academicJournals

Vol. 4(3), pp.54-61, June 2013
DOI 10.5897/JSSEM12.0364
ISSN 2141-2391 ©2013 Academic Journals
http://www.academicjournals.org/JSSEM

Journal of Soil Science and Environmental Management

Full Length Research Paper

Genotypic variations in phosphorus use efficiency and yield of some groundnut cultivars grown on an Alfisol at Samaru, Nigeria

A. I. Gabasawa* and A. A. Yusuf

Department of Soil Science, Faculty of Agriculture/Institute for Agricultural Research, Ahmadu Bello University, P. M. B. 1044, Zaria, Nigeria.

Accepted 13 May, 2013

A field trial was conducted in 2008 at the Institute for Agricultural Research farm at Samaru, to evaluate the phosphorus uptake, phosphorus use efficiency (PUE) and yield potentials, of five groundnut (*Arachis hypogaea* L.) genotypes (SAMNUT 10, 11, 21, 22 and 23). Four levels of phosphorus (0, 20, 40 and 60 kg P_2O_5 ha^{-1}) were applied to each genotype in a randomized complete block design (RCBD) with three replications. In addition to PUE indices, haulms and pod yields were also recorded. Among the genotypes evaluated, SAMNUT 23 recorded the highest total P uptake of 68.96 mg P kg^{-1} while SAMNUT 10 recorded the least (44.22 mg P kg^{-1}). SAMNUT 23 also produced the highest (2,298 kg ha^{-1}) dry pod yield. The highest PUE of 71.71 and 64.53% were recorded by SAMNUT 10 and 21 respectively, while SAMNUT 23 recorded the least (31.46%) PUE. The early or medium, maturing genotypes, SAMNUT 21 and 22, were observed to be better than both the extra-early, SAMNUT 23, and late-maturing SAMNUT 10 and 11, in terms of dry haulms yield. Therefore, SAMNUT 10 and 21 had greater adaptation for low soil P conditions than the other genotypes, and hence more suitable to resource-poor farmers.

Key words: Groundnut genotypes, phosphorus, phosphorus use efficiency.

INTRODUCTION

Grain legumes are vital cropping system components of the Northern Guinea Savanna (NGS) of Nigeria (Yusuf et al., 2008; Chude et al., 2011), and when supplied with the required amounts of phosphorus (P), they can fix more than 250 kg N ha^{-1} (Vance, 2001; Ogoke et al., 2005). This amount, however, varies with crop and genotype (Takishima et al., 1989). Groundnut (*Arachis hypogaea* L.), the 13th most important food crop of the world, world's fourth most important source of edible oil and third most important source of vegetable protein (Taru et al., 2008), belongs to the family Fabaceae (syn. Papilionaceae) and sub-family of the *Papilionoidae* (Raemaekers, 2001). It is grown throughout the tropics and some sub-tropical regions and on various soil types (Norman et al., 1995; Raemaekers, 2001; ICRISAT, 2012). Like other legumes, groundnut is considered by farmers to stabilize crop yields, as it is intercropped with some cereals, and serves as source of income and protein for their families.

Although the concept of nutrient use efficiency was developed using nitrogen as an example, it can also be applied to phosphorus. A definition was proposed by Moll et al. (1982) for wheat cultivars, expressing nitrogen (and phosphorus) use efficiency as their grain yield per unit of nutrient supplied (from the soil and/or fertilizer), and can be used for both low and high P input situations. They divided nutrient (P) use efficiency into two components: uptake, or the ability of the plant to extract P from the soil, and utilization efficiency, or the ability of the plant to

*Corresponding author. E-mail: algabasawiyyu@yahoo.com.

convert the absorbed P into grain yield. However, other nutrient efficiency classification systems take crops performance, both in the presence and absence of nutrient stress, into account. The system proposed by Gerloff (1977) for example, separates cultivars into four P response groups as: (1) efficient responder; (2) inefficient responder; (3) efficient non-responder and (4) inefficient non-responder. An efficient cultivar has higher yield than the other cultivars under low nutrient supply, while a responder cultivar has higher yield under high nutrient supply. This classification groups cultivars based on performance under low (efficient versus inefficient) and high (responder versus non-responder) nutrient supply, and allows the identification of those cultivars with adaptation to a range of soil P conditions (Isherwood, 2003).

Generally, phosphorus use efficiency (PUE) can be expressed in agronomic, physiologic, and economic terms, but so far in some parts of the world, this subject remains largely confined to the scientific community. As P use to these parts is largely subsidy-driven and not science-based (Rao, 2007), the practical benefits of high P use efficiency are distorted since N; the cheapest or most subsidized nutrient is used most, while other nutrients are presently ignored. It is important to understand that nutrient use efficiency is dependent on several agronomic factors including: soil degradation, land tillage, time of sowing, appropriate crop variety, proper planting or seeding, sufficient irrigation, weed control, pest/disease management, and balanced and proper nutrient use (Rao, 2007; Syers et al., 2008). Selection of proper planting material, population density, and balanced fertilization could collectively improve nutrient use efficiency by 25 to 50% (Rao, 2007).

Several authors (Gunawardena et al., 1993; Abdelgadir, 1998; Sanginga et al., 2000; Sanginga, 2003) reported intraspecific differences in P uptake, accumulation and use by some genotypes of mungbean (*Vigna radiate*), soybean (*Glycine max*) and cowpea (*Vigna unguiculata*). The need to conduct P use efficiency studies on these groundnut cultivars in the Northern Guinea Savanna (NGS) of Nigeria cannot be over emphasized. No similar study has so far been reported on the selected genotypes, which have been classified to be resistant to the rosette virus. This study was therefore aimed at screening five selected groundnut genotypes for PUE and yield potentials, with the objectives of determining their PUE, physiological efficiency (PE), agronomic efficiency (AE) and haulms and pod yields.

MATERIALS AND METHODS

Experimental site, soil sampling and analysis

Field experiment was conducted in 2008 at the Institute for Agricultural Research (IAR), experimental field, Samaru (latitude 11°11' 0'' N, and longitude 7°36' 52'' E). Samaru has a monomodal rainfall pattern (annual rainfall mean, 1011 ± 161 mm) concentrated almost entirely in 5 months (May or June to September or October) of the cropping season (Oluwasemire and Alabi, 2004). The soil was classified to be leached tropical ferruginous, Typic Haplustalf in Soil Taxonomy, Acrisol in the FAO system or Alfisol in the USDA system (Tomlinson, 1965; Jones and Wild, 1975; Uyovbisere et al., 2000). Savanna soils are generally low in fertility (Vanlauwe et al., 2002), and to a large extent, highly weathered, coarse-textured, and low in organic matter content, cation exchange capacity (CEC) (Agbenin, 1996), and total P (Mokwunye, 1979).

Core soil samples at the depth of 0 to 15 cm were collected at random from the field and bulked into a composite. A sub-sample was then taken from the composite, and air-dried, sieved through a 2 mm mesh and analyzed for some physical and chemical properties following standard procedures as described by Anderson and Ingram (1993).

Seed source and preparation

The five groundnut (SAMNUT 10, 11, 21, 22 and 23) genotypes were sourced and selected from the Institute for Agricultural Research's collections. The genotypes are among the most cultivated by farmers as sole or intercrop (IAR, 1989). The genotypes are improved varieties developed by IAR at Samaru, and hence the name SAMARUNUT (or SAMNUT for short) coined.

Field management

The experimental field was ploughed, disc harrowed, and ridged at an inter-row distance of 0.75 m. The experimental design was a randomized complete block design (RCBD) with three replications. Each of the four-ridge plots was 3.0 m long. Three seeds were sown at 0.20 m intra-row and 0.75 m between rows by hand. The crops were thinned to two plants per stand a week after sowing. At 2 to 3 weeks after sowing, each plot received a basal application of 20 kg N ha^{-1} as urea (46% N) and 20 kg K ha^{-1} as muriate of potash (60% K_2O). Four levels of P (0, 20, 40, or 60 kg P_2O_5 ha$^{-1)}$ as triple super phosphate (46% P_2O_5) were, however, applied to each genotype in all the replicates. All plots were hand-weeded at about three and 6 weeks after sowing

Plant sampling and analysis

Plant sampling for the determination of PUE indices was carried out on the two outer row while the two inner rows (net plot) was sampled for the determination of haulms and pod yields at harvest, in which two plants were sampled in each case. Wet and sun-dried haulms and pods weights were recorded. This assisted to ascertain the phosphorus use, physiological and agronomic efficiencies of the genotypes by using the following formulae Kasinath (1997):

$$\text{Phosphorus use efficiency (PUE)} = \frac{\text{Total dry matter per unit area}}{\text{Total phosphorus uptake per unit area}} \times 100$$

$$\text{Physiological efficiency (PE)} = \frac{\text{Pod Yield per Unit Area}}{\text{Total Phosphorus Uptake per Unit Area}} \times 100$$

$$\text{Agronomic efficiency (AE)} = \frac{\text{Pod Yield per Unit Area}}{\text{Total Phosphorus Applied per Unit Area}} \times 100$$

Sub-samples of the haulms and roots were taken, ground and sieved through a 500 µm mesh. These were analyzed for P. The data generated were subjected to analysis of variance (ANOVA) using the general linear model (GLM) procedure of SAS (SAS, 1999). Treatment means were separated using the Duncan's multiple

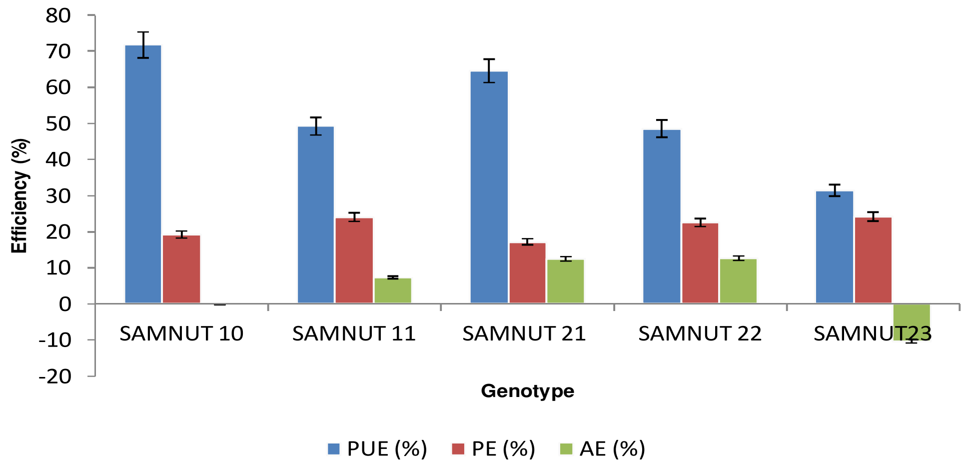

Figure 1. Effect of genotype on PUE, PE and AE.

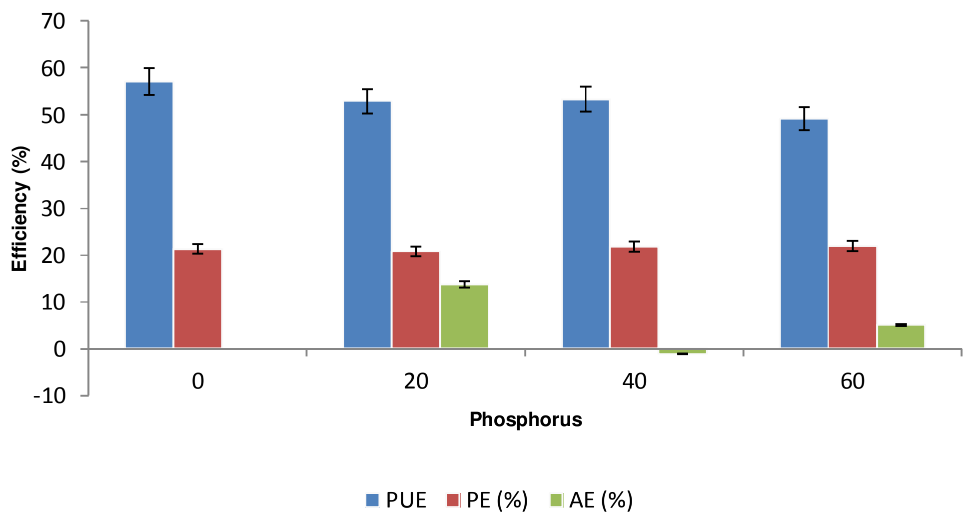

Figure 2. Effect of phosphorus on PUE, PE and AE.

range test (DMRT) at 5% level of probability where the F-ratios were found to be significant

RESULTS

The soil was sandy-loam in texture with the following properties: pH (water), 5.50; organic carbon, 0.39 %; total N, 0.14 %; available P, 10.50 mg kg $^{-1}$; and exchangeable cations (cmol^{+} kg^{-1}) of Mg^{2+}, 0.86; Ca^{2+}, 4.00; K^{+}, 0.29 and Na^{+}, 0.15.

Phosphorus use efficiency of the groundnuts

Genotype highly significantly (P<0.0001) influenced phosphorus use efficiency (PUE), and the highest PUE of 71.71 and 64.53% were recorded by SAMNUT 10 and 21, respectively, which were statistically similar. SAMNUT 23 recorded the least PUE of 31.46%, whereas SAMNUT 11 and 22 were statistically not different (P>0.05), and each recorded the second highest PUE of 49.22 and 48.56 respectively (Figure 1). Phosphorus rate had no significant (P>0.05) effect on PUE of the genotypes (Figure 2).

Physiological efficiency of the groundnuts

The influence of genotype on PE was statistically significant (P<0.05), in that, SAMNUT 11 and 23 had the highest values which were statistically higher than SAMNUT 10 and 21 (Figure 1). There was, however, no significant (P>0.05) difference between these genotypes

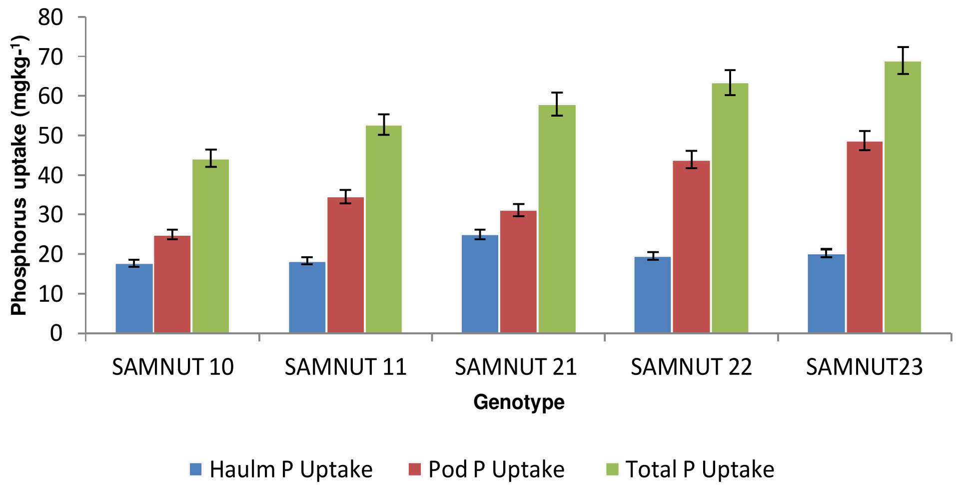

Figure 3. Effect of genotype on haulms, pod and total phosphorus uptakes.

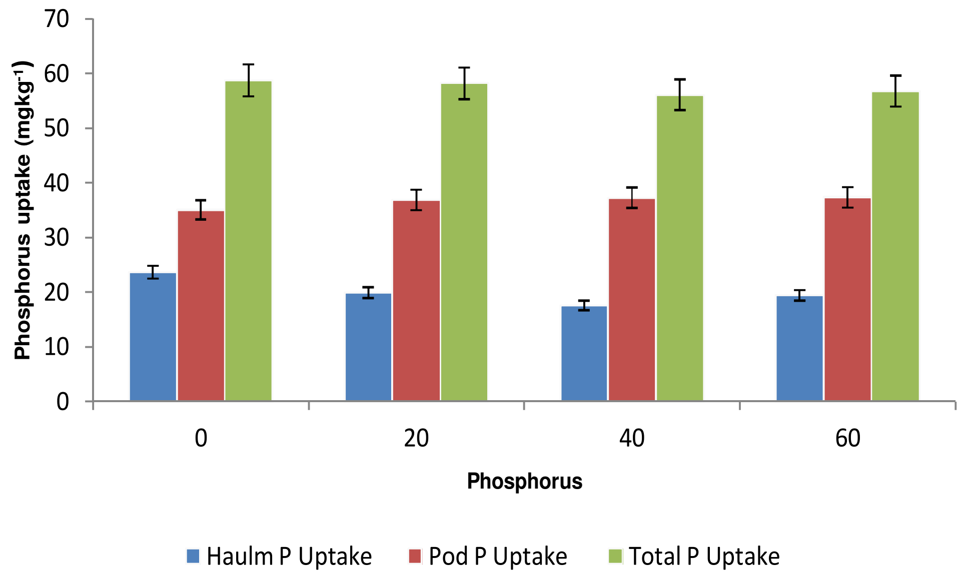

Figure 4. Effect of phosphorus on haulms, pod and total phosphorus uptakes.

and SAMNUT 22 except SAMNUT 21. The contribution of P addition to PE of the genotypes was not significant ($P>0.05$) (Figure 2), nor was there any significant ($P>0.05$) interaction between genotype and the phosphorus.

Agronomic efficiency of the groundnuts

Genotypes had no significant ($P>0.05$) influence on the AE of the groundnuts (Figure 1). There was also neither significant influence of P rate nor (Figure 2), significant interaction between the genotype and P on the AE. Negative AE was recorded in late-maturing SAMNUT 10 (-0.14%) and extra-early SAMNUT 23 (-10.26%) (Figure 1).

Haulms phosphorus uptake

Genotype had no significant ($P>0.05$) influence in terms of haulms P uptake (Figure 3). Phosphorus rate was also not significant ($P>0.05$) (Figure 4). There was equally no significant interaction between the groundnut genotype and P rate applied in terms of haulms P uptake.

Pod phosphorus uptake

Genotype highly significantly ($P<0.0001$) influenced the pod P uptake of the groundnuts. As such, SAMNUT 22 (43.91 mg kg^{-1}) and 23 (48.75 mg kg^{-1}) were statistically similar, and together, out yielded all other genotypes

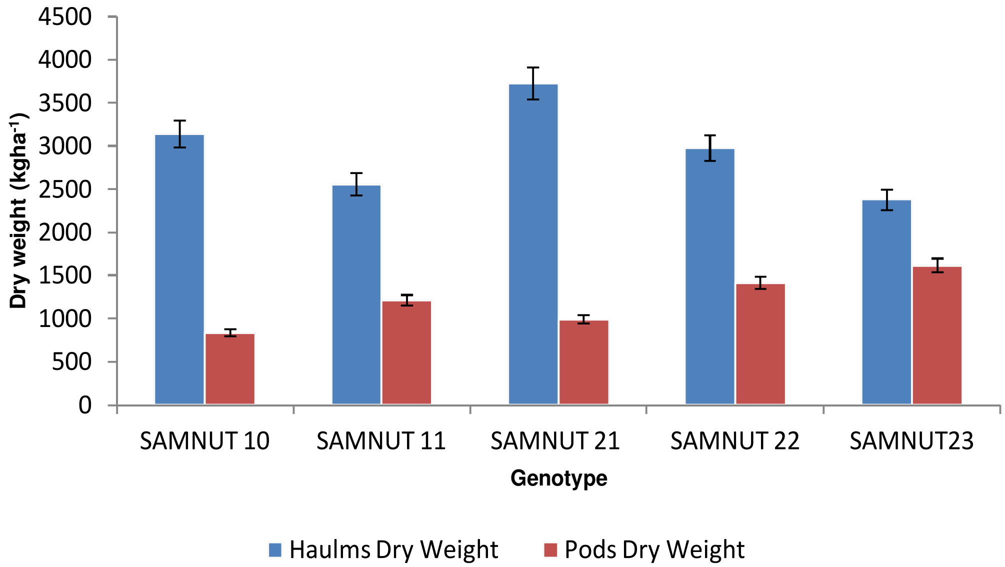

Figure 5. Effect of genotype on haulms and pods dry weights.

In terms of the pod P uptake. SAMNUT 10 (24.95 mg kg^{-1}) and 21 (31.13 mg kg^{-1}) were at par, and together recorded the least pod P uptake. SAMNUT 11 recorded 34.47 mg kg^{-1} and was in between those two extremes (Figure 3). There was, however, no significant (P>0.05) difference between the P rates in terms of pod P uptake (Figure 4). There was also no significant (P>0.05) interaction between the genotype and P rate in terms of pod P uptake.

Total phosphorus uptake

The total P uptake was significantly (P<0.05) influenced by the genotype. SAMNUT 23 recorded the highest total P uptake of 68.96 mg P kg^{-1}, and was statistically similar to SAMNUT 11 and 21. SAMNUT 10 recorded the least total P uptake of 44.22 mg P kg^{-1}, although at par with SAMNUT 11 and 21 (Figure 3). Phosphorus rate had no significant (P>0.05) influence on the total P uptake (Figure 4). There was also no significant (P>0.05) interaction between genotype and P rate in terms of the parameter.

Haulms dry yield

Genotype significantly (P<0.005) influenced the haulms dry weight. In that, SAMNUT 21 recorded the highest haulms yield, but was statistically similar to SAMNUT 22. SAMNUT 23 recorded the lowest haulms yield. SAMNUT 10 and 11 were statistically similar and together followed SAMNUT 21 and 22 (Figure 5). However, there was no statistical (P>0.05) difference between the P rates in terms of the parameter (Figure 6).

Dry pod weight

The extra-early maturing SAMNUT 23 statistically produced the highest dry pod yield. SAMNUT 22 was statistically similar to SAMNUT 23. SAMNUT 10, however, recorded the least dry pod yield, and was statistically similar to SAMNUT 21. SAMNUT 11 followed SAMNUT 22 and 23 (Figure 5). Increase in P from 0 to 60 kg ha^{-1} to the genotypes, growing in a moderate to high soil P condition, is undesirable for pod yield (Figure 6). There was no significant (P>0.05) interaction between genotype and P rate in terms of the pod dry weight.

DISCUSSION

The soil texture is suitable for groundnut production (Raemaekers, 2001). Based on the pH (in water), the soil is acidic in reaction, regarded within a moderate pH range (5.5 to 6.0) and, hence satisfactory for most crops, including groundnuts. Unless calcium (Ca) is deficient, soils with this type of acidity require no liming (Chude et al., 2004). The organic carbon value indicates that the soil falls within the low (<20 g kg^{-1}) organic matter category (FMAWRRD, 1989; FMANR, 1990). It, however, also indicates that, the soil can be vulnerable to some physicochemical problems, unless careful management practices are employed. This being obvious because quantitative and qualitative distribution of C in soils is, for example, a precondition to such soil physicochemical properties as bulk density, cation exchange capacity (CEC), availability of N, P and sulphur (S), etc (Agbenin, 1995). The values of exchangeable bases (Cmolkg^{-1}) indicated low status of Ca, magnesium (Mg) and sodium (Na); and medium potassium (K) bas indicated by

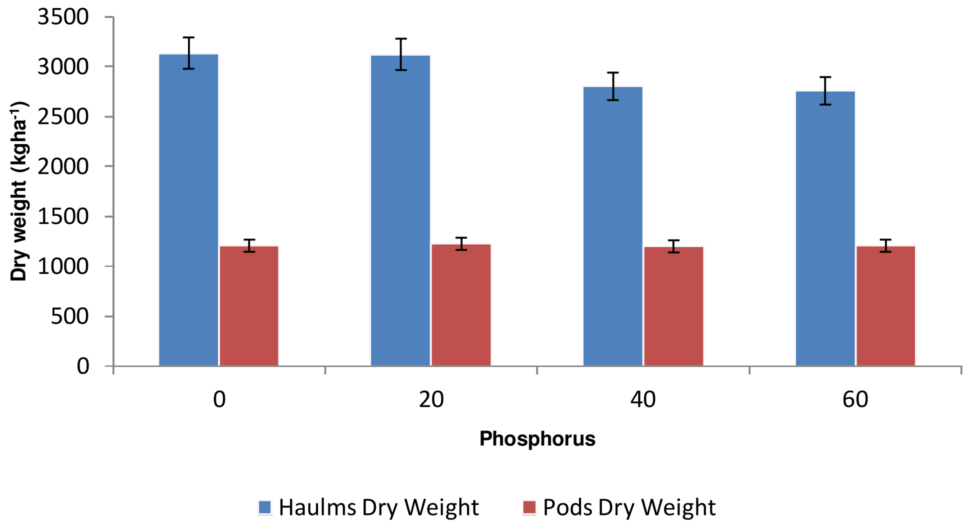

Figure 6. Effect of phosphorus on haulms and pods dry weights.

FMAWRRD, (1989) and FMANR, (1990). The result, therefore, suggests that cropping system on this soil has to be carefully managed in order to avoid further decrease in pH and Ca which will tantamount to the need for an expensive liming (Chude et al., 2004), besides, low soil Ca will result in its low uptake by plants. The consequent low Ca uptake by the groundnuts will result in poor P efficiency of the crops, as speculated by Hayes et al. (1999). The total N and available P values at the site suggest a low N (FMAWRRD, 1989; FMANR, 1990) and medium P (Chude et al., 2004) status of the soil. This however, suggests the need for additional N supply to the soil from possible means, including BNF.

Efficiency as defined in this context, by Lynch and Beebe, (1995), is the plant growth and seed yield with sub-optimal P availability. This therefore means that, majority of the genotypes under the study; especially SAMNUT 10 and 21; and SAMNUT 11 and 22, to a certain extent, have a better chance of efficiently utilizing a minimal quantity of soil P, and hence their better chances of adapting to a P-deficient soil environment like that of the NGS. In terms of PE, the result indicated that SAMNUT 11, 22, and 23 have shown more yield potentials with respect to the amount of P uptake than SAMNUT 10 and 21 (Figure 2). Being also the highest in terms of haulms dry weight (yield), SAMNUT 21 and 22 can be of tremendous benefit in supplying livestock with reasonable amount of P through feeds. According to Jones and Jacobsen, (2005), soils with moderate to high available P, like that in our experimental field (10.50 mg P ha^{-1}), may be “mined” of P until yields are negatively impacted. SAMNUT 22 and 23, due to their high pod P uptake, can readily be used as raw materials in an animal feed formulation, especially when there is need for supplementing P in livestock rations for bone development. The lack of significant difference between the P rates of application suggests that, the amount of P that was taken up by and found in pods of the groundnut genotypes is relatively not dependent on the rate of P applied. This may, to some extent, be due to the inherently moderate soil available P, effect of mycorrhizae, such soil enzymes as phosphatase, etc, among other possible reasons. The contribution of P rate was, however, not significant (P>0.05) in terms of total P uptake of the genotypes, although the figures indicated optimum total P uptake at 0 and 20 P ha^{-1} (Figure 4). The moderate P nature of soil of the experimental site may directly be responsible for the little to no significance of P rate in terms of the total P uptake of the genotypes. This is because, addition of nutrient mineral above its optimum level naturally tantamount to a setback in its availability, as the fixation becomes its fate. There was also no significant (P>0.05) interaction between genotype and P rate in terms of the parameter.

The result for haulms dry weight indicated that early (or medium) - maturing genotypes are better than extra - early and late - maturing genotypes in terms of dry haulms yield of the groundnuts. This may be due sub-optimum to excessive weather conditions in extra-early -, and late - maturing genotypes coupled with possible soil biological and physicochemical factors at play. In a study by Bello et al. (2012), there was also no significant difference, in terms of number of branches, between rates of P applied to some cowpea crops. This in a way, corroborates our finding. Highly significant difference in shoot dry weight among cowpea lines at both low (0 kg P ha^{-1}) and high P (60 kg P ha^{-1}) levels was, however, reported by Sanginga et al. (2000). This may, among other reasons, be due to anatomical, physiological and morphological differences in the plants (Krasilnikoff et al., 2003) and the low condition of, especially, inherent soil phosphorus obtainable at Fashola (derived savanna zone of Nigeria), where that trial was conducted. The low P may possibly made it necessary for the cowpeas to secrete acid phosphatase into their rhizosphere (Yadav and Tarafdar, 2001), thereby transforming, cycling and utilizing the limited soil P (Acosta-Martinez and Tabatabai, 2000) present. The cowpea plants are, however, still expected to respond to the high P applied as the inherent soil P of Fashola site stood at 5.33 mg P kg^{-1} (10.66 kg P ha^{-1}) (Sanginga et al., 2000) which is <15 kg P ha^{-1} and hence the need for additional P (Singh and Oswalt, 1995).

For the dry pod weight (yield), plant yield per unit P uptake was reported by Greenwood et al. (1980, 2005) to be greater when P supply was limited than when it was not. It could, therefore, be possible to increase yield per unit loss of plant available P when genotypes that are capable of growing well on low P soils are used in cropping systems. The fact is that there was no significant (P>0.05) interaction between genotype and P rate in terms of the pod dry weight, however, contradicts the finding of Ibrahim and Eleiwa (2008) who observed an increase in dry pod yield with increase in P. They, however, explained that this, proportional increase in yield, is realistic until a limit is reached when the increase tends to depress N and P uptake which results into a decrease in the pod yield per plant.

Conclusion

Generally, the groundnut genotypes performed well in terms of many of the parameters observed. There were also some genotypic differences that exist amongst the selected groundnut cultivars in terms P uptake and PUE, PE, AE and the various yields observed. The differences, however, lead to diverse potentials been observed amongst the genotypes. These potentials make them a kind of “multi-purpose crops”. In that a farmer with various farming interests and capacities or constraints, ranging from subsistent cropping system, livestock keeping to commercial production purpose can judiciously have a most befitting genotype selected for subsequent use, depending on edaphic, socioeconomic and related factors. Besides, resource-poor farmers, incapable of adequately accessing mineral P fertilizers can successfully exploit such P use efficient genotypes as SAMNUT 10 and 21. This can, invariably, affect the farmers’ income for the better.

ACKNOWLEDGEMENTS

The authors are grateful to the Legumes and Oil Seeds Research Program of the Institute for Agricultural Research, Ahmadu Bello University, Samaru-Zaria, Nigeria, for the financial support rendered. Authors also acknowledged Messrs U. O. Bello, I. Ibrahim, and A. Jibrin, for thier contributions in the field and/or laboratories, and all those that contributed to the success of this work.

REFERENCES

Abdelgadir AH (1998). The role of mycorrhiza in soybean growth in P-deficient soil in the humid tropics. Ph.D. Thesis, Cornell University, P. 255.

Acosta-Martinez V, Tabatabai MA (2000). Enzyme activity in a limed agricultural soil. Biol. Fert. Soils 31:85-91.

Agbenin JO (1996). Phosphorus sorption by three cultivated savanna alfisols as influenced by pH. Fertilizer Research. 44:107-112.

Agbenin JO (1995). Laboratory Manual for Soil and Plant Analysis (selected methods and data analysis).

Anderson JM, Ingram JSI (1993). Tropical soil biology and fertility: A handbook of methods (2nd Ed.). C. A. B. International Wallingford, U. K. P. 221.

Bello TT, Miko S, Mohammed IB (2012). Effects of irrigation intervals and phosphorus levels on the performance of irrigated cowpea (vigna unguiculata l. Walp). In: Jibrin JM, Hussaini MA, Auwalu BM, Essiet EU, Muhammad IR, Mohammed SG, Daneji MI, Garba Y and Pantami SA (Eds). Proceedings of the 46th annual conference of the agricultural society of Nigeria, held at Kano, Nigeria, from 5th to 9th November, 2012.

Chude VO, Malgwi WB, Amapu, IY, Ano OA (2004). Manual on soil fertility assessment. Federal Fertilizer Department (FFD), in Collaboration with National Special Programme for Food Security, Abuja, Nigeria.

Chude VO, Olayiwola SO, Osho AO, Daudu CK (2011). Fertilizer use and management practices for crops in Nigeria (4th Ed.). Federal Fertilizer Department Federal Ministry of Agriculture and Rural Development, Abuja, Nigeria. P. 231.

FMANR (1990). Literature review on soil fertility investigations in Nigeria (in five volumes). Federal Ministry of Agriculture and Natural Resources, Abuja, Nigeria. P. 281.

FMAWRRD (1989). Fertilizer use and management practices for crops in Nigeria. Federal Ministry of Agriculture, Water Resources and Rural Development. Bobma Publishers, Ibadan. P. 163 .

Gerloff S (1977). Plant efficiencies in the use of N, P and K. In: Plant adaptation to mineral stress in problem soils. Wright MJ (ed.). Cornell Univ. Press: New York. pp. 161-174.

Greenwood DJ, Cleaver TJ, Turner MK, Hunt J, Niendorf KB, Loquens SHM (1980). Comparison of the effects of phosphate fertilizer on the yield, phosphate content and quality of 22 different vegetables and agricultural crops. J. Agric. Sci. Camb. 96:459-469.

Greenwood DJ, Stellacci AM, Meacham MC, Broadley MR, White P (2005). Phosphorus response components of different brassica oleracea genotypes are reproducible in different environments. Crop Sci. 45:1728-1735.

Gunawardena SFBN, Danso SKA, Zapata F (1993). Phosphorus requirements and N_2 accumulation by three mungbean (Vigna radiate (L) Wewlzek) Cultivars. Plant Soil. 147:267-274.

Hayes JE, Richardson AE, Simpson RJ (1999). Phytase and Acid Phosphatase Activities and Extracts from Roots of Temperate Pasture Grass and Legume Seedlings. Austr. J. Plant Physiol. 26:801-809.

IAR (1989). Code and descriptor list of crop varieties released by Institute for Agricultural Research, Samaru, Federal Ministry of Science and Technology, ABU, Zaria,

Ibrahim SA, Eleiwa ME (2008). Response of groundnut (*Arachis hypogaea* L.) plants to foliar feeding with some organic manure extracts under different levels of NPK fertilizers. World J. Agric. Sci. 4:140-148.

ICRISAT (2012). The Jewels of ICRISAT. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). P. 68 . ISBN 978-92-9066-549-6.

Isherwood KF (2003). Fertilizer consumption and production: long term world prospects. Proceedings 507. York, UK, International Fertilizer Society. P. 28.

Jones C, Jacobsen J (2005). Phosphorus cycling, testing and fertilizer recommendations. nutrient management module No. 4. Montana State University Extension Service.

Jones MJ, Wild A (1975). Soils of the West African savanna. Tech. Comm. No. 55. Commonwealth Bureau of Soils. Harpenden, UK. In: Agbenin J O. Phosphorus sorption by three cultivated savanna Alfisols as influenced by pH. Fert. Res. 44:107-112.

Kasinath BL (1997). Nitrogen Use Efficiency of Different Bean (Phaseolus vulgaris L.) Varieties in an Alfisol. Thesis submitted to University of Agricultural Sciences for the Award of MSc (Agriculture) Degree.

Krasilnikoff G, Gahoonia T, Nielsen NE (2003). Variation in phosphorus uptake efficiency by genotypes of cowpea (Vigna unguiculata) due to differences in root and root hair length and induced rhizosphere processes. Plant Soil. 251:83-91.

Lynch JP, Beebe S (1995). Adaptation of beans (Phaseolus vulgaris L.) to low phosphorus availability. Hort. Sci. 30:1165-1171.

Mokwunye U (1979). Phosphorus needs of acid soil and crops of the savanna zones of Nigeria. Phosphorus in Agriculture. 76:87-95.

Moll RH, Kamprath EJ, Jackson WA (1982). Analysis and interpretation of factors which contribute to efficiency of nitrogen utilization. Agron. J. 74:562-564.

Norman MJT, Pearson CJ, Searle PGE (1995). Tropical food crops in their environment (2nd. Ed.). Cambridge University Press.

Ogoke IJ, Carsky RJ, Togun AO, Dashiell K (2005). Effect of phosphorus fertilizer application on nitrogen balance of soybean crop in the Guinea savanna of Nigeria. Agric. Ecosyst. Environ. 100:153-159.

Oluwasemire KO, Alabi SO (2004). Ecological impact on changing rainfall pattern, soil processes and environmental pollution in the Nigerian Sudan and northern Guinea savanna agro-ecological zones. Niger. J. Soil Res. 5:23-31.

Raemaekers RH (Ed.) (2001). Crop production in tropical Africa. Directorate General for International Co-operation (DGIC), Brussels, Belgium. P. 1540.

Rao TN (2007). Improving nutrient use efficiency: the role of beneficial management practices. Better Crops, India.

Sanginga N (2003). Role of biological nitrogen fixation in legumes based cropping systems; a case study of West Africa farming systems. Plant Soil. 252:25-30.

Sanginga N, Lyasse O, Singh BB (2000). Phosphorus use efficiency and nitrogen balance of cowpea breeding lines in a low p soil of the derived savanna zone in West Africa. Plant Soil 220:119-128.

Singh F, Oswalt DL (1995). Groundnut production practices. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) training and fellowships program. Skill development series No. 3.

Statistical Analysis System Institute (1999). SAS 6.12. SAS Institute, Inc., Cary, NC.

Syers JK, Johnston AE, Curtin D (2008). Efficiency for soil and fertilizer P use: Reconciling changing concepts of soil phosphorus behavior with agronomic information. FAO Fertilizer and Plant Nutrition Bulleting 18:108 (FAO: Rome).

Takishima Y, Shimura J, Ugawa Y, Sugawara H (1989). Guide to world data center on microorganisms with a list of culture collections in the world (1st Ed). Saitama, Japan: WFCC World Data Center on Microorganisms.

Taru VB, Kyagya IZ, Mshelia SI, Adebayo EF (2008). Economic efficiency of resource use in groundnut production in Adamawa State of Nigeria. World J. Agric. Sci. 4:896-900.

Tomlinson PR (1965). Soils of northern Nigeria: a generalized account of their distribution and contemporary classification. Samaru Miscellaneous Paper No. 11.

Uyovbisere EO, Chude VO, Bationo A (2000). Promising nutrient ratios in fertilizer formulations for optimal performance of maize in the Nigerian savanna: the need for a review of current recommendation. Nig. J. Soil Res. 1:29-34.

Vance CP (2001). Symbiotic nitrogen fixation and phosphorus acquisition: plant nutrition in a world of declining renewable resources. Plant Physiol. 127:390-397.

Vanlauwe B, Diels J, Lyasse O, Aihou K, Iwuafor ENO, Sanginga N, Merckx R, Deckers J (2002). Fertility status of soils of the derived savanna and northern Guinea savanna and response to major plant nutrients, as influenced by soil type and land use management. Nutrient Cycling Agroecosys. 62:139-150.

Yadav RS, Tarafdar JC (2001). Influence of organic and inorganic phosphorus supply on the maximum secretion of acid phosphatase by plants. Biol. Fert. Soils. 34:140-143.

Yusuf AA, Abaidoo RC, Iwuafor ENO, Olufajo OO, Sanginga N (2008). Rotation effects of grain legumes and fallow on maize yield, microbial biomass and chemical properties of an Alfisol in the Nigerian savanna. Agric. Ecosys. Environ. 129:325–331.