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 P₂O₅ 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 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 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 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 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 10 and 21 respectively, while SAMNUT 23 recorded the least (31.46%) PUE.

Key words: Groundnut genotypes, phosphorus, phosphorus use efficiency.
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 experimental design was a randomized complete block design (RCBD) with three replications. 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. The experimental design was a randomized complete block design (RCBD) with three replications. The experimental design was a randomized complete block design (RCBD) with three replications. The experimental design was a randomized complete block design (RCBD) with three replications.

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 range test.
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.
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.
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 (FMAWRD, 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
FMAWRD, (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 (FMAWRD, 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 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

![Figure 6. Effect of phosphorus on haulms and pods dry weights.](image-url)
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.

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