

## EFFECTS OF PHOSPHORUS AND SULPHUR ON DRY MATTER YIELD OF MAIZE (*Zea mays*) IN SOME SOILS AT ABEOKUTA, OGUN STATE, NIGERIA

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### ABSTRACT

*Phosphorus and Sulphur fertilizers are important for increasing the productivity of maize in most parts of Nigeria. A screen-house experiment was conducted to investigate the effects of phosphorus (P) and sulphur (S) on maize dry-matter yield (MDY) in soils of five locations (Obantoko I, II, Alabata I, II, and III) in Abeokuta, Ogun State of Nigeria. Three levels of sulphur (0, 10 and 20 kg S ha<sup>-1</sup>) and phosphorus (0, 30 and 45 kg P ha<sup>-1</sup>) were evaluated in a 3 × 3 × 5 factorial experiment laid in Completely Randomised Design with three replications. Pre-planting analyses were performed to determine soil pH, particle size, organic matter, K, Na, P and S. Eight weeks after planting, maize parts above the soil level were harvested, oven-dried and dry-matter yield were computed and recorded. Application of S fertilizer appears not to be critical to maize production in the study areas since singly added S did not produce significant increase in biomass yield. In contrast, applied P significantly increased MDY in all the soils except Obantoko II, which already contained high amount of P sufficient for maize yield. Both synergism (Alabata II and III) and antagonistic (Alabata I) interactions were observed between P and S on MDY without any interactive effect in Obantoko I soil. Application rate of 30-45 kg P ha<sup>-1</sup> with or without 10 or 20 kg S ha<sup>-1</sup> resulted in significant effects on the MDY in the study areas. Field studies on effects of P and S on maize grain yield are recommended.*

**Key words:** available P and S, maize productivity, Nigeria soils, biomass, fertilizers

### INTRODUCTION

Maize is the third most important cereal crops in the world next to wheat (*Triticum aestivum* L.) and rice (*Oryza sativum* L.) (Muhammad *et al.*, 2015). It is grown extensively in the temperate, sub-tropical and tropical regions of the world. World total maize production is 1.04 billion tonnes from which USA is the highest (50.4%) producer producing 361 million tonnes, followed by China and Brazil (FAO, 2014). Africa produces 77.6 million tonnes of which 10.8 m tonnes is from Nigeria, harvested from 5.9 million ha land area (FAOSTAT, 2014). Maize is a popular cereal in the tropics. It is consumed as a staple food to supply energy to man (Onasanya *et al.*, 2009). In Nigeria, maize is a staple food and one of the most abundant crops (Ayinde *et al.*, 2015). It is produced in all parts of the country, from the north to the south (Abdulrahman and Kolawole, 2006). Traditionally, it was mostly grown in the forest ecology in Nigeria but large scale production has shifted to the savanna zone, especially the Northern Guinea savanna (Olaniyan, 2015). Maize has been rated the second

grown food crop in Nigeria after cassava, followed by sorghum and rice (FAO, 2013). Its production has increased in the guinea savanna ecology, owing to the adoption of high yielding and adapted varieties and increased use of fertilizer (Fajemisin, 1991). As a food crop, it is prepared and consumed in a multitude of ways which vary from region to region or from one ethnic group to the other (Abdulrahman and Kolawole, 2006). It is used in livestock feeds (Olaniyan, 2015; Fabunmi and Agbonlahor, 2012), and also serves as raw material for many agro-based industries (Iken and Amusa, 2004). Maize production plays key role toward sustainable development of rural economy, food security and poverty reduction in Nigeria (Oyakhilomen, 2014). Maize is a dominant component of the crop production system in Abeokuta in the derived savanna zone which is part of the grain belt of Nigeria (Fabunmi and Agbonlahor, 2012). Importance of maize in this region is tied to its uses both as staple food and in formulating livestock feed (Fabunmi and Agbonlahor, 2012).

Despite its importance, maize yield is still low in Nigeria due to biotic, abiotic and agronomic factors (Olaniyan, 2015; Onasanya *et al.*, 2009). The average yield in Nigeria is 1,845 kg ha<sup>-1</sup> (FAO, 2014). Parts of the major abiotic causes of the low yield in Africa are declining soil fertility and insufficient use of fertilizers, resulting in severe nutrient depletion of soils (Buresh *et al.*, 1997). In order to achieve optimum productivity of maize crop, balanced soil nutrients are required. Increased in human population growth rate in Nigeria has lead into short fallow period. Continuous cultivation of crops on the same soil has also resulted in increased rate of rapid loss of soil fertility (Uzoh *et al.*, 2015). This has necessitated the supplementing of soil natural fertility with fertilizers to replenish the soil for optimum yield. Also, the increasingly high cost of mineral fertilizers in crop production had necessitated an investigation into the optimum fertilizer rate for profitable maize production in Nigeria (Adekayode and Ogunkoya, 2010). Today, commercial agriculture without the use of fertilizers is not yet achievable in Nigeria. Several studies had revealed the need for application of various nutrient elements such as nitrogen (N), phosphorus (P), potassium (K), sulphur (S), and some trace elements in order to boost crop productivity in Nigeria (Ayodele and Omotosho, 2008; Adekayode and Ogunkoya, 2010; Isitekhale *et al.*, 2013).

The P is the second major nutrient essential for plant growth (Muhammad *et al.*, 2015) and one of the most limiting plant nutrients in crop production next to N, in most agricultural soils in Nigeria (Akande *et al.*, 2010). It plays an important role in many physiological processes that occur within a developing and maturing plant. It is involved in enzymatic reactions in plant, essential for cell division, important for seed and fruit formation, affects the quality of the grains and may increase the plant resistance to diseases (Onasanya *et al.*, 2009). The P deficient plants show stunting, dark green or blue green foliage, often with a purple tint on the leaves and stem, starting from lower leaves. Application of P had showed significant effects on grain yield, dry-matter yield, number of leaves and leaf area (Ali *et al.*, 2002; Ayub *et al.*, 2002; Yusuf *et al.*, 2003). Low soil P availability is well established in Nigeria (Adepetu, 1993). Application rate of 120 kg N ha<sup>-1</sup> and 40 kg P ha<sup>-1</sup> had significantly increased the growth and yield of maize in Southwestern Nigeria (Adetunji, 1997; Onasanya *et al.*, 2009).

The S is also becoming increasingly important as a yield limiting factor in many Nigeria soils (Adetunji and Adepetu, 1989). The continuous use of non-sulphur nitrogen fertilizers has generated S deficiency problem. The S is recognized as the fourth major nutrient after N, P and K. It plays a key role in

the synthesis of amino acids cysteine and methionine which are essential components of protein and useful in secondary metabolism. It has beneficial effects by lowering soil pH and improving physical condition of the soil (Choudhary and Das, 1996). Increasing level of S progressively enhanced the average total N uptake by maize and this increase in N uptake may be attributed to increase in N content of plant and dry matters yield due to increasing S levels (Jaliya *et al.*, 2012). Ray and Mughogho (2000) reported that S is a secondary nutrient taken up by most grain crops in amount namely 10 to 30 kg ha<sup>-1</sup>. Its deficiency is reported to be higher in savanna area than in the forest zone due to very long period of plant burning during which sulphur in the grass and other plant goes up in smoke as sulphur dioxide (Adetunji and Adepetu, 1989; Tandon, 1989).

Interaction between P and S has been observed. Several studies reported both synergistic and antagonistic relationship between P and S, depending on their rate of application and crop species. Synergistic effect of applied P and S was observed by Kumawat (2004). Antagonistic relationship between P and S was observed in mung and wheat (Islam *et al.*, 2006) and in maize (Muhammad *et al.*, 2015). This interaction influences the absorption of sulphur, in form of sulphate, in the soil (Adetunji, 1991). It is important to study the level of soil S and P required for optimum crop yield and the likely effect of S application on the crop utilization of P. This study was carried out to determine the optimum level of P and S fertilizer requirements and their interaction on the dry-matter yield of maize in soils of some selected locations in Abeokuta, Ogun State.

## MATERIALS AND METHODS

### Soil Sample Collection

The pot experiment was conducted at the Department of Soil Science and Land Management, Federal University of Agriculture Abeokuta (FUNAAB), Ogun State, Nigeria. Bulk samples of surface soil (0-15 cm depth) were collected from five locations in Odeda Local Government Area, Abeokuta. Two soil samples were collected from Obantoko area; Obantoko I and II in Abeokuta (Obantoko I is a farm land located about 2 km away from the Ibadan-Abeokuta Road, Somorin area of Obantoko and Obantoko II is in Alogi area of Obantoko located about 3 km off Ibadan-Abeokuta Road). Three samples were from different locations in Alabata area (Alabata I, II, and III) all within FUNAAB campus (Alabata I is the experimental farm beside College of Plant Science and Crop Production (COLPLANT), Alabata II is the land area beside the FUNAAB

Student Centre and Alabata III is the FUNAAB Teaching and Research Farm at Alabata). A total of 5 soil samples were collected from the five locations, all of which are within Ekiti soil series.

### Soil Preparation for Planting

Soil samples were air-dried, ground and passed through a 2-mm sieve. Soil samples from each of the five locations were analysed to determine their physical and chemical properties before planting. Two kg of each soil was weighed into planting pots. There were three rates of S: 0, 10 and 20 kg S ha<sup>-1</sup> supplied as elemental S and three rates of P: 0, 30 and 45 kg P ha<sup>-1</sup> applied as NPK 20-10-10. The two applied rates of NPK supplied the 30 kg P ha<sup>-1</sup> (0.57 g per pot) and 45 kg P ha<sup>-1</sup> (0.87 g per pot) to the soils which also supplied the N and K required for maize yield. After two weeks of planting, two rates of Nitrogen 200 kg N ha<sup>-1</sup> and 64 kg N ha<sup>-1</sup>, as Urea, was applied to all pots receiving no phosphorus (0 kg P ha<sup>-1</sup>) and those receiving 35 kg P ha<sup>-1</sup> respectively to supply the basal dose of N. These additional rates of N thus provided a uniform supply 200 kg N ha<sup>-1</sup> to all the pots. The experiments were in a Completely Randomized Design (CRD) laid in 3 (rates of S) × 3 (rates of P) × 5 (soils) factorial with three replicates making 27 pots per soil and 135 experimental units. After fertilizer application into the soils, maize cultivar Suwan1 obtained from the Institute of Agricultural Research and Training (IAR&T) was planted in each pot at three seed per pot and thinned to two seedlings per pot two weeks after planting. Maintenance practices like watering and weeding were carried out as required.

### Soil Laboratory Analysis

Soil samples were taken for pre-planting laboratory analysis. Soil pH was measured by glass electrode pH meter in 1:2 soil-water ratio. Organic matter content was determined using Walkley and Black (1934) procedure. Particle size analysis of the soils was by pipette method with sodium-hexameta-phosphate as dispersant (Gee and Bauder, 1986). The S in the soil was extracted using 0.01M Ca(H<sub>2</sub>PO<sub>4</sub>)<sub>2</sub> extractant and determined turbidimetrically by Chesin and Yien (1951) procedure. The P was extracted by Bray-1 procedure (Bray and Kurtz, 1945) and determined

colourimetrically using molybdenum blue method. Exchangeable cations K and Na were extracted using neutral 1M Ammonium Acetate and then determined by flame photometry (Thomas, 1982).

### Data Collection and Analysis

Eight weeks after planting, the plant parts above the soil level were harvested and oven-dried at 65°C for 48 hours. Each maize plant was then weighed to obtain the dry matter yield. Data were analyzed with analysis of variance (ANOVA) using SAS software version 9.3 (SAS, 2010). Means were compared using Duncan's Multiple Range Test.

## RESULTS

### Pre-treatment soil analysis

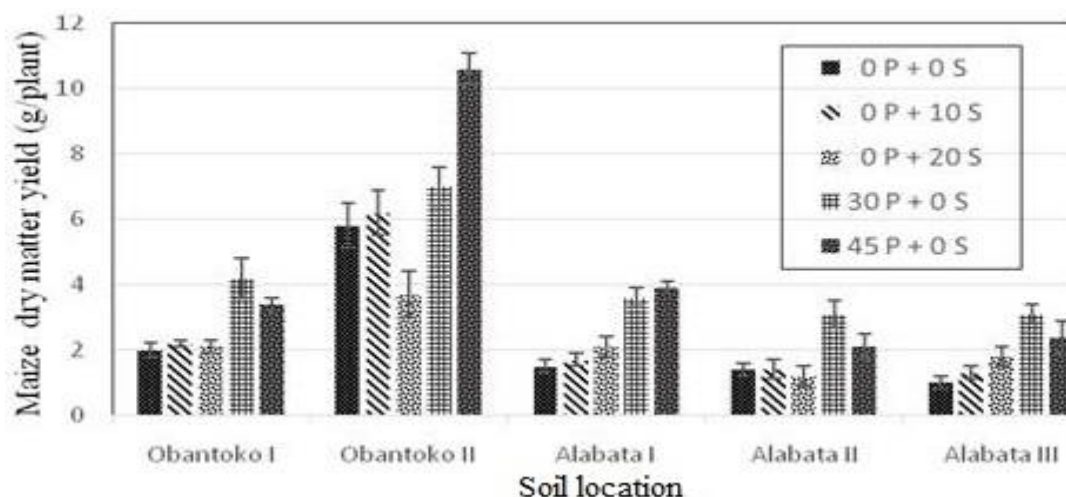
Physico-chemical properties of the soils before fertilizer applications are shown in Table 1. The soils ranged from being slightly acidic to slightly alkaline with pH value from 5.9 in Alabata II to 7.2 in Obantoko II soils. Organic matter content of the soils ranged from low (1.3%) in Alabata II to high (3.2%) in Obantoko II. Available S of the surface (0-15 cm) soils were low, ranging from 1.25 mg kg<sup>-1</sup> in Alabata II to 3.70 mg kg<sup>-1</sup> in Obantoko I while the K content was higher in Obantoko II (0.37 cmol(+) kg<sup>-1</sup>) than in other soils. Available soil P values ranged from low (5.15 mg kg<sup>-1</sup>) in Alabata I to high (18.50 mg kg<sup>-1</sup>) in Obantoko II. The soils textural class range from sandy loam in Obantoko II through loamy sand in Alabata I, II and III to sand in Obantoko I.

### Effect of Single Application of P and S on Maize Dry Matter Yield

The effects of single application of different rates of P and S on dry matter yield are presented in Fig. 1 and Table 2. Maize dry matter yield (MDY) produced by either of the two rates of S fertilizer (0 P + 10 S and 0 P + 20 S kg ha<sup>-1</sup>) were not significantly higher than that of the control (0 P + 0 S) in the soils from the five locations. For instance, all three treatments of S rates (0 P + 0 S, 0 P + 10 S and 0 P + 20 S kg ha<sup>-1</sup>) produced similar DMY of maize of 2.0±0.4, 2.2±0.1 and 2.1±0.5 g per plant, respectively in Obantoko I soil and similar trend was observed in the soils of the remaining four locations.

**Table 1:** Physico-chemical properties of the soils from pre-treatment analysis

Location	pH	Organic matter (%)	Exchangeable		Available P mg kg <sup>-1</sup>	S mg kg <sup>-1</sup>	Particle size (%)			Textural name
			K cmol(+) kg <sup>-1</sup>	Na cmol(+) kg <sup>-1</sup>			Sand	Silt	Clay	
Obantoko I	6.2	2.3	0.11	0.01	16.1	3.7	89	3	8	Sand
Obantoko II	7.2	.2	0.37	0.05	18.5	3.55	68	26	6	Sandy loam
Alabata I	6.3	2.5	0.09	0.01	5.15	2.22	77	16	7	Loamy sand
Alabata II	5.9	1.3	0.07	0.01	6.06	1.25	84	9	7	Loamy sand
Alabata III	6.0	2.3	0.07	0.01	5.7	2.35	85	9	6	Loamy sand



**Figure 1:** Effect of single application of different rates of phosphorus and sulphur on dry matter yield of maize

On the contrary, the two rates of the singly applied P (30 P + 0 S and 45 P + 0 S) resulted in significantly ( $p \leq 0.05$ ) higher dry matter yield relative to the control in all the soils except Obantoko II. Alabata I soil supplied with 45 kg  $\text{ha}^{-1}$  resulted in  $3.9 \pm 0.4$  g biomass yield which was significantly higher than that of the same soil without of P ( $1.5 \pm 0.4$  g) application (Table 2). The two single application rates of P yielded higher maize biomass than the two applied rates of S. However, comparing the general effect of the P and S among the five soils, highest dry matter yield response per plant was obtained in the soil from Obantoko II, followed by that of Obantoko I while lowest yields were produced in the three soils from Alabata areas (Fig. 2).

#### Interactive Effects of P and S on Maize DMY

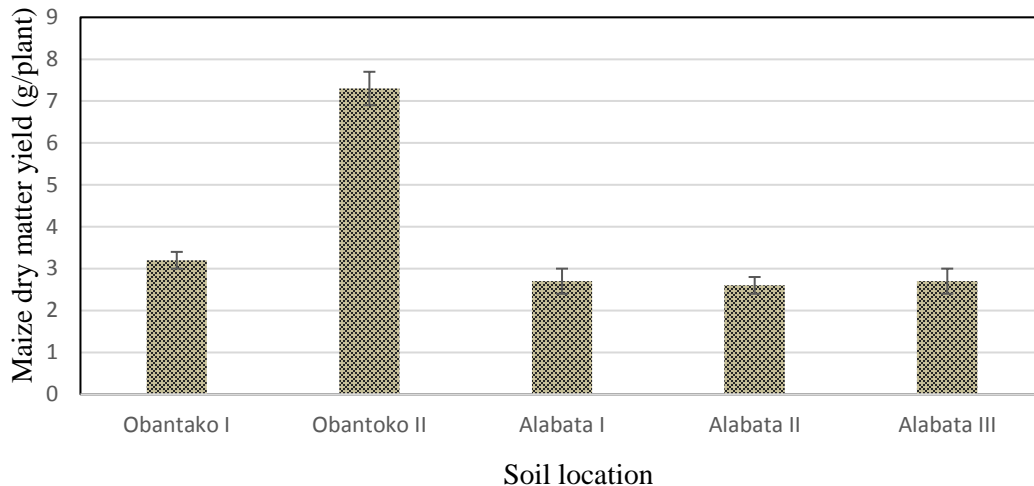
Results of single and interactive effects of P and S on maize DMY are shown in Table 2. The two rates of P with or without S resulted in significant increase in the DMY in all soils except Obantoko II. Highest biomass yield was produced by 45 kg  $\text{P ha}^{-1}$  + 10 kg  $\text{S ha}^{-1}$  in Obantoko I soil, which was similar to those produced by either 30 or 45 kg  $\text{P ha}^{-1}$  with or without S. For Alabata I soil, 45 kg  $\text{P ha}^{-1}$  + 20 kg  $\text{S ha}^{-1}$

showed the highest yield, which was also achieved with 45 kg  $\text{P ha}^{-1}$  with or without 10 kg  $\text{S ha}^{-1}$  and at 30 kg  $\text{P ha}^{-1}$  without S. Both synergy and antagonism were observed between P and S on MDY. Synergistic interaction was observed between P and S on maize biomass in Alabata II and III soils where single application of 45 kg  $\text{P ha}^{-1}$  did not increase DMY unless combined with 10 or 20 kg  $\text{S ha}^{-1}$ . The synergy produced by the addition of S to P in Alabata II caused a significant increase in MDY from  $2.1 \pm 1.2$  following addition of 45 kg  $\text{P ha}^{-1}$  to  $2.8 \pm 0.4$  g and  $4.2 \pm 0.7$  g from the applied 45 kg  $\text{P ha}^{-1}$  + 10 kg  $\text{S ha}^{-1}$  and 45 kg  $\text{P ha}^{-1}$  + 20 kg  $\text{S ha}^{-1}$  respectively. A similar significant increase following addition of 10 and 20 kg  $\text{S ha}^{-1}$  was observed in Alabata III. Contrarily, antagonism was observed between P and S in Alabata I. Although 30 kg  $\text{P ha}^{-1}$  applied solely ( $3.1 \pm 1.2$  g) or combined with 10 kg  $\text{S ha}^{-1}$  ( $3.3 \pm 1.9$  g) and 20 kg  $\text{S ha}^{-1}$  ( $3.4 \pm 0.4$  g) resulted in similar high biomass yield in Alabata II (Table 2), the same rate of P and S (30 P + 10 S kg  $\text{ha}^{-1}$  and 30 P + 20 S kg  $\text{ha}^{-1}$ ) produced an antagonistic effect that resulted in significant reduction in maize DMY to  $1.4 \pm 0.6$  g and  $1.7 \pm 0.9$  g in Alabata I soil compared with yield ( $3.6 \pm 0.7$  g) produced by single application of 30 kg  $\text{P ha}^{-1}$ .

**Table 2:** Effects of phosphorus (P) and sulphur (S) on maize dry matter yield in five soils from Abeokuta, Ogun State

Soil S and P rates (kg $\text{ha}^{-1}$ )	Maize dry matter yield (g per plant) of soils				
	Obantoko I	Obantoko II	Alabata I	Alabata II	Alabata III
0P + 0S	2.0±0.4b	5.8±4.0a	1.5±0.4c	1.4±0.4cd	1.0±0.4b
30P + 0S	4.2±2.9ab	7.0±3.1a	3.6±0.7abc	3.1±1.2abc	3.1±0.9ab
45P + 0S	3.4±0.5ab	10.6±2.1a	3.9±0.4ab	2.1±1.2bcd	2.4±2.0b
0P + 10S	2.2±0.1b	6.2±4.0a	1.7±0.2bc	1.4±0.6cd	1.3±0.5b
30P + 10S	4.1±1.5ab	8.0±1.5a	1.4±0.6c	3.3±1.9ab	2.1±0.5b
45P + 10S	4.9±0.8a	10.2±3.6a	3.3±0.6abc	2.8±0.4abcd	5.0±1.6a
0P + 20S	2.1±0.5b	3.7±4.0a	2.1±0.8bc	1.2±0.6d	1.8±0.8b
30P + 20S	2.9±0.7ab	8.8±5.0a	1.7±0.9bc	3.4±0.4ab	2.0±0.5b
45P + 20S	3.1±0.6ab	5.2±1.7a	5.0±3.2a	4.2±0.7a	5.5±2.5a

Values are means±SE. Means followed by the same letter in each column are not significantly ( $p \leq 0.05$ ) different.



**Figure 2:** Effect of soils with phosphorus and sulphur applications on dry matter yield of maize

## DISCUSSION

The beneficial effects of fertilizer application on soils for a sustainable food crop production has made the need for information in fertilizer supply and use for increased food production desirable (Adekayode and Ogunkoya, 2010). In this study, all the soils were slightly acid to neutral (pH 5.9 to 7.2) which is good for most arable crops (Ayodele and Omotosho, 2008). Based on the criteria for soil test interpretation and soil fertility classes established for Maize in South-Western Nigeria (Agboola and Ayodele, 1985; FMANR, 1990), the organic matter content was low in Alabata II, medium in Obantoko I, Alabata I and III but high in Obantoko II soil. The low organic matter content of Alabata II may be due to previous cropping on the soil without nutrient replenishment.

Despite the low level ( $< 5 \text{ mg kg}^{-1}$ ) of available S in all the soils, application of S without P fertilizer did not result in significant increase in maize dry matter yield. This may be due to medium level of organic matter content plus the adequate supply of N to all the soils. Such result is also conceivable since S content depends on level of organic matter content of the soil because mineralization of organic matter releases S into the soil (Weil and Mughogho, 2000). Similar effect of S has been reported in (Wortmann *et al.*, 2006a,b, 2009; Shapiro *et al.*, 2003). Also, it was reported that response to applied S is not likely on sandy soils with more than 1% soil organic matter (Wortmann *et al.*, 2009). However, a contrary result was observed by Jaliya *et al.*, (2015) where 5-15 S kg ha<sup>-1</sup> produced high maize grain yield in Zaria, Nigeria. Similar observation was reported in Malawi, where applied S rates of 5-10 kg ha<sup>-1</sup> resulted in optimum maize grain yield (Weil and Mughogho, 2000). The highest MDY was observed in Obantoko II soil. This result was not surprising since the soil

showed a high fertility status from pre-treatment test, containing high organic matter, K and P when compared with the critical soil nutrient levels established for maize in South-Western Nigeria (Agboola and Ayodele, 1985; FMANR, 1990). This soil was observed to be sandy loam while others were sand or loamy sand. Hence, consequent upon the high nutrient content of the Obantoko II soil, there was no significant effect of the added P and S either singly or mixed on the maize biomass yield. Also, P and S observed in the soils from both locations in Obantoko area were higher than that of soil samples from Alabata. We also observed that contrary to the single supply of S, the two single P rates resulted in significant higher dry matter yield in all the soils except Obantoko II, which already contained adequate nutrients and in Alabata II and III where 45 kg P ha<sup>-1</sup> yielded high biomass only when S was applied. Increased maize grain yield to P application has been earlier reported from various studies in Nigeria (Adediran and Banjoko, 1995; Adetunji, 1997; Yusuf *et al.*, 2003; Ayodele and Omotosho, 2008) and in other countries (Taalab *et al.*, 2008; Wortmann *et al.*, 2009). Similar observation on effect of P on maize grain yield has been reported for biomass yield. According to Akande *et al.* (2010), phosphate application enhanced dry matter yields of maize and cowpea in Ibadan, Nigeria.

The two applied P rates, with or without S, resulted in significant increase in dry matter yield from all the soils except in Obantoko II. Findings from this study show that 30 to 45 kg P ha<sup>-1</sup> with or without 10 or 20 kg S ha<sup>-1</sup> produced the highest MDY in the soils of the studied locations. Similar results have been reported. Phosphorus treatments individually or in combination with S yielded a significant increase in the dry matter yield and

consequently the grain yield of maize plants (Taalab *et al.*, 2008). Positive response of maize to low P application in the derived and Southern guinea savanna zones of Nigeria reported by Adediran and Banjoko (1995) showed that application of 40 kg P ha<sup>-1</sup> appeared to be optimum. The increased grain yield observed in a part of Southern guinea savanna at 60 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> was not significantly different from that from 40 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> (Adediran and Banjoko 1995). Grain yield reduction in maize observed from higher P application (60 kg P ha<sup>-1</sup>) was suggested to be due to the increase in P from 40 to 60 kg P ha<sup>-1</sup> (Onasanya *et al.*, 2009).

Interactions of soil nutrient affect their availability to crops as an overabundance of one may result in deficiency of another (Karimizarchi *et al.*, 2014). The synergism (Alabata II and III soils) and antagonism (Alabata I soil) between P and S fertilizers on maize yield observed in this study are also in line with previous findings. Synergistic relationship was reported by Rajan *et al.* (1996) where treatments receiving phosphate fertilizer with S had higher dry matter and grain yield of maize than those without S application. It was also observed from other studies that treating rock phosphate with elemental S resulted in a considerable increase in available P with time (Taalab *et al.*, 2008). The effective utilization of P sources in combination with S was obvious because S decrease soil pH, which helped in transformation of insoluble P to available form. This synergy between the two nutrient elements plus citric acid on improving maize yield through the solubilising effects of S and citric acid has been reported, in which mixing the various P sources with S and/or citric acid significantly increased the P uptake by maize plants (Taalab *et al.*, 2008). In addition, application of P fertilizer results in increased anion adsorption sites, which releases sulphate ions into the solution (Tiwari and Gupta, 2006). The capacity of applied S to reduce soil pH and increase availability of other nutrients to plant has enhanced the synergy between P and S. A previous report showed that application of elemental S at a rate of 0.5 g S kg<sup>-1</sup> soil decreased soil pH value from 7.03 to 6.29 and significantly increased availability of Mn and Zn which resulted in a 45% increase in total MDY (Karimizarchi *et al.*, 2014). Apart from the synergistic effect of S on P, a number of studies also indicted synergism from combined application of S and N on maize (Fazli *et al.*, 2008). Maize crop fertilized at the rate of 150 kg P ha<sup>-1</sup> and 20 kg S ha<sup>-1</sup> produced significantly maximum grain yield (Muhammad *et al.*, 2004).

The observed antagonistic relationship between P and S has been earlier reported in mung and wheat (Islam *et al.*, 2006) and in maize grain yield

(Muhammad *et al.*, 2015). Studies have showed that P and S content in maize leaves indicated that higher level of S (75 kg ha<sup>-1</sup>) resulted in low uptake of P and vice versa, indicating their antagonistic effect. This effect was displayed in the yield whereby maximum grain yield was obtained where higher dose of P along with lower level of S was beneficial (Muhammad *et al.*, 2015). In related studies in some South-western Nigerian soils (Adetunji, 1991), phosphorus addition resulted in depression in sulphate adsorption in which when lime was added together with phosphorus, resulted in displacement of adsorbed sulphate, suggesting high leaching losses of sulphur in soils receiving high phosphorus fertilizer application. Application of P and S beyond a certain level also results in adverse effects on maize productivity depending on soil type. According to Karimizarchi *et al.* (2014) despite the inverse relationship between S and soil pH, continued decreasing trend of soil pH by S became detrimental to crops as pH reduction to 3.93 resulted in significant loss of 57% total dry weight of maize. Increasing S application beyond 45 kg ha<sup>-1</sup> also reduced the available P content in soil (Muhammad, 2015). Interaction between P and N on maize grain yield has also been reported. Response of maize plant to application of N and P fertilizers varies with crop varieties, location and availability of the nutrients and application of 120 kg N ha<sup>-1</sup> + 40 kg P ha<sup>-1</sup> significantly enhanced maize grain yield in Southern Nigeria (Onasanya *et al.*, 2009). Application of high rate of P was reported to be capable of causing nutrient imbalance and consequently yield depression of maize (Adediran and Banjoko, 1995). This implies that both antagonism and synergy do occur between P and S on their effects on dry matter and grain yield of maize and the interaction of these plant nutrients may affect the critical level of available P and S in soils and plants (Choudry and Das, 1996). The type of interaction between nutrients also depend on soil type since Obantoko I soil showed similar dry matter yield to P with or without S application. Higher level of P with lower S usually results in better maize yield (Muhammad *et al.*, 2015; Adediran and Banjoko, 1995); however, optimum rates of P and S fertilizer for maize productivity vary with soil type.

## CONCLUSION

Application of S fertilizer appears not to be critical to production of maize on the soils of the study areas. However, responses to P applications were observed. Our findings show that P rate of 30 or 45 kg P ha<sup>-1</sup> with or without 10 or 20 kg S ha<sup>-1</sup> produced the maximum maize dry matter yield in the soils with the exception of soil of Obantoko II, where the effect of P application was not significant since the soil

contain sufficient amount of P. Also, both synergistic and antagonistic relationship was observed between P and S based on soil type and this resulted in significant effects on the biomass yield of maize. Higher level of P with lower S rate synergistically enhanced maize yield. However, an optimum combination of the two nutrient elements must be determined for specific locations in order to avoid their antagonism and reduction in maize productivity. The observed optimum rate of P and S fertilizers is recommended for the soil of the study locations for high maize yield since interaction of the two nutrients affects their availability to plant. Meanwhile, for effective use of P and S fertilizers in the study areas, field studies on their single and interactive effects on maize grain yield are recommended.

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