Indian Journal of Agronomy **60** (1): 76–81 (March 2015)

Research Paper

Productivity, nutrient-use efficiency and economics of rainy-season grain sorghum (*Sorghum bicolor*) as influenced by fertility levels and cultivars

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Received: September 2014; Revised accepted: March 2015

ABSTRACT

Field experiments were conducted under All India Coordinated Sorghum Improvement Project (AICSIP) at 6 locations during rainy seasons of 2009 and 2010 in a split plot design having 3 fertility levels, *viz.,* control (0:0:0 kg/ha of N: P_2O_5:K_2O), recommended dose of nutrients-RDF (80:40:40 kg/ha of N: P_2O_5: K_2O) and 150% of RDF (120:60:60 kg/ha of N: P_2O_5: K_2O) in main-plots, while 8 sorghum cultivars including 3 hybrids ('CSH 14', 'CSH 16', 'CSH 23') and 5 varieties ('SPV 462', 'CSV 15', 'CSV 17', 'CSV 23', 'SPV 1616') constituted the sub-plot to find out their effects on productivity and nutrient-use efficiency in rainy-season grain sorghum [*Sorghum bicolor* (L.) Moench]. Results revealed that increasing levels of fertility up to 150% RDF significantly increased the grain yield (3.28 t/ha), nutrient uptake, net returns (25.97 $\times 10^3$₹/ha) and benefit: cost ratio (1.79) as compared to control. Hybrids produced 20.6% higher grain yield over varieties. Among hybrids 'CSH 16' (3.07 t/ha) and among varieties 'SPV 462' (2.56 t/ha) produced the maximum grain yields. The nutrient-use efficiency (NUE) was higher in hybrids (6.66 kg grain/kg NPK) than the varieties (5.54 kg grain/kg NPK). Increasing fertility levels from 100% RDF to 150% RDF increased the NUE of all the test hybrids, but decreased the efficiency of varieties except 'CSV 17'.

Key words **:** Net returns, Nutrient uptake, Nutrient-use efficiency, Sorghum, Yield

Sorghum, the fifth most important cereal crop on the globe, is traditionally grown for grain both as food (Africa and India) and as animal feed (developed countries like USA, China, Australia, etc) and stalks as animal fodder, building material and fuel. Because of its drought adaptation capability, sorghum is a preferred crop in tropical, warmer and semi-arid regions of the world with high temperature and water stress. With the threat of climate change looming large on the crop productivity, sorghum being a drought hardy crop will play an important role in food, feed and fodder security in dryland economy. In India, sorghum is generally grown under less favourable conditions with meagre amounts of nutrients. Prior to 1950's relatively very little or no fertilizer was used on sorghum. However, with the development of improved sorghum cultivars and other improved production practices the average nutrient consumption reached to 47.5 kg/ha (29.2, 14.2 and 4.1 kg N+P_2O_5+K_2O) in 2003-04 as against 60.2 kg/in maize, 119.1 kg/ha in paddy and 136.7 kg/ha in wheat (FAO, 2005).

Development of better adapted, high yielding sorghum cultivars has increased the yield potential and the amounts of plant nutrients required by the crop. Consequently, the fertilizer application in sorghum has increased substantially. In semi-arid tropics where sorghum is an important crop, inorganic fertilizer use is limited due to high cost and non-availability, and limited soil moisture availability. Improving nutrient-use efficiency is important to reduce costs of crop production (Bernal *et al.,* 2002). Cultivars producing large amounts of biomass remove greater quantities of soil nutrients. High yielding varieties of sorghum removed on an average 22 kg N, 13.3 kg P_2O_5 and 34 kg K_2O to produce one tone of grains (Kaore, 2006). Sorghum genotypes vary significantly for various root characteristics which may affect the nutrient uptake and use efficiency (Seetharama *et al.,* 1990). To reduce the impact of nutrient deficiency on sorghum production, the selection of genotypes that are superior in the utilization of available nutrients either due to enhanced uptake capacity or because of more efficient use of the absorbed nutrients in grain production can be a desirable option. Hence, the

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present investigation was undertaken to study the effect of fertility levels and cultivars on productivity and nutrient-use efficiency in rainy-season grain sorghum.

MATERIALS AND METHODS

Field experiments were conducted under All India Co-ordinated Sorghum Improvement Project (AICSIP) at 6 locations, *viz.* Coimbatore (11°01'N, 76°97'E, 411 m above mean sea-level) in Tamil Nadu, Dharwad (15°26'N, 75°07'E, 678 m above mean sea-level) in Karnataka, Parbhani (19°16'N, 76°47'E, 357 m above mean sea-level) in Maharashtra, Palem (16°46'N, 77°56'E) in Telangana, Indore (22°20'N, 75°25'E, 553 m above mean sea-level) in Madhya Pradesh and Udaipur (23°34'N, 73°42'E, 582.17 m above mean sea-level) in Rajasthan during rainy season of 2009 and 2010. Soils of different locations ranged from sandy clay loam to clay loam in texture with 75–100 cm depth, pH 7.3–8.04, low in organic carbon and nitrogen, low to medium in available phosphorus and high in available potassium content. Details of the physico-chemical properties of soils at various locations are given in Table 1. The total rainfall during crop season (June–October) varied from 465 mm at Coimbatore to 903 mm at Indore during 2009 and 629 mm at Coimbatore to 1260 mm at Parbhani during 2010 (Fig. 1).

The experiment was laid out in a split plot design with 3 replications on a net plot of 3.6 × 4.4 m. The main plot consisted of 3 fertility levels, *viz.* control (0:0:0 kg/ha of N: P_2O_5:K_2O), recommended dose of nutrients-RDF (80:40:40 kg/ha of N: P_2O_5: K_2O) and 150% of RDF (120:60:60 kg/ha of N: P_2O_5: K_2O), while 8 sorghum cultivars including 3 hybrids (‘CSH 14’, ‘CSH 16’, ‘CSH 23’) and 5 varieties (‘SPV 462’, ‘CSV 15’, ‘CSV 17’, ‘CSV 23’, ‘SPV 1616’), constituted the sub-plot. The crop was sown in rows 45 cm × 15 cm apart during 4 week of June to 1 week of July at different locations. Half dose of nitrogen and full dose of phosphorus and potash were applied basal, while remaining nitrogen was applied at 30 days after sowing (DAS). Furadan 3 G (@20 kg/ha) was applied in furrows at planting to control the shoot fly (*Atherigona soccata* R). To control the weeds, atrazine at 0.50 kg/ha was applied as pre-emergence with 500 l/ha of water with the help of 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. Thinning was done manually at 20 DAS by removing excess plants. Data on days to 50% flowering and physiological maturity, and plant height was measured as per standard procedures. The crop was grown under rainfed condition at all the locations.

N, P and K concentrations in sorghum grain and stover, and initial soil samples collected from 0-30 cm depth for NPK status and organic carbon content were analysed using standard laboratory procedures (Jackson, 1973) and uptake was obtained as product of concentration and yield. The nutrient use-efficiency, in terms of Agronomic efficiency (AE) was calculated as per the following formula (Prasad, 2009) and reported as kg grain/kg nutrient (NPK) applied.

$$AE = \frac{Yf - Yc}{Na}$$

Yf: Grain yield (kg/ha) in fertilized plot; Yc: Grain yield (kg/ha) in control plot; Na: Nutrient (N+ P_2O_5+ K_2O) applied (kg/ha).

Data of both the years and all the 6 locations were pooled and relative economics was computed considering the local price of input and output. Net income was calculated as the difference between gross income and total cost. Benefit: cost ratio was worked out by dividing gross returns with total cost of cultivation. 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 fertility

Table 1. Physico-chemical properties of soils of different locations

Particular	Coimbatore	Parbhani	Indore	Palem	Dharwad	Udaipur
Soil texture	Clay loam	Clay loam	Clay loam	Clay	Clay	Sandy clay loam
Soil depth (cm)	>75 cm	>75 cm	>100 cm	>100 cm	>100 cm	>75 cm
Soil pH value (1:2.5 soils: water)	8.04	7.84	7.60	7.82	7.3	7.9
EC (1:2.5 soils: water) (dS/m)	0.47	0.25	0.48	0.36	0.60	0.40
Soil organic carbon (%)	0.45	0.36	0.41	0.43	0.54	0.32
Available Nitrogen (kg/ha)	216	101	203	174	220	276
Available P_2O_5 (kg/ha)	31	17.2	37.94	15.4	21.2	32
Available K_2O (kg/ha)	605	702	391	372	305	459

levels for growth and yield attributes (Table 2). Application of 150% RDF (120:60:60 kg/ha of N: P_2O_5: K_2O) being on a par with 100% RDF (80:40:40 kg/ha of N: P_2O_5: K_2O), recorded significantly taller plants, longer panicles, more number of grains/panicle and 100-grain weight than the control. Days to 50% flowering differed significantly with increase infertility levels, but days to maturity was not significant. Application of 150% RDF (66 days) being on a par with 100 % RDF (67 days) significantly reduced the number of days required for 50% flowering as compared to control (69 days). Similar results on variation in days to flowering and maturity due to increasing levels of fertility were reported by Mishra *et al*. (2014). Grain yield is the manifestation of yield-attributing characters. Significant increase in grain yield of sorghum with increasing levels of fertility can be ascribed to the significant increase in the yield components, viz. number of grains/panicle and 100-grain weight. Maximum grain (3.28 t/ha) and stover (13.72 t/ha) yields of sorghum were obtained with 150% RDF and was on a par with the application of 100% RDF. Higher biomass production with increasing levels of fertility to sorghum could be ascribed to enhanced availability of nutrients that helped in the expansion of leaf area and chlorophyll content which together might have accelerated the photosynthetic rate, and in turn increased the grain and stover yields. Harvest index increased with increasing levels of fertility but the differences were not significant.

Among cultivars, mean plant height differed significantly and ranged from 146 cm (‘CSV 17’) to 228 cm (‘SPV 1616’). The mean plant height of hybrids (182 cm) was lower than that of varieties (204 cm). Days to 50% flowering and days to physiological maturity also differed significantly among the cultivars. In general, hybrids flowered earlier (64-67 days) than the varieties (70-71 days), but the duration required for physiological maturity was almost the same (108-11 days), except for ‘CSV 17’, which is a short duration variety that flowered in 60 days and matured in 103 days. Variation in phenology of sorghum cultivars was also reported by Rao *et al*. (2013). Yield attributes, viz. panicle length, number of grains/panicle and 100-grain weight differed significantly among the sorghum cultivars. Among hybrids, ‘CSH 16’ (31.52 cm) and among the varieties, ‘CSV 17’ (29.37 cm) produced the longest panicle. Hybrids produced more number of seeds per panicle (1,239–1,253) and bolder seeds (100-seed weight 2.84–2.98 g) than the varieties (1,123–1,230 and 2.60–2.88g). On mean basis, hybrids produced 20.6% higher grain yield over varieties. Among genotypes ‘CSH 16’ (3.07 t/ha), being on a par with ‘CSH 23’ (3.05 t/ha) and ‘CSH 14’ (2.80 t/ha) produced the highest grain yield and ‘CSV 17’ (2.33 t/ha), the lowest. However, the stover yield was higher in varieties (except ‘CSV 17’) due to higher plant height. The mean harvest index (HI) was also significantly higher in hybrids (21.00) than the varieties (18.36) except that of ‘CSV 17’, which had the highest HI (22.43). Higher HI in sorghum hybrids and ‘CSV 17’ showed that these genotypes were more efficient in con-

Table 2. Effect of fertility levels and cultivars on growth, yield attributes and yield of sorghum (Mean of 2 years and 6 locations)

Treatment	Plant height (cm)	Days to 50% flowering	Days to maturity	Panicles/ m^2	Panicle length (cm)	Grains/ panicle	100-seed weight (g)	Grain yield (t/ha)	Stover yield (t/ha)	HI (%)
Fertility level										
Control	184	69	108	12.60	27.53	1147	2.65	1.86	9.20	17.67
100% RDF	200	67	109	12.59	28.30	1224	2.80	2.80	11.95	19.82
150% RDF	208	66	110	12.48	29.75	1240	2.92	3.28	13.72	20.12
SEm±	4	1	1	1	0.67	24	0.09	0.25	0.56	1.2
CD (P=0.05)	12	2	NS	NS	1.99	71	0.25	0.77	1.66	NS
Cultivar										
‘CSH 14’	177	64	108	12.63	28.63	1240	2.84	2.80	11.09	20.16
‘CSH 16’	189	67	111	12.68	31.52	1239	2.98	3.07	11.73	20.69
‘CSH 23’	180	64	109	12.73	28.22	1253	2.96	3.05	11.00	22.16
‘SPV 462’	213	71	111	12.09	28.30	1230	2.60	2.56	11.50	18.83
‘CSV 15’	219	70	108	12.94	28.00	1178	2.65	2.52	12.73	16.77
‘CSV 17’	146	60	103	12.91	29.37	1123	2.61	2.33	8.78	22.43
‘CSV 23’	213	70	110	12.33	27.15	1171	2.88	2.42	12.60	16.96
‘SPV 1616’	228	71	111	12.63	27.11	1230	2.79	2.50	13.37	16.80
SEm±	4	1	1	1	0.71	25	0.06	0.11	0.52	0.95
CD (P=0.05)	12	3	3	NS	2.05	74	0.18	0.31	1.64	2.91

RDF, (80:40:40 kg N:P_2O_5: K_2O/ha) verting biological yield into economic yield (Kusalkar *et al*., 2003).

The mean grain yield across the locations was higher in 2010 (2.92 t/ha) than in 2009 (2.41 t/ha) due to favourable weather conditions especially rainfall, which was higher during 2010 than that of 2009 (Fig. 1). However, the favourable effect of higher rainfall on grain yield was comparatively less in case of 'CSV 17' during 2010 (Table 3). Being a short duration variety, 'CSV 17' matured 8–10 days earlier than the other cultivars, and hence did not respond much to the higher rainfall. Irrespective of the cultivars, sorghum grain yield increased with increasing levels of fertility. The interaction effect between fertility levels and cultivars for grain yield across the locations was not significant during both the years.

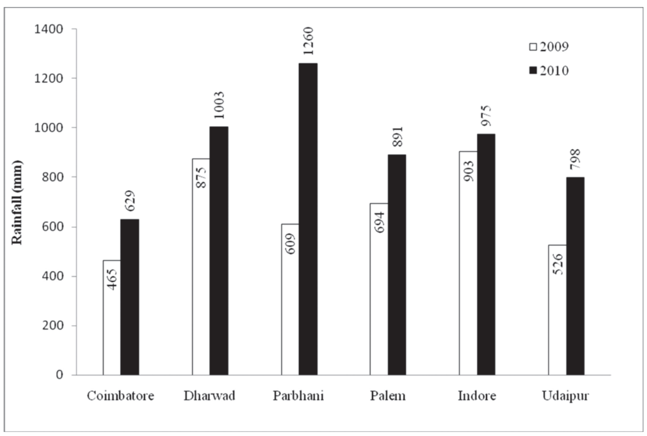

Fig. 1. Total rainfall (mm) received during crop season at different locations.

Nutrient uptake

Increasing levels of fertility up to 150% RDF significantly increased uptake of N, P and K in grain and stover of sorghum crop (Table 4). Total N, P and K uptake by sorghum increased from 108 to 178, 28.37 to 46.85 and 153 to 241 kg/ha, respectively, with increase in the level of NPK from 0 to 150% RDF. This increase in nutrient uptake was due to increase in NPK contents and grain and stover yields with nutrients application. Higher concentration and availability of nutrients in rhizosphere led to higher N, P and K uptake by the plant biomass. The short supply of nutrients in the control plot was amply reflected by the lower NPK uptake. Similar findings were also reported by Jat *et al.* (2013). Sorghum cultivars differed in nutrient uptake pattern. The varietal differences for N and P uptake might be due to additive gene action for N and non-additive for P (Krishna *et al*., 1985). Sorghum genotypes greatly influence the nutrient accumulation in plants due to variation in rate of absorption, translocation and accumulation of nutrients in plant tissues. In general, the NPK uptake by hybrids was higher than the varieties mainly due to higher grain yield. Among cultivars 'CSV 15' recorded significantly higher N (189 kg/ha) and P (43.63 kg/ha) uptake followed by 'CSH 14' (172 and 42.89 kg/ha) mainly because of relatively higher N and P contents in the stover of these cultivars. However, the highest K uptake (211 kg/ha) was recorded with 'CSH 23' followed by 'CSH 14' (198 kg/ha). Genotypic differences in nutrient uptake in sorghum were also reported by Seetharama *et al*. (1990) and Maraanville *et al*. (2002).

Nutrient-use efficiency

Sorghum cultivars varied with respect to nutrient-use efficiency (NUE). Increasing fertility levels from 100% RDF to 150% RDF increased the NUE of all the test hybrids, but decreased the efficiency of varieties except 'CSV 17' (Fig. 2). Bernal *et al.* (2002) also reported higher NUE of commercial hybrids at high levels of nitrogen.

Table 3. Effect of fertility levels and cultivars on grain yield (t/ha) of sorghum (Mean of Coimbatore, Parbhani, Palem, Dharwad, Indore and Udaipur)

Treatment	2009				2010			
	Control	100% RDF	150% RDF	Mean	Control	100% RDF	150% RDF	Mean
'CSH 14'	1.69	2.83	3.12	2.55	2.06	3.15	4.07	3.09
'CSH16'	1.73	2.87	3.37	2.66	2.56	3.61	4.26	3.48
'CSH23'	1.96	3.09	3.54	2.86	2.53	3.25	3.93	3.24
'SPV 462'	1.56	2.38	2.92	2.27	1.92	3.08	3.48	2.83
'CSV 15'	1.35	2.28	2.88	2.17	2.09	3.08	3.42	2.86
'CSV17'	1.45	2.33	2.91	2.23	1.79	2.51	2.98	2.43
'CSV 23'	1.52	2.38	2.76	2.22	2.05	2.72	3.10	2.63
'SPV 1616'	1.47	2.59	2.80	2.29	1.99	2.89	3.52	2.78
Mean	1.59	2.59	3.04	2.41	2.12	3.02	3.59	2.92

CD (P=0.05): Fertility levels (F): 0.45; Cultivars (C): 0.27; F × C interaction: NS CD (P=0.05): Fertility levels (F): 0.60; Cultivars (C): 0.36; F × C interaction: NS

Table 4. Effect of fertility levels and cultivars on nutrient uptake and economics (Mean of 2 years and 6 locations)

Treatment	Nitrogen uptake(kg/ha)			Phosphorus uptake (kg/ha)			Potassium uptake (kg/ha)			Net returns ($\times 10^3$ ₹/ha)	Benefit : cost ratio
	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total		
Fertility level											
Control	29.2	79.1	108.3	7.7	20.7	28.4	6.6	146.3	152.9	17.35	1.51
100% RDF	46.3	106.3	152.6	11.6	28.1	39.7	9.9	197.2	207.2	23.31	1.76
150% RDF	55.9	122.5	178.4	13.9	32.9	46.8	11.6	229.5	241.1	25.97	1.79
SEm±	2.5	3.2	4.1	0.9	1.5	2.1	0.8	6.2	8.3	1.52	0.08
CD (P=0.05)	7.3	10.1	12.3	2.5	4.4	6.3	2.2	18.1	23.8	4.66	0.24
Cultivars											
‘CSH 14’	51.9	120.2	172.1	11.9	31.0	42.9	8.6	189.6	198.2	23.22	1.73
‘CSH 16’	47.0	62.6	109.6	12.8	18.3	31.6	11.0	177.6	188.6	24.72	1.81
‘CSH 23’	48.6	73.2	121.8	13.1	24.9	38.0	10.6	200.2	210.8	25.52	1.89
‘SPV 462’	40.1	90.4	130.5	10.5	23.8	34.3	9.6	123.1	132.7	21.35	1.65
‘CSV 15’	39.0	150.1	189.1	9.6	34.0	43.6	9.0	184.5	193.5	23.87	1.77
‘CSV 17’	37.2	83.4	120.6	9.2	17.0	26.2	7.4	119.1	126.5	14.85	1.24
‘CSV 23’	41.5	73.7	115.2	9.8	23.8	33.6	8.5	184.2	192.7	21.64	1.67
‘SPV 1616’	37.0	111.2	148.2	10.2	27.7	37.9	9.2	168.3	177.5	23.61	1.78
SEm±	1.5	3.2	3.1	0.4	1.1	1.5	0.7	4.2	6.3	1.25	0.07
CD (P=0.05)	4.3	9.5	10.0	1.2	3.2	4.5	1.9	13.1	17.2	3.64	0.21

RDF = (80:40:40 kg N: P_2O_5: K_2O/ha)

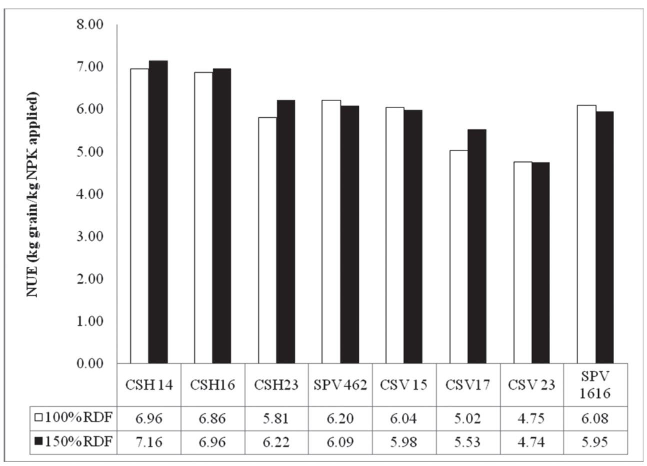

Fig. 2. Nutrient-use efficiency of grain sorghum cultivars (mean of 2 years)

With increase in fertility levels from 100% RDF to 150% RDF, the NUE increased from 6.96 to 7.16, 6.86 to 6.96, 5.81 to 6.22 kg grain/kg NPK applied, respectively for ‘CSH 14’, ‘CSH 16’ and ‘CSH 23’. The NUE was higher in hybrids (6.66 kg grain/kg NPK) than the varieties (5.54 kg grain/kg NPK). 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.

Economics

The economic parameters for sorghum were calculated and presented in Table 4. The highest net returns (25.97×10^3 ₹/ha) and benefit: cost ratio (1.79) were obtained with application of 150% RDF which were on a par with 100% RDF, but significantly superior to control. Among cultivars, hybrids were more economical than the varieties. Hybrid ‘CSH 23’ being on a par with ‘CSH 16’ and ‘CSH 14’ recorded the maximum net returns (25.52×10^3 ₹/ha) and benefit: cost ratio (1.89).

It may be concluded that the grain sorghum hybrids ‘CSH 23’ ‘CSH 16’ and ‘CSH 14’ should be grown with application of 150% RDF (120:60:60 kg/ha of N: P_2O_5: K_2O) to get maximum productivity, nutrient-use efficiency and profitability during rainy season.

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