Response of sorghum to NP fertilizers and cropping sequences at the Rahad Scheme

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Abstract

Field experiments were conducted at the Rahad Research Station over three seasons to evaluate the response of sorghum to NP fertilizers and cropping sequences. Results indicated that grain yield of more than 5 t/ha can be achieved without fertilizers. Effect of N on sorghum yield in the wheat-sorghum sequence was consistently significant and with high nitrogen use efficiency (NUE). The response in the groundnut-sorghum sequence, however, varied with the levels of initial soil testing for NO_3-N and total-N. Despite differences between levels of fertilizers above IN (43 kg N/ha) being statistically insignificant, regression analysis indicated that economic optimum would be obtained at higher rates. Accordingly economic optimum yield was achieved at approximately 2N (85 and 95 kg N/ha for groundnut-sorghum and wheat-sorghum, respectively). Leaf-N of 2.5 percent at heading emerged as the optimum for maximum yields in both cropping sequences. The insignificant response of sorghum to P fertilizers was attributed to its sufficiency level, i.e. 6-8 ppm available P. On the other hand, depletion of the available P caused by increasing rates of applied-N was discussed in relation to a dilution effect. Hence, frequent soil testing is needed to assess for how long such an adequate supply of P could be maintained.

Introduction

The irrigated Rahad Scheme (lat. 13°31' 14° 25' N and long. 33°31' 34°32' E), located in the eastern Sudan, was established in 1978. Sorghum was previously cultivated in this area as a rain-fed crop, using local varieties like Fatarita Gadarif, Safra and Wadakar, despite the fact that several improved varieties including Gadam Elhamam 47 and Dabar, were developed and released in the 1970'S (Mahmoud, 1977). In 1986, however, the launching of the Agricultural Research and Training Project (ARETP) promoted the adoption of the improved genotypes. Since then technological packages have emerged as pillars of success for the vertical upgrading of productivity, hence, irrigation and the improved genotypes are made available. Despite of this, yield average in farmers' fields is only 1.3 t/ha compared to 7.14 t/ha in research plots (Ishag and Ageeb, 1987). Such yield gap indicates the yield potential which could be obtained from the so far released sorghum varieties as compared to those under farmers' fields. Nevertheless, plant breeders are continuing to improve the genetical potential. Yet, emphasis needs to be directed towards crop management for exploiting this potential. This could be through the improved management of the various cultural practices, including avoidance of water logging, optimization of fertilizers, proper planting density, optimum sowing dates and the appropriate rotation. However, this study will be focused on fertilizers because they constitute the major portion of the costly imported inputs. Efforts to optimize their use are, therefore, beneficial to the tenants and also to the inflated economy.

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Limited research endeavours have been attempted on plant nutrition before, but their results were variable and sometimes conflicting. Thus of the early investigations for example by Ishag and Babiker (1972) had revealed that the economic optimum rate of N fertilizers for the irrigated sorghum was 123 kg N/ha. This was in support of Ali (1981) who reported that application of 43 and 86 kg N/ha had increased the grain yield by 62 and 114 percent over 0N, respectively. Farah and Faki (1991) found that grain yield of HD-l was significantly affected by the application of N at the rate of 86 kg/ha amounting to 88% over that of the control. Higher doses of N alone or in combination with P at the rate of 43 or 86 kg/ha did increase yield. Economic evaluation using partial budget analysis showed that the application of N at 86 kg/ha could result in net benefits amounting to Ls 20,400/ha compared to the control (ON). The marginal rate of return reached 3043% with an average addition net benefit of Ls 238 (23 kg of grain per kg of added N).

Reports from the rainfed areas (Ali, 1988) indicated insignificant differences due to NP fertilizers and/or their interactions on yields and yield components of HD-l and Gadam Elhamam at Damazin. However, Farah and Eastin (1988) tested the effects of N, P and tied ridges on HD-I and found that 43 kg N/ha increased grain yield by 90% (1.69 t/ha) over the control (0.89 t/ha) while 43 kg/ha of P increased the yield over the control by 100%. Higher yields were obtained from N and P in the presence of tied ridges especially in the case of P. On the other hand, AIi and Salih (1972) found significant effects of N and P on rainfed sorghum, though, economic increases were obtained by the application of 43 kg/ha of N only. Apart from that of Ishag and Babiker (1972) and of Farah and Faki (1991), the earlier work on crop response to fertilizers was not designed in a manner that permitted applying appropriate response analysis to results obtained and has therefore been limited to the conventional analysis of variance. This has resulted in a lack of reliable information on the economic optimum. Moreover, data on soil and plant tissue analysis were lacking. Hence, diagnostic analysis are needed for interpreting the variation in response to fertilizers at the different soil-plant environments,The present study, therefore, aimed at investigating the response of sorghum to different levels of NP fertilizers in groundnut-sorghum and wheat-sorghum cropping sequences. Accordingly, levels of fertilizers for an economic optimum can be computed from regression equations based on fertilizers yield targeting response curves.

Materials and methods

Sorghum variety Gadam Elhamam, which is a locally improved selection (Mohmoud, 1977) was experimented on to study its responses to N and P fertilizers in groundnut-sorghum and wheat sorghum. cropping sequences. The physical and chemical properties of the experimental site (Rahad Research Station) were analysed prior to sowing as summarized in Table 1. This study comprised of the following four experiments.

Experiments 1 and 2

The treatments for both experiments were the same except that the preceding crop for experiment I was groundnut whereas for experiment 2 was wheat. Experiment I was carried out in 1992-93 season and experiment 2 in 1993-94 season (Table 2). It comprised four levels of N (0N, IN, 2N and 3N) and three levels off (0P, IP and 2P) making 12 factorial combinations in a randomized complete block design with four replications. The source of N fertilizer was urea (IN = 43 kg N/ha) while that of phosphorus was trisuperphosphate (IP = 43 kg P_2O_5/ha). The experimental site was disc harrowed and ridged into 80 cm rows. The plot size was of 5 rows x 7 m x 0.8 m (28 m^2). Sowing was done in the first week of July in both seasons at intra-row spacing of 15 cm. Five seeds were planted and thinned to 2 plants/hill after 15 days (168000 plants/ha). Fertilizers were side-dressed at the time of sowing. Hand weeding was carried out twice, a month and two months after sowing. Irrigation water was applied at sowing and every 2-weeks thereafter.

Experiment 3 and 4

Both experiments were carried out in 1996-97 with the same cultural practices, experimental design, fertilizer treatments and plot size except that groundnut was the preceding crop for experiment 3 and wheat for experiment 4. The treatments were comprised of 6 levels of N (0N, IN, 2N, 3N, 4N and 5N).

Soil and plant tissue analysis

Prior to seeding and after harvest soil samples were collected from the 0-30 cm depth using an auger, for determination of soil physical and chemical properties. For the tissue analysis the whole plant was sampled for determination of N and P uptake in experiments 1 and 2 at harvest. For experiments 3 and 4 percent leaf N was determined by taking samples from the second leaf below the flag one at heading. Soil and plant samples were dried at 65 °C for 72 hrs and ground in a Wiley mill. Then available P was determined by extraction with sodium bicarbonate method as suggested by Oslen and Dean (1965). The total-N and NO_3-N were determined by the Standard Kjeldhal procedure as reported by Bremner (1965).

Total N and P uptake

This was calculated by multiplying the total N and P percentages in the whole plant by the total biological yield at harvest.

Nitrogen use efficiency (NUE)

This was determined by dividing the grain yield by the N fertilizer applied, i.e. grain yield obtained per kg N applied (kg grain/kg N)

Data analysis

Analysis of variance was computed on data for all measured attributes to test treatment differences. Regression analysis was also performed for quantifying the relationship between the yield and the amount of added fertilizer to determine the economic optima. The economic decision rule for optimizing input use is a function of three variables: the marginal contribution of the input to output as measured through the production function, the price of input and the price of output. Thus the optimum application rates are computed from the following:

$$\delta y/\delta x = q/p \quad (1)$$

where $\delta y/\delta x$ is the first derivative of the variable of concern including the quadratic terms, q is the cost per unit of fertilizer and p is the price per unit of sorghum. Using the physical production function expected returns at the specified optimal dose were performed as:

$$pr = p_y \ f(N)P_n N_o$$

where pr is the expected return, p_y is the price/kg of sorghum, P_n is the price /kg of N and N_0 is the optimum level of N.

Results

Soil at the experimental site is non-sodic and non-saline, though being physically constrained by the very high clay content. High NO_3-N and total-N were observed in the groundnut-sorghum cropping sequence of 1992-93 (experiment I). Throughout this study the available Na HCO_3-P was in the range of 6-8 ppm (Table I).

Experiments 1 and 2

Effect of NP fertilizers on grain yield and NUE

The influence of previous crop and rates of NP application on sorghum yield and nitrogen use efficiency are shown in Table 2. Differences due to N, P and their interactions in the groundnut-sorghum cropping sequence were not significant, despite a general trend of yield increase due to N, ranging from 3.3 to I 0.8%. On the other hand, significant differences in % yield increase due to N were obtained in the wheat-sorghum cropping sequence (Table 2), ranging from 13.2 to 26.3%. However, the effects of P on yield and yield attributes were not significant. In both cropping sequences the nitrogen use efficiency (NUE) decreased with the increase in the rate of applied N, showing the highest values with IN, particularly in the wheat-sorghum cropping sequence (Table 2). Increasing the rate of N application increased the biological yield, P and N uptake but consistently decreased the residual-P (Table 3). Also a consistent but insignificant trend of increased residual total-N due to the increase in the rate of N fertilizer was observed. On the other hand, increasing the rate of P application had no effect on biological yield, residual total-N, N and P uptake but enhanced the residual Na $HC0_3$ P (Table 3).

Experiments 3 and 4

Effect of rate of N fertilizers on grain yield and NUE

The effect of rates of N fertilizers and the preceding crop on grain yield are shown in Table 4. Significant higher grain yields were obtained in response to different rates of N (Table 4a), in the wheat-sorghum cropping sequence (experiment 4). The differences in grain yield between varying N rates are not significant. Nitrogen use efficiency reduced by increasing the rate of N and the highest value was obtained with IN (Table 4a).The same trend of results were obtained in the groundnut-sorghum (experiment 3) cropping sequence (Table 4b) but the range of response to N being less than that of the wheat-sorghum cropping sequence.

Response function for grain yield and rates of N

Regression analysis showed that a curvilinear relationship exists between yield and the N rate in wheat-sorghum cropping sequence (Fig. 1a) as indicated by the following quadratic function:

$$Y = 5302.4 + I071.IN - 173.IN^2$$

The sign of the quadratic coefficient confirms the hypothesis of the decline marginal product. Economic optima is obtained from equation (I). Prices used were those prevailed during 1996-97, where LS 180/kg of sorghum and LS 57964/ha for nitrogen. At these prices the economic level for N is 95 kg N/ha. Under this optimal level the estimated function resulted in an increase in yield by applying this dose will add a net profit of 145827/ha at the prevailing prices (Table 5).

The same trend of results was obtained for experiment 3 (groundnut-sorghum sequence). The estimated quadratic response function is:

$$y= 5526.6+ 1011N -174.IN^2$$

The economic level of N is 2N. This resulted in maximum economic computed yield of 6845 kg/ha (Fig. 1b). The expected additional production/ha by the application of the optimum dose would be 1329 kg/ha. The increase in yield resulting from applying this dose will add a net profit of I22695/ha at the prevailing prices (Table 5).

Effect of the preceding crop and rates of N fertilizers on the percent leaf-N

Percent leaf-N increased linearly with the increase of the rates of applied-N in both cropping sequences (Table 4). However, a curvilinear relationship was observed between the grain yield and the percent leaf-N. The response function (Fig. 2a and 2b) indicated that leaf-N of 2.5 percent was estimated to be the optimum for both cropping patterns. Thus corresponding maximum yield values were 6860 and 6976 kg/ha for wheat-sorghum and groundnut-sorghum, respectively.

Discussion

Throughout this study grain yields of more than 5 ton/ha were obtained by the control treatment (0N). Yet, the yield average for Rahad scheme never exceeds 2 ton/ha, even though N was applied at 43 kg/ha. Such yield gap was also reported by Ishag and Ageeb (1987). Accordingly more emphasis needs to be embarked upon improving cultural practices in farmers' fields.

The insignificance differences due to varying levels of N fertilizers in the groundnut-sorghum sequence (Table 2) may be attributed to the high level of NO_3-N and total-N (Table1) as compared to all other seasons. However, the significant response obtained in 1996-97 with the same cropping sequence could be associated with the deterioration of soil fertility with time. Thus soil NO_3-N was two-folds higher in 1992-93 compared to that of 1996-97 (Table 1). The high rate of mineralization being evident in 1992-93, may be associated with a relatively high available total-N compared to that of 1996-97 (Table 1). Accordingly-yield levels and soil test data do not justify recommending N-fertilizers under conditions prevailing in 1992-93 for groundnut-sorghum sequence. However, application of N-fertilizer to the same cropping sequence was eminent in 1996-97 due to the Iow soil test values for NO_3-N and total-N (Table l).

The response of sorghum to N was consistently significant in the wheat-sorghum cropping sequence, despite N fertilizer being applied at 86 kg/ha to the preceding crop (wheat). Therefore, both the high response to N fertilizer by sorghum and the lower level of initial soil test for NO_3-N in wheat-sorghum sequence suggest that the residual effect of N applied to wheat may be negligible. Hence, in wheat--

sorghum sequence application of N fertilizer, should be on annual basis. This may be attributed to the immobilization of N via remaining stalks of wheat (high C/N ratio) and/or to the short period between harvesting of wheat and sowing of sorghum (about 2 months). On the other hand, the relatively high level of soil-NO_3-N in the groundnut-sorghum sequence may have resulted from groundnut being leguminous crop (low C/N ratio) in addition to mineralization being enhanced by the long period between harvesting of groundnut and sowing of sorghum (about 7 months). This soil-plant relationship being reflected in greater NUE obtained in wheat-sorghum as compared to groundnut-sorghum cropping sequence, particularly under the lower rate of N.

The pertaining investigation indicated that differences in yield due to the varying levels of N-fertilizers (IN, 2N, 3N, 4N, 5N) were statistically insignificant (Tables 4a and 4b). Despite of this, the recommended rate of N-fertilizers for irrigated sorghum was 86 kgN/ha (2N), on economic basis. Data in Tables 4a and 4b on grain yield and rates of N-fertilizers, resembled the law of diminishing return. Therefore, response function analysis would be more appropriate for comparing the economic optimum as compared to the conventional analysis of variance. Hence, statistically insignificant levels, might be economically feasible. Thus, quadratic equations (Fig. 1a and 1b) for the best fit to the data, the estimated optimum levels for N-fertilizers, their corresponding yields and net profit are shown in Table 5. Economic optimum yield was achieved at about 2N. Accordingly, N-fertilizer recommendation should be based on the results of long term field tests that consider crop sequence and field goal in addition to soil characterization according to the initial testing, input and yield prices at harvest. The relatively high net profit (Table 5) in wheat-sorghum sequence suggests that it is more economical to apply N to this cropping sequence as compared to groundnut-sorghum sequence.

The percent leaf N (Tables 4a and 4b) exhibited linear increase with increasing the rate of N-fertilizer. However a curvilinear relationship was found between grain yield and the % leaf-N, hence, the optimum leaf N at heading was found to be 2.5 % for both cropping sequences (Fig. 2a and 2b). This was to some extent consistent with the findings of Hipp and Gerad (1971) who found that an average of about 2.3% leaf -N associated with maximum grain yield. In this study the estimated grain yields corresponding to 2.5% leaf N were almost near to the optimum yields obtained (Table 5). Accordingly, tissue analysis for the second leaf of variety Gadamalhamam, sampled at heading, indicated the 2.5% leaf-N was about the optimum for diagnosing the N sufficiency in both cropping sequences.

Throughout this study, the range for the available Na HCO_3-P was 6-8 ppm (Table I). However, grain yield response to P and/or NxP interaction were insignificant (Table 2) in both cropping sequences. Hence, the consistently insignificant response to P indicated that the available Na HCO_3 P of 6-8 ppm was adequate and that the critical-P level for sorghum was within this range. Nevertheless, Babiker and Abdalla (1991) found highly significant response to P with wheat in the same location. Others (Olsen et aI, 1962) emphasized the poor response of sorghum to P. They suggested that the root of sorghum usually provides uptake of soil-P adequate for later growth. In wheat, however, the need for P exceeds the capacity of the young root system to absorb soil-P. Goswami et al (1971) reported that critical levels of soil test for P varied with location, crop and soil texture. They reported sufficiency levels of 5 and 10 ppm for wheat in alluvial and black soils, respectively. The low response of sorghum to P-fertilizers as compared to wheat was also reported in Ohio (Anon, Ohio Agronomy guide, 1984). Different rates of P had no effect on biological yield, residual total-N, N and P uptake but the residual Na HCO_3-P increased with increasing the rate of application (Table 3). Hence, the initial soil test was in the adequacy level (6-8 ppm) and biological yield, N and P uptake-were not affected by the additional application of P-fertilizers. However, unlike N-fertiliser where N carryover is hindered by N losses, application of P-fertilizers could build up the soil test for P as indicated by the high level of residual-P corresponding to varying levels of P application (Table 3). The depletion of soil residual-P, with the increased rates of N application (Table 3), may be attributed to the high rate of growth in response to addition of N. Therefore, P concentration in the plant tissue was diluted and accordingly more P uptake is needed (N and P dilution effect). Thus with continuous application of N-fertilizers, without maintenance supply of P, the present optimum level for P (6-8 ppm) will be depleted. Accordingly, frequent soil testing is needed to assess the longevity of adequate supply of P in the soil. However, more recent results (2001-02) did not indicate significant response due to phosphorus whereas grain yields at (0N) were still high.

Recommendations

Based on the evidence presented in this paper, the following recommendation are proposed:

1. Blanket rate of N fertilizers at 43 kg N/ha (1N) is recommended for sorghum, regardless of the cropping sequence.
2. Application rate of 86 kg N/ha (2N) is to be recommended for yield maximization environments. Hence, the crop potential of more than 6 ton/ha has been revealed at 2N as an economic optimum.

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Table 1. Soil properties of the experimental sites sampled at 30 cm depth before sowing of sorghum in different seasons and cropping sequences

Season	Cropping sequence	Total N (ppm)		NO_3-N (ppm)		$NaHCO_3$-P (ppm)	
		Range	Mean	Range	Mean	Range	Mean
1992-93	GN-sorghum	546-625	588	33-36	34	6-8	7.0
1993-94	Wheat-sorghum	434-494	474	8-9	9	6-8	7.2
1996-97	GN-sorghum	420-480	440	13-23	18	6-8	6.5
1996-97	Wheat-sorghum	400-434	407	9-13	11	6-8	7.0

Other characteristics: clay=72%,pH =8.4,E.C.(mmho/cm)=0.7,ESP=4%

Table 2. Effect of NP fertilizers on grain yield (kg/ha), nitrogen use efficiency and percent yield increase in groundnut-sorghum and wheat-sorghum sequences

Treatments		Groundnut-sorghum (1992-93)			Wheat-sorghum (1993-94)		
P Levels	N Levels	Grain yield (kg/ha)	Yield increase (%)	NUE*	Grain yield (kg/ha)	Yield Increase (%)	NUE
OP	ON	5396	0	0	5270	0	0
	IN	5840	8.2	10.3	5966	13.2	16.2
	2N	5834	8.1	5.1	6331	20.1	12.3
	3N	5734	6.3	2.6	6479	22.9	9.4
Mean		5701			6012		
IP	ON	5417	0	-	5401	0	-
	IN	5818	7.8	9.8	6003	13.9	17
	2N	5852	8.5	5.3	6418	21.8	13.3
	3N	5921	9.7	4.1	6499	23.3	9.5
Mean		5752			6080		
2P	ON	5512	0	-	5160	0	-
	IN	5575	3.3	4.2	5998	13.8	16.9
	2N	5734	6.3	3.9	6253	18.7	11.4
	3N	5977	10.8	4.5	6656	26.3	10.7
Mean		5700			6017		
	SE ±	498.13			170.41		
	CV%	17.2			8.9		

*NUE = Nitrogen Use Efficiency, kg grain/kg N

Table 3. Effect of NP fertilizers on biological yield, N uptake, P uptake, residual total-N and residual Na HCO_3-P in wheat-sorghum cropping sequence(1993-94)

Treatment		Biological Yield (kg/ha)	N-uptake (kg/ha)	P-uptake (kg/ha)	Residual total N (PPM)	Residual NaHco3-P (PPM)
P- level	N- level					
0P	ON	15270	202	18.1	491	6.9
	IN	16088	216	18.9	496	6.6
	2N	17403	251	21.2	500	6.4
	3N	18472	256	22.3	502	6.3
1P	ON	15422	201	18.8	493	7.3
	IN	16218	212	19.8	504	7.0
	2N	17944	256	22.0	505	6.9
	3N	18597	260	22.3	504	6.6
2P	ON	15351	211	18.8	492	7.8
	IN	16172	220	20.0	500	7.5
	2N	17505	254	21.8	508	7.3
	3N	18736	261	22.5	512	7.0
	SE ±	(562.6)	(13.2)	(0.866)	(7.2)	(0.177)

Table 4. efficiency (kg grain/kg N) and percent yield increase (1996-97)

N rate	Grain yield (kg/ha)	Total leaf N (%)	Nitrogen use efficiency (kg grain/kg N)	yield increase (%)
		4a. Wheat-sorghum		
ON	5250	2.1	0	0
IN	6250	2.3	23.3	19
2N	6833	2.3	18.4	30
3N	6944	2.4	13.1	32
4N	6666	2.5	8.2	27
5N	6416	2.7	5.4	22
SE ±	287.3	0.03		
		4b. groundnut-sorghum		
ON	5416	2.2	0	0
IN	6500	2.4	25.2	20
2N	7000	2.4	18.4	29
3N	6833	2.5	11.0	26
4N	6666	2.6	7.3	23
5N	6333	2.8	4.3	17
SE ±	353.9	0.018	-	-

Table 5. Estimated response of sorghum to N and economics of N application in the two cropping sequences (1996-97)

	Groundnut-sorghum	**Wheat-sorghum**
Response function	$y=5526.6 + 1011N - 174.1N^2$	$y=5302.4+ 1071.1N-173.1N^2$
Sorghum price	180	180
Cost of N (LS kg/N)	1348	1348
Price of IN/ha	57964	57964
Economic optimum yield	6845	6821
Rate of fertilizer for the economic optimum	2.0 N (85 kg N/ha)	2.2N(95kg N/ha)
Net profit (LS/ha at optimum dose)	122695	14582

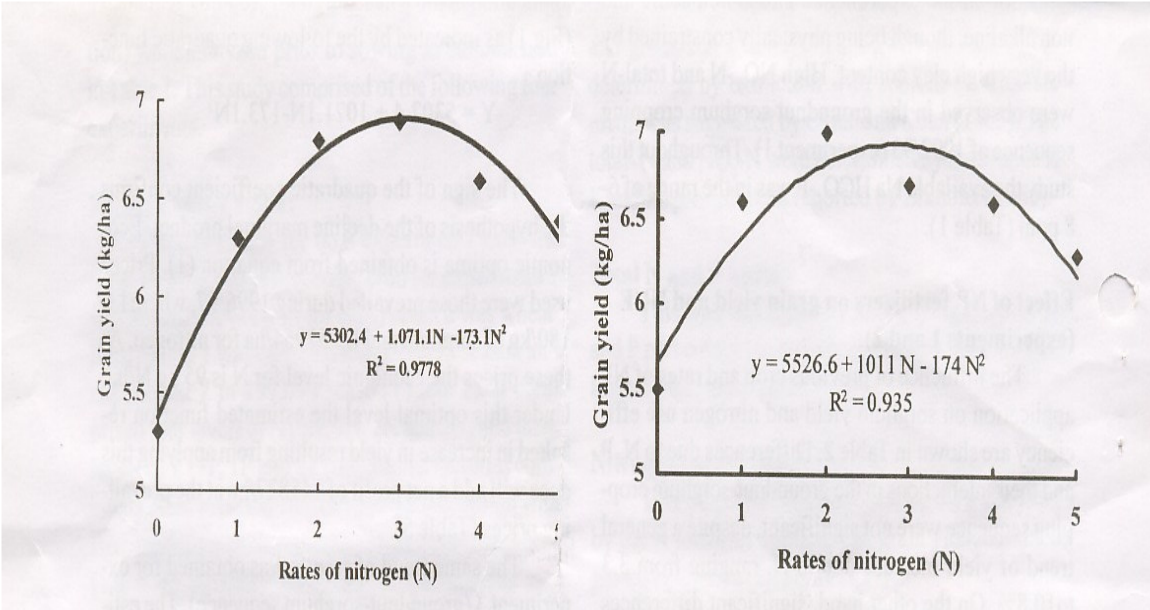

Fig. 1a. Effect of N rates on grain yield of sorghum in wheat-sorghum sequence (Left)
Fig. 1b. Effect of N rate on grain yield of sorghum in groundnut-sorghum (right)

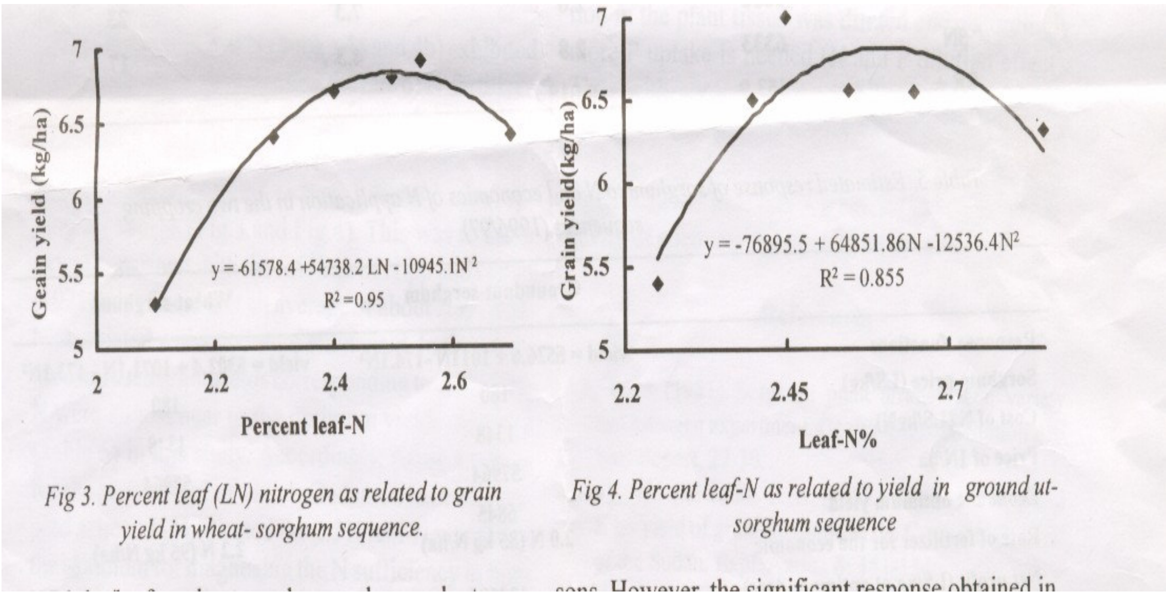

Fig. 2a. Percent leaf-N as related to grain yield in wheat-sorghum sequence (left)
Fig 2b. Percent of leaf-N as related to grain yield in groundnut-sorghum sequence (right)