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Nitrogen, Sulphur and Thiourea Nutrition of Pearl millet [*Pennisetum glaucum* (L.) R. Br.] I. Effect on Growth and Dry Matter Production

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Abstract: Effects of nitrogen, sulphur and thiourea application on growth and dry matter production of pearl millet [*Pennisetum glaucum* (L.) R. Br.] were studied for three years under arid conditions. On an average, 80 kg N ha^{-1} was as good as 120 kg N ha^{-1} but proved superior to 40 kg N ha^{-1}. Depending on the crop growth stage, N at 80 kg ha^{-1} increased the plant height by 15.5 to 40.9% and number of green leaves by 17.1 to 37.0% over the control. Maximum leaf area index (LAI) of 3.5 was recorded with 80 kg N ha^{-1} as against 2.4 in control plants at peak growth period (45 DAS). Nitrogen application also significantly increased number of tillers and dry matter accumulations. The improvements in crop growth were reflected in increased net assimilation rate (NAR) and crop growth rate (CGR) at 45 and 60 DAS. Soil application of sulphur did not significantly improve any of the growth parameters, inspite of the low availability of S in soil (<10 ppm), indicating presence of efficient sulphur uptake and translocation mechanisms in pearl millet. Thiourea, seed plus foliar, treatment increased the plant height by 5.7, 7.5 and 9.9 cm over untreated control at 45, 60, and 75 DAS, respectively. The increase in number of green leaves plant^{-1} was between 0.9 and 2.6 which increased the LAI by 0.1-0.2 at various growth stages. Additional gain in dry matter accumulation due to thiourea over untreated control ranged between 1.6-4.7 g plant^{-1}. The NAR improved from 4.8 g m^{-2} day^{-1} under untreated to 5.4 g m^{-2} day^{-1} with thiourea treatment at 45 DAS. Corresponding improvement in CGR was from 9.9 g m^{-2} day^{-1} to 11.4 g m^{-2} day^{-1}. Delayed leaf ageing, slower senescence and increased photosynthetic efficiency led to enhanced growth due to thiourea treatment.

Key words: Pearl millet, nitrogen, sulphur, thiourea, growth, dry matter.

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is an important cereal crop of Sahelian and Southern Africa, and south-east Asia (O'Neill and Diaby, 1987; Soman *et al*., 1987). The crop is grown under rainfed conditions, and aberrant rainfall regime (150-400 mm) is the main factor responsible for low productivity. Organic matter content of most soils in arid regions is very low (0.10-0.25%), therefore nitrogen plays an important role in improving the crop productivity, as it capacitates the plant for effective use of soil water (Joshi, 1988). Gautam *et al*. (1983) reported 63 to 105 kg ha^{-1} N requirement of rainfed pearl millet,

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for most of the Indian states. Similarly Joshi and Kalla (1986) reported pearl millet response from 64 to 84 kg N ha^{-1} for aridisols. In arid regions the soils are mainly loamy sand (85-90% sand) and have low available sulphur (<10 ppm) and S fertilization has been found to benefit crop like cowpea (Aggarwal *et al.*, 1985). Poor and inadequate plant stand is a major productivity constraint for pearl millet in the arid zone (Joshi and Panjab Singh, 1981). Inadequate land preparation and inefficient sowing method result in poor seed germination and seedling establishment (Joshi, 1987). Low seedbed moisture and high seedbed temperature further kill most seedlings before they emerge (Soman *et al.*, 1984).

Pre-conditioning of seeds by soaking in solutions of biostimulants is known to improve seedling emergence and vigour (Khan *et al.*, 1979). Uppal and Banerji (1985) observed the growth regulating effects of substituted thioureas. Treatment of barley seeds with 500 ppm solution of a thiourea derivative effectively enhanced the seedling growth. Agarwal (1971) has found thiourea application an effective treatment for improving plant growth and development. Improvement in plant growth and development due to application of thiourea has been reported in some crops grown in semi-arid regions (Sharma, 1988 and Sahu *et al.*, 1993). In view of these preliminary evidences, present investigation was conducted to find out the response of pearl millet to graded levels of N and S, and to assess efficacy of thiourea in relation to growth and dry matter production of pearl millet grown in an arid environment.

Materials and Methods

Field experiment was conducted at Agricultural Research Station, Mandor-Jodhpur, (latitude 26°18′N, Latitude 73°01′E) for three consecutive years. The soil of experimental site was coarse loamy, mixed, hyperthermic, Camborthids with bulk density of 1.51 kg m^{-3} containing 0.18% organic carbon, 82 kg ha^{-1} available nitrogen, 18 kg ha^{-1} available phosphorus, 353 kg ha^{-1} available potassium and 8.4 ppm available sulphur.

Treatments consisted of four levels of N (0, 40, 80 and 120 kg ha^{-1}), two levels of S (0 and 50 kg ha^{-1}) and four thiourea treatments (untreated control, seed soaking in 500 ppm thiourea solution for 8 hrs prior to sowing, foliar sprays of 1000 ppm thiourea at 30 and 45 days after sowing, and seed soaking plus foliar spray). The experiment was laid out in split plot design with combination of N and S levels in main plot and thiourea treatments in subplots, with three replications.

Nitrogen was applied through di-ammonium phosphate and urea in two splits, half at sowing and remaining half top dressed through urea about a month after sowing. Phosphorus supplied through di-ammonium phosphate was taken into account while giving a general dressing of 20 kg P_2O_5 ha^{-1}. Similarly, N supplied through di-ammonium phosphate was adjusted with that supplied through urea. Urea and di-ammonium phosphate were mixed together at the time of sowing and drilled in rows at a depth of 10 cm. S was applied through elemental S and was drilled with fertilizer mixture at sowing as per treatment combination. For thiourea foliar spray (800

L ha^{-1}) mixed with teepol (detergent) at 0.5 ml L^{-1} for better retention, was used.

Plant height, number of leaves $plant^{-1}$, leaf area index (LAI), number of tillers $plant^{-1}$ and dry matter accumulation were recorded at 15 day interval after sowing. Crop growth rate (CGR) and net assimilation rate (NAR) were also calculated at fortnightly interval (Leopold and Kriedemann, 1975). Available S was analysed following turbidimetric method as suggested by Chesnin and Yien (1950).

The total rainfall during the crop growth period was 205 mm in 1989, 783 mm in 1990 and 215 mm in 1991. In 1990, 355 mm was lost as runoff and deep percolation, with 428 mm available for effective storage. The results presented in this paper are based on pooled analyses of data over three years. The statistical analyses were done as per the procedure suggested by Fisher (1949).

Results

Plant height

Nitrogen application significantly increased the plant height at all growth stages (Table 1). Application of 80 kg N ha^{-1} increased plant height at 15, 30, 45, 60, 75 DAS and at harvest by 22.9, 24.5, 40.9, 28.1, 15.5 and 14.6%, respectively, over non use of N. S at 50 kg ha^{-1} did not influence plant height. Seed soaking in 500 ppm thiourea significantly increased plant height at 15 and 30 DAS while at other growth stages increases were not significant. Foliar spray of 1000 ppm thiourea did not influence plant height but effects of seed plus foliar treatment were significant.

Table 1. Effect of nitrogen, sulphur and thiourea application on plant height of pearl millet at different growth stages (Pooled over 3 years)

Treatment	Plant height (cm) at DAS					
	15	30	45	60	75	Harvest
Nitrogen (kg ha^{-1})						
0	18.8	46.9	81.0	150.5	178.2	178.0
40	21.5	53.4	100.9	174.0	194.9	196.0
80	23.1	58.4	114.1	192.8	205.9	204.0
120	23.6	59.3	114.9	194.6	205.2	205.3
CD (P=0.05)	1.4	2.9	5.3	6.6	9.3	9.5
Sulphur (kg ha^{-1})						
0	21.5	53.9	101.7	176.8	194.2	194.3
50	21.9	55.1	103.7	179.1	197.8	197.4
CD (P=0.05)	*NS	NS	NS	NS	NS	NS
Thiourea application						
Untreated	21.1	53.5	99.7	174.2	191.2	191.1
Seed soaking	22.4	53.6	103.2	178.6	196.4	196.5
Foliar spray	–	–	102.3	177.4	195.4	195.7
Seed plus foliar	–	–	105.4	181.7	201.1	199.4
CD (P=0.05)	0.8	1.4	3.9	4.7	6.0	5.5

* Non-significant.

Table 2. Effect of nitrogen, sulphur and thioura application on number of green leaves of pearl millet at different growth stages (Pooled over 3 years)

Treatment	Number of green leaves plant^{-1} at DAS					
	15	30	45	60	75	Harvest
Nitrogen (kg ha^{-1})						
0	6.1	13.0	19.2	16.1	7.6	5.4
40	7.1	14.9	22.9	18.7	8.4	6.2
80	7.4	17.2	26.3	20.7	8.9	6.9
120	7.7	19.3	27.0	21.5	9.0	6.8
CD (P=0.05)	0.5	1.0	1.4	1.1	0.6	0.4
Sulphur (kg ha^{-1})						
0	7.0	15.9	23.6	19.0	8.4	6.3
50	7.1	16.3	24.1	19.5	8.6	6.4
CD (P=0.05)	*NS	NS	NS	NS	NS	NS
Thiourea application						
Untreated	6.9	15.6	22.3	18.4	8.0	5.6
Seed soaking	7.2	16.6	23.9	19.0	8.4	6.3
Foliar spray	–	–	24.1	19.5	8.7	6.5
Seed plus foliar	–	–	24.9	20.2	8.9	6.6
CD (P=0.05)	0.3	0.6	1.3	1.0	0.5	0.4

* Non-significant.

Number of green leaves

Application of N at all levels increased the leaf number. From 30 DAS onward the effects of levels of N on number of green leaves plant^{-1} were consistent (Table 2). Based on pooled data 40, 80 and 120 kg N ha^{-1} increased number of green leaves plant^{-1} by 14.6, 32.3 and 48.5% at 30 DAS, by 19.3, 37.0 and 40.6% at 45 DAS, by 16.1, 28.6 and 33.5% at 60 DAS, by 10.5, 17.1 and 18.4% at 75 DAS, and by 14.8, 27.8 and 25.9% at harvest, respectively. The number of green leaves plant^{-1} decreased after 45 DAS due to increased leaf senescence. Soil application of S did not influence the number of leaves plant^{-1} in comparison to control given no-sulphur. Seed soaking in thiourea significantly increased the number of green leaves plant^{-1} by 4.3, 6.4 and 7.2% at 15, 30 and 45 DAS, respectively, over untreated control. Thiourea seed plus foliar treatment significantly increased number of green leaves plant^{-1} at all the growth stages. When compared with untreated control, thiourea seed plus foliar treatment increased mean number of green leaves plant^{-1} by 2.6, 1.8, 0.9 and 1.0 at 45, 60, 75 DAS and at harvest, accounting for 11.7, 9.8, 11.3 and 17.9%, respectively.

Leaf area index

The LAI from 15 DAS to harvest improved significantly due to application of N (Table 3). The LAI was maximum (3.5) at 45 DAS and there after gradually declined due to leaf senescence. S application at 50 kg ha^{-1} increased the LAI significantly. Thiourea seed soaking significantly im-

Table 3. Effect of nitrogen, sulphur and thiourea application on leaf area index (LAI) of pearl millet at different growth stages (Pooled over 3 years)

Treatment	LAI at DAS					
	15	30	45	60	75	Harvest
Nitrogen (kg ha^{-1})						
0	0.24	1.1	2.4	2.3	1.8	1.1
40	0.33	1.2	3.2	2.6	2.1	1.3
80	0.38	1.5	3.5	3.0	2.3	1.4
120	0.39	1.6	3.5	3.1	2.4	1.4
CD (P=0.05)	0.02	0.04	0.1	0.1	0.1	0.1
Sulphur (kg ha^{-1})						
0	0.33	1.3	3.1	2.7	2.1	1.3
50	0.34	1.4	3.2	2.8	2.2	1.3
CD (P=0.05)	*NS	NS	NS	NS	NS	NS
Thiourea application						
Untreated	0.33	1.3	3.0	2.7	2.0	1.2
Seed soaking	0.34	1.4	3.1	2.7	2.1	1.3
Foliar spray	–	–	3.1	2.8	2.2	1.3
Seed plus foliar	–	–	3.2	2.8	2.2	1.4
CD (P=0.05)	0.01	0.02	0.1	0.1	0.1	0.1

* Non-significant.

proved LAI at 15, 30 and 45 DAS while its foliar spray significantly increased LAI from 45 DAS to harvest. Seed plus foliar treatment of thiourea increased LAI (3.7 to 16.7%) and proved superior to foliar spray alone.

Number of tillers

Significant increase in number of tillers plant^{-1} due to N was recorded at 45 and 60 DAS (Table 4). Application of 40, 80 and 120 kg N ha^{-1} increased number of tillers plant^{-1} by 20.0, 40.0 and 46.7% at 45 DAS, and by 12.5, 25.0 and 31.3% at 60 DAS, respectively over control. The effect of 120 kg N ha^{-1} was at par with that of 80 kg N ha^{-1}. Application of S at 50 kg ha^{-1} had no significant influence on tiller number. Thiourea seed soaking alone and soaking plus foliar spray significantly increased number of tillers at 45 DAS by 5.6%. Thiourea seed plus foliar treatment increased number of tillers plant^{-1} by 11.1% at both 45 and 60 DAS.

Net assimilation rate

Nitrogen application improved net assimilation rate (NAR) significantly (Table 4). When compared with the control, application of 40, 80 and 120 kg N ha^{-1} increased NAR by 14.3, 38.1 and 47.6% at 30 DAS, by 22.5, 42.5 and 42.5% at 45 DAS, and by 16.7, 24.2 and 25.8%, at 60 DAS, respectively. Soil application of S did not influence NAR at any of the growth stages. Thiourea foliar and seed plus foliar treatments improved NAR significantly at the peak growth stage (45 DAS) only.

Table 4. Effect of nitrogen, sulphur and thiourea application on number of tillers plant^{-1}, net assimilation rate (NAR) and crop growth rate (CGR) at different days after sowing (Pooled over 3 years)

Treatment	Tiller plant^{-1}		NAR (g m^{-2} day^{-1})			CGR (g m^{-2} day^{-1})		
	45	60	30	45	60	30	45	60
Nitrogen (kg ha^{-1})								
0	1.5	1.6	2.1	4.0	6.6	1.2	6.5	16.0
40	1.8	1.8	2.4	4.9	7.7	1.7	9.7	22.2
80	2.1	2.0	2.9	5.7	8.2	2.4	13.0	26.6
120	2.2	2.1	3.1	5.7	8.3	2.7	13.6	27.6
CD (P=0.05)	0.2	0.2	0.2	0.6	0.8	0.1	1.2	2.7
Sulphur (kg ha^{-1})								
0	1.9	1.9	2.7	5.0	7.7	2.0	10.5	23.2
50	1.9	1.9	2.7	5.1	7.6	2.0	10.8	23.0
CD (P=0.05)	*NS	NS	NS	NS	NS	NS	NS	NS
Thiourea application								
Untreated	1.8	1.8	2.6	4.8	7.4	1.9	9.9	21.6
Seed soaking	1.9	1.9	2.7	5.0	7.6	2.0	10.6	22.6
Foliar spray	1.9	1.9	–	5.2	7.8	–	10.8	23.6
Seed plus foliar	2.0	2.0	–	5.4	7.9	–	11.4	24.5
CD (P=0.05)	0.1	0.1	NS	0.4	NS	0.1	1.0	NS

*Non-significant.

Crop growth rate (CGR)

Nitrogen significantly improved CGR at all growth stages (Table 4). When compared with non use of N, application of 40, 80 and 120 kg N ha^{-1} increased CGR by 41.7, 100.0 and 125.0% at 30 DAS, by 49.2, 100.2 and 109.2% at 45 DAS and by 38.8, 66.3 and 72.5% at 60 DAS, respectively. Soil application of S had no significant effect on CGR. Thiourea seed soaking improved CGR from 1.9 to 2.0 g m^{-2} day^{-1} at 30 DAS which accounted for an increase of 5.3%. Thiourea seed plus foliar treatment increased CGR significantly from 9.9 g m^{-2} day^{-1} under control to 11.4 g m^{-2} day^{-1}, accounting for 15.2% increase over control at 45 DAS.

Dry matter accumulation

Application of 40, 80 and 120 kg N ha^{-1} increased dry matter accumulation at 15 DAS by 35.0, 55.0 and 55.0%, by 42.9, 92.9 and 121.4% at 30 DAS, by 47.5, 97.5 and 110.5% at 45 DAS, by 41.7, 71.9 and 85.1% at 60 DAS, by 29.0, 43.3 and 43.9% at 75 DAS and by 20.4, 31.1 and 32.2% at harvest, respectively, over control (Table 5). Differences at 80 and 120 kg N ha^{-1} were comparable but significantly superior to 40 kg N ha^{-1}. When compared with 40 kg N ha^{-1}, application of 80 kg N ha^{-1} brought about increases of 14.8, 35.0, 33.9, 24.8, 11.0 and 8.8% at 15, 30, 45, 60, 75 DAS and at harvest, respectively. Soil application of S at 50 kg ha^{-1} had no discernible effect on dry matter accumulation. Seed soaking with

Table 5. Effect of nitrogen, sulphur and thiourea application on dry matter accumulation in pearl millet at different growth stages (Pooled over 3 years)

Treatment	Dry matter accumulation (g plant^{-1}) at DAS					
	15	30	45	60	75	Harvest
Nitrogen (kg ha^{-1})						
0	0.20	1.4	8.0	24.2	40.7	47.2
40	0.27	2.0	11.8	34.3	52.6	56.8
80	0.31	2.7	15.8	42.8	58.4	61.8
120	0.31	3.1	16.8	44.8	58.6	62.4
CD (P=0.05)	0.01	0.1	1.2	3.0	2.6	2.9
Sulphur (kg ha^{-1})						
0	0.27	2.3	12.9	36.4	52.0	56.4
50	0.28	2.3	13.3	36.6	53.1	57.6
CD (P=0.05)	*NS	NS	NS	NS	NS	NS
Thiourea application						
Untreated	0.27	2.2	12.2	34.1	50.3	54.7
Seed soaking	0.28	2.4	13.2	36.0	52.4	56.3
Foliar spray	–	–	13.2	37.1	53.4	58.0
Seed plus foliar	–	–	13.8	38.8	54.3	59.1
CD (P=0.05)	0.01	0.1	1.0	2.4	2.4	2.3

* Non-significant.

thiourea significantly increased dry matter accumulation at 15 and 30 DAS (Table 5). The increases were of the order of 3.7 and 9.1%, respectively, over untreated control. Thiourea foliar and seed plus foliar treatments were also effective in increasing dry matter accumulation, but the effects were more consistent under thiourea seed plus foliar treatment.

Discussion

Application of N significantly increased plant height, number of leaves, LAI and dry matter accumulation right from early vegetative stage (15 DAS) to maturity. Number of tillers plant^{-1} also increased significantly in comparison to the unfertilized control. These growth improvements were reflected further in increased NAR and CGR at 45 and 60 DAS, which coincided with a transition from vegetative to reproductive phase of the crop. Studies on temperate cereals show that the main effect of nitrogenous fertilizer is to increase the rate of leaf expansion leading to increased interception of daily solar radiation by the canopy (Squire *et al*., 1987). In the present study, the N-fertilized crop attained a LAI of 3.5 at 45 DAS while in control it was only 2.4. At this LAI, daily dry matter accumulation by the fertilized crop was of the order of 13.6 g m^{-2} while the control crop accumulated 6.5 g m^{-2}. In pearl millet the growth rate of the above ground parts is reported to be linearly related to the amount of radiation intercepted (Pearson, 1984). In the semi-arid tropics, low plant populations result in smaller LAI and therefore growth rate may depend on leaf area and the amount of light intercepted through out the life of the crop and this effect persists throughout the season (ICRISAT, 1978). Maximum LAI in the pearl millet grown at ICRISAT was only 2.9 in *kharif* season, the crop intercepted about 65% of the incident radiation at its maximum LAI (ICRISAT, 1978). In the present investigation crop with LAI greater than 3.0, under N treatments, might have intercepted more than 65% of the solar radiation, leading to optimum photosynthesis. The effects of N on dry matter partitioning provide a clue to such a possibility, as increasing the light intensity above that required to saturate carbon dioxide fixation changes the distribution pattern of the carbon assimilated (Miflin, 1965). In the present investigation, N fertilization improved dry matter partitioning to ears consistently during the grain filling period. For example, at 75 DAS which was the peak period of grain filling, the dry matter distribution in stems decreased significantly and increased in ears rather proportionately, thus indicating mobilization of the stem reserves to the developing ears. All these effects of N fertilization on crop photosynthesis and dry matter partitioning were a result of improved N status of the crop plants. On an average, 80 kg N ha^{-1} proved superior to 40 kg N ha^{-1}, while 120 kg N ha^{-1} was as good as 80 kg N ha^{-1}. Superiority of 80 kg N ha^{-1} over 40 kg N ha^{-1} appears to be due to improved crop growth. When compared with 40 kg N ha^{-1}, application of 80 kg N ha^{-1} increased LAI, CGR, number of tillers $plant^{-1}$ and dry matter production $plant^{-1}$ at flowering stage (60 DAS). Similarly dry matter partitioning to ears was relatively greater under 80 kg N ha^{-1}. At peak period of grain filling (75 DAS), there was an increase in dry matter distribution in ears, coupled with a reduction in dry matter distribution in stems, over 40 kg N ha^{-1}. A part of the increased efficacy of 80 kg N ha^{-1} *vis-a-vis* 40 kg N ha^{-1} seems to have resulted from improved crop photosynthesis, photosynthetically active leaf surface was larger under 80 kg N ha^{-1} on account of delayed leaf senescence due to sustained availability of N in crop plants during grain filling, particularly because foliar application of 500 ppm urea solution has been found to prevent chlorophyll degradation and leaf senescence (Purohit and Chandra, 1981). The results of the present investigation have shown that application of 50 kg S ha^{-1} had no significant effect on crop growth parameters. Sarkar *et al*. (1991) also did not observe improvement of growth, dry matter production and grain yield of pearl millet, although available S content of the soil was increased from 8.0 ppm to 15.1 ppm through S addition. It thus appears convincing that perhaps S uptake and translocation mechanisms in pearl millet it self are efficient enough to mine adequate S from native pool of the soil and did not respond to exogenous supply of S. Foliar spray of thiourea at vegetative stage (30 and 45 DAS) of the crop increased number of leaves $plant^{-1}$, LAI and dry matter accumulation $plant^{-1}$ and also influenced number of tillers $plant^{-1}$, NAR and CGR in comparison to control. These effects on the vegetative growth of the plants appear to be due to improved photosynthetic efficiency, as thiourea is reported to stimulate dark fixation of CO_2 (Hernandez-Nistal *et al*., 1983). It also appears that photosynthesis in the crop plants in the present study continued for a longer time due to thiourea treatment, because number of green leaves plant^{-1} were more in later part of the crop growth, owing to delayed leaf ageing due to thiourea treatments. This appears logical because thiourea exhibits cytokinin like activity (Vassilev and Mashev, 1974 and Erez, 1978) and cytokinins are known to delay leaf senescence (Osborne, 1967; Paranjothy and Wareing, 1971 and Woolhouse, 1974). More number of green leaves in the later part of crop growth due to foliar spray of thiourea were also recorded in pearl millet by Sharma (1988) and in maize by Sahu *et al.* (1993). The dry matter partitioning to ears significantly increased due to thiourea spray. More consistent effects on most of the crop growth parameters were recorded under thiourea seed plus foliar treatment.

We conclude that high N management in rainfed pearl millet is required for improving the production and the chemicals with $^{-}$SH group or those capable of potentiating $^{-}$SH formation can be future means for improving cereal food production via bioregulation and improvement of the photosynthetic efficiency of the crop plants.

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