U. of K. J. Agric. Sci. 20 (2),169-183, 2012

Response of Sorghum [*Sorghum bicolor*(L.) Moench] to Phosphorus and Nitrogen Fertilization under Rainfed Conditions, Blue Nile State – Sudan*

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Abstract: 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 sorghum [*Sorghum bicolor* (L.) Moench] growth and grain yield. A randomized complete block design with four replicates was used to execute the experiments. Plant height, grain yield and dry matter were significantly increased by N and P applications, in both seasons.The average yield of sorghum grain in the two seasons was 0.6 tons ha^{-1} for the control and 4.4 tons $ha^{-1}$for the highest fertilizer treatment ($P_{80}N_{80}$). There were mutually synergistic effects between N and P which significantly ($P<0.0001$) promoted growth and yield of sorghum. 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 sorghum to P and N fertilizers warrant recommending their application under the rainfed conditions of Damazin, Sudan.

Key words: Rainfed sorghum; phosphorus; nitrogen; Blue Nile State; Sudan

* Part of a Ph.D. thesis by the second author, University of Khartoum, Sudan

INTRODUCTION

Sorghum is the major food crop grown in the Sudan, occupying about 80% of the cultivated area. Soil fertility and, hence, sorghum yields in the Sudan have been declining, because of lack of fertilization and of crop rotation (Metz 1991). Nitrogen and phosphorus fertilization of rainfed sorghum is generally not practiced in dry land farming of the clay plains of 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, increase 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 (Ali and Salih 1972; Ali 1988; Abuswar and Omer 2011). This is in spite of the fact that the $NaHCO_3$ extractable P rarely exceeded 2-3 mg l^{-1} in most of these alkaline calcareous dry lands (Dawelbeit *et al*. 2007). Such values are considered low according to the American Society of Agronomy standards (Olsen and Sommers 1982). Rainfall of the southern part of Sudan, however, usually ranges between 600 and 700 mm (Table 1) during a four month growing summer season, and the soil pH therein is near neutral which decreases P fixation. Elhassan *et al*. (2007) found significant response of sorghum to urea nitrogen fertilization in two wet seasons, but the response was not significant in a third dry season in Damazin Research Farm. However, using nitrophoska as N source, which contains nitrogen plus phosphorus and potassium, gave significantly higher yields of sorghum than urea N, which points at the beneficial effect of phosphorus, as K is usually adequate in these soils. Limited soil moisture is an important factor as it is known to lower N uptake and hence lower sorghum dry matter production in fertilized and unfertilized soils (Herron *et al*. 1963).

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

Table 1. Accumulation of rainfall in millimetres (mm), per day (d) during 2005/06 (a) and 2006/2007 (b) growing seasons

(a)

May		June		July		Aug.		Sept.		Oct.		Totlal Season
d	mm	d	mm	d	mm	d	mm	d	mm	d	mm	
4	20.2	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	27.0	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)

June		July		Aug.		Sept.		Oct.		Totlal Season
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	3.0	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	8.8	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

MATERIALS AND METHODS

Two experiments were carried out at two adjacent 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 1976). Sorghum [*Sorghum bicolor* (L.) Moench] was cultivated in the first site in the growing season of 2005/06 and in the other 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 2. The two sites have similar soil properties: Heavy clay, non-saline, non-sodic, non-calcareous and with similar NPK contents. 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-molybdate 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).

Two factorial experiments were conducted using randomized complete block design with four replicates in the first season and three replicates in the second season. The levels of fertilizer used were 0, 20, 40 and 80kg.ha^{-1} for both P and N. Phosphorus was applied as triple-superphosphate (before 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 (12x5 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 the 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 grain yield were recorded after harvest. 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).

Table 2. Some chemical and physical properties of Damazin soils cultivated in 2005/06 and 2006/07 seasons

Season	Chemical properties													
	pH paste	EC (dSm^{-1})	$CaCO_3$ (%)	Nitrogen (%)	Organic carbon(%)	Soluble cation			Soluble anions		Exchange cations		CEC	Available P
						Na	Ca	Mg	Cl	HCO_3	Na	K	Soil	($mgkg^{-1}$ soil)
2005/06	7.00	0.23	0.60	0.049	0.756	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	2.0	2.0	1.5	0.84	0.63	53	5.4

	Physical properties										
	Mechanical analysis				Saturation (%)	Soil moisture				Bulk density (gm/cm^3)	
	CS	FS	Si	C		0.3bar	15 bar	AWC	Vol (%)	Dry	moist
2005/06	3	3	24	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

RESULTS AND DISCUSSION

Table 1 shows low total soil N, according to Australian soil resource standards (ASRIS 2009), and that the average available P ($NaHCO_3$ extractable- P) was 5.2 mg kg^{-1} soilin 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 first season (Table 3), there was no significant increase in plant height (109 days after sowing) due to P application, but the increase was significant in the second season (Table 4). Nitrogen application gave significant ($P<0.0001$) increase in plant height in both seasons (Tables 3 and 4). Although Khybri and Singhal (1977) reported that sorghum grown in dry land did not respond to the applied P or may have marginal response in Vertisols, Candra and Rao (1990) found significant response of millet and sorghum to applied P in Vertisols. The results of the present experiment also indicated a significant ($P<0.0001$) interactive effect of P and N application on sorghum plant height in both seasons (Tables 3 and 4).

Tables 3 and 4 also show that N and P application produced significant increases in dry matter and grain yield in the two seasons. The synergistic effect of phosphorus and nitrogen on each other was also clear on grain yield in the two seasons (Figure 1). The increases in dry matter and yield due to N fertilizer application were expected as these Vertisols are usually deficient in nitrogen (Table 2), according to the Australian standards (ASRIS 2009). This deficiency is generally attributed to the low amount of soil organic matter as mentioned by Syers *et al*. (2001). The increase in grain yield, dry matter and plant height may be due to increase in N and P uptake by sorghum (Tables 3 and 4). In both seasons, nitrogen and phosphorus uptake showed highly significant ($P<0.0001$) increases due to P and N, and their interactions as compared with the control.

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

Treatment	Plant height (cm)	Dry matter ($kgha^{-1}$)	Grain yield ($tonha^{-1}$)	N uptake ($kgha^{-1}$)	P uptake ($kgha^{-1}$)
*** P($kgha^{-1}$)**					
0	136.3a	5593a	0.868a	123.7a	8.7a
20	136.3a	6402b	2.253b	141.4b	11.1b
40	136.5a	6568b	2.708c	146.5b	11.5b
80	137.4a	6758c	3.562d	161.7c	13.5c
***N($kgha^{-1}$)**					
0	116.8a	6005a	1.93a	124.6a	09.70a
20	137.0b	6321b	2.16b	141.1b	10.95b
40	143.4c	6468c	2.43c	149.9c	11.80c
80	149.2c	6529c	2.87d	157.7d	12.65d
N/Pcombination (kg-ha^{-1})					
$P_{00}M_{00}$	117.2a	4924a	0.626a	94.5a	7.21a
$P_{00}N_{20}$	138.7bc	5707a	0.798ab	113.8b	8.55b
$P_{00}N_{40}$	141.5c	5921ab	1.008b	140.6de	9.35bcd
$P_{00}N_{80}$	147.8d	5821ab	1.037b	1459ef	9.91cd
$P_{20}N_{00}$	115.8a	6145b	1.792c	125.7c	10.11ed
$P_{20}N_{20}$	134.2b	6438b	2.231de	132.2cd	10.92ef
$P_{20}N_{40}$	145.0cd	6519b	2.475gf	141.6de	11.17f
$P_{20}N_{80}$	150.3d	6506b	2.515hg	165.9g	12.11g
$P_{40}N_{00}$	114.3a	6348b	2.082d	131.5cd	9.65cd
$P_{40}N_{20}$	140.1bc	6446b	2.310ge	153.0f	11.06f
$P_{40}N_{40}$	141.8c	6676b	2.629h	148.ef	12.46g
$P_{40}N_{80}$	149.3d	6804b	3.812j	153.0f	13.02h
$P_{80}N_{00}$	119.8a	6601b	3.206i	146.6ef	11.19f
$P_{80}N_{20}$	135.0b	6694b	3.311i	165.5g	13.09h
$P_{80}N_{40}$	145.3cd	6754b	3.609j	168.8g	14.15j
$P_{80}N_{80}$	149.5d	6984b	4.120k	165.9g	15.59j
CV(%)	3.9	3.38	12.17	17.55	9.12

* Mean P effect at different N applications, and mean N effect at different P applications

Means in the same column followed by the same letter(s) are not significantly different at 0.05 probability level, according to Duncan's Multiple Range Test.

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

Treatment	Plant height (cm)	Dry matter ($kgha^{-1}$)	Grain yield ($tonha^{-1}$)	N uptake ($kgha^{-1}$)	P uptake ($kgha^{-1}$)
*** P($kgha^{-1}$)**					
0	125.00a	5770a	1.027a	99.5a	10.42a
20	133.33b	6439b	2.070b	133.1b	15.11b
40	133.35b	6654c	3.060c	157.6c	16.89c
80	143.25c	6949d	4.083d	158.5c	19.55d
***N(kgha-1)**					
0	115.3a	6073a	1.962a	119.1a	11.62a
20	131.8b	6437b	2.362b	123.3a	15.60b
40	140.8c	6598c	2.759c	152.1b	17.25c
80	147.0d	6705c	3.156d	154.3b	17.35c
N/Pcombination (kg-ha-1)					
$P_{00}M_{00}$	103.0a	4882a	0.576a	63.0a	7.43a
$P_{00}N_{20}$	126.0d	5890b	0.798a	83.3b	10.29b
$P_{00}N_{40}$	133.0f	6108c	1.307b	110.2c	12.28d
$P_{00}N_{80}$	138.0hg	6200cd	1.426b	142.6e	11.67cd
$P_{20}N_{00}$	119.3bc	6255d	1.479b	118.8d	11.14bc
$P_{20}N_{20}$	129.7de	6470e	1.968c	118.5d	15.05f
$P_{20}N_{40}$	135.3fg	6498e	2.298d	147.2e	16.86g
$P_{20}N_{80}$	149.0jk	6534ef	2.535d	148.0e	17.39gh
$P_{40}N_{00}$	117.0b	6151ef	2.537d	147.7e	13.31e
$P_{40}N_{20}$	126.3d	6576ef	2.773e	144.8e	17.97hi
$P_{40}N_{40}$	141.4h	6686gh	3.037ef	180.5h	17.45gh
$P_{40}N_{80}$	148.7ij	6840i	3.892g	157.4f	18.84ij
$P_{80}N_{00}$	122.0c	6639fg	3.255f	146.9e	15.34f
$P_{80}N_{20}$	145.3L	6810hi	3.910g	147.6e	19.12j
$P_{80}N_{40}$	153.3k	7101j	4.396h	170.4g	22.72L
$P_{80}N_{80}$	152.3k	7247k	4.769h	169.1g	21.04k
CV%	4.08	19.1	17.63	11.52	11.68

* Mean P effect at different N applications, and mean N effect at different P applications

Means in the same column followed by the same letter(s) are not significantly different at 0.05 probability level, according to Duncan's Multiple Range Test.

Grain yield increased with increase in nitrogen use efficiency (NUE) at all rates of P application, in the two seasons (Table 5). At zero P application, NUE increased with increasing N application up to N_{40} level then decreased at N_{80} in the two seasons. This may be attributed to increase in vegetative growth and consequently, higher evapotranspiration resulting in negative soil moisture/high nitrogen rate of application interaction. In the two seasons, application of 20 kg P per ha tended to give the highest NUE. P application possibly increased root growth (Singa Rao *et al.* 1989), thus, leading to increase in both water and nitrogen absorption from the soil.

Table 5. Effect of P and N application on nutrients use efficiency of sorghum

NP	2005/06		2006/07	
	NUE*	PUE*	NUE	PUE
$P_{00}M_{00}$	0.0	0.00	0.00	0.00
$P_{00}N_{20}$	8.60	0.00	11.10	0.00
$P_{00}N_{40}$	9.55	0.00	18.28	0.00
$P_{00}N_{80}$	5.14	0.00	10.63	0.00
$P_{20}N_{00}$	0.00	58.30	0.00	45.15
$P_{20}N_{20}$	21.95	71.65	42.45	58.50
$P_{20}N_{40}$	17.08	68.35	20.48	49.55
$P_{20}N_{80}$	9.04	73.90	13.02	55.45
$P_{40}N_{00}$	0.00	36.40	0.0	49.03
$P_{40}N_{20}$	11.40	35.30	11.80	49.38
$P_{40}N_{40}$	13.68	38.02	12.05	43.25
$P_{40}N_{80}$	21.63	69.37	16.94	61.65
$P_{80}N_{00}$	0.00	32.25	0.00	33.49
$P_{80}N_{20}$	5.25	31.41	32.75	38.90
$P_{80}N_{40}$	10.08	31.27	28.53	38.61
$P_{80}N_{80}$	11.43	38.54	18.93	41.79

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

In both seasons, at 40 and 80 kg P levels, NUE tended to increase with increasing N rates. Table 3 shows the highest grain yield in the first season, which was 4120 kg ha^{-1}at $P_{80}N_{80}$, increased to 4769 kg ha^{-} at $P_{80}N_{80}$, (Table 4) in the second season. This indicates grain yield and

NUE variation with season, which is probably associated with better rainfall distribution in the second season especially at the grain filling stage (Table 1). Rainfall during grain filling and maturation in September and October was 99.5 mm in 2005/2006 and 142 mm in 2006/2007. This is in spite of the fact that the total annual rainfall was higher in first season. The importance of adequate moisture/N interaction at grain filling stage has been emphasized by van Oosterom *et al.* (2010a).

In both seasons, N and P uptake by sorghum showed highly significant ($P<0.0001$) increases due to P and N and their interactions as compared with the control. This may be the cause of associated higher yields (Tables 3 and 4). At the grain filling stage, a large portion of the nitrogen and phosphorus but only a small portion of potassium is expected to be moved into the grains (Vanderlip 1993). Amounts removed or translocated from the leaves during grain filling are related to the nutrient (NPK) supply–demand balance during grain filling (van Oosterom *et al*. 2010a). However, although sorghum grown under water limitation has been associated with high leaf nitrogen content at the start of grain filling, N translocation to grains is governed by adequate moisture content (van Oosterom *et al*. 2010a and 2010b). This may explain the difference between the negative and erratic sorghum response to N and P reported in the dryer parts of the Sudan Vertisols and the wetter Vertisols at Damazin area. The relatively low pH of Damazin soil, and hence low P fixation, may also account for the high P response of sorghum in this soil as compared with the alkaline soils of central Sudan even with irrigation.

Phosphorus uptake and accumulation in sorghum showed significant increase due to N and P application. The efficiency of P uptake was clearly reflected in high P use efficiency (PUE), calculated for the two seasons (Table 5). For each N application level, PUE decreased with increasing P application rate; but the highest P application rate gave the highest yield at the highest N application, irrespective of the decrease in PUE (Table 5). Unused P may have favourable residual effects on crops in subsequent seasons. Soil available P which averaged 5.2 mg kg^{-1} before sowing (Table 2) increased to 8.2 mg kg^{-1} after harvest in the first season and to 8.8 mg kg^{-1} in the second season.

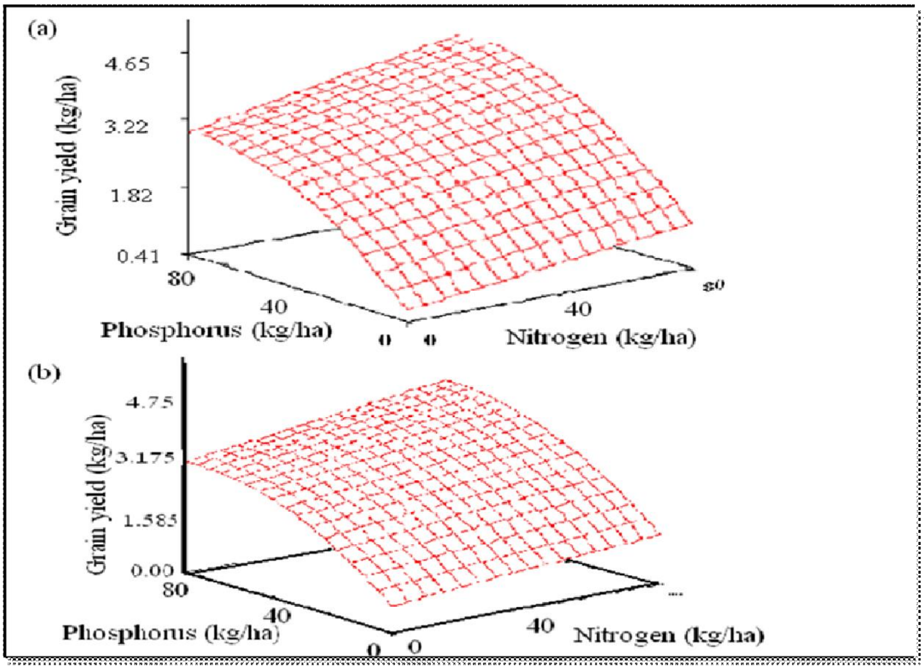

Figure 1. Response surface curve showing the interactive effect of added phosphorus and nitrogen on sorghum grain yield in 2005/06(a) and 2006/07 (b) seasons.

a) Grain yield=0.63+0.06P+0.01N-0.0004P^2+0.0001NP-0.00001N^2 ton ha^{-1}**,** (R^2=0.90).

b) Grain yield=0.51+0.06P+0.02N **-**0.0003P^2 +0.0001NP-0.0001N^2 ton ha^{-1}, (R^2=0.91).

CONCLUSIONS

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 recommend. Thus, other remedial measures like incorporating crop residues in the soil may be necessary to obtain sustainable soil fertility and crop yield under high P fertilization. The highest N_{80} P_{80} fertilizer rate is recommended as it gave the highest grain yield, although it did not give the highest N and P use efficiencies.

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إستجابة الذرة الرفيعة [*Sorghum bicolor* (L.) Moench] للتسميد الفسفورى والنيتروجين تحت ظروف الزراعة المطرية بولاية النيل الأزرق ، السودان

يوسف القرشى الماحى وطارق محمد نور صالح

قسم علوم التربة والبيئة – كلية الزراعة
جامعة الخرطوم ، شمبات – السودان

المستخلص: أجريت تجربتان حقليتان فى تربة مزرعة هيئة البحوث الزراعية بمدينة الدمازين بالسودان تصنيفها:

Typic chromusterts, fine, smectitic, isohyperthermic

خلال الموسمين الزراعيين 06/2005 و 07/2006 . هدفت هذه التجارب إلى التحقق من تأثير إضافة وتفاعلات أسمدة النيتروجين والفسفور لهذه التربه على نمو وإنتاجية الذره الرفيعه (*Sorghum bicolor*). أستخدم تصميم القطاعات العشوائية الكاملة بأربعة مكررات لإجراء التجارب . أدت إضافة الفسفور والنيتروجين إلى زيادة معنويه ($P<0.0001$) فى طول النبات والمادة الجافة والإنتاجية من الحبوب فى كلا الموسمين. وبلغ متوسط الإنتاجية من الحبوب فى الموسمين 0.6 طناً للهكتار للشاهد و 4.4 طناً للهكتار لأعلى معاملة تسميد ($P_{80}N_{80}$). لوحظ وجود تأثيرات تحفيزية متبادلة بين النيتروجين والفسفور أدت إلى زيادة معنوية ($P<0.0001$) فى النمو والإنتاجية من الحبوب. كما أدت إضافة الفوسفور إلى زيادة إمتصاص النيتروجين وكفاءة إستخدامه (NUE) والعكس كان صحيحاً . تحت كل معدلات سماد النيتروجين، مالت كفاءة إستخدام الفسفور إلى التناقص مع زيادة معدلات التسميد الفسفورى . تعطي الإستجابه عالية المعنوية ($P<0.0001$) من قبل محصول الذرة الرفيعة لسمادى النيتروجين والفسفور مبررات كافية للتوصية بإضافتهما لأراضى مناطق الزراعة المطرية بالدمازين .