundnut	0-20	83	130	160	86	114.8	574	546	126
3	7.Medium duration pigeon pea + groundnut	0-20	380	430	400	550	440.0	2200	2172	500
3	7.Medium duration pigeon pea + groundnut	0-20	160	96	160	78	123.5	618	590	136
3	7.Medium duration pigeon pea + groundnut	0-20	210	290	230	-	182.5	913	885	203
3	8.Long duration pigeon pea + groundnut	0-20	480	460	480	450	467.5	2338	2310	531
3	8.Long duration pigeon pea + groundnut	0-20	100	120	100	98	104.5	523	495	114

Appendix 4.10: Soil nitrate nitrogen, day 7

Rep.	Treatment	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N(Adj. Mean x0.23)
			Readings in mg L^{-1}							
1	1.Sole maize	0-20	200	180	190	-	142.5	713	685	157
1	1.Sole maize	0-20	62	69	84	-	53.8	269	241	55
1	1.Sole maize	0-20	300	350	350	150	287.5	1438	1410	324
1	2.Medium duration pigeon pea	0-20	180	180	210	200	192.5	963	935	215
1	2.Medium duration pigeon pea	0-20	84	100	110	88	95.5	478	450	103
1	2.Medium duration pigeon pea	0-20	230	250	220	160	215.0	1075	1047	241
1	3.Long duration pigeon pea	0-20	190	210	240	220	215.0	1075	1047	241
1	3.Long duration pigeon pea	0-20	82	84	69	130	91.3	456	428	98
2	3.Long duration pigeon pea	0-20	350	180	230	370	282.5	1413	1385	318
2	4.Sole groundnut	0-20	100	79	110	89	94.5	473	445	102
2	4.Sole groundnut	0-20	84	92	150	130	114.0	570	542	125
2	4.Sole groundnut	0-20	310	280	370	-	240.0	1200	1172	270
2	5.Medium duration pigeon pea + groundnut	0-20	150	170	190	120	157.5	788	760	175

Rep.	Treatments	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N(Adj. Meanx0.23)
2	5.Medium duration pigeon pea + groundnut	0-20	120	110	170	110	127.5	638	610	140
2	5.Medium duration pigeon pea + groundnut	0-20	170	390	370	360	322.5	1613	1585	364
2	6.Long duration pigeon pea + groundnut	0-20	53	140	110	120	105.8	529	501	115
3	6.Long duration pigeon pea + groundnut	0-20	110	120	110	100	110.0	550	522	120
3	6.Long duration pigeon pea + groundnut	0-20	150	140	230	270	197.5	988	960	221
3	7.Medium duration pigeon pea + groundnut	0-20	100	160	120	92	118.0	590	562	129
3	7.Medium duration pigeon pea + groundnut	0-20	110	91	98	81	95.0	475	447	103
3	7.Medium duration pigeon pea + groundnut	0-20	240	220	120	-	145.0	725	697	160
3	8.Long duration pigeon pea + groundnut	0-20	110	110	160	83	115.8	579	551	127
3	8.Long duration pigeon pea + groundnut	0-20	83	82	92	130	96.8	484	456	105
3	8.Long duration pigeon pea + groundnut	0-20	360	490	390	320	390.0	1950	1922	442

Appendix 4.11: Soil nitrate nitrogen, day 1

Readings in mg L^{-1}

Rep.	Treatments	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N (Adj. Mean x0.23)
1	1.Sole maize	20-40	490	410	240	200	335.0	1675	1647	379
1	1.Sole maize	20-40	250	350	290	360	312.5	1563	1535	353
1	1.Sole maize	20-40	250	500	270	280	325.0	1625	1597	367
1	2.Medium duration pigeon pea	20-40	220	230	300	350	275.0	1375	1347	310
1	2.Medium duration pigeon pea	20-40	470	330	420	440	415.0	2075	2047	471
1	2.Medium duration pigeon pea	20-40	280	330	330	300	310.0	1550	1522	350
1	3.Long duration pigeon pea	20-40	350	42	260	130	195.5	978	950	218
1	3.Long duration pigeon pea	20-40	130	250	360	200	235.0	1175	1147	264
2	3.Long duration pigeon pea	20-40	360	240	190	160	237.5	1188	1160	267
2	4.Sole groundnut	20-40	390	460	500	370	430.0	2150	2122	488
2	4.Sole groundnut	20-40	300	260	340	330	307.5	1538	1510	347
2	4.Sole groundnut	20-40	320	240	390	-	237.5	1188	1160	267

Rep.	Treatments	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N (Adj. Mean x0.23)
2	5.Medium duration pigeon pea + groundnut	20-40	510	580	210	110	352.5	1763	1735	399
2	5.Medium duration pigeon pea + groundnut	20-40	390	150	300	240	270.0	1350	1322	304
2	5.Medium duration pigeon pea + groundnut	20-40	14	350	30	350	186.0	930	902	207
2	6.Long duration pigeon pea + groundnut	20-40	280	250	220	220	242.5	1213	1185	272
3	6.Long duration pigeon pea + groundnut	20-40	540	250	200	180	292.5	1463	1435	330
3	6.Long duration pigeon pea + groundnut	20-40	240	180	120	370	227.5	1138	1110	255
3	7.Medium duration pigeon pea + groundnut	20-40	320	270	220	240	262.5	1313	1285	295
3	7.Medium duration pigeon pea + groundnut	20-40	210	190	220	270	222.5	1113	1085	249
3	7.Medium duration pigeon pea + groundnut	20-40	430	460	470	-	340.0	1700	1672	385
3	8.Long duration pigeon pea + groundnut	20-40	370	740	420	600	532.5	2663	2635	606
3	8.Long duration pigeon pea + groundnut	20-40	290	380	370	220	315.0	1575	1547	356
3	8.Long duration pigeon pea + groundnut	20-40	320	430	260	310	330.0	1650	1622	373

Appendix 4.12: Soil nitrate nitrogen, day 2

Readings in mg L^{-1}

Rep No.	Treatment 2	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N(Adj. Meanx 0.23)
1	1.Sole maize	20-40	280	400	290		242.5	1213	1185	272
1	1.Sole maize	20-40	740	230	93	160	305.8	1529	1501	345
1	1.Sole maize	20-40	170	130	180	140	155.0	775	747	172
1	2.Medium duration pigeon pea	20-40	140	310	420	200	267.5	1338	1310	301
1	2.Medium duration pigeon pea	20-40	180	120	340	300	235.0	1175	1147	264
1	2.Medium duration pigeon pea	20-40	220	190	170	110	172.5	863	835	192
1	3.Long duration pigeon pea	20-40	300	590	140	250	320.0	1600	1572	362
1	3.Long duration pigeon pea	20-40	390	660	190	200	360.0	1800	1772	408
2	3.Long duration pigeon pea	20-40	620	600	400	-	405.0	2025	1997	459
2	4.Sole groundnut	20-40	450	67	24	460	250.3	1251	1223	281
2	4.Sole groundnut	20-40	230	180	110	350	217.5	1088	1060	244
2	4.Sole groundnut	20-40	420	490	130	520	390.0	1950	1922	442
2	5.Medium duration pigeon pea + groundnut	20-40	140	290	290	190	227.5	1138	1110	255
2	5.Medium duration pigeon pea + groundnut	20-40	520	230	510	440	425.0	2125	2097	482

Rep.	Treatments	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N(Adj. Meanx 0.23)
2	6.Long duration pigeon pea + groundnut	20-40	210	750	450	260	417.5	2088	2060	474
3	6.Long duration pigeon pea + groundnut	20-40	180	170	200	75	156.3	781	753	173
3	6.Long duration pigeon pea + groundnut	20-40	620	770	210	330	482.5	2413	2385	548
3	7.Medium duration pigeon pea + groundnut	20-40	310	260	98	280	237.0	1185	1157	266
3	7.Medium duration pigeon pea + groundnut	20-40	51	310	160	780	325.3	1626	1598	368
3	7.Medium duration pigeon pea + groundnut	20-40	200	160	220	-	145.0	725	697	160
3	8.Long duration pigeon pea + groundnut	20-40	69	130	150	480	207.3	1036	1008	232

Appendix 4.13: Soil nitrate nitrogen, day 3

Rep No.	Treatment 3	Depth (cm)	Readings in mg L^{-1} Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N(Adj. Meanx 0.23)
1	1.Sole maize	20-40	190	180	170		135.0	675	647	149
1	1.Sole maize	20-40	270	700	500	420	472.5	2363	2335	537
1	1.Sole maize	20-40	140	140	160	83	130.8	654	626	144
1	2.Medium duration pigeon pea	20-40	140	230	270	250	222.5	1113	1085	249
1	2.Medium duration pigeon pea	20-40	410	420	570	290	422.5	2113	2085	479
1	2.Medium duration pigeon pea	20-40	150	100	150	210	152.5	763	735	169
1	3.Long duration pigeon pea	20-40	300	250	200	220	242.5	1213	1185	272
1	3.Long duration pigeon pea	20-40	180	220	140	110	162.5	813	785	180
2	3.Long duration pigeon pea	20-40	97	140	95	190	130.5	653	625	144
2	4.Sole groundnut	20-40	220	420	180	420	310.0	1550	1522	350
2	4.Sole groundnut	20-40	190	370	250	200	252.5	1263	1235	284
2	4.Sole groundnut	20-40	200	140	200	-	135.0	675	647	149
2	5.Medium duration pigeon pea + groundnut	20-40	310	230	240	310	272.5	1363	1335	307
2	5.Medium duration pigeon pea + groundnut	20-40	79	240	160	200	169.8	849	821	189
2	5.Medium duration pigeon pea + groundnut	20-40	290	210	270	160	232.5	1163	1135	261

Rep.	Treatments	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N(Adj. Meanx 0.23)
2	6.Long duration pigeon pea + groundnut	20-40	640	660	460	390	537.5	2688	2660	612
3	6.Long duration pigeon pea + groundnut	20-40	740	200	130	320	347.5	1738	1710	393
3	6.Long duration pigeon pea + groundnut	20-40	190	220	290	110	202.5	1013	985	226
3	7.Medium duration pigeon pea + groundnut	20-40	250	510	720	360	460.0	2300	2272	523
3	7.Medium duration pigeon pea + groundnut	20-40	110	150	130	320	177.5	888	860	198
3	7.Medium duration pigeon pea + groundnut	20-40	130	240	150	-	130.0	650	622	143
3	8.Long duration pigeon pea + groundnut	20-40	340	410	510	480	435.0	2175	2147	494
3	8.Long duration pigeon pea + groundnut	20-40	560	510	560	190	455.0	2275	2247	517
3	8.Long duration pigeon pea + groundnut	20-40	140	120	130	230	155.0	775	747	172

Appendix 4.14: Soil nitrate nitrogen, day 4

Rep No.	Treatment	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N(Adj. Meanx 0.23)
					Readings in mg L^{-1}					
1	1.Sole maize	20-40	190	160	150		125.0	625	597	137
1	1.Sole maize	20-40	790	340	220	210	390.0	1950	1922	442
1	1.Sole maize	20-40	640	630	690	450	602.5	3013	2985	686
1	2.Medium duration pigeon pea	20-40	370	310	370	230	320.0	1600	1572	362
1	2.Medium duration pigeon pea	20-40	220	490	370	390	367.5	1838	1810	416
1	2.Medium duration pigeon pea	20-40	500	380	430	630	485.0	2425	2397	551
1	3.Long duration pigeon pea	20-40	290	430	650	390	440.0	2200	2172	500
1	3.Long duration pigeon pea	20-40	210	280	510	250	312.5	1563	1535	353
2	3.Long duration pigeon pea	20-40	290	390	530	510	430.0	2150	2122	488
2	4.Sole groundnut	20-40	190	340	260	380	292.5	1463	1435	330
2	4.Sole groundnut	20-40	410	550	370	420	437.5	2188	2160	497
2	4.Sole groundnut	20-40	450	620	570	-	410.0	2050	2022	465
2	5.Medium duration pigeon pea + groundnut	20-40	420	210	510	570	427.5	2138	2110	485
2	5.Medium duration pigeon pea + groundnut	20-40	290	320	300	540	362.5	1813	1785	410
2	5.Medium duration pigeon pea + groundnut	20-40	470	190	110	750	380.0	1900	1872	431

Rep.	Treatments	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N(Adj. Meanx 0.23)
2	6.Long duration pigeon pea + groundnut	20-40	370	540	450	440	450.0	2250	2222	511
3	6.Long duration pigeon pea + groundnut	20-40	490	540	560	350	485.0	2425	2397	551
3	6.Long duration pigeon pea + groundnut	20-40	490	440	460	220	402.5	2013	1985	456
3	7.Medium duration pigeon pea + groundnut	20-40	290	440	330	380	360.0	1800	1772	408
3	7.Medium duration pigeon pea + groundnut	20-40	410	390	230	590	405.0	2025	1997	459
3	7.Medium duration pigeon pea + groundnut	20-40	210	230	240	-	170.0	850	822	189
3	8.Long duration pigeon pea + groundnut	20-40	360	260	330	290	310.0	1550	1522	350
3	8.Long duration pigeon pea + groundnut	20-40	310	360	240	170	270.0	1350	1322	304
3	8.Long duration pigeon pea + groundnut	20-40	400	490	670	240	450.0	2250	2222	511

Appendix 4.15: Soil nitrate nitrogen, day 5

Rep No.	Treatment	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N(Adj. Meanx 0.23)
						Readings in mg L^{-1}				
1	1.Sole maize	20-40	190	290	250		243.3	1217	1189	273
1	1.Sole maize	20-40	470	670	380	340	465.0	2325	2297	528
1	1.Sole maize	20-40	280	330	260	310	295.0	1475	1447	333
1	2.Medium duration pigeon pea	20-40	290	220	270	420	300.0	1500	1472	339
1	2.Medium duration pigeon pea	20-40	400	550	390	350	422.5	2113	2085	479
1	2.Medium duration pigeon pea	20-40	310	400	310	160	295.0	1475	1447	333
1	3.Long duration pigeon pea	20-40	350	290	580	420	410.0	2050	2022	465
1	3.Long duration pigeon pea	20-40	170	230	290	310	250.0	1250	1222	281
2	3.Long duration pigeon pea	20-40	290	230	390	220	282.5	1413	1385	318
2	4.Sole groundnut	20-40	340	260	270	270	285.0	1425	1397	321
2	4.Sole groundnut	20-40	350	200	140	410	275.0	1375	1347	310
2	4.Sole groundnut	20-40	290	360	250	-	225.0	1125	1097	252
2	5.Medium duration pigeon pea + groundnut	20-40	240	210	240	210	225.0	1125	1097	252
2	5.Medium duration pigeon pea + groundnut	20-40	300	360	230	370	315.0	1575	1547	356

Rep.	Treatments	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N(Adj. Meanx 0.23)
2	5.Medium duration pigeon pea + groundnut	20-40	390	330	530	500	437.5	2188	2160	497
2	6.Long duration pigeon pea + groundnut	20-40	360	290	420	300	342.5	1713	1685	387
3	6.Long duration pigeon pea + groundnut	20-40	750	300	240	250	385.0	1925	1897	436
3	6.Long duration pigeon pea + groundnut	20-40	290	260	370	300	305.0	1525	1497	344
3	7.Medium duration pigeon pea + groundnut	20-40	460	200	370	330	340.0	1700	1672	385
3	7.Medium duration pigeon pea + groundnut	20-40	350	350	370	340	352.5	1763	1735	399
3	7.Medium duration pigeon pea + groundnut	20-40	420	370	220	-	252.5	1263	1235	284
3	8.Long duration pigeon pea + groundnut	20-40	250	420	370	410	362.5	1813	1785	410
3	8.Long duration pigeon pea + groundnut	20-40	490	430	560	440	480.0	2400	2372	546
3	8.Long duration pigeon pea + groundnut	20-40	290	360	370	400	355.0	1775	1747	402

Appendix 4.16: Soil nitrate nitrogen, day 6

Readings in mg L^{-1}

Rep No.	Treatment 6	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N(Adj. Meanx 0.23)
1	1.Sole maize	20-40	130	100	97	-	81.8	409	381	88
1	1.Sole maize	20-40	120	120	76	-	79.0	395	367	84
1	1.Sole maize	20-40	160	110	150	370	197.5	988	960	221
1	2.Medium duration pigeon pea	20-40	77	31	88	86	70.5	353	325	75
1	2.Medium duration pigeon pea	20-40	66	150	53	140	102.3	511	483	111
1	2.Medium duration pigeon pea	20-40	260	250	210	160	220.0	1100	1072	247
1	3.Long duration pigeon pea	20-40	570	550	480	550	537.5	2688	2660	612
1	3.Long duration pigeon pea	20-40	120	100	170	350	185.0	925	897	206
2	3.Long duration pigeon pea	20-40	160	160	120	160	150.0	750	722	166
2	4.Sole groundnut	20-40	520	700	800	760	695.0	3475	3447	793
2	4.Sole groundnut	20-40	120	120	190	160	147.5	738	710	163
2	4.Sole groundnut	20-40	180	250	180	-	152.5	763	735	169
2	5.Medium duration pigeon pea + groundnut	20-40	77	180	210	190	164.3	821	793	182

Rep.	Treatments	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N(Adj. Meanx 0.23)
2	6.Long duration pigeon pea + groundnut	20-40	530	290	130	92	260.5	1303	1275	293
3	6.Long duration pigeon pea + groundnut	20-40	70	180	160	100	127.5	638	610	140
3	6.Long duration pigeon pea + groundnut	20-40	110	170	280	180	185.0	925	897	206
3	7.Medium duration pigeon pea + groundnut	20-40	410	460	510	660	510.0	2550	2522	580
3	7.Medium duration pigeon pea + groundnut	20-40	190	150	150	76	141.5	708	680	156
3	7.Medium duration pigeon pea + groundnut	20-40	190	270	210	-	167.5	838	810	186
3	8.Long duration pigeon pea + groundnut	20-40	500	450	520	430	475.0	2375	2347	540

Appendix 4.17: Soil nitrate nitrogen, day 7

Readings in mg L^{-1}

Rep.	Treatments 7	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N(Adj. Meanx 0.23)
1	1.Sole maize	20-40	220	210	180	-	152.5	763	735	169
1	1.Sole maize	20-40	82	110	84	-	69.0	345	317	73
1	1.Sole maize	20-40	270	270	220	250	252.5	1263	1235	284
1	2.Medium duration pigeon pea	20-40	180	180	180	210	187.5	938	910	209
1	2.Medium duration pigeon pea	20-40	83	130	90	100	100.8	504	476	109
1	2.Medium duration pigeon pea	20-40	470	150	270	230	280.0	1400	1372	316
1	3.Long duration pigeon pea	20-40	300	260	220	210	247.5	1238	1210	278
1	3.Long duration pigeon pea	20-40	110	130	90	150	120.0	600	572	132
2	3.Long duration pigeon pea	20-40	290	260	210	270	257.5	1288	1260	290
2	4.Sole groundnut	20-40	100	110	92	100	100.5	503	475	109
2	4.Sole groundnut	20-40	140	150	140	120	137.5	688	660	152
2	4.Sole groundnut	20-40	190	260	250	-	175.0	875	847	195
2	5.Medium duration pigeon pea + groundnut	20-40	130	190	140	110	142.5	713	685	157

Rep.	Treatments	Depth (cm)	Point No. 1	Point No. 2	Point No. 3	Point No. 4	Mean	Corrected Mean (Meanx5)	Adjusted mean (Corr mean-28)	Nitrate-N(Adj. Meanx 0.23)
2	5.Medium duration pigeon pea + groundnut	20-40	240	300	290	330	290.0	1450	1422	327
2	6.Long duration pigeon pea + groundnut	20-40	100	230	110	130	142.5	713	685	157
3	6.Long duration pigeon pea + groundnut	20-40	130	170		91	130	130.3	651	623
3	6.Long duration pigeon pea + groundnut	20-40	220	170		140	180	177.5	888	860
3	7.Medium duration pigeon pea + groundnut	20-40	130	87		93	110	105.0	525	497
3	7.Medium duration pigeon pea + groundnut	20-40	130	70		100	150	112.5	563	535
3	7.Medium duration pigeon pea + groundnut	20-40	170	300		230	-	175.0	875	847
3	8.Long duration pigeon pea + groundnut	20-40	150	130		130	130	135.0	675	647
3	8.Long duration pigeon pea + groundnut	20-40	170	67		130	130	124.3	621	593

Appendix 4.6: Off season nitrate nitrogen data from the nitrate meter and the KCl method

Rep. No.	Plot No.	Depth (cm)	Trt. No.	NO^{-3} (ppm)	Nitrate-N (Meter) mg L^{-1}	Nitrate-N (KCl) mg L^{-1}
Rep1	1	0-20	3	510	117.3	40
1	1	20-40	3	280	64.4	65
1	2	0-20	6	28	6.44	15
1	2	20-40	6	560	128.8	40
1	3	0-20	9	130	29.9	90
1	3	20-40	9	110	25.3	465
1	4	0-20	7	600	138	165
1	4	20-40	7	90	20.7	65
1	5	0-20	10	37	8.51	12.5
1	5	20-40	10	73	16.79	15
1	6	0-20	2	420	96.6	40
1	6	20-40	2	250	57.5	115
1	7	0-20	5	110	25.3	52.5
1	7	20-40	5	210	48.3	65
1	8	0-20	1	280	64.4	7.5
1	8	20-40	1	720	165.6	40
1	9	0-20	4	73	16.79	17.5
1	9	20-40	4	47	10.81	265
1	10	0-20	8	160	36.8	15

Rep. No.	Plot No.	Depth (cm)	Trt. No.	NO^{-3} (ppm)	Nitrate-N (Meter) mg l^{-1}	Nitrate-N (KCl) mg l^{-1}
Rep1	10	20-40	8	80	18.4	340
Rep 2	1	0-20	9	220	50.6	140
Rep 2	1	20-40	9	140	32.2	115
2	2	0-20	3	520	119.6	65
2	2	20-40	3	480	110.4	265
2	4	0-20	2	130	29.9	1490
2	4	20-40	2	110	25.3	840
2	5	0-20	4	78	17.94	965
2	5	20-40	4	110	25.3	90
2	6	0-20	6	330	75.9	65
2	6	20-40	6	680	156.4	290
2	7	0-20	5	630	144.9	165
2	7	20-40	5	280	64.4	190
2	8	0-20	7	250	57.5	140
2	8	20-40	7	100	23	115
2	9	0-20	1	390	89.7	15
2	9	20-40	1	570	131.1	65
2	10	0-20	8	260	59.8	315
Rep2	10	20-40	8	150	34.5	90
Rep 3	1	0-20	1	230	52.9	165

Rep. No.	Plot No.	Depth (cm)	Trt. No.	NO^{-3} (ppm)	Nitrate-N (Meter) mg l^{-1}	Nitrate-N (KCl) mg L^{-1}
Rep3	1	20-40	1	290	66.7	90
3	2	0-20	6	490	112.7	465
3	2	20-40	6	50	11.5	15
3	3	0-20	5	170	39.1	22.5
3	3	20-40	5	51	11.73	10
3	4	0-20	9	47	10.81	165
3	4	20-40	9	780	179.4	115
3	5	0-20	10	190	43.7	37.5
3	5	20-40	10	240	55.2	152.5
3	6	0-20	2	600	138	40
3	6	20-40	2	200	46	90
3	8	0-20	4	740	170.2	140
3	8	20-40	4	710	163.3	215
3	9	0-20	8	240	55.2	590
3	9	20-40	8	210	48.3	147.5
Rep3	10	0-20	9	420	96.6	815
Rep3	10	20-40	9	310	71.3	15

Appendix 5.0a: N and P yield in groundnut haulms parallel experiment, season two

Rep	Treatment	Haulms yield ha^{-1}	N(%)	P(%)	N Yield ha^{-1}	P Yield ha^{-1}
1	1.Medium duration pigeon pea + Groundnut	1530	2.0	0.18	30.4	2.8
1	3.Groundnut + 25 kg P ha^{-1}	2410	1.8	0.16	43.0	3.9
1	5.Long duration pigeon pea + Groundnut	1428	2.2	0.20	31.2	2.9
1	7.Long duration pigeon pea + Groundnut + 25 kg P ha^{-1}	1813	2.2	0.20	39.7	3.7
1	8.Medium duration pigeon pea + Groundnut + 25 kg P ha^{-1}	1108	2.1	0.20	23.5	2.2
1	9.Groundnut	1872	2.3	0.19	42.2	3.6
2	1.Medium duration pigeon pea + Groundnut	1647	2.0	0.18	32.7	3.0
2	3.Groundnut + 25 kg P ha^{-1}	1076	2.6	0.23	27.9	2.5
2	5.Long duration pigeon pea + Groundnut	1500	2.1	0.17	30.8	2.6
2	7.Long duration pigeon pea + Groundnut + 25 kg P ha^{-1}	2010	1.7	0.17	34.5	3.5
2	8.Medium duration pigeon pea + Groundnut + 25 kg P ha^{-1}	1778	1.8	0.15	31.7	2.7
2	9.Groundnut	1486	2.3	0.24	33.5	3.6
3	1.Medium duration pigeon pea + Groundnut	1370	1.9	0.18	26.3	2.5
3	3.Groundnut + 25 kg P ha^{-1}	3904	2.1	0.20	82.8	7.9
3	5.Long duration pigeon pea + Groundnut	1261	2.0	0.16	25.1	2.1
3	7.Long duration pigeon pea + Groundnut + 25 kg P ha^{-1}	1359	2.1	0.20	28.8	2.8
3	8.Medium duration pigeon pea + Groundnut + 25 kg P ha^{-1}	1351	2.6	0.24	35.0	3.3
3	9.Groundnut	-	-	-	-	-

Appendix 5.0b: N and P yield in groundnut shells parallel experiment, season two

Rep	Treatment	Wt of shell kg ha^{-1}	N(%)	P(%)	N Yield ha^{-1}	P Yield ha^{-1}
1	1.Medium duration pigeon pea + Groundnut	1609	1.4	0.16	22.2	2.6
1	3.Groundnut + 25 kg P ha^{-1}	3070	1.4	0.15	44.5	4.5
1	5.Long duration pigeon pea + Groundnut	1062	0.9	0.13	9.7	1.4
1	7.Long duration pigeon pea + Groundnut + 25 kg P ha^{-1}	1659	1.0	0.11	16.3	1.8
1	8.Medium duration pigeon pea + Groundnut + 25 kg P ha^{-1}	1370	1.2	0.14	17.1	1.9
1	9.Groundnut	848	1.9	0.17	15.7	1.4
2	1.Medium duration pigeon pea + Groundnut	1500	1.0	0.10	14.7	1.5
2	3.Groundnut + 25 kg P ha^{-1}	1506	1.4	0.16	20.8	2.5
2	5.Long duration pigeon pea + Groundnut	1260	1.0	0.14	13.2	1.7
2	7.Long duration pigeon pea + Groundnut + 25 kg P ha^{-1}	1751	1.1	0.12	19.5	2.1
2	8.Medium duration pigeon pea + Groundnut + 25 kg P ha^{-1}	1185	1.1	0.10	12.8	1.2
2	9.Groundnut	2634	1.1	0.14	29.3	3.8
3	1.Medium duration pigeon pea + Groundnut	1274	1.0	0.12	13.3	1.6
3	3.Groundnut + 25 kg P ha^{-1}	1379	1.4	0.13	19.1	1.8
3	5.Long duration pigeon pea + Groundnut	1141	0.8	0.09	8.9	1.1
3	7.Long duration pigeon pea + Groundnut + 25 kg P ha^{-1}	1633	1.1	0.14	18.2	2.3
3	8.Medium duration pigeon pea + Groundnut + 25 kg P ha^{-1}	1634	1.2	0.12	19.3	2.0
3	9.Groundnut	-	-	-	-	-

Appendix 5.0c: N and P yield in groundnut grain parallel experiment, season two

Rep.	Treatments	Gn Grain yield ha^{-1}	N(%)	P(%)	N Yield ha^{-1}	P Yield ha^{-1}
1	1.Medium duration pigeon pea + Groundnut	1721	3.1	0.43	52.8	7.4
1	3.Groundnut + 25 kg P ha^{-1}	3629	2.7	0.45	98.0	16.3
1	5.Long duration pigeon pea + Groundnut	1567	3.3	0.47	51.5	7.3
1	7.Long duration pigeon pea + Groundnut + 25 kg P ha^{-1}	2074	2.8	0.41	59.0	8.4
1	8.Medium duration pigeon pea + Groundnut + 25 kg P ha^{-1}	1459	3.3	0.45	48.0	6.6
1	9.Groundnut	2650	3.3	0.47	87.2	12.3
2	1.Medium duration pigeon pea + Groundnut	2530	3.1	0.41	77.6	10.5
2	3.Groundnut + 25 kg P ha^{-1}	1467	3.3	0.40	48.2	5.8
2	5.Long duration pigeon pea + Groundnut	1467	3.1	0.44	45.0	6.5
2	7.Long duration pigeon pea + Groundnut + 25 kg P ha^{-1}	1456	2.8	0.45	41.4	6.6
2	8.Medium duration pigeon pea + Groundnut + 25 kg P ha^{-1}	1826	3.1	0.36	56.0	6.6
2	9.Groundnut	1041	3.1	0.47	31.9	4.9
3	1.Medium duration pigeon pea + Groundnut	1255	2.8	0.42	35.7	5.3
3	3.Groundnut + 25 kg P ha^{-1}	3979	2.4	0.40	97.3	15.9
3	5.Long duration pigeon pea + Groundnut	1506	2.8	0.41	42.8	6.1
3	7.Long duration pigeon pea + Groundnut + 25 kg P ha^{-1}	1625	3.1	0.44	49.8	7.1
3	8.Medium duration pigeon pea + Groundnut + 25 kg P ha^{-1}	1677	3.3	0.44	55.2	7.4
3	9.Groundnut	-	-	-	-	-

Appendix 5.0d: Yield parameters for groundnut in the parallel experiment, season two

REP	Treatment	Grain yield ha^{-1}	Haulms yield ha^{-1}	Ave. No of pods $plant^{-1}$	Popu	100 gn Wt g	Shells 100 g	Pods 100 g
1	9.Groundnut	2650	1872	24	16	131	38	167
1	3.Groundnut + 25 kg P ha^{-1}	3629	2410	45	17	65	37	167
1	5.Pigeon pea long duration + Groundnut	1567	1428	19	16	124	36	160
1	7.Pigeon pea long duration + Groundnut + 25 kg P ha^{-1}	2074	1813	27	15	125	34	159
1	1.Pigeon pea medium duration + Groundnut	1721	1530	22	14	135	35	170
1	8.Pigeon pea medium duration + Groundnut + 25 kg P ha^{-1}	1459	1108	21	17	128	22	150
2	8.Pigeon pea medium duration + Groundnut + 25 kg P ha^{-1}	1826	1778	23	11	116	32	147
2	1.Pigeon pea medium duration + Groundnut	2530	1647	17	15	123	39	162
2	7.Pigeon pea long duration + Groundnut + 25 kg P ha^{-1}	1456	2010	25	13	115	32	147

REP	Treatment	Grain yield ha^{-1}	Haulms yield ha^{-1}	Ave. No of pods $plant^{-1}$	Popu	100 gn Wt g	Shells 100 g	Pods 100 g
2	3.Groundnut + 25 kg P ha^{-1}	1467	1076	20	20	132	40	172
2	9.Groundnut	1041	1486	24	14	136	37	172
3	1.Pigeon pea medium duration + Groundnut	1255	1370	19	17	120	34	154
3	6.Pigeon pea medium duration + 25 kg P ha^{-1}	1235	1319	34	18	147	39	154
3	5.Pigeon pea long duration + Groundnut	1506	1261	21	16	111	34	145
3	3.Groundnut + 25 kg P ha^{-1}	3979	3904	20	13	108	36	144
3	8.Pigeon pea medium duration + Groundnut + 25 kg P ha^{-1}	1677	1351	13	15	122	31	145
3	7.Pigeon pea long duration + Groundnut + 25 kg P ha^{-1}	1625	1359	22	14	132	37	169

Appendix 5.1a: N and P yield in pigeon pea litter parallel experiment, season two

REP	Treatment	DL kg ha^{-1}	N(%)	P(%)	N Yield ha^{-1}	P Yield ha^{-1}
1	1.Medium duration pigeon pea + Groundnut	620	2.2	0.09	13.5	0.5
1	2.Long duration pigeon pea + 25 kg P ha^{-1}	519	2.0	0.07	10.1	0.4
1	4.Medium duration pigeon pea	544	2.0	0.09	10.8	0.5
1	5.Long duration pigeon pea + Groundnut	540	2.0	0.09	10.7	0.5
1	6.Medium duration pigeon pea + 25 kg P ha^{-1}	889	2.2	0.08	19.4	0.7
1	7.Long duration pigeon pea + Groundnut + 25 kg P ha^{-1}	459	2.4	0.07	11.0	0.3
1	8.Medium duration pigeon pea + Groundnut + 25 kg P ha^{-1}	770	2.1	0.07	16.1	0.5
1	10.Long duration pigeon pea	593	2.0	0.09	11.6	0.5
2	1.Medium duration pigeon pea + Groundnut	607	2.2	0.07	13.3	0.4
2	2.Long duration pigeon pea + 25 kg P ha^{-1}	593	2.0	0.07	11.6	0.4
2	4.Medium duration pigeon pea	741	2.0	0.07	14.5	0.5
2	5.Long duration pigeon pea + Groundnut	637	2.4	0.07	15.2	0.4
2	6.Medium duration pigeon pea + 25 kg P ha^{-1}	681	2.0	0.07	13.3	0.4
2	7.Long duration pigeon pea + Groundnut + 25 kg P ha^{-1}	593	2.4	0.07	14.1	0.4

REP	Treatment	DL kg ha^{-1}	N(%)	P(%)	N Yield ha^{-1}	P Yield ha^{-1}
2	8.Medium duration pigeon pea + Groundnut + 25 kg P ha^{-1}	489	2.1	0.07	10.2	0.4
2	10.Long duration pigeon pea	519	2.0	0.07	10.5	0.3
3	1.Medium duration pigeon pea + Groundnut	770	2.2	0.09	16.8	0.7
3	2.Long duration pigeon pea + 25 kg P ha^{-1}	696	2.8	0.09	19.5	0.6
3	4.Medium duration pigeon pea	889	2.2	0.04	19.4	0.4
3	5.Long duration pigeon pea + Groundnut	533	2.0	0.09	10.6	0.5
3	6.Medium duration pigeon pea + 25 kg P ha^{-1}	919	2.2	0.04	20.1	0.4
3	7.Long duration pigeon pea + Groundnut + 25 kg P ha^{-1}	919	3.0	0.08	27.6	0.7
3	8.Medium duration pigeon pea + Groundnut + 25 kg P ha^{-1}	770	3.0	0.08	23.1	0.6
3	10.Long duration pigeon pea	830	3.0	0.07	24.9	0.6

Appendix 5.1b: N and P yield in pigeon pea fresh leaves parallel experiment, season two

Rep.	Treatments	FL kg ha^{-1}	N(%)	P(%)	N Yield ha^{-1}	P Yield ha^{-1}
1	1.Medium duration pigeon pea + Groundnut	919	3.6	0.18	33.2	1.6
1	2.Long duration pigeon pea + 25 kg P ha^{-1}	741	3.4	0.18	25.2	1.3
1	4.Medium duration pigeon pea	785	3.7	0.67	29.1	5.3
1	5.Long duration pigeon pea + Groundnut	889	3.2	0.21	28.5	1.8
1	6.Medium duration pigeon pea + 25 kg P ha^{-1}	904	3.4	0.19	30.8	1.8
1	7.Long duration pigeon pea + Groundnut + 25 kg P ha^{-1}	933	3.4	0.22	31.8	2.0
1	8.Medium duration pigeon pea + Groundnut + 25 kg P ha^{-1}	948	3.7	0.60	35.2	5.7
1	10.Long duration pigeon pea	889	3.6	0.27	32.1	2.4
2	1.Medium duration pigeon pea + Groundnut	963	4.0	0.26	38.7	2.5
2	2.Long duration pigeon pea + 25 kg P ha^{-1}	889	3.6	0.19	32.1	1.7
2	4.Medium duration pigeon pea	978	3.3	0.53	32.3	5.2
2	5.Long duration pigeon pea + Groundnut	815	2.6	0.20	21.1	1.7
2	6.Medium duration pigeon pea + 25 kg P ha^{-1}	889	3.2	0.67	28.8	5.9
2	7.Long duration pigeon pea + Groundnut + 25 kg P ha^{-1}	904	3.2	0.22	29.0	2.0
2	8.Medium duration pigeon pea + Groundnut + 25 kg P ha^{-1}	993	3.8	0.22	37.9	2.1
2	10.Long duration pigeon pea	741	2.8	0.26	20.7	1.9
3	1.Medium duration pigeon pea + Groundnut	948	3.4	0.17	32.3	1.6
3	2.Long duration pigeon pea + 25 kg P ha^{-1}	741	3.6	0.19	26.8	1.4
3	4.Medium duration pigeon pea	963	3.5	0.60	33.8	5.8

Appendix 5.1c: N and P yield in pigeon pea twigs parallel experiment, season two

Rep.	Treatments	Twig kg ha^{-1}	N(%)	P(%)	N Yield ha^{-1}	P Yield ha^{-1}
1	1.Medium duration pigeon pea + Groundnut	859	3.0	0.11	25.8	0.9
1	2.Long duration pigeon pea + 25 kg P ha^{-1}	667	2.6	0.33	17.5	2.2
1	4.Medium duration pigeon pea	637	3.2	0.19	20.4	1.2
1	5.Long duration pigeon pea + Groundnut	593	3.2	0.15	19.0	0.9
1	6.Medium duration pigeon pea + 25 kg P ha^{-1}	889	3.0	0.21	26.7	1.9
1	7.Long duration pigeon pea + Groundnut + 25 kg P ha^{-1}	622	3.4	0.17	21.2	1.1
1	8.Medium duration pigeon pea + Groundnut + 25 kg P ha^{-1}	830	2.3	0.33	19.0	2.7
1	10.Long duration pigeon pea	889	2.0	0.11	17.6	1.0
2	1.Medium duration pigeon pea + Groundnut	800	3.2	0.15	25.6	1.2
2	2.Long duration pigeon pea + 25 kg P ha^{-1}	593	3.6	0.25	21.4	1.5
2	4.Medium duration pigeon pea	904	2.2	0.33	19.5	3.0
2	5.Long duration pigeon pea + Groundnut	622	3.0	0.14	18.7	0.9
2	6.Medium duration pigeon pea + 25 kg P ha^{-1}	874	2.1	0.33	18.2	2.9
2	7.Long duration pigeon pea + Groundnut + 25 kg P ha^{-1}	593	3.0	0.15	17.8	0.9
2	8.Medium duration pigeon pea + Groundnut + 25 kg P ha^{-1}	785	3.0	0.12	23.6	1.0
2	10.Long duration pigeon pea	607	2.4	0.14	14.5	0.8
3	1.Medium duration pigeon pea + Groundnut	770	3.0	0.13	23.1	1.0
3	2.Long duration pigeon pea + 25 kg P ha^{-1}	741	3.8	0.26	28.3	1.9

Appendix 5.1d: N and P yield in pigeon pea stems parallel experiment, season two

Rep.	Treatments	Stems kg ha^{-1}	N(%)	P(%0	N Yield ha^{-1}	P Yield ha^{-1}
1	1.Medium duration pigeon pea + Groundnut	667	1.8	0.11	12.1	0.7
1	2.Long duration pigeon pea + 25 kg P ha^{-1}	1037	1.6	0.15	16.7	1.6
1	4.Medium duration pigeon pea	593	1.6	0.15	9.6	0.9
1	5.Long duration pigeon pea + Groundnut	444	1.8	0.10	7.9	0.5
1	6.Medium duration pigeon pea + 25 kg P ha^{-1}	1037	2.0	0.16	21.0	1.7
1	7.Long duration pigeon pea + Groundnut + 25 kg P ha^{-1}	667	2.0	0.11	13.2	0.8
1	8.Medium duration pigeon pea + Groundnut + 25 kg P ha^{-1}	1037	2.0	0.13	20.3	1.3
1	10.Long duration pigeon pea	622	2.4	0.14	14.9	0.9
2	1.Medium duration pigeon pea + Groundnut	993	2.4	0.09	23.7	0.9
2	2.Long duration pigeon pea + 25 kg P ha^{-1}	489	1.6	0.10	7.7	0.5
2	4.Medium duration pigeon pea	978	2.0	0.12	19.1	1.2
2	5.Long duration pigeon pea + Groundnut	563	1.6	0.10	8.8	0.5
2	6.Medium duration pigeon pea + 25 kg P ha^{-1}	1037	1.8	0.15	18.8	1.6
2	7.Long duration pigeon pea + Groundnut + 25 kg P ha^{-1}	593	2.4	0.14	14.1	0.8
2	8.Medium duration pigeon pea + Groundnut + 25 kg P ha^{-1}	1007	2.2	0.11	22.0	1.1
2	10.Long duration pigeon pea	607	2.0	0.12	12.0	0.7
3	1.Medium duration pigeon pea + Groundnut	711	1.8	0.11	12.4	0.8

Rep.	Treatments	Stems kg ha^{-1}	N(%)	P(%)	N Yield ha^{-1}	P Yield ha^{-1}
3	2.Long duration pigeon pea + 25 kg P ha^{-1}	741	2.6	0.15	19.2	1.1
3	4.Medium duration pigeon pea	593	2.4	0.11	14.1	0.7
3	5.Long duration pigeon pea + Groundnut	756	1.4	0.10	10.3	0.8
3	6.Medium duration pigeon pea + 25 kg P ha^{-1}	667	1.9	0.14	12.6	0.9
3	7.Long duration pigeon pea + Groundnut + 25 kg P ha^{-1}	889	2.8	0.12	24.9	1.1
3	8.Medium duration pigeon pea + Groundnut + 25 kg P ha^{-1}	800	2.4	0.11	19.1	0.9
3	10.Long duration pigeon pea	978	2.4	0.09	23.3	0.9

Appendix 5.1e: N and P yield in pigeon pea roots parallel experiment, season two

Rep	Treatments	Roots kg ha^{-1}	N(%)	P(%)	N Yield ha^{-1}	P Yield ha^{-1}
1	1.Medium duration pigeon pea + Groundnut	474	1.3	0.07	6.0	0.3
1	2.Long duration pigeon pea + 25 kg P ha^{-1}	519	1.0	0.07	5.4	0.3
1	4.Medium duration pigeon pea	548	1.1	0.10	6.3	0.5
1	5.Long duration pigeon pea + Groundnut	533	1.51	0.11	8.0	0.6
1	6.Medium duration pigeon pea + 25 kg P ha^{-1}	593	1.1	0.08	6.8	0.5
1	7.Long duration pigeon pea + Groundnut + 25 kg P ha^{-1}	622	1.16	0.07	7.2	0.4
1	8.Medium duration pigeon pea + Groundnut + 25 kg P ha^{-1}	444	1.4	0.06	6.1	0.3
1	10.Long duration pigeon pea	415	1.51	0.08	6.3	0.3
2	1.Medium duration pigeon pea + Groundnut	652	1.5	0.06	9.7	0.4
2	2.Long duration pigeon pea + 25 kg P ha^{-1}	415	1.16	0.07	4.8	0.3
2	4.Medium duration pigeon pea	637	0.8	0.07	5.1	0.5
2	5.Long duration pigeon pea + Groundnut	459	1.16	0.07	5.3	0.3
2	6.Medium duration pigeon pea + 25 kg P ha^{-1}	607	0.9	0.05	5.6	0.3
2	7.Long duration pigeon pea + Groundnut + 25 kg P ha^{-1}	533	0.98	0.08	5.2	0.4
2	8.Medium duration pigeon pea + Groundnut + 25 kg P ha^{-1}	519	1.6	0.07	8.3	0.4
2	10.Long duration pigeon pea	593	1.68	0.09	10.0	0.5
3	1.Medium duration pigeon pea + Groundnut	593	1.0	0.81	6.1	4.8

Rep.	Treatments	Roots kg ha^{-1}	N(%)	P(%)	N Yield ha^{-1}	P Yield ha^{-1}
3	2.Long duration pigeon pea + 25 kg P ha^{-1}	593	1.33	0.07	7.9	0.4
3	4.Medium duration pigeon pea	607	0.9	0.08	5.6	0.5
3	5.Long duration pigeon pea + Groundnut	607	1.16	0.07	7.0	0.4
3	6.Medium duration pigeon pea + 25 kg P ha^{-1}	622	1.0	0.06	6.4	0.4
3	7.Long duration pigeon pea + Groundnut + 25 kg P ha^{-1}	652	0.98	0.06	6.4	0.4
3	8.Medium duration pigeon pea + Groundnut + 25 kg P ha^{-1}	578	1.16	0.05	6.7	0.3
3	10.Long duration pigeon pea	563	1.51	0.08	8.5	0.5

Appendix 6.0: Nutrient uptake, groundnut at flowering parallel experiment season two

Rep	Treatment	N(%)	P(%)
1	7.Long duration pigeon pea + groundnut + 25 kg P ha^{-1}	3.7	1.34
1	9.Groundnut only	4.3	1.41
1	1.Medium duration pigeon pea + groundnut	4.5	1.55
1	5.Long duration pigeon pea + groundnut	3.8	1.48
1	3.Groundnut + 25 kg P ha^{-1}	3.2	1.28
1	8.Medium duration pigeon pea + groundnut + 25 kg P ha^{-1}	4.4	1.48
2	9.Groundnut only	2.8	1.28
2	9.Long duration pigeon pea + groundnut + 25 kg P ha^{-1}	4.5	1.48
2	3.Groundnut + 25 kg P ha^{-1}	4.2	1.34
2	5.Long duration pigeon pea + groundnut	4.3	1.41
2	1.Medium duration pigeon pea + groundnut	4.0	1.34
2	8.Medium duration pigeon pea + groundnut + 25 kg P ha^{-1}	4.5	1.48
3	9.Groundnut only	3.5	1.34
3	3.Groundnut + 25 kg P ha^{-1}	3.6	1.31
3	8.Medium duration pigeon pea duration + 25 kg P ha^{-1}	3.6	1.28
3	5.Long duration pigeon pea + groundnut	3.7	1.48
3	7.Long duration pigeon pea + groundnut + 25 kg P ha^{-1}	3.6	1.28
3	8.Medium duration pigeon pea + groundnut + 25 kg P ha^{-1}	4.0	1.48

Appendix 6.1: Nutrient uptake, pigeon pea at flowering parallel experiment season two

Rep	Treatments	N(%)	P(%)
1	10.long duration pigeon pea	4.0	0.29
1	2.long duration pigeon pea + 25 kg P ha^{-1}	3.3	0.31
1	7.long duration pigeon pea + groundnut	3.4	0.31
1	1.medium duration pigeon pea + groundnut	2.9	0.31
1	4.medium duration pigeon pea	3.4	0.29
1	8.medium duration pigeon pea + groundnut	3.4	0.27
2	7.long duration pigeon pea + groundnut	3.1	0.23
2	5.long duration pigeon pea + groundnut	3.2	0.32
2	6.medium duration pigeon pea + 25 kg P ha^{-1}	3.8	0.32
2	4.medium duration pigeon pea	3.6	0.29
2	2.long duration pigeon pea + 25 kg P ha^{-1}	4.0	0.29
2	10.long duration pigeon pea	4.0	0.30
3	5.long duration pigeon pea + groundnut	3.4	0.28
3	10.long duration pigeon pea	4.1	0.34
3	2.long duration pigeon pea + 25 kg P ha^{-1}	3.8	0.31
3	4.medium duration pigeon pea	2.2	0.21
3	8.medium duration pigeon pea + groundnut	2.6	0.27
3	7.long duration pigeon pea + groundnut	2.6	0.28

Appendix 6.2a: N and P uptake by the maize plants at silking stage

Rep	Plot	Sub plot	Treatment	N(%)	P(%)
1	1	1	17.Medium duration pigeon pea + Groundnut-biomass	1.2	0.20
1	1	2	20.Medium duration pigeon pea + Groundnut-biomass + 50 kg N ha^{-1}	2.3	0.24
1	1	3	18.Medium duration pigeon pea + Groundnut-biomass + 100 kg N ha^{-1}	2.7	0.26
1	1	4	19.Medium duration pigeon pea + Groundnut-biomass + 150 kg N ha^{-1}	2.8	0.27
1	2	1	5.Medium duration pigeon pea-biomass	1.4	0.26
1	2	2	8.Medium duration pigeon pea-biomass + 50 kg N ha^{-1}	1.4	0.27
1	2	3	6.Medium duration pigeon pea-biomass + 100 kg N ha^{-1}	2.6	0.23
1	2	4	7.Medium duration pigeon pea-biomass + 150 kg N ha^{-1}	2.7	0.20
1	3	1	1.Sole maize-no biomass	1.6	0.26
1	3	2	4.Sole maize-no biomass + 50 kg N ha^{-1}	2.1	0.31
1	3	3	2.Sole maize-no biomass + 100 kg N ha^{-1}	2.3	0.34
1	3	4	3.Sole maize-no biomass + 150 kg N ha^{-1}	2.5	0.33
1	4	1	9.Long duration pigeon pea-biomass	2.0	0.21

Rep	Plot	Sub plot	Treatment	N(%)	P(%)
1	4	2	12.Long duration pigeon pea-biomass + 50 kg N ha^{-1}	2.1	0.25
1	4	3	10.Long duration pigeon pea-biomass + 100 kg N ha^{-1}	2.4	0.28
1	4	4	11.Long duration pigeon pea-biomass + 150 kg N ha^{-1}	2.5	0.30
1	5	1	13.Sole groundnut-biomass	0.4	0.09
1	5	2	16.Sole groundnut-biomass + 50 kg N ha^{-1}	1.0	0.12
1	5	3	14.Sole groundnut-biomass + 100 kg N ha^{-1}	2.3	0.09
1	5	4	15.Sole groundnut-biomass + 150 kg N ha^{-1}	2.3	0.23
1	6	1	29.Long duration pigeon pea + Groundnut-no biomass	1.4	0.18
1	6	2	32.Long duration pigeon pea + Groundnut-no biomass + 50 kg N ha^{-1}	1.8	0.21
1	6	3	30.Long duration pigeon pea + Groundnut-no biomass + 100 kg N ha^{-1}	2.2	0.19
1	6	4	31.Long duration pigeon pea + Groundnut-no biomass + 150 kg N ha^{-1}	2.5	0.19
1	7	1	25.Medium duration pigeon pea + Groundnut-no biomass	1.2	0.18
1	7	2	28.Medium duration pigeon pea + Groundnut-no biomass + 50 kg N ha^{-1}	1.7	0.25
1	7	3	26.Medium duration pigeon pea + Groundnut-no biomass + 100 kg N ha^{-1}	2.1	0.26
1	7	4	27.Medium duration pigeon pea + Groundnut-no biomass + 150 kg N ha^{-1}	2.5	0.29
1	8	1	21.Long duration pigeon pea + Groundnut-biomass	2.3	0.20
1	8	2	24.Long duration pigeon pea + Groundnut-biomass + 50 kg N ha^{-1}	2.5	0.22
1	8	3	22.Long duration pigeon pea + Groundnut-biomass + 100 kg N ha^{-1}	2.6	0.21

Rep	Plot	Sub plot	Treatment	N(%)	P(%)
1	8	4	23.Long duration pigeon pea + Groundnut-biomass + 150 kg N ha^{-1}	2.7	0.25
2	1	1	29.Long duration pigeon pea + Groundnut-no biomass	2.0	0.34
2	1	2	32.Long duration pigeon pea + Groundnut-no biomass + 50 kg N ha^{-1}	2.2	0.39
2	1	3	30.Long duration pigeon pea + Groundnut-no biomass + 100 kg N ha^{-1}	2.3	0.31
2	1	4	31.Long duration pigeon pea + Groundnut-no biomass + 150 kg N ha^{-1}	2.8	0.37
2	2	1	1.Sole maize-no biomass	1.7	0.29
2	2	2	4.Sole Maize-no biomass + 50 kg N ha^{-1}	2.0	0.30
2	2	3	2.Sole maize-no biomass + 100 kg N ha^{-1}	2.2	0.33
2	2	4	3.Sole maize-no biomass + 150 kg N ha^{-1}	2.3	0.31
2	3	1	5.Medium duration pigeon pea-biomass	1.8	0.39
2	3	2	8.Medium duration pigeon pea-biomass + 50 kg N ha^{-1}	1.8	0.40
2	3	3	6.Medium duration pigeon pea-biomass + 100 kg N ha^{-1}	2.6	0.31
2	3	4	7.Medium duration pigeon pea-biomass + 150 kg N ha^{-1}	2.9	0.28
2	4	1	21.Long duration pigeon pea + Groundnut-biomass	1.5	0.37
2	4	2	24.Long duration pigeon pea + Groundnut-biomass + 50 kg N ha^{-1}	1.7	0.35
2	4	3	22.Long duration pigeon pea + Groundnut-biomass + 100 kg N ha^{-1}	2.2	0.34
2	4	4	23.Long duration pigeon pea + Groundnut-biomass + 150 kg N ha^{-1}	2.4	0.29
2	5	1	13.Sole groundnut-biomass	1.3	0.28
2	5	2	16.Sole groundnut-biomass + 50 kg N ha^{-1}	1.8	0.30
2	5	3	14.Sole groundnut-biomass + 100 kg N ha^{-1}	2.0	0.30
2	5	4	15.Sole groundnut-biomass + 150 kg N ha^{-1}	2.4	0.31
2	6	1	9.Long duration pigeon pea-biomass	0.8	0.34

Rep	Plot	Sub plot	Treatment	N(%)	P(%)
2	6	2	12.Long duration pigeon pea-biomass + 50 kg N ha^{-1}	1.5	0.29
2	6	3	10.Long duration pigeon pea-biomass + 100 kg N ha^{-1}	1.9	0.29
2	6	4	11.Long duration pigeon pea-biomass + 150 kg N ha^{-1}	3.4	0.30
2	7	1	17.Medium duration pigeon pea + Groundnut-biomass	1.3	0.30
2	7	2	20.Medium duration pigeon pea + Groundnut-biomass + 50 kg N ha^{-1}	1.9	0.24
2	7	3	18.Medium duration pigeon pea + Groundnut-biomass + 100 kg N ha^{-1}	2.2	0.34
2	7	4	19.Medium duration pigeon pea + Groundnut-biomass + 150 kg N ha^{-1}	2.6	0.31
2	8	1	25.Medium duration pigeon pea + Groundnut-no biomass	1.3	0.29
2	8	2	28.Medium duration pigeon pea + Groundnut-no biomass + 50 kg N ha^{-1}	1.6	0.21
2	8	3	26.Medium duration pigeon pea + Groundnut-no biomass + 100 kg N ha^{-1}	1.3	0.23
2	8	4	27.Medium duration pigeon pea + Groundnut-no biomass + 150 kg N ha^{-1}	2.9	0.23
3	1	1	21.Long duration pigeon pea + Groundnut-biomass	2.7	0.25
3	1	2	24.Long duration pigeon pea + Groundnut-biomass + 50 kg N ha^{-1}	2.4	0.22
3	1	3	22.Long duration pigeon pea + Groundnut-biomass + 100 kg N ha^{-1}	2.5	0.20
3	1	4	23.Long duration pigeon pea + Groundnut-biomass + 150 kg N ha^{-1}	2.1	0.23
3	2	1	9.Long duration pigeon pea-biomass	1.4	0.22
3	2	2	12.Long duration pigeon pea-biomass + 50 kg N ha^{-1}	1.9	0.21
3	2	3	10.Long duration pigeon pea-biomass + 100 kg N ha^{-1}	2.4	0.24
3	2	4	11.Long duration pigeon pea-biomass + 150 kg N ha^{-1}	2.7	0.10
3	3	1	13.Sole groundnut-biomass	0.5	0.08

Rep	Plot	Sub plot	Treatment	N(%)	P(%)
3	3	2	16.Sole groundnut-biomass + 50 kg N ha^{-1}	0.9	0.11
3	3	3	14.Sole groundnut-biomass + 100 kg N ha^{-1}	2.3	0.09
3	3	4	15.Sole groundnut-biomass + 150 kg N ha^{-1}	2.7	0.22
3	4	1	5.Medium duration pigeon pea-biomass	1.5	0.27
3	4	2	8.Medium duration pigeon pea-biomass + 50 kg N ha^{-1}	1.7	0.27
3	4	3	6.Medium duration pigeon pea-biomass + 100 kg N ha^{-1}	2.2	0.22
3	4	4	7.Medium duration pigeon pea-biomass + 150 kg N ha^{-1}	3.1	0.19
3	5	1	1.Sole maize-no biomass	2.7	0.29
3	5	2	4.Sole maize-no biomass + 50 kg N ha^{-1}	2.1	0.30
3	5	3	2.Sole maize-no biomass + 100 kg N ha^{-1}	2.5	0.29
3	5	4	3.Sole maize-no biomass + 150 kg N ha^{-1}	3.1	0.22
3	6	1	29.Long duration pigeon pea + Groundnut-no biomass	1.4	0.20
3	6	2	32.Long duration pigeon pea + Groundnut-no biomass + 50 kg N ha^{-1}	1.7	0.19
3	6	3	30.Long duration pigeon pea + Groundnut-no biomass + 100 kg N ha^{-1}	2.5	0.18
3	6	4	31.Long duration pigeon pea + Groundnut-no biomass + 150 kg N ha^{-1}	2.7	0.19
3	7	1	17.Medium duration pigeon pea + Groundnut-biomass	1.3	0.19
3	7	2	20.Medium duration pigeon pea + Groundnut-biomass + 50 kg N ha^{-1}	1.9	0.26
3	7	3	18.Medium duration pigeon pea + Groundnut-biomass + 100 kg N ha^{-1}	2.2	0.25

Rep	Plot	Sub plot	Treatment	N(%)	P(%)
3	8	1	25.Medium duration pigeon pea + Groundnut-no biomass	1.9	0.26
3	8	2	28.Medium duration pigeon pea + Groundnut-no biomass + 50 kg N ha^{-1}	2.1	0.24
3	8	3	26.Medium duration pigeon pea + Groundnut-no biomass + 100 kg N ha^{-1}	2.2	0.22
3	8	4	27.Medium duration pigeon pea + Groundnut-no biomass + 150 kg N ha^{-1}	2.7	0.19

Appendix 6.2c: Stover yield, main experiment season two

Rep No.	Plot No.	Treatment	Maize Population	Stover Wt (kg)	Adj. Stover Wt (kg)	Stover Wt ha^{-1}
1	3	1.Sole maize-no biomass	18	0.8	0.9	1481
1	2	2.Medium duration pigeon pea-biomass	21	1	1.0	1587
1	4	3.Long duration pigeon pea-biomass	22	1.8	1.6	2727
1	5	4.Sole groundnut-biomass	19	2.2	2.3	3860
1	1	5.Medium duration pigeon pea + Groundnut-biomass	21	2.6	2.5	4127
1	8	6.Long duration pigeon pea + Groundnut-biomass	18	2	2.2	3704
1	7	7.Medium duration pigeon pea + Groundnut-no biomass	22	1.6	1.5	2424
1	6	8.Long duration pigeon pea + Groundnut-no biomass	20	1.6	1.6	2667
2	2	1.Sole maize-no biomass	20	1.2	1.2	2000
2	3	2.Medium duration pigeon pea-biomass	24	0.6	0.5	833
2	6	3.Long duration pigeon pea-biomass	22	1	0.9	1515
2	5	4.Sole groundnut-biomass	20	1	1.0	1667
2	7	5.Medium duration pigeon pea + Groundnut-biomass	19	1	1.1	1754
2	4	6.Long duration pigeon pea + Groundnut-biomass	20	0.2	0.2	333
2	8	7.Medium duration pigeon pea + Groundnut-no biomass	20	1.2	1.2	2000
2	1	8.Long duration pigeon pea + Groundnut-no biomass	20	1	1.0	1667
3	5	1.Sole maize-no biomass	21	2.1	2.0	3333
3	4	2.Medium duration pigeon pea-biomass	20	2.2	2.2	3667

Rep.	Plot No.	Treatments	Maize Population	Stover Wt (kg)	Adj. Stover Wt (kg)	Stover Wt ha^{-1}
3	2	3.Long duration pigeon pea-biomass	21	2.8	2.7	4444
3	3	4.Sole groundnut-biomass	24	2.1	1.8	2917
3	7	5.Medium duration pigeon pea + Groundnut-biomass	23	2.2	1.9	3188
3	1	6.Long duration pigeon pea + Groundnut-biomass	20	1.5	1.5	2500
3	8	7.Medium duration pigeon Pea + Groundnut-no biomass	23	2.2	1.9	3188
3	6	8.Long duration pigeon pea + Groundnut-no biomass	23	2.3	2.0	3333
1	3	1.Sole maize-no biomass + 50 kg N ha^{-1}	20	1.6	1.6	2667
1	2	2.Medium duration pigeon pea-biomass + 50 kg N ha^{-1}	20	1.4	1.4	2333
1	4	3.Long duration pigeon pea-biomass + 50 kg N ha^{-1}	18	2.8	3.1	5185
1	5	4.Sole groundnut-biomass + 50 kg N ha^{-1}	20	1.8	1.8	3000
1	1	5.Medium duration pigeon pea + Groundnut-biomass + 50 kg N ha^{-1}	19	3	3.2	5263
1	8	6.Long duration pigeon pea + Groundnut-biomass + 50 kg N ha^{-1}	22	3.8	3.5	5758
1	7	7.Medium duration pigeon pea + Groundnut-no biomass + 50 kg N ha^{-1}	20	1.8	1.8	3000
1	6	8.Long duration pigeon pea + Groundnut-no biomass + 50 kg N ha^{-1}	22	1.6	1.5	2424
2	2	1.Sole maize-no biomass + 50 kg N ha^{-1}	21	1.2	1.1	1905
2	3	2.Medium duration pigeon pea-biomass + 50 kg N ha^{-1}	24	3.2	2.7	4444

Rep.	Plot No.	Treatments	Maize Population	Stover Wt (kg)	Adj. Stover Wt (kg)	Stover Wt ha^{-1}
2	6	3.Long duration pigeon pea-biomass + 50 kg N ha^{-1}	23	2.2	1.9	3188
2	7	5.Medium duration pigeon pea + Groundnut-biomass + 50 kg N ha^{-1}	19	1.4	1.5	2456
2	4	6.Long duration pigeon pea + Groundnut-biomass + 50 kg N ha^{-1}	12	1	1.7	2778
2	8	7.Medium duration pigeon pea + Groundnut-no biomass + 50 kg N ha^{-1}	15	1.6	2.1	3556
2	1	8.Long duration pigeon pea + Groundnut-no biomass + 50 kg N ha^{-1}	33	1.6	1.0	1616
3	5	1.Sole maize-no biomass + 50 kg N ha^{-1}	23	2.2	1.9	3188
3	4	2.Medium duration pigeon pea-biomass + 50 kg N ha^{-1}	25	2.4	1.9	3200
3	2	3.Long duration pigeon pea-biomass + 50 kg N ha^{-1}	26	2.2	1.7	2821
3	3	4.Sole groundnut-biomass + 50 kg N ha^{-1}	20	1.8	1.8	3000
3	7	5.Medium duration pigeon pea + Groundnut-biomass + 50 kg N ha^{-1}	26	2.6	2.0	3333
3	1	6.Long duration pigeon pea + Groundnut-biomass + 50 kg N ha^{-1}	17	1.8	2.1	3529
3	8	7.Medium duration pigeon pea + Groundnut-no biomass + 50 kg N ha^{-1}	24	2.1	1.8	2917

Rep.	Plot No.	Treatments	Maize Population	Stover Wt (kg)	Adj. Stover Wt (kg)	Stover Wt ha^{-1}
3	6	8.Long duration pigeon pea + Groundnut-no biomass + 50 kg N ha^{-1}	21	2.5	2.4	3968
1	3	1.Sole maize-no biomass + 100 kg N ha^{-1}	23	1.5	1.3	2174
1	2	2.Medium duration pigeon pea-biomass + 100 kg N ha^{-1}	23	2	1.7	2899
1	4	3.Long duration pigeon pea-biomass + 100 kg N ha^{-1}	23	2.6	2.3	3768
1	5	4.Sole groundnut-biomass + 100 kg N ha^{-1}	22	1.8	1.6	2727
1	1	5.Medium duration pigeon pea + Groundnut-biomass + 100 kg N ha^{-1}	18	2.4	2.7	4444
1	8	6.Long duration pigeon pea + Groundnut-biomass + 100 kg N ha^{-1}	21	3.6	3.4	5714
1	7	7.Medium duration pigeon pea + Groundnut-no biomass + 100 kg N ha^{-1}	20	1	1.0	1667
1	6	8.Long duration pigeon pea + Groundnut-no biomass + 100 kg N ha^{-1}	22	1.4	1.3	2121
2	2	1.Sole maize-no biomass + 100 kg N ha^{-1}	19	1.2	1.3	2105
2	3	2.Medium duration pigeon pea-biomass + 100 kg N ha^{-1}	25	3	2.4	4000
2	6	3.Long duration pigeon pea-biomass + 100 kg N ha^{-1}	13	1	1.5	2564

Rep.	Plot No.	Treatments	Maize Population	Stover Wt (kg)	Adj. Stover Wt (kg)	Stover Wt ha^{-1}
2	5	4.Sole groundnut-biomass + 100 kg N ha^{-1}	22	1.2	1.1	1818
2	7	5.Medium duration pigeon pea + Groundnut-biomass + 100 kg N ha^{-1}	26	2	1.5	2564
2	4	6.Long duration pigeon pea + Groundnut-biomass + 100 kg N ha^{-1}	15	1	1.3	2222
2	8	7.Medium duration pigeon pea + Groundnut-no biomass + 100 kg N ha^{-1}	25	1.8	1.4	2400
2	1	8.Long duration pigeon pea + Groundnut-no biomass + 100 kg N ha^{-1}	23	2.6	2.3	3768
3	5	1.Sole maize-no biomass + 100 kg N ha^{-1}	27	2.8	2.1	3457
3	4	2.Medium duration pigeon pea-biomass + 100 kg N ha^{-1}	22	2.1	1.9	3182
3	2	3.Long duration pigeon pea-biomass + 100 kg N ha^{-1}	19	1.9	2.0	3333
3	3	4.Sole groundnut-biomass + 100 kg N ha^{-1}	24	3.4	2.8	4722
3	7	5.Medium duration pigeon pea + Groundnut-biomass + 100 kg N ha^{-1}	23	2.6	2.3	3768
3	1	6.Long duration pigeon pea + Groundnut-biomass + 100 kg N ha^{-1}	21	2.2	2.1	3492

Rep.	Plot No.	Treatments	Maize Population	Stover Wt (kg)	Adj. Stover Wt (kg)	Stover Wt ha^{-1}
3	6	8.Long duration pigeon pea + Groundnut-no biomass + 100 kg N ha^{-1}	24	2.6	2.2	3611
1	3	1.Sole maize-no biomass + 150 kg N ha^{-1}	23	1.4	1.2	2029
1	2	2.Medium duration pigeon pea-biomass + 150 kg N ha^{-1}	24	1.6	1.3	2222
1	4	3.Long duration pigeon pea-biomass + 150 kg N ha^{-1}	21	2	1.9	3175
1	5	4.Sole groundnut-biomass + 150 kg N ha^{-1}	23	2.8	2.4	4058
1	1	5.Medium duration pigeon pea + Groundnut-biomass + 150 kg N ha^{-1}	22	2.6	2.4	3939
1	8	6.Long duration pigeon pea + Groundnut-biomass + 150 kg N ha^{-1}	24	3	2.5	4167
1	7	7.Medium duration pigeon pea + Groundnut-no biomass + 150 kg N ha^{-1}	21	1.2	1.1	1905
1	6	8.Long duration pigeon pea + Groundnut-no biomass + 150 kg N ha^{-1}	20	1	1.0	1667
2	2	1.Sole naize-no biomass + 150 kg N ha^{-1}	23	2	1.7	2899
2	3	2.Medium duration pigeon pea-biomass + 150 kg N ha^{-1}	24	1.4	1.2	1944
2	6	3.Long duration pigeon pea-biomass + 150 kg N ha^{-1}	18	1.8	2.0	3333
2	5	4.Sole groundnut-biomass + 150 kg N ha^{-1}	22	3.2	2.9	4848

Rep.	Plot No.	Treatments	Maize Population	Stover Wt (kg)	Adj. Stover Wt (kg)	Stover Wt ha^{-1}
2	7	5.Medium duration pigeon pea + Groundnut-biomass + 150 kg N ha^{-1}	14	1.4	2.0	3333
2	4	6.Long duration pigeon pea + Groundnut-biomass + 150 kg N ha^{-1}	18	0.8	0.9	1481
2	8	7.Medium duration pigeon pea + Groundnut-no biomass + 150 kg N ha^{-1}	18	1.9	2.1	3519
2	1	8.Long duration pigeon pea + Groundnut-no biomass + 150 kg N ha^{-1}	24	3.2	2.7	4444
3	5	1.Sole maize-no biomass + 150 kg N ha^{-1}	22	2.7	2.5	4091
3	4	2.Medium duration pigeon pea-biomass + 150 kg N ha^{-1}	20	2.8	2.8	4667
3	2	3.Long duration pigeon pea-biomass + 150 kg N ha^{-1}	23	2.2	1.9	3188
3	3	4.Sole groundnut-biomass + 150 kg N ha^{-1}	20	2.6	2.6	4333
3	7	5.Medium duration pigeon pea + Groundnut-biomass + 150 kg N ha^{-1}	20	3.1	3.1	5167
3	1	6.Long duration pigeon pea + Groundnut-biomass + 150 kg N ha^{-1}	20	2.2	2.2	3667
3	8	7.Medium duration pigeon pea + Groundnut-no biomass + 150 kg N ha^{-1}	20	2.7	2.7	4500

Rep.	Plot No.	Treatments	Maize Population	Maize Rachids Wt (kg)	Adj. rachids Wt (kg)	Rachids Wt kg ha^{-1}
1	3	1.Sole maize-no biomass	18	0.2	0.2	370
1	2	2.Medium duration pigeon pea-biomass	21	0.2	0.2	317
1	4	3.Long duration pigeon pea-biomass	22	0.8	0.7	1212
1	5	4.Sole groundnut-biomass	19	0.4	0.4	702
1	1	5.Medium duration pigeon pea + Groundnut-biomass	21	0.5	0.5	794
1	8	6.Long duration pigeon pea + Groundnut-biomass	18	0.3	0.3	556
1	7	7.Medium duration pigeon pea + Groundnut-no biomass	22	0.2	0.2	303
1	6	8.Long duration pigeon pea + Groundnut-no biomass	20	0.6	0.6	1000
2	2	1.Sole maize-no biomass	20	0.6	0.6	1000
2	3	2.Medium duration pigeon pea-biomass	24	1	0.8	1389
2	6	3.Long duration pigeon pea-biomass	22	0.6	0.5	909
2	5	4.Sole groundnut-biomass	20	0.4	0.4	667
2	7	5.Medium duration pigeon pea + Groundnut-biomass	19	0.2	0.2	351
2	4	6.Long duration pigeon pea + Groundnut-biomass	20	0.4	0.4	667
2	8	7.Medium duration pigeon pea + Groundnut-no biomass	20	0.2	0.2	333
2	1	8.Long duration pigeon pea + Groundnut-no biomass	20	0.2	0.2	333

Rep.	Plot No.	Treatments	Maize Population	Maize Rachids Wt (kg)	Adj. rachids Wt (kg)	Rachids Wt kg ha^{-1}
3	5	1.Sole maize-no biomass	21	0.6	0.6	952
3	4	2.Medium duration pigeon pea-biomass	20	0.8	0.8	1333
3	2	3.Long duration pigeon pea-biomass	21	0.6	0.6	952
3	3	4.Sole groundnut-biomass	24	0.4	0.3	556
3	7	5.Medium duration pigeon pea + Groundnut-biomass	23	0.6	0.5	870
3	1	6.Long duration pigeon pea + Groundnut-biomass	20	0.4	0.4	667
3	8	7.Medium duration pigeon Pea + Groundnut-no biomass	23	0.4	0.3	580
3	6	8.Long duration pigeon pea + Groundnut-no biomass	23	0.2	0.2	290
1	3	1.Sole maize-no biomass + 50 kg N ha^{-1}	20	0.4	0.4	741
1	2	2.Medium duration pigeon pea-biomass + 50 kg N ha^{-1}	20	1	1.0	1667
1	4	3.Long duration pigeon pea-biomass + 50 kg N ha^{-1}	18	0.8	0.9	1481
1	5	4.Sole groundnut-biomass + 50 kg N ha^{-1}	20	0.3	0.3	526
1	1	5.Medium duration pigeon pea + Groundnut-biomass + 50 kg N ha^{-1}	19	0.2	0.3	417
1	8	6.Long duration pigeon pea + Groundnut-biomass + 50 kg N ha^{-1}	22	0.8	0.6	1026
1	7	7.Medium duration pigeon pea + Groundnut-no biomass + 50 kg N ha^{-1}	20	0.2	0.2	317
1	6	8.Long duration pigeon pea + Groundnut-no biomass + 50 kg N ha^{-1}	22	0.6	0.6	952
2	1	1.Sole maize-no biomass + 50 kg N ha^{-1}	33	0.8	0.6	988
2	2	2.Medium duration pigeon pea-biomass + 50 kg N ha^{-1}	21	0.6	0.6	952

Rep.	Plot No.	Treatments	Maize Population	Maize Rachids Wt (kg)	Adj. rachids Wt (kg)	Rachids Wt kg ha^{-1}
2	3	3.Long duration pigeon pea-biomass + 50 kg N ha^{-1}	24	0.4	0.3	533
2	4	4.Sole groundnut-biomass + 50 kg N ha^{-1}	12	0.4	0.5	889
2	5	5.Medium duration pigeon pea + Groundnut-biomass + 50 kg N ha^{-1}	13	0.2	0.3	444
2	6	6.Long duration pigeon pea + Groundnut-biomass + 50 kg N ha^{-1}	23	0.6	0.5	909
2	7	7.Medium duration pigeon pea + Groundnut-no biomass + 50 kg N ha^{-1}	19	0.4	0.4	702
2	8	8.Long duration pigeon pea + Groundnut-no biomass + 50 kg N ha^{-1}	15	0.6	0.6	1000
3	1	1.Sole maize-no biomass + 50 kg N ha^{-1}	17	0.2	0.2	333
3	2	2.Medium duration pigeon pea-biomass + 50 kg N ha^{-1}	26	0.4	0.4	667
3	3	3.Long duration pigeon pea-biomass + 50 kg N ha^{-1}	20	0.6	0.6	1000
3	4	4.Sole groundnut-biomass + 50 kg N ha^{-1}	25	0.8	0.8	1333
3	5	5.Medium duration pigeon pea + Groundnut-biomass + 50 kg N ha^{-1}	23	0.2	0.2	290
3	6	6.Long duration pigeon pea + Groundnut-biomass + 50 kg N ha^{-1}	21	0.8	0.8	1270
3	7	7.Medium duration pigeon pea + Groundnut-no biomass + 50 kg N ha^{-1}	26	0.8	0.8	1333
3	8	8.Long duration pigeon pea + Groundnut-no biomass + 50 kg N ha^{-1}	24	0.8	0.7	1111
						926
1	1	1.Sole maize-no biomass + 100 kg N ha^{-1}	18	0.5	0.6	

Rep.	Plot No.	Treatments	Maize Population	Maize Rachids Wt (kg)	Adj. rachids Wt (kg)	Rachids Wt kg ha^{-1}
						513
1	2	2.Medium duration pigeon pea-biomass + 100 kg N ha^{-1}	23	0.4	0.3	
1	3	3.Long duration pigeon pea-biomass + 100 kg N ha^{-1}	23	0.2	0.2	333
1	4	4.Sole groundnut-biomass + 100 kg N ha^{-1}	23	0.6	0.5	870
1	5	5.Medium duration pigeon pea + Groundnut-biomass + 100 kg N ha^{-1}	22	0.4	0.3	580
1	6	6.Long duration pigeon pea + Groundnut-biomass + 100 kg N ha^{-1}	22	0.4	0.4	635
1	7	7.Medium duration pigeon pea + Groundnut-no biomass + 100 kg N ha^{-1}	20	0.6	0.6	952
1	8	8.Long duration pigeon pea + Groundnut-no biomass + 100 kg N ha^{-1}	21	0.8	0.7	1212
2	2	1.Sole maize-no biomass + 100 kg N ha^{-1}	19	0.2	0.2	370
2	3	2.Medium duration pigeon pea-biomass + 100 kg N ha^{-1}	25	1	0.7	1235
2	6	3.Long duration pigeon pea-biomass + 100 kg N ha^{-1}	13	0.4	0.6	1026
2	5	4.Sole groundnut-biomass + 100 kg N ha^{-1}	22	0.6	0.5	870
2	7	5.Medium duration pigeon pea + Groundnut-biomass + 100 kg N ha^{-1}	26	1.2	0.9	1538

Rep.	Plot No.	Treatments	Maize Population	Maize Rachids Wt (kg)	Adj. rachids Wt (kg)	Rachids Wt kg ha^{-1}
2	8	7.Medium duration pigeon pea + Groundnut-no biomass + 100 kg N ha^{-1}	25	0.6	0.5	800
2	1	8.Long duration pigeon pea + Groundnut-no biomass + 100 kg N ha^{-1}	23	0.4	0.4	635
3	5	1.Sole maize-no biomass + 100 kg N ha^{-1}	27	0.8	0.8	1333
3	4	2.Medium duration pigeon pea-biomass + 100 kg N ha^{-1}	22	0.6	0.7	1111
3	2	3.Long duration pigeon pea-biomass + 100 kg N ha^{-1}	19	0.8	0.8	1333
3	3	4.Sole groundnut-biomass + 100 kg N ha^{-1}	24	1.2	1.2	2000
3	7	5.Medium duration pigeon pea + Groundnut-biomass + 100 kg N ha^{-1}	23	0.6	0.6	1000
3	1	6.Long duration pigeon pea + Groundnut-biomass + 100 kg N ha^{-1}	21	0.6	0.6	1000
3	8	7.Medium duration pigeon pea + Groundnut-no biomass + 100 kg N ha^{-1}	21	0.6	0.6	1000
3	6	8.Long duration pigeon pea + Groundnut-no biomass + 100 kg N ha^{-1}	24	0.4	0.4	635
1	3	1.Sole maize-no biomass + 150 kg N ha^{-1}	23	0.6	0.5	870
1	2	2.Medium duration pigeon pea-biomass + 150 kg N ha^{-1}	24	0.4	0.4	606

1	4	3.Long duration pigeon pea-biomass + 150 kg N ha^{-1}	21	0.4	0.4	635
1	5	4.Sole groundnut-biomass + 150 kg N ha^{-1}	23	1	0.7	1190
1	1	5.Medium duration pigeon pea + Groundnut-biomass + 150 kg N ha^{-1}	22	0.8	0.6	988
1	8	6.Long duration pigeon pea + Groundnut-biomass + 150 kg N ha^{-1}	24	0.8	0.6	1067
1	7	7.Medium duration pigeon pea + Groundnut-no biomass + 150 kg N ha^{-1}	21	0.4	0.4	741
1	6	8.Long duration pigeon pea + Groundnut-no biomass + 150 kg N ha^{-1}	20	0.4	0.5	784
2	2	1.Sole naize-no biomass + 150 kg N ha^{-1}	23	0.6	0.5	833
2	3	2.Medium duration pigeon pea-biomass + 150 kg N ha^{-1}	24	0.8	0.6	1067
2	6	3.Long duration pigeon pea-biomass + 150 kg N ha^{-1}	18	0.6	0.7	1111
2	5	4.Sole groundnut-biomass + 150 kg N ha^{-1}	22	1	0.9	1515
2	7	5.Medium duration pigeon pea + Groundnut-biomass + 150 kg N ha^{-1}	14	0.6	0.7	1176
2	4	6.Long duration pigeon pea + Groundnut-biomass + 150 kg N ha^{-1}	18	0.4	0.4	741
2	8	7.Medium duration pigeon pea + Groundnut-no biomass + 150 kg N ha^{-1}	18	0.4	0.4	667
2	1	8.Long duration pigeon pea + Groundnut-no biomass + 150 kg N ha^{-1}	24	0.4	0.3	513

Rep.	Plot No.	Treatments	Maize Population	Maize Rachids Wt (kg)	Adj. rachids Wt (kg)	Rachids Wt kg ha^{-1}
3	5	1.Sole maize-no biomass + 150 kg N ha^{-1}	22	0.8	0.8	1333
3	4	2.Medium duration pigeon pea-biomass + 150 kg N ha^{-1}	20	0.2	0.2	333
3	2	3.Long duration pigeon pea-biomass + 150 kg N ha^{-1}	23	0.8	0.8	1333
3	3	4.Sole groundnut-biomass + 150 kg N ha^{-1}	20	0.6	0.6	1000
3	7	5.Medium duration pigeon pea + Groundnut-biomass + 150 kg N ha^{-1}	20	0.1	0.1	167
3	1	6.Long duration pigeon pea + Groundnut-biomass + 150 kg N ha^{-1}	20	0.6	0.6	1000
3	8	7.Medium duration pigeon pea + Groundnut-no biomass + 150 kg N ha^{-1}	20	0.6	0.6	1000
3	6	8.Long duration pigeon pea + Groundnut-no biomass + 150 kg N ha^{-1}	21	0.8	0.8	1270

Appendix 6.2d: Rachids yield, main experiment season twoAppendix 6.2e: Cob length, main experiment season two

Rep.	Plot No.	Treatments	Cob Length (cm)	1	2	3	4	Average Cob length (cm)
1	3	1.Sole maize-no biomass	7	8	11	15	19	13
1	2	2.Medium duration pigeon pea-biomass	7	9	11	16	20	14
1	4	3.Long duration pigeon pea-biomass	5	12	13	20	21	17
1	5	4.Sole groundnut-biomass	7	9	11	16	20	14
1	1	5.Medium duration pigeon pea + Groundnut-biomass	5	12	13	20	21	17
1	8	6.Long duration pigeon pea + Groundnut-biomass	6	10	14	17	10	13
1	7	7.Medium duration pigeon pea + Groundnut-no biomass	4	6	11	13	14	11
1	6	8.Long duration pigeon pea + Groundnut-no biomass	7	8	11	15	19	13
2	2	1.Sole maize-no biomass	11	12	16	19	22	17
2	3	2.Medium duration pigeon pea-biomass	3	8	16	17	19	15
2	6	3.Long duration pigeon pea-biomass	11	12	13	17	18	15
2	5	4.Sole groundnut-biomass	11	14	16	19	22	18
2	7	5.Medium duration pigeon pea + Groundnut-biomass	6	9	13	17	22	15
2	4	6.Long duration pigeon pea + Groundnut-biomass	5	9	11	15	18	13
2	8	7.Medium duration pigeon pea + Groundnut-no biomass	15	15	20	21	21	19

2	1	8.Long duration pigeon pea + Groundnut-no biomass	11	13	14	17	22	17
3	5	1.Sole maize-no biomass	11	14	17	22	22	19
3	4	2.Medium duration pigeon pea-biomass	10	13	18	19	19	17
3	2	3.Long duration pigeon pea-biomass	12	13	18	20	20	18
3	3	4.Sole groundnut-biomass	11	13	17	19	19	17
3	7	5.Medium duration pigeon pea + Groundnut-biomass	10	14	16	20	20	18
3	1	6.Long duration pigeon pea + Groundnut-biomass	13	16	17	19	19	18
3	8	7.Medium duration pigeon Pea + Groundnut-no biomass	14	19	20	22	22	21
3	6	8.Long duration pigeon pea + Groundnut-no biomass	12	17	18	19	19	18
1	3	1.Sole maize-no biomass + 50 kg N ha^{-1}	6	10	12	16	20	15
1	2	2.Medium duration pigeon pea-biomass + 50 kg N ha^{-1}	8	13	15	17	19	16
1	4	3.Long duration pigeon pea-biomass + 50 kg N ha^{-1}	12	14	16	19	21	18
1	5	4.Sole groundnut-biomass + 50 kg N ha^{-1}	6	8	12	15	18	13
1	1	5.Medium duration pigeon pea + Groundnut-biomass + 50 kg N ha^{-1}	11	14	15	17	20	17
1	8	6.Long duration pigeon pea + Groundnut-biomass + 50 kg N ha^{-1}	5	8	12	16	19	14
1	7	7.Medium duration pigeon pea + Groundnut-no biomass + 50 kg N ha^{-1}	5	7	9	11	14	10
1	6	8.Long duration pigeon pea + Groundnut-no biomass + 50 kg N ha^{-1}	11	13	15	17	18	16

2	2	1.Sole maize-no biomass + 50 kg N ha^{-1}	9	11	15	19	22	17
2	3	2.Medium duration pigeon pea-biomass + 50 kg N ha^{-1}	11	14	15	17	20	17
2	6	3.Long duration pigeon pea-biomass + 50 kg N ha^{-1}	11	13	15	18	21	17
2	5	4.Sole groundnut-biomass + 50 kg N ha^{-1}	6	10	12	16	20	15
2	7	5.Medium duration pigeon pea + Groundnut-biomass + 50 kg N ha^{-1}	8	12	14	18	19	16
2	4	6.Long duration pigeon pea + Groundnut-biomass + 50 kg N ha^{-1}	8	13	15	17	19	16
2	8	7.Medium duration pigeon pea + Groundnut-no biomass + 50 kg N ha^{-1}	10	14	17	18	18	17
2	1	8.Long duration pigeon pea + Groundnut-no biomass + 50 kg N ha^{-1}	9	11	16	18	20	16
3	5	1.Sole maize-no biomass + 50 kg N ha^{-1}	10	13	18	19	19	17
3	4	2.Medium duration pigeon pea-biomass + 50 kg N ha^{-1}	9	15	17	20	20	18
3	2	3.Long duration pigeon pea-biomass + 50 kg N ha^{-1}	12	15	17	18	18	17
3	3	4.Sole groundnut-biomass + 50 kg N ha^{-1}	13	16	17	20	20	18
3	7	5.Medium duration pigeon pea + Groundnut-biomass + 50 kg N ha^{-1}	12	14	15	21	21	18
3	1	6.Long duration pigeon pea + Groundnut-biomass + 50 kg N ha^{-1}	12	14	17	19	19	17

3	8	7.Medium duration pigeon pea + Groundnut-no biomass + 50 kg N ha^{-1}	13	15	16	19	19	17
3	6	8.Long duration pigeon pea + Groundnut-no biomass + 50 kg N ha^{-1}	9	14	16	19	19	17
1	3	1.Sole maize-no biomass + 100 kg N ha^{-1}	10	11	14.5	19	21	16
1	2	2.Medium duration pigeon pea-biomass + 100 kg N ha^{-1}	11	13	14	17	21	16
1	4	3.Long duration pigeon pea-biomass + 100 kg N ha^{-1}	9	10	13	17	21	15
1	5	4.Sole groundnut-biomass + 100 kg N ha^{-1}	8	12	14	18	22	17
1	1	5.Medium duration pigeon pea + Groundnut-biomass + 100 kg N ha^{-1}	6	8	15	17	21	15
1	7	7.Medium duration pigeon pea + Groundnut-no biomass + 100 kg N ha^{-1}	6	8	12	14	20	14
1	6	8.Long duration pigeon pea + Groundnut-no biomass + 100 kg N ha^{-1}	9	12	13	15	18	15
2	2	1.Sole maize-no biomass + 100 kg N ha^{-1}	11	13	14	17	21	16
2	3	2.Medium duration pigeon pea-biomass + 100 kg N ha^{-1}	10	11	14.5	19	21	16
2	6	3.Long duration pigeon pea-biomass + 100 kg N ha^{-1}	9	11	15	19	22	17
2	5	4.Sole groundnut-biomass + 100 kg N ha^{-1}	7	14	16	17	20	17
2	7	5.Medium duration pigeon pea + Groundnut-biomass + 100 kg N ha^{-1}	4	11	15	17	19	16

2	4	6.Long duration pigeon pea + Groundnut-biomass + 100 kg N ha^{-1}	7	12	13	18	21	16
2	8	7.Medium duration pigeon pea + Groundnut-no biomass + 100 kg N ha^{-1}	8	10	15	17	20	16
2	1	8.Long duration pigeon pea + Groundnut-no biomass + 100 kg N ha^{-1}	6	8	15	17	21	15
3	5	1.Sole maize-no biomass + 100 kg N ha^{-1}	10	14	16	20	20	18
3	4	2.Medium duration pigeon pea-biomass + 100 kg N ha^{-1}	10	15	18	19	19	18
3	2	3.Long duration pigeon pea-biomass + 100 kg N ha^{-1}	14	15	18	19	19	18
3	3	4.Sole groundnut-biomass + 100 kg N ha^{-1}	9	12	18	22	22	19
3	7	5.Medium duration pigeon pea + Groundnut-biomass + 100 kg N ha^{-1}	11	13	17	20	20	18
3	1	6.Long duration pigeon pea + Groundnut-biomass + 100 kg N ha^{-1}	13	14	16	21	21	18
3	8	7.Medium duration pigeon pea + Groundnut-no biomass + 100 kg N ha^{-1}	14	17	19	20	20	19
3	6	8.Long duration pigeon pea + Groundnut-no biomass + 100 kg N ha^{-1}	10	15	19	22	22	20
1	3	1.Sole maize-no biomass + 150 kg N ha^{-1}	11	13	17	20	20	18
1	2	2.Medium duration pigeon pea-biomass + 150 kg N ha^{-1}	10	15	19	22	22	20
1	4	3.Long duration pigeon pea-biomass + 150 kg N ha^{-1}	14	17	19	20	20	19
1	5	4.Sole groundnut-biomass + 150 kg N ha^{-1}	11	13	16	20	25	19
1	1	5.Medium duration pigeon pea + Groundnut-biomass	10	14	16	20	20	18

		+ 150 kg N ha^{-1}						
1	8	6.Long duration pigeon pea + Groundnut-biomass + 150 kg N ha^{-1}	6	10	13	15	20	15
1	7	7.Medium duration pigeon pea + Groundnut-no biomass + 150 kg N ha^{-1}	10	14	16	17	20	17
1	6	8.Long duration pigeon pea + Groundnut-no biomass + 150 kg N ha^{-1}	12	13	14	18	21	17
2	2	1.Sole naize-no biomass + 150 kg N ha^{-1}	11	14	16	19	22	18
2	3	2.Medium duration pigeon pea-biomass + 150 kg N ha^{-1}	12	15	17	19	21	18
2	6	3.Long duration pigeon pea-biomass + 150 kg N ha^{-1}	7	11	17	18	21	17
2	5	4.Sole groundnut-biomass + 150 kg N ha^{-1}	10	14	16	21	22	18
2	7	5.Medium duration pigeon pea + Groundnut-biomass + 150 kg N ha^{-1}	9	10	12	17	19	15
2	4	6.Long duration pigeon pea + Groundnut-biomass + 150 kg N ha^{-1}	12	14	15	15	22	17
2	8	7.Medium duration pigeon pea + Groundnut-no biomass + 150 kg N ha^{-1}	10	13	14	19	19	16
2	1	8.Long duration pigeon pea + Groundnut-no biomass + 150 kg N ha^{-1}	12	13	16	18	21	17
3	5	1.Sole maize-no biomass + 150 kg N ha^{-1}	10	14	16	19	19	17
3	2	3.Long duration pigeon pea-biomass + 150 kg N ha^{-1}	13	14	19	21	21	19
3	3	4.Sole groundnut-biomass + 150 kg N ha^{-1}	10	14	18	19	19	18

Appendix 7.0: Fertilizer calculations main and parallel experiment

TSP to legumes

P_2O_5 in TSP= 46%

Elemental P= 46 x 0 .437=20.102

100 kg contains 20 kg elemental P

to apply 25 kg P ha^{-1} requires =124.3657 kg

1 planting station of 90cm x 75cm will require

= 0.9*0.75/10000*124.3657*1000

8.4g

Fertilizer (TSP) calculations main experiment: Maize

P_2O_5 in TSP = 46% Elemental P = 46 x 0 .437 =20.102

100 kg contains 20 kg elemental P

to apply 50 kg P ha^{-1} requires =250 kg

1 planting station of 25cm x 75cm required

=0.25*0.75/10000*250*1000

4.7g

Urea

Content of N in the urea = 46%

1. **Rate to be applied = 50 kg N ha^{-1}**

   46 kg of N is contained in 100 kg of urea

   50 kg of N will be contained in

   50/46*100 kg

=108.7 kg

Amount per planting station

0.25*0.75/10000*108.7*1000g

=2g

2. **Rate to be applied = 100 kg N ha^{-1}**

   46 kg of N is contained in 100 kg of urea

   100 kg of N will be contained in

   100/46*100 kg

   =217.4 kg

Amount per planting station

0.25*0.75/10000*217.4*1000g

= 4g

3. **Rate to be applied = 150 kg N ha^{-1}**

   46 kg of N is contained in 100 kg of urea

   150 kg of N will be contained in

   150/46*100 kg

   =326.1 kg

Amount per planting station 0.25*0.75/10000*326.1*1000g **=6g**