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RESPONSE OF SUNFLOWER (*Helianthus annuus* L.) TO PHOSPHORUS AND NITROGEN FERTILIZATION UNDER RAINFED CONDITIONS, BLUE NILE STATE-SUDAN

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SUMMARY

Two field experiments were conducted on a typic chromusterts, fine, smectitic, isohyperthermic soil series in the Damazin Research Station Farm during two seasons (2005/06 and 2006/07). The objective was to investigate the effect of phosphorus (P) and nitrogen (N) and their interactions on sunflower (*Helianthus annuus* L.) growth, seed and oil yield. A randomized complete block design with four replicates was used to execute the experiments. Plant height, dry matter and seed yield were significantly increased by N and P applications in both seasons. The average yield of sunflower seed in the two seasons was 0.486 tons·ha^{-1} for the control and 4.893 tons·ha^{-1} for the highest fertilizer treatment ($N_{80}P_{80}$). Oil seed % gave significant increases in the two seasons due to P, N treatments and their interaction, and the average oil seed was 31.3% for the control compared to 37.5% for the highest treatment ($N_{80}P_{80}$). Phosphorus alone had pronounced effect on oil seed % in the two seasons. There were mutually synergistic effects between N and P which significantly ($P<0.01$) promoted growth and yield of sunflower. Phosphorus enhanced nitrogen uptake and nitrogen use efficiency and *vice versa*. At all N applications, phosphorus use efficiency tended to decrease with increase in the rate of P application. The highly significant response of sunflower to P and N fertilizers warrant recommending their application under the rainfed conditions of Damazin, Sudan.

Key words: sunflower (*Helianthus annuus* L.), phosphorus, nitrogen, semi-arid conditions, rainfed conditions, vertisols

INTRODUCTION

The majority of cultivated lands of the Sudan lie within the rainfed sector; some of them are semi-mechanized and mono-cropped and the rest belong to the traditional subsistence sector. Despite the short periods of rainy season, in most parts rainfed agriculture remains the cheapest economic activity, but it depends on rainfall. Fertility loss is the main common problem associated with shifting cultivation without fertilization practiced on such soils. The deterioration of soil fertility on these soils may be attributed to natural and human activity such as erosion factors, beside mono-cropping, poor agricultural management and practice and inadequate rain fall.

Soil fertility and, hence, sunflower yields in semi arid regions of the Sudan have been declining, because of lack of fertilization and lack of crop rotation. Production of sunflower in Sudan started 1990-1991 and the cultivated area reached 293000 feddans (1 feddan=4200 m^2) mainly in the rainfed area with average yield of 99 kg/ feddan (Faisal *et al.*, 2005). Sunflower research program implemented by Agricultural Research Corporation of the Sudan reported that commercial production of sunflower started in 1986 in the rainfed sector. Areas under the crop had declined dramatically in recent years, productivity is low and production was as low as 0.2 ton per feddan in 1998/1999 according to Faisal *et al.* (2005). Gorashi and Elzein, (2005) reported the average yield in the Blue Nile State as about 0.2 tons/ feddan, and the cultivated area is about 18000 feddan in season 1999/2000.

Application of P affects sunflower growth and yield. The results by Muralidharudu *et al.* (2003) showed high increase in the sunflower plant height, head diameter, shoot dry matter yield and seed yield, as a response to applied phosporus. The response to applied P was more pronounced on soils low in available phosphorus than in the other soils. Rodriguez *et al.* (1998) observed that under P deficiencies sunflower showed a reduction in the rate of leaf expansion and in photosynthetic rate per unit of leaf area.

Fixation of applied phosphorus fertilizer is expected to be high under these conditions. However, the summer rainfall in the southern part of northern Sudan exceeds 700 mm, which is sufficient for many food and cash crops, and the soil pH is near neutral (Table 2) which may decrease P fixation. Research results by Abdalla and El Mahi (1986) indicated good positive response to P and P N interactions of rainfed sunflower grown in the vertisols of the Blue Nile State, Sudan.

Thus, the objective of this study was to investigate the effect of N and P fertilizers and their interactions on rainfed sunflower grown in the neutral to slightly acid soils of the Blue Nile State, Sudan.

MATERIALS AND METHODS

Two experiments were carried out at two sites in the Agricultural Research Station Farm, Damazin, Sudan, located at longitude 34°22' E, latitude 11°47' N and altitude 470 m. Soil is classified as typic chromusterts, fine, smectitic, isohyperthermic (Soil Survey staff, 1976). Sunflower (*Helianthus annuus* L.) was cultivated in the first site in the growing season of 2005/06 and in the other neighboring site in the season of 2006/07. Surface soil samples (0-30 cm) were collected and analyzed. Physical and chemical properties of these soils are presented in Table 1. Soil nitrogen was determined by a modified semi-micro Kjeldhal method (Hesse, 1971). Available soil phosphorus was extracted by sodium bicarbonate and determined spectrometrically, using stannous-chloride - molybdenum-blue method described by Olsen and Sommers (1982). Other soil properties were determined according to the methods of soil analysis described by Page *et al.* (1982).

Table 1: Some chemical and physical properties of Damazin soils cultivated in seasons 2005/06 and 2006/07

Chemical properties

Season	pH paste	EC	$CaCO_3$	Nitrogen	Organic carbon	Soluble cations			Soluble anions		Exchange cations		CEC	Available P
						Na	Ca	Mg	Cl	HCO_3	Na	K		
		dSm^{-1}	%			mel^{-1}					Cmol (+) kg^{-1} soil			$mg{\cdot}kg^{-1}$ soil
2005/06	7.00	0.23	0.60	0.049	0.156	0.68	2.5	0.5	0.5	0.5	1.10	0.65	54	5.0
2006/07	6.92	0.35	0.00	0.031	0.782	1.20	2.3	0.8	2.0	1.5	0.24	0.63	53	5.4

Physical properties

Season	Mechanical analysis				Saturation	Soil moisture				Bulk density $g{\cdot}cm^{-3}$	
	CS	FS	Si	C	%	0.3 bar	15 bar	AWC	Vol %	Dry	Moist
2005/06	7	3	20	70	78	42.5	22.7	22.8	33.7	1.77	1.19
2006/07	3	3	26	68	60	47.7	24.9	23.3	34.5	1.80	1.16

Two factorial experiments were conducted using randomized complete block design with four replicates in both seasons. The levels of fertilizer used were 0, 20, 40 and 80 $kg{\cdot}ha^{-1}$ for both P and N. Phosphorus was applied as triple-superphosphate (before ploughing and planting) and N as urea (split dose after sowing and one month later), and the fertilizer combinations were assigned as 16 different treatments. The plot area was 60 m^2 (12 × 5 m), ridged 75 cm apart. The sowing date in the first season was 3-4 July and the harvest date was 12-14 November, while in second season the dates were 16-17 July and 5-7 December for sowing and harvest, respectively. Plant height was recorded 109 and 107 days after sowing in the first and second seasons, respectively. Dry matter and seed yield were recorded after harvest. Oil content in seed (in %) was determined at Faculty of Agriculture laboratories, University of Khartoum, Shambat, Sudan, using hexane solvent in soxhlet extraction apparatus, according to the procedure described by American Oil Chemists Society (1995). Whole plant samples were randomly taken after harvest for determination of P and N contents, using nitro-vanado-molybdate method for determination of phosphorus (Cottoni, 1980) and modified Kjeldhal method, for determination of nitrogen (Chapman and Pratt, 1961). Nitrogen use efficiency and phosphorus use efficiency were calculated as seed yield per unit area (kg seed ha^{-1}) produced per unit of N and P applied (kg N ha^{-1} and kg P ha^{-1}).

The collected data were statistically analyzed using Statistical Analysis Software SAS version 9.1 (SAS 2009).

RESULTS AND DISCUSSION

Nitrogen and phosphorus fertilization of rainfed cultivation is generally not practiced in dry land farming of the clay plains of northern Sudan. This is probably because water deficit remains the major limiting factor of crop production, and that nitrogen fertilization in particular may encourage vegetative growth, increasing evapotranspiration and, thus, exacerbates the water deficit problem.

Rainfed as well as irrigated crops in the Sudan central clay plain have shown erratic responses to P fertilization. This is in spite of the fact that the $NaHCO_3$ extractable P rarely exceeded 2-3 mg·kg^{-1} in most of these alkaline calcareous dry lands (Dawelbeit *et al.*, 2007). Such values are considered deficient according to the American Society of Agronomy standards (Olsen and Sommers, 1982). Rainfall of the southern part of northern Sudan, however, usually ranges between 600 and 700 mm (Table 2) during a four month growing summer season, and the soil pH therein is near neutral which decreases P fixation.

Table 2: Accumulation of rainfall in millimetres (mm), per day (d) during growing seasons 2005/06 (**a**) and 2006/2007 (**b**)

a)

May		June		July		August		September		October		Total season
d	mm	d	mm	d	mm	d	mm	d	mm	d	mm	
4	20.0	4	15.0	3	42.0	3	4.0	1	3.0	10	4.0	
23	3.0	6	3.5	6	13.0	4	39.0	5	3.0	19	3.0	
25	27	9	23.5	13	21.0	6	22.0	9	21.5	20	1.5	
26	14.5	10	40.0	17	37.0	10	63.0	14	4.0			
27	7.5	13	3.0	21	36.0	14	8.0	18	5.0			
		19	6.0	25	64.0	15	38.0	21	16.0			
		20	3.0	28	8.0	16	43.0	26	37.0			
		23	40.0			17	16.0	28	1.5			
		28	4.5			18	10.0					
						27	4.0					
						31	1.0					
						Total						
70.0		138.5		221.0		248.0		91.0		8.5		777.0

b)

May		June		July		August		September		October		Total season
d	mm	d	mm	d	mm	d	mm	d	mm	d	mm	
		12	10.0	16	8.0	1	5.5	1	6.0	17	33.0	
		13	7.0	18	13.0	4	43.0	8	8.0	22	42.0	
		18	16.0	20	47.0	14	59.0	10	17.0	29	2.0	
		20	18.0	22	8.0	23	26.0	14	2.0			
		22	11.5	25	43.0	25	58.0	17	2.0			
		25	13.0	28	26.5	29	2.0	23	25.0			
								26	5.0			
						Total						
		75.5		145.5		193.5		65.0		77.0		556.5

Table 1 shows low total N, and that available P ($NaHCO_3$ extractable- P) was 5 $mg{\cdot}kg^{-1}$soil in the soil of the experimental sites. Olsen and Sommers (1982) consider that crops grown in such soils are likely to respond to P fertilization. In the two seasons there was significant ($P<0.01$) increase in plant height (109 days after sowing) due to P application, also nitrogen application gave significant increase in plant height in both seasons (Tables 3 and 4). The results of the present experiment also indicated a significant ($P<0.01$) interactive effect of P and N application on sunflower plant height in both seasons (Table 3 and 4).

Table 3: Effect of N, P and their interaction on plant height, dry matter production seed yield and nutrients uptake of sunflower grown in season 2005/2006

Treatments	Plant height	Dry matter	Seed yield	N uptake	P uptake	Oil
	cm	$kg{\cdot}ha^{-1}$	$ton{\cdot}ha^{-1}$	$kg{\cdot}ha^{-1}$	$kg{\cdot}ha^{-1}$	%
P ($kg{\cdot}ha^{-1}$)						
0	92.49 a	2170 a	0.898 a	64.82 a	5.42 a	23.18 a
20	101.45 b	3325 b	2.180 b	82.81 b	10.48 b	25.01 b
40	113.46 c	3599 c	3.144 c	97.81 c	13.17 c	28.44 c
80	141.59 d	3906 d	3.884 d	118.70 d	16.04 d	32.00 d
N ($kg{\cdot}ha^{-1}$)						
0	95.20 a	2724 a	1.520 a	61.20 a	8.73 a	24.21 a
20	108.0 b	3262 b	2.410 b	84.70 b	11.11 b	26.89 ab
40	118.6 c	3446 c	3.010 c	99.70 c	12.16 c	27.87 b
80	127.2 d	3570 c	3.170 c	118.50 d	13.12 d	29.66 c
N*P combination ($kg{\cdot}ha^{-1}$)						
$P_{00}N_{00}$	82.98 a	1501a	0.335 a	33.03a	3.00a	21.99 a
$P_{00}N_{20}$	90.63 a	2182a	0.886 a	62.53a	4.99a	22.35 a
$P_{00}N_{40}$	96.38 a	2400a	1.177 a	79.40a	6.56a	23.34 ab
$P_{00}N_{80}$	99.98 a	2597a	1.195 a	84.33a	7.15a	25.08 b
$P_{20}N_{00}$	88.70 a	2934b	1.574c	61.48b	8.55b	21.99 a
$P_{20}N_{20}$	96.03 a	3198b	1.785b	70.35b	10.12b	25.49 bc
$P_{20}N_{40}$	107.73 b	3549b	2.562 b	88.10b	11.04b	25.97 bcd
$P_{20}N_{80}$	113.38 b	3622b	2.799 b	111.3b	12.19b	26.58 bcd
$P_{40}N_{00}$	95.30 b	2987b	1.468b	67.73bc	9.89c	26.39 bcd
$P_{40}N_{20}$	102.05 b	3661c	2.842 c	87.30c	13.13c	27.58 de
$P_{40}N_{40}$	121.50 c	3851c	4.074 c	103.55b	14.50c	28.66 e
$P_{40}N_{80}$	134.98 c	3896c	4.193c	132.60c	15.16c	31.15 f
$P_{80}N_{00}$	114.03 c	3473c	2.685 d	82.75b	13.47d	26.49 bcd
$P_{80}N_{20}$	143.23 c	4005d	4.138 d	118.65d	16.19d	32.16 f
$P_{80}N_{40}$	148.60 d	3983c	4.226 d	127.65c	16.56d	33.50 fg
$P_{80}N_{80}$	160.50 d	4163d	4.486 d	145.6d	17.97d	35.84 h
CV%	9.24	7.147	20.63	17.17	9.67	5.97

Means in the same columns followed by the same letter(s) are not significantly different at 0.05 probability level according to Duncan's multiple range test.

The synergistic effect of phosphorus and nitrogen on each other was also clear on dry matter production and seed yield (Figure 1) in the two seasons. The increases in dry matter and yield due to N fertilizer application were expected as these vertisols are usually deficient in nitrogen (Table 1). This deficiency is generally attributed to the low amount of soil organic matter as mentioned by Syers *et al.* (2001). Tables 3 and 4 show that sunflower seed yield was highly significantly (P<0.01) increased due to P and N application in the two seasons. The increase in yield also due to high P applications on vertisols could be attributed to the fixing capacity of these soils even at neutral pH as stated by Wild (1988). N and P uptake by sunflower had rather similar trends to those in seed yield and plant height (Tables 3 and 4). In both seasons nitrogen and phosphorus uptake showed highly significant increases (P<0.01) due to P and N, and their interactions as compared with the control.

Table 4: Effect of N, P and their interaction on plant height, dry matter production seed yield and nutrients uptake of sunflower grown in season 2006/ 2007

Treatments	Plant height (cm)	Dry matter $kg \cdot ha^{-1}$	Seed yield $ton \cdot ha^{-1}$	N uptake $kg \cdot ha^{-1}$	P uptake $kg \cdot ha^{-1}$	Oil %
P ($kg \cdot ha^{-1}$)						
0	96.4 a	2351 a	1.616a	77.5 a	07.51 a	26.07 a
20	137.0 b	2946 b	3.211 b	94.1 ab	12.29 bc	31.36 b
40	160.7 c	3404 bc	4.298 c	112.9 bc	11.07 b	33.01 b
80	174.7 d	3558 c	4.806 d	132.9 c	14.47 c	35.63 c
N ($kg \cdot ha^{-1}$)						
0	132.6 a	2626 a	2.580 a	74.6 a	8.50 a	26.55 a
20	139.3 b	2818 a	3.430 b	92.1 a	9.95 a	28.51 a
40	143.2 b	3499 b	3.500 c	123.0 b	13.36 b	35.13 b
80	153.6 c	3318 b	4.050 d	125.6 b	13.54 b	35.88 b
N*P combination ($kg \cdot ha^{-1}$)						
$P_{00}N_{00}$	84.6 a	1467 a	0.636 a	33.9a	04.03 a	24.56 a
$P_{00}N_{20}$	93.2 a	2009 a	0.840 a	58.5a	06.27 a	26.20 abc
$P_{00}N_{40}$	96.1 a	3007 a	1.449 a	112.1 a	10.42 a	27.66 bc
$P_{00}N_{80}$	111.8 a	2923 a	1.737 a	105.6 b	09.33 a	25.87 ab
$P_{20}N_{00}$	124.8 b	3227 c	2.410 b	94.9 c	10.09 c	28.67 cd
$P_{20}N_{20}$	129.6 b	3477 d	3.535 b	113.7 c	11.48 c	26.88 abc
$P_{20}N_{40}$	140.1 b	3433 c	2.854 b	114.5 a	13.01 b	33.47 e
$P_{20}N_{80}$	153.3 b	3478 b	4.045 b	128.2 c	14.59 c	36.43 f
$P_{40}N_{00}$	152.9 c	3512 d	3.708 c	99.5 c	12.10 d	24.99 a
$P_{40}N_{20}$	160.4 c	2591 b	4.258 c	80.3 b	09.30 b	30.43 d
$P_{40}N_{40}$	163.2 c	3146 b	4.460 c	106.9 a	12.39 c	37.77 f
$P_{40}N_{80}$	166.1 c	3534 b	4.767 c	89.8 a	10.47 b	38.87 fg
$P_{80}N_{00}$	168.1 d	2295 b	3.550d	70.2 b	07.77 b	27.98 bcd
$P_{80}N_{20}$	174.1 d	3193 c	5.084 d	116.0 c	12.76 d	30.53 d
$P_{80}N_{40}$	173.4 d	4410 d	5.230 d	168.9 b	18.32 d	41.67 g
$P_{80}N_{80}$	183.0 d	4334 c	5.300 d	176.3 d	19.04 d	42.33 g
CV%	5.5	19.10	20.78	23.65	23.6	8.22

Means f in the same columns ollowed by the same letter(s) are not significantly different at 0.05 probability level according to Duncan's multiple range test.

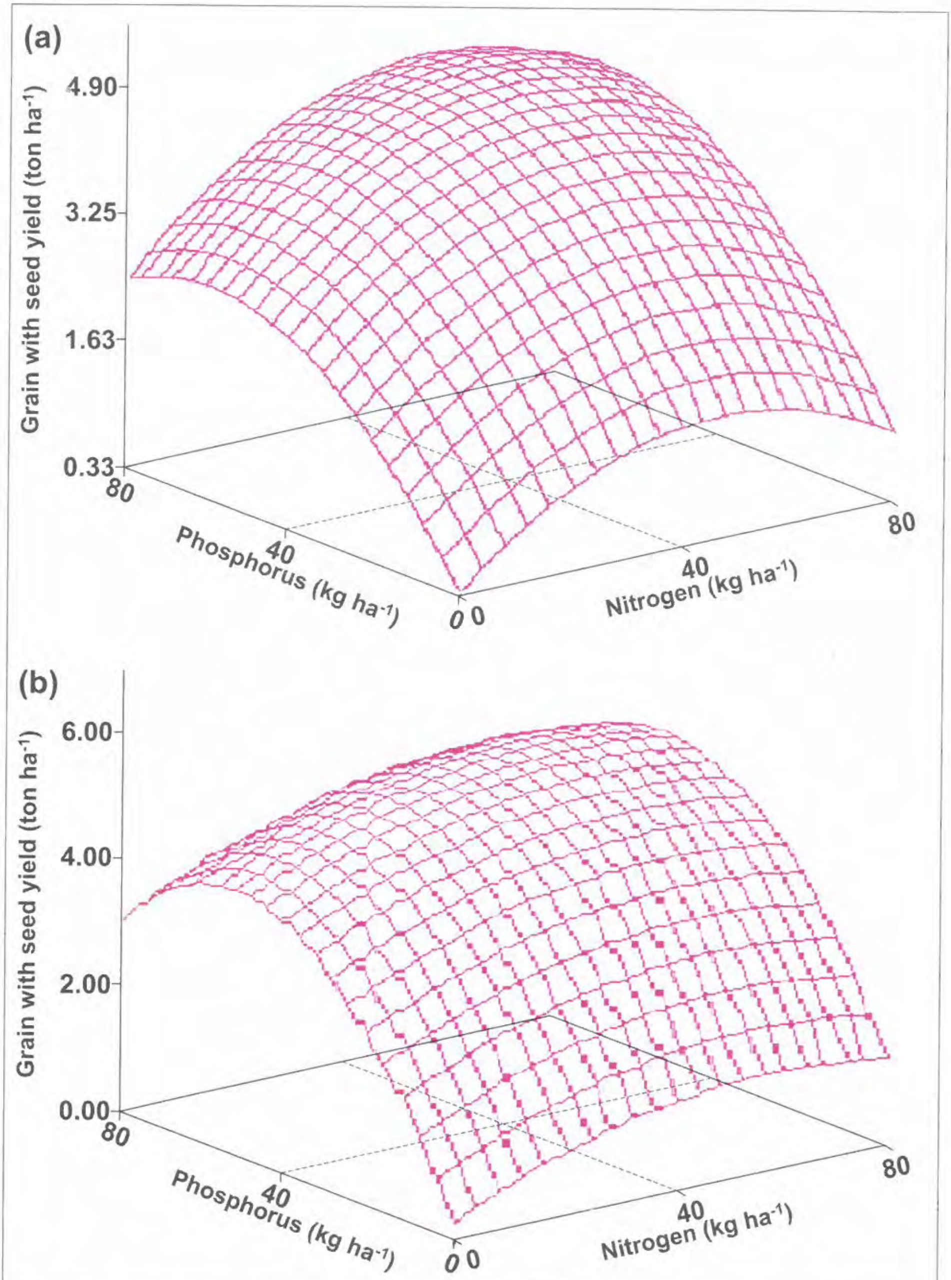

Figure 1. Response surface curve showing the interactive effect of added phosphorus and nitrogen on sunflower seed yield in season 2005/06 (a) and season 2006/07 (b).
***(a)** Seed yield=0.11+0.26P+0.18N-0.002P^2+0.0005NP-0.002N^2, (R^2=0.85).*
***(b)** Seed yield=1.97+0.41P+0.12N-0.003P^2+0.001NP-0.001N^2, (R^2=0.84).*

Phosphorus gave significant increase in sunflower oil content in both seasons, while nitrogen gave significant increase only in the first season. P application seems to increase oil yield per unit area through the increase in seed yield without a reduction in % oil due to dilution with increase in yield. This study conclude that P is recommended to increase oil percentage, Furthermore, nitrogen seems to play a vital role in increasing the quality of sunflower oil and protein content by increasing seed weight and yield

Nitrogen use efficiency (NUE) decreased with increasing N rate nearly at every P application level, in the two seasons (Table 5). At specific N level, despite the effect of P, NUE was not regular but it seems to be rather additive. This may be attributed to increase in vegetative growth (especially in the second season) and, consequently, higher evapotranspiration resulting in negative soil moisture\ high nitrogen rate of application interaction. Application of 40 kg P in the first season and 80 kg P in the second season per ha tended to give the highest NUE. P application, possibly increased root growth according to Rajendran and Veeraputhiran (2001), leading to increase in both water and nitrogen absorption from the soil. In the two seasons PUE approximately increased with increasing N application rate at every P level, and PUE seems to be decreased with increasing P rate of application. At zero P application, NUE decreased with increasing N application in the first season and increased with increasing N application up to N_{40} level then decreased at N_{80} in the second season. These results suggest that at southern Blue Nile environment sunflower may respond to high P additions for better NUE and respond to lower addition of P for the best PUE. However, these results concerning nutrients use efficiency on seed yield bases rather than the oil content to get the real efficiency.

Table 5: Effect of P and N application on nutrients use efficiency of sunflower

NP	season 2005/06		season 2006/07	
	NUE*	PUE*	NUE*	PUE*
$P_{00}N_{00}$	0.00	0.00	0.00	0.00
$P_{00}N_{20}$	27.5	0.00	10.20	0.00
$P_{00}N_{40}$	21.05	0.00	20.33	0.00
$P_{00}N_{80}$	10.75	0.00	13.76	0.00
P_{20} N_{00}	0.00	61.95	0.00	88.70
P_{20} N_{20}	10.55	44.95	56.25	33.69
P_{20} N_{40}	24.70	69.25	55.45	70.25
P_{20} N_{80}	15.31	80.20	42.61	81.75
P_{40} N_{00}	0.00	28.33	0.00	76.80
P_{40} N_{20}	68.70	48.90	27.50	85.45
P_{40} N_{40}	65.15	72.43	18.8	75.27
P_{40} N_{80}	34.06	74.95	75.27	75.75
P_{80} N_{00}	0.00	29.38	0.00	36.43
P_{80} N_{20}	72.65	40.65	76.70	53.05
P_{80} N_{40}	38.53	38.11	42.00	45.44
P_{80} N_{80}	22.51	41.14	21.88	44.54

NUE* = kg seed/kg N. PUE* = kg seed/kg P.

Since P uptake by sunflower did not exceed 40 kg ha^{-1} per season and that N uptake was well above the highest N (80 kg N ha^{-1}) application, it seems that for soil and crop yield conservation $N_{80}P_{40}$ (80 kg N + 40 kg P) may be the most appropriate for sunflower crop for the range and fertilizer addition used in these experiments. Seed yield read with NUE and PUE showing in Table 5, may indicate that the treatment $N_{80}P_{80}$ should be recommended if the cash return from increase in seed yield (above 300 kg ha^{-1}) price did not exceeded that of the price of excess fertilizer added (40 kg ha^{-1}) in the last treatment. Also $N_{80}P_{80}$ treatment gave significantly higher N (protein for animals) and oil content in the first season over and above highest seed yield. In order to maintain N status in these soils heavy N fertilization should be practiced, and the incorporation of crop residues may be necessary to obtain sustainable soil fertility and high yields of sunflower crop studied in these experiments.

Interaction effect of N and P on sunflower seed yield can be represented by the response surface curve (Figures 1a and b) and the relation was expressed by regression equations 1and 2 in the first and second seasons respectively.

$$\text{Seed yield}=0.32+0.16P+0.018N-0.002P^2+0.0005NP-0.002N^2 \quad \text{ton}\cdot\text{ha}^{-1}, \quad (R^2=0.85) \tag{1}$$

$$\text{Seed yield}=0.619+0.41P+0.12N-0.003P^2+0.001NP-0.001N^2 \quad \text{ton}\cdot\text{ha}^{-1}, \quad (R^2=0.842) \tag{2}$$

Equation (2) shows several folds contribution of P as compared to N. The highest sunflower seed yield (5.3 tons·ha^{-1}) was given by $N_{80}P_{80}$ treatment.

CONCLUSIONS

This study suggests that intensive P and N fertilization should be practiced in the neutral to slightly acidic Vertisols of South Eastern Sudan. Heavy N fertilization under adequate P supply is necessary to obtain sustainable soil fertility and high crop yields. The amounts of N taken by plants exceed any economically practical N fertilizer to be added. Thus, other remedial measures like incorporating crop residues in the soil may be necessary to obtain sustainable soil conditions and crop yield under high P fertilization. The calculations of NUE proved that 72.6 and 76.7 kg seed/kg N are the best NUE at the two seasons, respectively, obtained at ($N_{80}P_{20}$), while calculation of PUE indicated 80.2 kg seed/kg P at the first and 88.7 kg seeds/ kg P at the second season, respectively, at $N_{20}P_{00}$ and $N_{20}P_{80}$ level. The highest yield, however, was obtained at the highest N and P applications

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