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Research Paper

Response of sorghum (*Sorghum bicolor*) parental lines to split application of nitrogen

J.S. MISHRA[1]

Indian Institute of Millets Research, Rajendranagar, Hyderabad, Telangana 500 030

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ABSTRACT

A field experiment was conducted during the rainy seasons of 2012 and 2013 at the Hyderabad, Telangana, to investigate the optimal timing and proportion of N applications for increasing partial factor productivity (PFP_N) of sorghum parental lines. Treatments comprised combinations of 6 parental lines of 3 popular grain sorghum hybrids, viz. 'CSH 14' ('AKMS 14B' and 'AKR 150'), 'CSH 16' ('27B' and 'C 43') and 'CSH 23' ('7B' and 'RS 627') and 4 different times of nitrogen fertilizer application, viz. 50% N at sowing and 50% at 30 days after sowing (DAS), 25% N at sowing + 50% N at 30 DAS + 25% N at boot-leaf stage (BLS-55 DAS), 25% N at sowing + 50% N at 30 DAS + 15% N at BLS-55 DAS + 10% at flowering (70 DAS) and 25% N at sowing + 45% N at 30 DAS + 5% at 45 DAS (foliar spray) + 15% N at BLS-55 DAS + 10% at flowering (70 DAS).These were replicated thrice in a split-plot design. Medium-duration parental lines, viz. 'RS 627', 'C 43' and 'AKR 150' produced the higher leaf-area index (4.14–5.28) than short-duration 'AKMS 14 B' (2.76). Significantly maximum plant height (141 cm), leaf-area index (4.29) and harvest index (25.73%) were recorded with application of 25% N at sowing + 45% N at 30 DAS + 5% at 45 DAS (foliar spray) + 15% N at BLS-55 DAS + 10% at flowering (70 DAS). This treatment also gained a yield advantage of 0.27 t/ha over the control (50% N at sowing and 50% at 30 DAS), and recorded the highest PFP_N (68.10 kg grain/kg N applied). The highest net returns (33.60 × 10^3 ₹/ha) and benefit: cost ratio (2.08) was however obtained with application of 25% N at sowing + 50% N at 30 DAS + 15% N at BLS-55 DAS + 10% at flowering (70 DAS).

Key words **:** Net returns, N- uptake, Parental lines, Partial factor productivity, Sorghum, Yield

Sorghum is an important crop in the semi-arid tropical regions of India. Its productivity is limited by soil fertility, especially nitrogen (N). Nitrogen availability influences the uptake of N and other nutrients (Onasanya *et al*., 2009). Since N is highly mobile, it is subjected to the greater losses from the soil-plant system (Abd El-Lattief, 2011). Nitrogen stress during critical stages of crop growth is a major abiotic challenge. Leaf chlorosis, indicating poor N nutrition, is prevalent on most soils at pre-anthesis and grain-filling stages. Poor N nutrition may be due to inadequate N fertilization or temporal mismatch between N availability in soil solution and crop uptake. Poor synchrony occurs when large pre-plant applications of fertilizer N are available before the crop has sufficient root capacity for rapid uptake (Shanahan *et al*., 2008). Matching N availability in soil solution and crop uptake is critical to nitrogen-use efficiency (NUE) and economic viability. There is a need for greater synchrony between crop N demand and the N supply from all sources throughout the growing season for improving NUE in crop-production systems (Cassman *et al*., 1993). Since N in soil solution is vulnerable to losses, large pre-plant applications may pollute the environment and also waste resources (Cassman *et al*., 2002). Only about 50% of the N applied to soil is taken up and used by sorghum plants (Maiti, 1996). The remainder is lost through leaching, volatilization and denitrification making the nutrient unavailable during critical stage of crop growth. With the cost of chemical fertilizer increasing, farmers feel the consequence of this loss more than ever. This problem can be solved either through developing nutrient-efficient genotypes to effectively utilize supplemental nitrogen added to the soil or through developing alternative crop and soil management practice that will minimize the loss.

Partial factor productivity (PFP) is a useful measure of nutrient-use efficiency (Yadav, 2003). Adoption of inefficient nitrogen-management practices is responsible for low PFP. Timing of fertilizer application is a low-cost

[1]**Corresponding author's Email:** jsmishra31@gmail.com
[1]Head, Division of Crop Research, ICAR-Research Complex for Eastern Region, Patna, Bihar 800 014

strategy to reduce nutrient leaching, so that nutrient supply is synchronized with plant demand (Gehl *et al.*, 2005). The N content in plant tissues is influenced by the dose and time of fertilizer application, variety and management practices. Split application of nitrogen is one of the methods to increase the N-use efficiency and factor productivity by the crop while reducing the nutrient loss through leaching and volatilization (Tolessa *et al*. 1994; Muthukumar *et al*., 2007). Presently, the recommended split application used for rainy season grain sorghum in India is 1/2 of the total N at planting and the remainder at 30–35 days after sowing (DAS). Most sorghums today are grown from hybrid (or F_1) seed. For obtaining the N-efficient F_1 seed in the hybrid seed production programme, use of the N efficient parental lines is a prerequisite. Hence for developing N-efficient sorghum hybrids any improvements have to be bred into the parental lines. Sorghum genotypes are known to vary in their response to nitrogen; however, the information on response of sorghum parental lines as influenced by split application of N is limited. The objective of this study was to determine the optimal timing and proportion for N applications for grain sorghum parental lines.

MATERIALS AND METHODS

The present experiment was conducted at the research farm (17° 31’ N, 78° 39’ E, and 545 m above mean sea-level) of the ICAR-Indian Institute of Millets Research, Hyderabad, Telengana during the rainy seasons of 2012 and 2013. The climate of the area is semi-arid and tropical. The total rainfall received during cropping season (June–October) was 730.2 and 817.8 mm in 2012 and 2013 respectively. The soil was an Alfisols, Udic Rhodustalf, sandy loam (66% sand, 13% silt and 21% clay), with 7.42 *p*H, 0.18 dS/m electrical conductivity, 0.39% organic carbon, 1.63 g/cc bulk density, 7.34% available soil moisture; low in available N (163 kg/ha), medium in available phosphorus (29 kg P_2O_5 /ha) and high in potassium (360 kg K_2O/ha) content. The experiment was conducted in a split-plot design with 3 replications. Parental lines of 3 popular grain sorghum hybrids ‘CSH 14’ (‘AKMS’ ’14B’ and ‘AKR 150’), ‘CSH 16’ (’27B’ and ‘C 43’) and ‘CSH 23’ (‘7B’ and ‘RS 627’) (Table 1) were randomized in the main-plots and time of nitrogen application was the sub-plots. Four different times of nitrogen fertilizer application evaluated were 50% N at sowing and 50% at 30 DAS, 25% N at sowing + 50% N at 30 DAS + 25% N at boot-leaf stage (BLS-55DAS), 25% N at sowing + 50% N at 30 DAS + 15% N at BLS (55 DAS) + 10% at flowering (70 DAS) and 25% N at sowing + 45% N at 30 DAS + 5% at 45 DAS (foliar spray) + 15% N at BLS (55DAS) + 10% at flowering (70 DAS).

Recommended fertilizer (80 kg N, 40 kg P_2O_5 and 40 kg K_2O/ha) was applied. Whole dose of P as single superphosphate and K as muriate of potash were applied basal. Nitrogen from the source of urea was applied as per the treatments. The sorghum parental lines were sown manually in rows at 45 cm × 15 cm on 5 July 2012 and 8 July 2013. Furadan 3G (@ 20 kg/ha) was applied in furrows at planting to control the shoot fly (*Atherigona soccata*). To control weeds, atrazine at 0.50 kg a.i./ha was applied as pre-emergence next day after sowing in 500 l/ha spray volume with knapsack sprayer fitted with flat-fan nozzle. Hand-hoeing was done with hand hoe at 25 DAS and intra-row weeds were removed by hand-weeding. Crop was cultivated under rainfed condition; however sprinkler irrigation was applied immediately after sowing to ensure proper germination. The land remained fallow during subsequent winter (*rabi*) season and the same treatments were allocated to same experimental units during both years. Data on days to 50% flowering and plant height were recorded as per standard procedures. Leaf chlorophyll concentration of the second leaf from the top was assessed at 50% flowering on 20 plants, with a portable Chlorophyll meter (SPAD-502 Minolta) and was expressed in arbitrary absorbance (or SPAD) values. All chlorophyll meter readings were taken midway between the stalk and the tip of the leaf. In addition, leaf-area index (LAI) was estimated with a portable canopy analyzer LICOR-2000 at flowering stage. Nitrogen concentrations in sorghum grain and sto-

Table 1. Brief description of sorghum parental lines

Parental line	Developed hybrid	Days to 50% flowering	Plant height (cm)	100-seed weight (g)	Institute where developed
‘AKMS 14B’	‘CSH 14’	56 (early)	145 (short)	2.68	IIMR, Hyderabad
‘AKR 150’	‘CSH 14’	66 (medium)	138 (short)	2.64	IIMR, Hyderabad
‘27 B’	‘CSH 16’	69 (medium)	161 (medium)	2.71	IIMR, Hyderabad
‘C 43’	‘CSH 16’	71 (medium)	155 (medium)	3.11	IIMR, Hyderabad
‘7 B’	‘CSH 23’	56 (early)	147 (short)	2.68	IIMR, Hyderabad
‘RS 627’	‘CSH 23’	74 (medium)	211 (medium)	2.58	IIMR, Hyderabad

IIMR, Indian Institute of Millets Research ver, and NPK content and soil organic carbon in initial soil samples were analysed using standard laboratory procedures (Jackson, 1973) and N uptake was obtained as product of concentration and yield. Partial factor productivity (PFP_N) under different methods of N application was calculated by dividing the grain yield (kg/ha) with amount of N applied (80 kg/ha). Data of both years were pooled and economics was computed considering the local price of input and output. Net income and Benefit: cost ratio were worked out. All the data were subjected to analysis of variance (ANOVA) by using a split-plot design and main effects and interactions were tested for significance. Treatment means obtained by ANOVA were compared using critical difference (CD) at *P*=0.05 level of significance.

RESULTS AND DISCUSSION

Growth, yield attributes and yield

Significant differences were observed among parental lines for growth and yield attributes (Table 2). Mean plant height differed significantly and ranged from 128 cm (‘C43’) to 148 cm (‘27B’). Leaf-area index (LAI) and SPAD values at 60 DAS, and days to 50% flowering also differed significantly among the parental lines. The highest LAI (5.28) was recorded with ‘RS 627’, followed by ‘C 43’ and ‘AKR 150’, and the lowest (2.76) with ‘AKMS 14B’. The leaf chlorophyll content in terms of SPAD values did not vary significantly among parental lines except for ‘C 43’ which produced significantly the lowest value (45.78). The highest SPAD value (49.50) was recorded with ‘AKR 150’ closely followed by ‘AKMS 14B’. Parental lines ‘AKMS 14 B’ and ‘7 B’ flowered earlier (55–56 days for 50% flowering) followed by ‘AKR 150’ (65 days), ’27B’ (69 days) and ‘C43’ (70 days). However, ‘RS 627’ was late and took the highest number of days (72 days) for 50% flowering. Mishra *et al*. (2015) also reported variation in phenology of sorghum cultivars. Yield attributes, viz. panicle length and 100-grain weight, differed significantly among the sorghum parental lines. Line ’27 B’ produced the longest panicle (29.81 cm) and ‘C 43’ (20.14 cm), the lowest. The 100-seed weight among parental lines ranged from 2.31 g (‘RS 627’) to 3.36 g (‘7 B’). Nitrogen scheduling significantly affected the plant height and LAI. The maximum plant height (141 cm) and LAI (4.29) were recorded with application of 25% N at sowing + 45% N at 30 DAS + 5% at 45 DAS (foliar spray) + 15% N at BLS (55 DAS) + 10% at flowering (70 DAS). Other parameters, viz. SPAD value at 60 DAS, days to 50% flowering, panicle length, 100-seed weight

Table 2. Growth, yield attributes and yield of sorghum parental lines as influenced by split application of nitrogen (pooled data of 2 years)

Treatment	Plant height (cm)	Leaf area index at 60 DAS	SPAD value at 60 DAS	Days to 50% flowering	Panicle length (cm)	100-seed weight (g)	Grain yield (t/ha)	Stover yield (t/ha)	Harvest index (%)
Parental lines									
‘7 B’	133	3.29	47.96	56	23.09	3.36	5.36	16.97	24.01
‘27 B’	148	3.87	48.89	69	29.81	2.43	4.25	12.34	25.60
‘AKMS 14 B’	130	2.76	49.34	55	22.13	2.60	5.53	16.27	25.37
‘C 43’	128	4.66	45.78	70	20.14	2.94	5.59	17.43	24.27
‘AKR 150’	139	4.14	49.50	65	23.26	2.78	5.24	16.21	24.43
‘RS 627’	147	5.28	48.26	72	23.84	2.31	5.92	17.30	24.96
SEm±	2	0.13	1.18	2	0.47	0.35	0.20	0.65	0.46
CD (P=0.05)	6	0.39	3.52	6	1.42	1.01	0.56	2.02	1.30
Nitrogen scheduling									
50% N at sowing and 50% at 30 DAS	134	3.75	47.45	66	23.62	2.57	5.18	15.19	24.41
25% N at sowing + 50% N at 30 DAS + 25% N at BLS (55 DAS)	136	4.16	48.59	63	23.89	3.09	5.25	15.94	24.92
25% N at sowing + 50% N at 30 DAS +15%N at BLS + 10% at flowering (70 DAS)	138	3.99	48.61	65	23.52	2.64	5.38	16.21	25.41
25% N at sowing + 45% N at 30 DAS + 5% at 45 DAS (foliar spray) + 15% N at BLS + 10% at flowering	141	4.29	48.45	65	23.79	2.64	5.45	15.74	25.73
SEm±	2	0.11	0.97	1	0.39	0.27	0.16	0.55	0.32
CD (P=0.05)	5	0.36	NS	NS	NS	NS	NS	NS	0.95

and grain and stover yields, were not significant.

Sorghum parental lines differed significantly (*P*<0.05) for grain yield (Table 2). The highest grain yield (5.92 t/ha) was obtained with 'RS 627', which was at par with 'C 43' (5.59 t/ha) and 'AKMS 14 B' (5.53 t/ha), but significantly superior to '7B', 'AKR 150' and '27B'. The lowest grain yield (4.25 t/ha) was recorded with '27B'. The differences among N application times were not significant for grain yield of parental lines. However, the highest grain yield (5.45 t/ha) was observed when nitrogen was applied 25% at sowing + 45% at 30 DAS + 5% as foliar spray at 45 DAS + 15% at boot-leaf stage-BLS (55 DAS) + 10% at flowering (70 DAS) (Table 3). The particular application exhibited a yield advantage of 0.27 t/ha (5.2%) over the recommended practice (50% N at sowing and 50% at 30 DAS). In light soils and in high rainfall areas, 3 splits of N fertilizer – 50% at sowing, 25% at floral primordial initiation and 25% at flowering – has been found beneficial (Choudhary, 1978). The stover yield did not vary significantly among parental lines except for '27 B' which produced significantly the lowest value (12.34 t/ha). The mean harvest index (HI) was significantly higher in '27B' (25.60) than '7 B' (24.01%). Higher HI in '27 B' and 'AKMS 14B' (25.37%) showed that these parental lines were more efficient in converting biological yield into economic yield (Kusalkar *et al*., 2003). Changes in harvest index of plants also depend on difference and rate of assimilates production and synthesis during grain-filling stage and assimilates remobilization before each genotype pollination and sink strength (Buah and Maranville, 2005). Variation in nitrogen scheduling had significant effect on HI. The highest HI (25.73%) was obtained with split application of 25% N at sowing + 45% N at 30 DAS + 5% at 45 DAS (foliar spray) + 15% N at BLS (55 DAS) + 10% at flowering (70 DAS) which was significantly higher than that of applying 50% N at sowing and 50% at 30 DAS (24.41%). This might be owing to increased synthesis of assimilates during grain-filling stage and assimilates remobilization (Amiri *et al*. 2014)

N uptake and partial factor productivity

Nitrogen content in grain and stover varied significantly among the parental lines (Table 3). Maximum N content in grain (1.46%) was recorded with '27 B', followed by 'AKR 150' (1.44%), while the minimum content (1.29%) was observed in 'AKMS 14B'. The N content in stover was however, maximum (1.09%) in 'AKR 150' and minimum (0.59%) with 'RS 627'. Methods of N schedul-

Table 3. Economics and nitrogen uptake of sorghum parental lines as influenced by split application of nitrogen (pooled data of 2 years)

Treatment	N content (%)		N uptake (kg/ha)			PFP_N (kg grain/kg N applied)	Net returns (× 10^3 ₹/ha)	Benefit: cost ratio
	Grain	Stover	Grain	Stover	Total (grain + stover)			
Parental lines								
'7 B'	1.31	0.92	70	110	180	67.10	33.19	2.07
'27 B'	1.46	0.97	62	105	167	53.08	19.75	1.63
'AKMS 14B'	1.29	0.96	71	104	175	69.18	35.20	2.13
'C 43'	1.30	0.93	73	143	216	69.78	35.80	2.15
'AKR 150'	1.44	1.09	76	149	225	65.55	31.72	2.02
'RS 627'	1.35	0.59	78	99	177	74.08	39.91	2.28
SEm±	0.05	0.04	5	7	9	4.56	0.95	0.13
CD (P=0.05)	0.14	0.12	15	21	28	13.21	2.71	0.38
Nitrogen scheduling								
50% N at sowing and 50% at 30 DAS	1.35	0.99	69	133	202	64.73	31.62	2.04
25% N at sowing + 50% N at 30 DAS + 25% N at BLS (55 DAS)	1.37	0.91	71	120	191	65.70	32.31	2.05
25% N at sowing + 50% N at 30 DAS + 15% N at BLS + 10% at flowering (70 DAS)	1.37	0.84	74	101	175	67.30	33.60	2.08
25% N at sowing + 45% N at 30 DAS + 5% at 45 DAS (foliar spray) + 15% N at BLS + 10% at flowering	1.34	0.90	73	121	194	68.10	32.86	2.01
SEm±	0.04	0.03	4	6	8	3.22	0.73	0.08
CD (P=0.05)	NS	0.10	NS	17	22	NS	NS	NS

ing did not cause significant variation in N content and uptake in grains. Sorghum parental lines differed significantly in response to N uptake. The highest N uptake in grain (78 kg/ha) was recorded with 'RS 627' and in stover (149 kg/ha) with 'AKR 150'. The total (grain + stover) N uptake (225 kg/ha) was however, maximum with 'AKR 150'. Application of 50% N at sowing and 50% at 30 DAS recorded the maximum total N uptake (202 kg/ha). The increase in N uptake was due to increase in N content and grain and stover yields. Higher concentration and availability of N in rhizosphere led to higher N uptake by the plant biomass. Gardner *et al*. (1994) demonstrated the genetic diversity for N use-efficiency in grain sorghum and concluded that the differences among sorghum cultivars for higher NUE mechanisms were associated with individual morphological, anatomical and biophysical traits. Exploiting these differences in nutrient demand and efficiency is a possible alternative for reducing the cost and reliance upon fertilizer.

Sorghum parental lines varied with respect to partial factor productivity (PFP_N). Maximum PFP_N (74.08 kg grain/kg N applied) was recorded with 'RS 627' and minimum (53.08 kg) with '27 B'. The variation in PFP_N was mainly due to differences in grain yields of respective parental lines. Methods of N scheduling did not cause significant variation in PFP_N, but it was higher (68.10 kg) with 25% N at sowing + 45% N at 30 DAS + 5% at 45 DAS (foliar spray) + 15% N at BLS (55 DAS) + 10% at flowering (70 DAS) as compared to 64.73 kg with 50% N at sowing and 50% at 30 DAS. The PFP_N of sorghum parental lines varied significantly in their response to N scheduling (Fig. 1). Sorghum parental lines, viz. 'AKMS 14B' and '27 B' did not respond much to more splitting of N over the control (50% N at sowing and 50% at 30 DAS). The maximum PFP_N of 'AKR 150' and '7 B' was recorded with application of 25% N at sowing + 50% N at 30 DAS + 15% N at BLS (55 DAS) + 10% at flowering (70 DAS), whereas 'RS 627' responded maximum with 25% N at sowing + 50% N at 30 DAS + 25% N at BLS (55 DAS). The PFP_N of 'C 43' increased linearly with splitting of N and the highest was recorded with application of 25% N at sowing + 45% N at 30 DAS + 5% at 45 DAS (foliar spray) + 15% N at BLS (55 DAS) + 10% at flowering (70 DAS).

Economics

The highest net returns (39.91 × 10^3₹/ha) and benefit: cost ratio (2.28) were obtained with 'RS 627' and the lowest with '27 B' (Table 4). Nitrogen scheduling at different stages did not influence the economic parameters significantly. However, application of 25% N at sowing + 50% N at 30 DAS + 15% N at BLS (55 DAS) + 10% at flowering (70 DAS) was more economical and recorded the maximum net returns (33.60 × 10^3₹/ha) and benefit: cost ratio (2.08).

It may be concluded that the grain yield, economic returns and nitrogen-use efficiency of sorghum parental lines varied with timing and split application of nitrogen. This strongly underscores the benefit of fine tuning nitrogen application in order to match nutrient supply to crop demand. Application of 25% N at sowing + 50% N at 30 DAS + 15% N at BLS (55 DAS) + 10% at flowering (70 DAS) was the more economical.

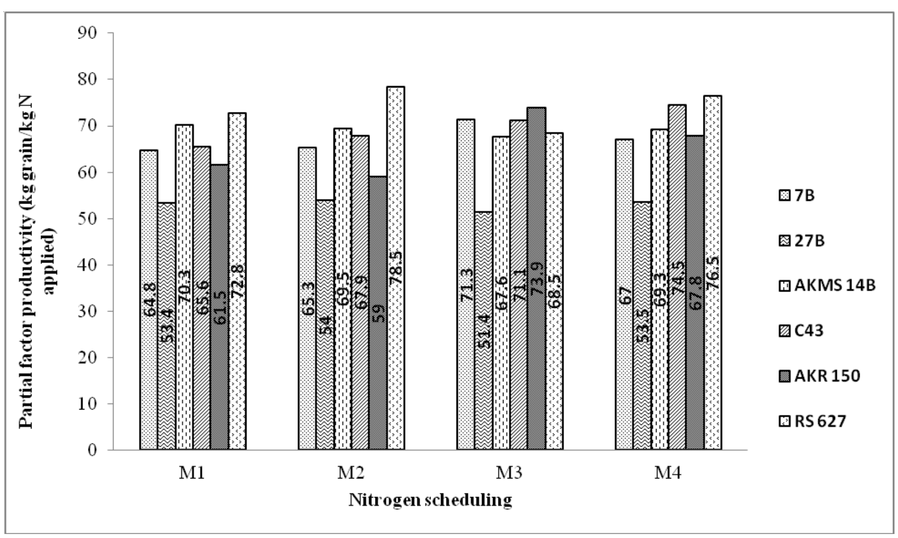

Fig 1. Partial factor productivity (PFP_N) of parental lines as influenced by N scheduling [M_1, 50% N at sowing and 50% at 30 DAS; M_2, 25% N at sowing + 50% N at 30 DAS + 25% N at BLS (55 DAS); M_3, 25% N at sowing + 50% N at 30 DAS + 15% N at BLS + 10% at flowering (70 DAS); M_4, 25% N at sowing + 45% N at 30 DAS + 5% at 45 DAS (foliar spray) + 15% N at BLS + 10% at flowering]

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