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Uptake and Agronomic Efficiencies of Nitrogen, Phosphorus and Potassium in Sesame (*Sesamum indicum* L.)

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ABSTRACT

Field experiments were conducted during the 2005 and 2006 rainy season at the Food and Agriculture Organisation/Tree Crop Programme (FAO/TCP) Teaching and Research farm of the Adamawa State University, Mubi to assess the uptake and agronomic efficiencies of N, P and K in sesame (*Sesamum indicum* L.) in Mubi, Northern Guinea savanna of Nigeria. The experiment consisted of 4 nitrogen rates (0, 37.5, 75 and 112.5 kg ha⁻¹), 3 phosphorus rates (0, 22.5 and 45 kg ha⁻¹) and 3 rates of potassium (0, 22.5 and 45 kg ha⁻¹), laid out in a Randomized Complete Block Design (RCBD) replicated three times. The results showed that seed yield (678.89 kg ha⁻¹) and dry matter yield (2005 kg ha⁻¹) were optimum at 75 kg N ha⁻¹ fertilization. Dry matter yield (1913 kg ha⁻¹) and seed yield (654 kg ha⁻¹) were optimum at 45 kg P₂O₅ ha⁻¹. Application of K did not significantly influence growth and yield components of sesame. All interactions were significant for seed yield and that of N×P×K (815 kg ha⁻¹) was the highest. N uptake (27.45 kg ha⁻¹) was highest at 45 kg P₂O₅ ha⁻¹, P uptake (2.0 kg ha⁻¹) at 75 kg N ha⁻¹ and K uptake (28.70 kg ha⁻¹) was at 112.5 kg ha⁻¹. Interaction of N×P and N×K were significant for P and K uptake, respectively. The different grain yield responses were linked to their differences in N and P uptake and their utilization efficiencies. Application of N increased shoot N:P ratio while P and K decreased it. Agronomic efficiencies of N (2.26) and P (3.32) were highest at 75 kg N and 22.5 kg P₂O₅ ha⁻¹, respectively. Apparent N recovery was 17.8% at 75 kg N ha⁻¹ while that of P was 2% at 22.5 kg P₂O₅ ha⁻¹. N and P utilization efficiencies were 14.33 and 168%, respectively making 75 kg N and 45 kg P₂O₅ ha⁻¹ better choice at low K for nutritional balance.

Key words: Nitrogen, phosphorus, potassium, nutrient use efficiency, sesame

INTRODUCTION

Understanding the factors involved in the uptake of nitrogen, phosphorus and potassium and their utilization by sesame in soils of low nutrient status has important implications for its improved nutrition and productivity. Sesame or benniseed (*Sesamum indicum* L.) is an ancient and important oil seed crop cultivated in almost all tropical and sub tropical Asia and African countries for its highly nutritious and edible seeds (Iwo *et al.*, 2002). Researches on the nutrition of sesame in the tropics have shown significant yield increase due to nitrogen (N), phosphorus (P) and potassium (K) in India (Subramanian *et al.*, 1979; Daulay and Singh, 1982; Kalaiselvan *et al.*, 2002), Pakistan (Malik *et al.*, 2003), N and P in Tanzania (Taylor *et al.*, 1986). However, in other investigations, Olowe and Busari (2000) and Muhamman *et al.* (2009) reported non-significant responses to P fertilization while Voh (1998) observed that of K fertilization.

Many studies have been conducted to elucidate the factors controlling N, P and K uptake efficiencies and nutrient content in plants; extent of root-soil association, amount of N, P and K

supply, uptake efficiency of the root system and soil moisture supply (Cox *et al.*, 1985; Tillman *et al.*, 1991). In another plant nutrition studies, Mengel *et al.* (1983) observed that nutrient uptake rates are determined mainly by the physiological need of the plant. Shoot N content and uptake increased with increased N fertilization (Shehu *et al.*, 2010). N and P are the two main nutrients responsible for biodiversity decline in grassland ecosystems (Gusewell, 2005). The contrasting effects of N and P fertilizations indicate that plants are sensitive to the ratio of nutrients but also these sensitivities may vary among species (Gusewell, 2004). Several field observations demonstrate the importance of a balance between N and P and in others N, P and K. Varying the N: P ratios by adding one or more elements may induce different responses in different plants. Therefore it becomes imperative to assess the dynamics of fertilizers applied for better understanding of the plant N, P and K utilization and efficiencies for optimum yield of the crop. Hence, this study was initiated with the objectives of assessing the uptake and agronomic efficiencies of N, P and K fertilizers in the nutrition of sesame.

MATERIALS AND METHODS

Two years field study were conducted during the 2005 and 2006 rainy seasons at the Food and Agricultural Organisation of the United nations/Tree Crop Programme (FAO/TCP) Teaching and Research farm of the Adamawa State University, Mubi (10° 11' N: 13° 19' E, altitude 594 m above sea level) Northern Guinea savanna of Nigeria. The climate of the area is characterized by alternate wet and dry seasons. The rains last from April to October with a mean annual rainfall ranging from 700 to 1.050 mm. The rainfall is unimodal, reaching its peak in the month of July and August. The vegetation is of typical Northern Guinea savanna. The soils of the experimental site have been classified as Entisols (Soil Survey Staff, 1975) or lithosols, FAO/UNESCO classification).

Soil sampling and analysis: Soil samples were collected at 0-15 cm depths, air dried, crushed and sieved through a 2 mm screen for analysis prior to the beginning of the experiment. Standard methods were used to analyze the samples as follows: Soil reaction (pH) were determined in the supernatant of 1:2.5 soil-water with a pH meter; particle size distribution by the hydrometer method (Bouyoucos, 1962); total N by a modified Kjeldahl method (Bremner, 1982); available P was extracted by Bray P1 method Bray and Kurtz (1945) and determined by spectrometry; exchangeable cations were extracted in 1M NH₄OAc buffered at pH 7 (Page *et al.*, 1982). Calcium and Mg were determined by atomic absorption spectrophotometer and K and Na by flame photometer. Effective cation exchange capacity was estimated by summation of exchangeable bases (Rhodes, 1982) and exchange acidity by KCl extraction method (McLean, 1965). Organic carbon was determined by wet oxidation method (Walkley and Black, 1934) while Zn and Mn as described by Lindsay and Norvell (1978).

Apparent Nutrient Recovery (ANR), agronomic and nutrient utilization efficiencies (AE and NUE) were calculated as follows:

$$\text{Apparent nutrient recovery (ANR)} = \frac{\text{N uptake}_t - \text{N uptake}_c}{\text{N fertilizer applied}} \text{ kg/kg}$$

$$\text{Agronomic efficiency (AE)} = \frac{\text{Grain yield}_f - \text{Grain yield}_c}{\text{Fertilizer N applied}} \text{ kg/kg}$$

$$\text{Nutrient utilization efficiency (NUE)} = \frac{\text{Grain yield}_f - \text{Grain yield}_c}{\text{N uptake}_f - \text{N uptake}_c} \text{ kg/kg}$$

where the indices, f and c denote ‘fertilized crop’ and ‘unfertilized controls’ respectively (Crasswell and Godwin, 1984; Mengel *et al.*, 2006).

Statistical analysis: Data collected were subjected to analysis of variance (ANOVA). Duncan’s Multiple Range Test (DMRT) was used for mean separation where differences were significant, at 5% level of probability and correlation analysis was also carried out using SAS (2000).

RESULTS

Texture and some chemical properties of the soil of the experimental site: Soil of the experimental site was sandy loam in texture and slightly acidic in reaction (Table 1). The soil was also characterized by low organic carbon (<1%), total N (<0.1%), available P (<7 mg ka⁻¹), K (<0.3 cmol kg⁻¹), zinc (<3.99 mg ka⁻¹) and Mn (37.83 mg kg⁻¹).

Seed yield: The effect of N, P and K fertilizers on the seed yield of sesame is presented in Table 2. Effect of N fertilizer application was significant on seed yield. Seed yield increased linearly with increasing N rates up to 75 kg N ha⁻¹ and yields at N rates up to 75 kg N ha⁻¹ were significantly different from each other. However, there was no significant difference between the seed yield obtained from the application of 75 and 112.5 kg N ha⁻¹ but significantly higher than at 0 and 37.5 kg ha⁻¹. Also seed yields produced from N application 0 and 37.5 kg N ha⁻¹ were not significantly different from each other. Similarly, seed yield increased linearly with increasing P

Table 1: Texture and some selected chemical characteristics of soil of the experimental site

Parameters	Value
Sand (g kg ⁻¹)	536
Silt (g kg ⁻¹)	302
Clay (g kg ⁻¹)	162
Textural class	Sandy loam
pH (1:2.5, H ₂ O)	6.2
Organic carbon (g kg ⁻¹)	6.44
Organic matter (g kg ⁻¹)	0.75
Total nitrogen (g kg ⁻¹)	0.15
Available P (mg kg ⁻¹)	2.1
Exchangeable K (Cmol kg ⁻¹)	0.33
Exchangeable Ca (Cmol kg ⁻¹)	4.8
Exchangeable Mg (Cmol kg ⁻¹)	2.27
Exchangeable Na (Cmol kg ⁻¹)	0.98
Available Zn (mg kg ⁻¹)	2.26
Mn (mg kg ⁻¹)	37.83

rates. The differences in seed yields between 0 and 22.5 kg P₂O₅ ha⁻¹ and between 22.5 and 45 kg P₂O₅ ha⁻¹ were significant (p<0.05). Though there was no significant difference in the influence of K fertilizer on seed yield, yield obtained from soils that received N and P were higher than K fertilizer rates. Interactions of N×K, P×K, N×P (Fig. 1a, b and c) and N×P×K (Table 3) were all significant.

Seed yield obtained at 112.5 kg N ha⁻¹ without K was highest (721.02 kg ha⁻¹) but was not significantly (p<0.05) different from the seed yields obtained at all N×K combinations. The interaction effect of P and K was significant on seed yield. Analysis revealed that P and K fertilizer interaction at 45 and 22.5 kg ha⁻¹ produced the highest seed yield of 682.99 kg ha⁻¹. However, this yield did not differ significantly from the other combinations except at 45 kg K₂O ha⁻¹ without P addition which gave the lowest seed yield of 520.27 (kg ha⁻¹). Interaction effects of N and P was significant with combinations of 112.5 and 45 kg ha⁻¹ recording the highest yields of 788.56 kg ha⁻¹. Combinations of N and P at 75 and 22.5, 75 and 45 and 112.5 and 22.5 kg ha⁻¹ were at par.

Table 2: Effect of N, P and K fertilizer on shoot content and uptake of N, P and K by sesame

(Kg ha ⁻¹)					
Fertilizers	Seed yield	Dry matter	N uptake	P uptake	K uptake
Year					
2005	661.11 ^{at}	2139.79 ^a	30.15 ^a	2.17	27.99 ^a
2006	546.52 ^b	1554.49 ^b	19.99 ^b	2.33	21.73 ^b
SE(±)	8.25	48.73	1.73		0.76
LS	**	**	**	ns	**
Nitrogen rates					
0	509.49 ^c	1485.38 ^c	15.40 ^b	1.32 ^b	19.91 ^c
37.5	556.82 ^b	1826.73 ^b	22.03 ^a	1.50 ^b	25.19 ^b
75	678.89 ^a	2005.37 ^{ab}	28.74 ^a	2.00 ^a	25.64 ^b
112.5	680.04 ^a	2071.07 ^a	27.30 ^a	2.14 ^a	28.70 ^a
SE(±)	16.21	97.47	3.24		1.54
LS	***	***	***	ns	***
Phosphorus rates					
0	545.01 ^c	1680.71 ^b	21.13 ^b	1.37 ^b	22.44 ^b
22.5	619.72 ^b	1913.30 ^a	21.51 ^b	1.82 ^a	26.15 ^a
45	654.21 ^a	1947.40 ^a	27.45 ^a	2.02 ^a	25.99 ^a
SE(±)	14.19	84.41			1.31
LS	***	**	ns	ns	*
Potassium rates					
0	620.13 ^a	1877.04	25.62 ^a	1.80	24.23
22.5	611.93 ^{ab}	1875.39	25.30 ^a	1.83	25.22
45	586.88 ^b	1789.00	19.18 ^b	2.59	25.14
SE(±)	14.19	97.47			
LS	ns	ns	ns	ns	ns
Interaction					
N×K	*	ns	ns	ns	*
P×K	*	ns	ns	ns	ns
N×P	***	ns	ns	*	ns
N×P×K	***	ns	ns	ns	ns

Means followed by the same letter (s) in each treatment group are not significantly different at 5% level of probability using duncan multiple range test, NS: Not significant at 5% level of probability, *Significant at 5% level of probability, **Significant at 1% level of probability, ***Significant at 0.1% level of probability

Table 3: Interaction effect of N, P and K fertilizers on seed yield of sesame

N (kg ha ⁻¹)	P (kg ha ⁻¹)	K (kg ha ⁻¹)		
		0	22.5	45
0	0	378.66 ^j	496.99 ^{fj}	475.93 ^{gj}
	22.5	535.27 ^{ej}	471.27 ^{hj}	490.55 ^{gj}
	45	604.83 ^{di}	515.38 ^{ej}	526.54 ^{ej}
37.5	0	572.33 ^{ei}	554.69 ^{ei}	507.00 ^{ej}
	22.5	552.42 ^{ei}	556.43 ^{ei}	608.16 ^{di}
	45	447.39 ^{ij}	596.41 ^{di}	616.59 ^{dh}
75	0	636.12 ^{eg}	656.52 ^{bf}	521.29 ^{ej}
	22.5	792.64 ^{ab}	66.96 ^{ae}	747.76 ^{ad}
	45	668.84 ^{ae}	815.44 ^a	603.42 ^{di}
112.5	0	614.06 ^{dh}	549.67 ^{ei}	576.85 ^{ei}
	22.5	771.51 ^{ac}	657.66 ^{bf}	584.98 ^{ei}
	45	777.49 ^{ac}	804.71 ^{ab}	783.47 ^{ac}
SE(±)			66.61	

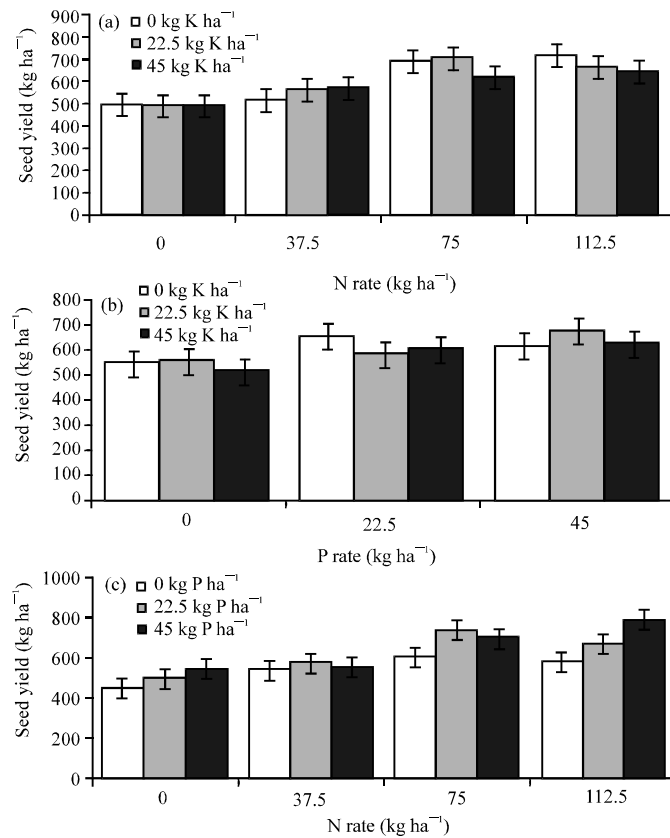


Fig. 1(a-c): Interaction effect of (a) N and K, (b) P and K and (c) N and P fertilizers on seed yield of sesame

Dry matter yield: Application of N fertilizer had significant influence on dry matter yield (Table 2). Dry matter yields obtained with 75 and 37.5 kg N ha⁻¹ were at par with the highest dry matter obtained from the application of N at 112.5 kg ha⁻¹. However, all the yields were

significantly different from the lowest dry matter yields obtained from treatments without N fertilizer application. Dry matter yields produced with P fertilizer application rates of 22.5 and 45 kg P ha⁻¹ were at par but significantly higher than that produced without P addition.

The effect of K showed that there was no significant difference among the dry matter yields at different P fertilizer rates. Application of 22.5 kg K₂O ha⁻¹ fertilizer produced the highest dry matter yield (1675.54 kg ha⁻¹) which did not differ significantly from that (1507.54 kg ha⁻¹) produced where K fertilizer was not applied. The lowest dry matter yield (1480.00 kg ha⁻¹) was recorded where 45 kg K₂O ha⁻¹ fertilizer was applied. First and second order interactions did not show any significant difference in dry matter yields.

N, P and K uptake by sesame: The effect of N fertilization on the uptake of N, P and K is shown in Table 2. The highest value of N uptake was 28.74 (kg ha⁻¹ with 75 kg N ha⁻¹). The amount of N uptake with 112.5 kg N ha⁻¹ was not significantly different from those with 37.5 and 75 kg N ha⁻¹ application. However, N uptake was higher by 6.63% at 37.5, 13.34% at 75 and 11.9% at 112.5 kg N ha⁻¹ over 0 kg N ha⁻¹. The influence of P fertilizer on N uptake was significant with highest value obtained at 45 kg P₂O₅ ha⁻¹ application which was significantly different from N uptake recorded at 0 and 22.5 kg P ha⁻¹. The N uptake advantage recorded with 45 kg P₂O₅ ha⁻¹ application over 0 and 22.5 kg P₂O₅ ha⁻¹ were 29.91 and 27.62%, respectively. Nitrogen uptake decreased with increase in K rates up to 45 kg K₂O ha⁻¹. The highest N uptake (25.62 kg ha⁻¹) was obtained with 0 kg K₂O ha⁻¹. The N uptake at 0 kg K₂O ha⁻¹ was greater by 1.26 and 33.5% over N uptakes at 22.5 and 45 kg ha⁻¹, respectively while interactions of N×K was significant (Fig. 2a). There were no significant effect of N×P×K fertilizers on the uptake of N in sesame.

The effect of N fertilizer application was significant on P uptake with 75 and 112.5 kg N ha⁻¹ application were statistically at par but differed significantly from P uptake recorded with 0 and 37.5 kg N ha⁻¹ (Table 2). Highest P uptake recorded was 2.14 kg ha⁻¹ as its optimum was obtained at 75 kg N ha⁻¹ application (2.00 kg ha⁻¹).

Application of P fertilizer had significant influence on P uptake (Table 2). Optimum P uptake of 1.82 kg ha⁻¹ was obtained with 22.5 kg P₂O₅ ha⁻¹ application in the combined analysis.

There was no significant P uptake response from K supply. Application of P fertilizer at 22.5 kg P₂O₅ ha⁻¹ gave the highest P uptake of 1.43 kg ha⁻¹ and this was at par with P uptake obtained from soils that did not receive K fertilizer. The interaction of N and P at 112.5 and 45 kg ha⁻¹ recorded the highest P uptake of 2.77 kg ha⁻¹ (Fig. 2b) while the second order interaction (N×P×K) effect was not significant in P uptake in sesame.

Application of N at 112.5 kg ha⁻¹ significantly increased K uptake by 44.15% over 0 kg N ha⁻¹ and was significantly higher than K uptake at 75 and 37.5 kg ha⁻¹ by 11.93 and 13.39%, respectively (Table 2). This showed that increase in N application rate increased K uptake in sesame.

Soils that did not receive P fertilizer recorded the lowest K uptake (22.4 kg ha⁻¹) and significantly different from K uptake at 22.5 and 45 kg ha⁻¹ which in turn were not significantly different from each other (26.15 and 25.99 kg ha⁻¹, respectively). There was significant effect on the uptake of K from K fertilizer application.

The highest K uptake of 31.32 kg ha⁻¹ was recorded at N and K application of 112.5 and 45 kg ha⁻¹, respectively. However this was only significantly different from the lowest K uptake of 18.05 kg ha⁻¹ obtained from soils that did not receive any N and K fertilizers. Phosphorus and K interaction was not significant for K uptake by sesame.

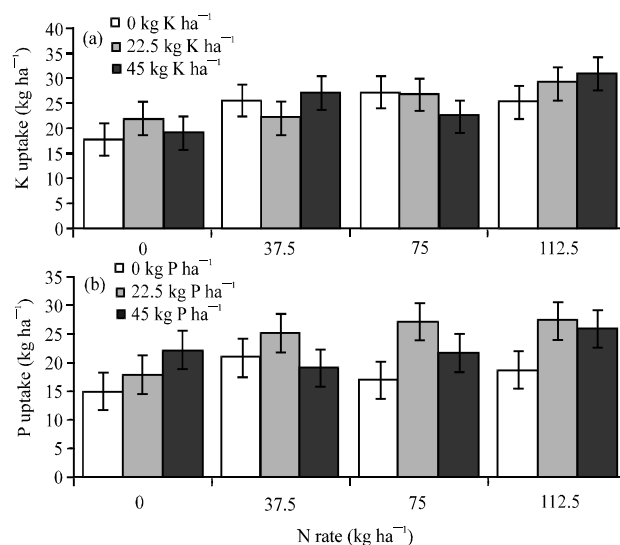


Fig. 2(a-b): Interaction effect of (a) N and K on K uptake, (b) N and P on P uptake

Table 4: Correlation among yield and N, P and K uptake by sesame

Parameters	Seed Yield	Dry matter	N uptake	P uptake	K uptake
Seed yield	1.000				
Dry matter	0.606***	1.000			
N uptake	0.495***	0.535***	1.000		
P uptake	0.664***	0.762***	0.450***	1.000	
K uptake	0.518***	0.904***	0.477***	0.659***	1.000

***Significant at 0.1% level of probability

Correlation coefficients among yield characters and N, P and K uptake by sesame: The association between growth, yield characters and N, P and K uptake by sesame is presented in Table 4. N uptake was positively related to number of branches, number of capsules, seed yield and dry matter ($r = 0.269, 0.150, 0.495$ and 0.535 , respectively) While P uptake was positively related with number of capsules, seed yield, dry matter and N uptake ($r = 0.266, 0.664, 0.762$ and 0.450 , respectively). K uptake was positively associated with number of branches, number of capsules, number of seed per capsule, seed yield, dry matter, N and P uptake ($r = 0.408, 0.253, 0.142, 0.518, 0.904, 0.477$ and 0.659 , respectively).

N:P stoichiometry: The effect of N, P and K fertilizers on N:P stoichiometry in sesame is presented in Table 5. Where no N fertilizer was applied, N:P was the lowest (12.56) while the widest N:P (15.57) was recorded with $37.5 \text{ kg N ha}^{-1}$ application followed by 75 and $112.5 \text{ kg N ha}^{-1}$ with corresponding N:P of 14.99 and 14.81 , respectively. The N:P recorded as a result of P fertilizer application shows that soils that did not receive P fertilizer and application at $45 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$ were at par with N:P of 16.06 each. For K fertilizer application, the narrowest N:P (13.06) was recorded with $45 \text{ kg K}_2\text{O ha}^{-1}$ fertilizer application while the widest (15.49) was produced by treatments that did not receive K fertilizer. The relationship between N uptake and P uptake is positive ($R^2 = 0.3$) as shown in Fig. 3. The strength of relationship between N:P ratio and N uptake and N:P ratio and P uptake is shown in Fig. 4 and 5, respectively.

Table 5: Effect of N, P and K fertilizer on the stoichiometry of N:P, efficiency, utilization and recovery of the nutrients in sesame

Treatment	N:P	Agronomic efficiency (AE)	Nutrient utilization efficiency (NUE)	Apparent nutrient recovery (ANR)
N (kg ha⁻¹)				
0	12.56			
37.5	15.57	1.26	7.14	17.68
75	14.99	2.26	12.70	17.79
112.5	14.81	1.52	14.33	10.58
P (kg ha⁻¹)				
0	16.06			
22.5	12.71	3.32	166.03	2.00
45	16.06	2.43	168.00	1.76
K (kg ha⁻¹)				
0	15.49			
22.5	14.68	-0.36		-0.13
45	13.06	-0.74		-0.64

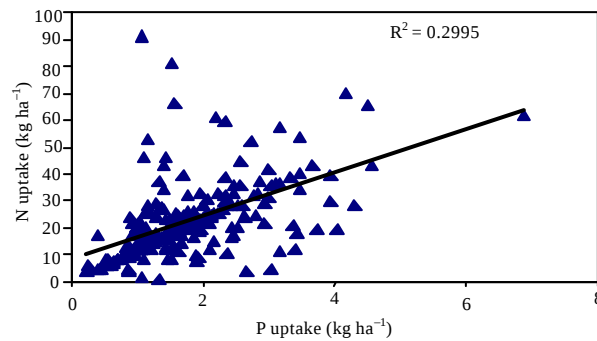


Fig. 3: Relationship between nitrogen uptake and phosphorus uptake in sesame

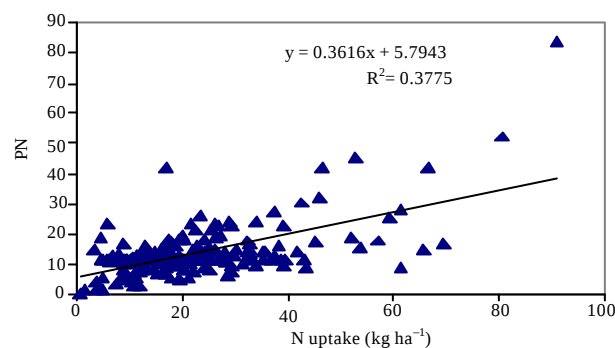


Fig. 4: Relationship between N:P ratios and uptake of N in sesame

Agronomic Efficiency (AE): The agronomic efficiency of N, P and K in sesame is shown in Table 5. In the three rates of fertilizer applied, 75 kg N ha⁻¹ had the highest (2.26) AE followed by 112.5 kg N ha⁻¹ application that had 1.52 while the application of 37.5 kg ha⁻¹ had the lowest with corresponding value of 1.26. In the P level, 22.5 kg P ha⁻¹ application had the highest AE compared

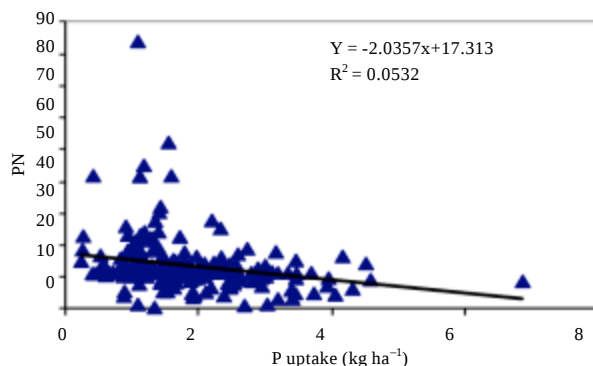


Fig. 5: Relationship between N:P ratios and P uptake in sesame

to 2.43 recorded with 45 kg P_2O_5 ha^{-1} . Potassium fertilizer application recorded a negative AE from 22.5 and 45 kg K_2O ha^{-1} application with corresponding values of -0.36 and -0.74, respectively.

Nutrient Utilization Efficiency (NUE): The NUE recorded as a result of N, P and K fertilizer application in sesame is presented in Table 5. The highest NUE (14.33) was obtained at 112.5 kg N ha^{-1} rate followed by 75 and 37.5 kg N ha^{-1} rates with corresponding NUE of 12.70 and 7.14, respectively. For P fertilizer, 45 kg P_2O_5 ha^{-1} rate recorded a higher NUE of 168 than 22.5 kg P_2O_5 ha^{-1} rate (166). Determining the NUE of K at 22.5 and 45 kg K_2O ha^{-1} is of no use since its application did not produce any significant influence on seed yield and its uptake.

Apparent Nutrient Recovery (ANR): The amount of N, P and K recovered from the application of their fertilizers are shown in Table 5. The highest ANR of 17.79% was recorded from the application of 75 kg N ha^{-1} followed by 17.68 and 10.58% recorded from 37.5 and 112.5 kg N ha^{-1} rates, respectively. For the application of P fertilizers, 2.00 and 1.76 % were recorded from 22.5 and 45 kg P_2O_5 ha^{-1} rates, respectively. Potassium fertilizer application recorded a negative value of 0.13 and 0.64% from 22.5 and 45 kg K_2O ha^{-1} rates, respectively.

DISCUSSION

After two years of field experimentation, the result shows that application of N significantly ($p < 0.05$) enhanced seed yield. Seed yield increased significantly with N application at 37.5 and 75 kg N ha^{-1} but further increase of N to 112.5 kg N ha^{-1} did not produce further beneficial effect. This might suggest that plant benefited from N application where growth characters such as number of branches and number of leaves provided better opportunity for higher sunlight interception. Present findings support earlier studies by Roy *et al.* (1995) from which highest seed yield of sesame in India was obtained at 120 kg N ha^{-1} . Sumathi and Jaganadham (1994) obtained maximum sesame yield with 60 kg N ha^{-1} . Babaji *et al.* (2006) also reported highest seed yield at 90 kg N ha^{-1} . Significant increase in seed yield from phosphorus fertilization at 22.5 and 45 kg P_2O_5 ha^{-1} was established in this study. Application of P at 45 kg P_2O_5 ha^{-1} increased seed yield by 20%. The significant increase in seed yield by phosphorus fertilization in this study corroborate with the findings of Dashmukh *et al.* (1990) and Kene *et al.* (1992) who reported significant increase in seed yield of sesame with application of 40 and 75 kg P_2O_5 ha^{-1} , respectively.

Weiss (1983) observed that over large areas of Africa, lack of P was a major factor limiting crop production and even where there is no deficiency, an annual application at planting resulted in considerable yield increases. However, this differs with the findings of Olowe and Busari (2000) who reported non significant increase in seed yield of sesame up to 60 kg P₂ O₅ ha⁻¹.

The lack of response of sesame seed yield to K fertilization has been noted by many workers. This study has shown that K fertilization at 22.5 and 45 kg K ha⁻¹ depressed seed yield by 1.3% and 5.4%, respectively. This result agrees with El-Emam *et al.* (1998) who reported that all characters including seed yield showed a negative response to K₂O except 1000 seed weight. Beltrao *et al.* (1991) confirms non response of seed yield to K fertilization.

The significant interaction effects of N×K and P×K for seed yield of sesame shows that the contribution of K to the nutrition of N is not significant since the significant difference is obtained where fertilization did not take place. Similar response was also recorded for P×K interaction. Phosphorus plays a major role in the formation of more roots thereby, enhancing the uptake of more nutrients including N. Similar results were reported by Cope and Hunter (1967).

While Haggai (2004) recommended combination of 60 kg N and 50 kg P₂ O₅ ha⁻¹ in northern guinea savanna, Olowe and Busari (2000) reported highest seed yield of sesame at 60 kg N and 30 kg P₂ O₅ ha⁻¹ combination in the southern guinea savanna. These results contradict the findings of Babaji *et al.* (2006) and Muhamman and Gungula (2008) who reported non significant interactions of N×P for seed yield of sesame. However, the N×P×K significant interaction could be attributed to nutritional balance.

Application of N at 112.5 kg ha⁻¹ produced 2071 kg ha⁻¹ dry matter which was a 39.4% increase over control. Increase in dry matter yield up to 112.5 kg N ha⁻¹ led to excessive vegetative growth at the expense of seed production. This concurs with the findings of Muhamman *et al.* (2009) who reported 3778 kg ha⁻¹ dry matter at 90 kg N ha⁻¹ application rate.

Application of 22.5 kg P₂O₅ ha⁻¹ increased dry matter yield by 13% while further increase in P rate did not significantly increase dry matter yields. This shows that vegetative production was also sacrificed for seed yield production. Different result was reported by Okpara *et al.* (2007) where 90 kg P₂O₅ ha⁻¹ increased dry matter yield by 40% over 0 kg P₂O₅ ha⁻¹ applications. The study also revealed that dry matter yields of sesame responded negatively to K fertilization as increases in K rate depressed dry matter yields. All interactions did not bring any significant change in dry matter yields. The findings of this study showed that for optimum vegetative performance of sesame, higher doses of N is required while for optimum seed yield, much lower doses of N nutrient should be used. Optimum vegetative performance of sesame requires lower doses of P while for optimum seed yield higher doses of P is required. Lower doses of K may be required for nutritional balance. This observation agrees with the findings of Gasques *et al.* (1979), Weiss (1983) and Ugbaja *et al.* (1993) on castor plant.

Higher yield components of sesame recorded in 2005 than in 2006 could be associated with the amount of rainfall received during these periods where annual rainfall of 1110.3 and 981.6 mm were received in 2005 and 2006, respectively. The response of sesame to the amount of rainfall in this study agrees with the findings of Weiss (1983) who reported that sesame will produce an excellent crop with annual rainfall of 500-650 mm.

In the two season of experiment, N fertilization enhanced N uptake and was optimum at 37.5 kg N ha⁻¹. Sieling *et al.* (2006) reported significant high N uptake at 240 kg N ha⁻¹ annual fertilization in oil seed rape. The optimum level of N uptake at low N rate could be due to low soil P, since, adequate P enhances N uptake through production of more roots for N uptake. This is also

indicated in the greater N uptake at 45 kg P ha⁻¹ fertilization. Also, Mengel *et al.* (2006) reported that without applications of P and K the yield responses to N application were smaller.

Phosphorus uptake was enhanced by 57% from N fertilization at 75 kg N ha⁻¹ over control. The uptake increased seed yield at N and P combination by 16.2 and 20.5% over seed yields for N and P separately. This agrees with the findings of Venterink *et al.* (2001) and Flynn (2002) who reported that when a response of a system to two or more factors (N×P) is greater than its response to each factor in isolation, co-limitation is operationally identified. Havlin *et al.* (2005) reported that N promotes P uptake by increasing tap root growth, increasing plant metabolism and increasing P solubility and availability through decreasing soil pH as a result of absorption of NH₄⁺ and thus increasing solubility of fertilizer P. It was also observed that, P fertilization enhanced P uptake by 32% at 22.5 kg P₂O₅ ha⁻¹ over control. Thus, the balance between uptake and remineralization result in a moderately stable nutrient concentration in the short term. This is indicated in P concentration to be optimum at 22.5 kg P₂O₅ ha⁻¹. Marschner *et al.* (1997) reported that low concentration of P associated with high shoot demand stimulates P uptake. The study also showed that interaction of N and P for P uptake was significant indicating the co-limitation of these nutrients.

Application of 37.5 and 112.5 kg N ha⁻¹ increased K uptake by 26 and 44% over the control, respectively. This was indicated in a significant and positive correlation between N fertilization and K uptake ($r = 0.318^{***}$) while N enhances structural build up of the plant (both phloem and xylem), K transport structures and medium were enhanced. This agrees with the findings of Glass (1983) who reported that the diversity of K uptake system allows an efficient control of K uptake and K distribution in plant tissues according to the needs of the plants. This was also indicated in the significant interaction between N and K for K uptake. Results also showed that P fertilization at 22.5 kg P₂O₅ ha⁻¹ enhanced K uptake by 16% over control while further increase in P fertilization reduced K uptake. Potassium uptake increased by 4.1% at 22.5 kg K ha⁻¹ and this agrees with Kemp (1983) who reported same.

N:P ratio varied between 15.57 and 14.81 at N fertilization. Scatter plots of N uptake as a function of P uptake indicated variation between 20.32 and 4.56. The N:P ratio is a direct function of N uptake and an inverse function of P uptake. Associations between N:P and N uptake were evident and N:P and P uptake was verified for sesame. The association found between N:P and N uptake is at variance with that of grain legume as reported by Sadras (2006). However, the relationship between N:P and P uptake for sesame as an oilseed crop differed with cereals and legumes. Therefore, there was a greater influence of N uptake than P uptake on N:P ratio, i.e., $R^2 = 0.053$ for N versus $R^2 = 0.377$ for P. This result varied with Sadras (2006) observation. He reported greater influence of P uptake than N uptake on N:P ratios for cereals. However, it concurred with that of domesticated legumes species where N had greater variation on N:P ratio than P.

Nitrogen agronomic efficiency of sesame applied at 75 kg N ha⁻¹ recorded the highest AE (2.26) indicating 2.26 kg grain (kg N applied)⁻¹. This value is 79 and 48% higher than AE obtained with 37.5 and 112.5 kg N ha⁻¹, respectively. According to Mengel *et al.* (2006), AE for a nutrient should not be less than 5. This result therefore shows that the highest AE of 2.26 at 75 kg N ha⁻¹ is only 45% of the minimum standard AE. Values of AE may be lower than 5 since it is dependent upon soil, crop, nutrient rate and losses and this indicates that higher rate of N were not well utilized though a limiting nutrient. This is indicated in the non significant difference in the seed yield at 75 and 112.5 kg N ha⁻¹.

Phosphorus fertilization indicated a higher AE at 22.5 kg P_2O_5 ha⁻¹ with 36% higher than 45 kg P_2O_5 ha⁻¹ and achieved 66% of the minimum AE standard. This agrees with the contribution of P to the variation in N:P. The reduction in AE of sesame from increased P rate and low net benefit of P fertilization was reported by Mengel *et al.* (2006) for maize. Result has also shown that AE for K from K fertilization were all negative. This has contributed to the non significant response in seed yield to K fertilization with reduced N uptake at higher K rate. This indicates that application of K to sesame plant at 22.5 and 45 kg K_2O ha⁻¹ rates is not beneficial to seed yield. This agrees with the finding of Weiss (1983) who reported that K fertilizer is often applied as part of compound mixture and also there are no reported instances of K toxicity affecting sesame, little or no harm results. Potassium may only be required for nutritional balance.

The variation in NUE of N, P and K applied to sesame indicated that fertilizer rate is a factor influencing its NUE. This result agrees with Sadras (2006) who reported that nutrient availability as affected by soils and fertilizer rates was a major source of variation in yield and nutrient uptake and subsequently nutrient utilization efficiency of oil seed crops. NUE variation of N and K was more than that of P. This is also shown from the close relationship of seed yield to P uptake ($r = 0.664^{***}$) than for N and K uptake ($r = 0.495^{***}$ and 0.518^{***} , respectively). However, these relationships varied with that obtained in cereals as reported by Sadras (2006) who found close relationship of grain to N uptake than P uptake.

The low NUE at low N rate is an indication that the soils is deficient of N and other factors like immobilization, leaching, erosion and volatilization must have contributed in the reduced NUE. However, the amount of NUE increase from increased N rate shows that the demand of the crop must have been met thus giving yields (0.8 ton ha⁻¹) from N, P and K that corroborated with those reported by Rao *et al.* (1993), Nageshwar *et al.* (1995) and Basavaraj *et al.* (2000) ranging between 0.7 to 1.8 ton ha⁻¹.

Phosphorus Utilization Efficiency (PUE) shows that greater proportion of P applied at 22.5 kg P_2O_5 ha⁻¹ has been utilized more than that at 45 kg P_2O_5 ha⁻¹. This is also indicated in the non significant difference in P uptake at the two rates. This corroborates with findings of Mugwira *et al.* (1997) who reported that PUE was mostly determined by P uptake under P deficient condition. This indicates that at higher P rates, after meeting the initial deficiency inherent in the soil and meeting the demand of the plant to completing its life cycle, other part of P might have been fixed to available Fe, Al and Mn in the soil, thus having a lower PUE compared to P at 22.5 kg P_2O_5 ha⁻¹.

The K Utilization Efficiency (KUE) at 22.5 kg ha⁻¹ is 6.5 times that at 45 kg K ha⁻¹. This shows that a small part of K at 22.5 kg ha⁻¹ was utilized. Increasing the rate of K to 45 kg ha⁻¹ reduced KUE. This is shown in the reduced seed yield at higher rate of K.

The amount of N recovered was 0.178 kg N (kg N applied)⁻¹ at 75 kg N ha⁻¹ corresponding with the optimum seed yield. Nitrogen recovery efficiency value of 0.18 obtained in this result is lower than the nutrient recovery efficiency range of 0.3 to 0.8 for cereals reported by Dobermann (2007). Amount of N recovered with 75 and 112.5 kg N ha⁻¹ application corresponds with the significant increase in seed yield by 68%. However, the amount of N recovered does not mean equivalent seed yield increase. The ANR at 37.5 kg N ha⁻¹ were approximately 0.177 kg N (kg N applied)⁻¹ and decreased as N rate exceeded 75 kg N ha⁻¹.

Apparent Phosphorus Recovery (APR) was 0.02 kg P_2O_5 (kg P applied)⁻¹ at 22.5 kg P_2O_5 ha⁻¹ rate. The non significant increase in P uptake from 22.5 to 45 kg P_2O_5 ha⁻¹ rates contributed to

higher P recovery at 22.5 kg P₂O₅ ha⁻¹. This agrees with Havlin *et al.* (2005) who reported that P absorption is greater in soils with little P adsorbed to mineral surfaces. Thus, as fertilizer P is added and the quantity of P increases the potential for additional P adsorption decreases. Therefore, recovery of applied fertilizer P increases when adsorption sites are saturated with phosphates as further adsorption will not occur.

CONCLUSION

The findings in this study indicate that different yield responses of both seed and dry matter were associated with their differences in nitrogen and phosphorus uptake and utilization efficiencies. The lower utilization efficiencies and recovery of nitrogen and phosphorus fertilizers shows that higher doses above 75 kg N and 45 kg P₂O₅ ha⁻¹ will not be beneficial as lower rates of K₂O be added for nutritional balance.

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