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M Udaya Sree
M.Sc scholar (Agronomy), College of Agriculture (PJTAU), Rajendranagar, Hyderabad, Telangana, India

GECH Vidya Sagar
Registrar, Professor Jayashankar Telangana Agricultural University (PJTAU), Rajendranagar, Hyderabad, Telangana, India

B Gangaiah
Principal Scientist (Agronomy), ICAR-Indian Institute of Millets Research (IIMR), Rajendranagar, Hyderabad, Telangana, India

G Kiran Reddy
Principal Scientist (Soil science), All India Coordinated Research Project on IFS, Rajendranagar, Hyderabad, Telangana, India

Corresponding Author:
M Udaya Sree
M.Sc scholar (Agronomy), College of Agriculture (PJTAU), Rajendranagar, Hyderabad, Telangana, India

Growth and yield of sorghum [*Sorghum bicolor* (L.) Moench] as affected by fertilizer levels and its cultivars

M Udaya Sree, GECH Vidya Sagar, B Gangaiah and G Kiran Reddy

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Abstract
A field experiment was conducted at Indian Institute of Millets Research, Hyderabad to evaluate the effect of fertilizer levels and cultivars on growth and yield of sorghum (*Sorghum bicolor* L. Moench). The study comprised four fertilizer levels based on the recommended dose of fertilizers (RDF): 0%, 50%, 100% and 150% RDF and three cultivars M 35-1, CSV 216R and CSH 15R. Results revealed that fertilizer application had a significant influence on plant height, drymatter accumulation, number of grains per panicle, grain yield, straw yield, biological yield and harvest index, while the number of panicles m^{-2} and test weight were not significantly affected.

Application of 150% RDF produced the tallest plants (210.9 cm), which was on par with 100% RDF (203.7 cm), showing an increase of 19.3% over the control (170.2 cm). Similarly, the highest drymatter accumulation (132.3 g $plant^{-1}$) was obtained with 150% RDF, followed by 100% RDF (126.6 g $plant^{-1}$). Enhanced nutrient availability at higher fertilizer levels improved plant vigor, photosynthetic activity and biomass accumulation. Delay in days to 50% flowering (77.7 days) and maturity (126.6 days) with higher fertilizer level of 150% RDF was attributed to prolonged vegetative growth induced by nitrogen application.

Among cultivars, M 35-1 recorded the highest plant height (207.4 cm) and drymatter (121.1 g $plant^{-1}$), whereas hybrid CSH 15R flowered (74.5) and matured (120.0) earlier. Grain yield was significantly influenced by fertilizer levels, with the highest yield (3.68 t ha^{-1}) recorded under 150% RDF, followed by 100% RDF (3.57 t ha^{-1}), representing yield improvements of 40.7% and 38.9%, respectively, over the control (2.18 t ha^{-1}). Similarly, straw and biological yields were highest under 150% RDF (8.59 and 12.27 t ha^{-1}, respectively). Among cultivars, CSH 15R recorded the highest grain yield (3.27 t ha^{-1}) and harvest index (30.8), while M 35-1 produced the highest straw (7.94 t ha^{-1}) and biological yields (10.93 t ha^{-1}).

Keywords: Fertilizer levels, cultivars, drymatter, grain yield, straw yield

Introduction
Sorghum (*Sorghum bicolor* (L.) Moench) is the fourth most widely grown cereal crop globally, following rice, wheat and maize. Its grain serves as a crucial staple food for over 300 million people, while its stover is an important livestock feed, particularly in the arid and semi-arid regions of Africa and Asia. The average per capita consumption of sorghum grain in key growing areas of India is around 75 kg annually [1]. During the 2023-2024 period, India produced 4.03 million tonnes of sorghum, with 61.6% of this output coming from the *rabi* season [2]. The *rabi* crop has gained importance for food consumption due to the absence of grain mold, unlike the *kharif* crop. In Telangana, the *rabi* season accounts for 88.5% of the total sorghum cultivation area (0.26 million hectares) and 94.2% of production (0.17 million tonnes) [3]. Despite this, the average productivity of sorghum in India is only 1090 kg per hectare [4], which is just 32.9% and 92.3% of the potential yields of 3.31 and 1.18 tonnes per hectare for the *kharif* and *rabi* seasons, respectively [5]. This low productivity is attributed to a range of biotic and abiotic stresses, with inadequate crop nutrition being a major limiting factor among the abiotic challenges.

Sorghum is commonly cultivated in India on low fertile soils, particularly in drought-affected regions, due to its hardy nature and ability to withstand harsh conditions. Prior to the development of hybrids and high-yielding varieties, it was typically grown with very limited nutrient inputs. Development of better adapted, high yielding sorghum cultivars has increased the yield potential and the quantity of nutrients required by the crop. Consequently, the fertilizer application in sorghum has increased significantly. High yielding varieties of sorghum remove on an average 22 kg N, 13.3 kg P_2O_5 and 34 kg K_2O to produce one tone of grains [6]. Cultivars exhibit genetic variability in growth characteristics and nutrient uptake efficiency, leading to differential responses to fertilizer application. Applying the right amount of nutrients tailored to each cultivar ensures better nutrient use efficiency, leading to improved plant growth, higher grain yield and better tolerance to environmental stresses. Proper fertilizer management also helps reduce unnecessary costs and minimizes negative effects on the environment. Therefore, keeping these in view the present trial was conducted to understand the relationship between fertilizer levels and cultivars in achieving sustainable and profitable sorghum production.

Materials and methods

The research trial on sorghum was performed at the ICAR-Indian Institute of Millet Research farm in Rajendranagar, Hyderabad, Telangana, India during the *rabi* season of 2022-23. The experimental soil was clay loam in nature and has a pH of 7.20, EC of 0.19 dSm^{-1} and was rated low in organic carbon (0.39%), low in available N (234 kg ha^{-1}), medium in P (18 kg ha^{-1}), medium in K (258 kg ha^{-1}) and DTPA Fe (1.82 ppm), Zn (0.51 ppm) were noticed to be below than critical limits (4.5 ppm, 0.6 ppm, respectively). The experiment was conducted using a split plot design with three replications. The main plots consisted of four fertilizer levels: F_1 - 0% RDF (control), F_2 - 50% RDF, F_3 - 100% RDF (80: 17.5: 33.2 NPK) and F_4 - 150% RDF. The subplots included three cultivars: V_1 - M 35-1, V_2 - CSV 216R and V_3- CSH 15R. Each gross plot measured 22.95 m^2, while the net plot size was 11.34 m^2. Sorghum seeds@ 10 kg ha^{-1} were treated with cyantraniliprole + thiamethoxam insecticide and sown with a spacing of 45 x 15 cm. At the time of sowing complete phosphorous and potassium were applied as per the treatments through 18:18:18 fertilizer and remaining nitrogen was top dressed at 30 DAS. Atrazine @0.75 kg/ha was applied to control pre-emergence weeds and hand weeding was done at 30 DAS to remove weeds. A total rainfall of 344.7 mm was received in 16 rainy days during the crop growth period. Crop was raised under sprinkler irrigation, while at critical stages only flooding was given to prevent water stress to the crop. Necessary management practices were taken to control the pests and diseases. Five healthy plants were tagged and growth and yield parameters were calculated as per the standard procedure. Entire net plot was harvested for grain and straw yield data. The data collected on different parameters were subjected to statistical analysis as described by Gomez and Gomez (1984) [7] for better interpretation of results.

Results and discussion

A. Growth parameters (Table 1)

a) Plant height (cm)

Plant height was significantly affected by the fertilizer levels. Application of 150% RDF recorded a plant height of 210.9 cm and this was on par with 100% RDF. The increment in plant height with nutrient application (50, 100 & 150% RDF) was 11.0%, 16.4% and 19.3%, respectively over the control treatment (170.2 cm). The increase in plant height with higher fertilizer levels was attributed to the improved availability of nutrients, which enhanced the nutritional environment in the root zone, promoting better plant growth and development [8]. Similar results were reported by Yadav *et al.* (2024) [9].

With respect to cultivars, superior plant height was recorded with M35-1 cultivar (207.4 cm) and it has recorded an increment in plant height by 7.9% and 11.4% over the cultivars CSV 216R (191.0 cm) and CSH 15R (183.7 cm). The variation between the cultivars was mostly due to their differences in their genetic makeup affecting the mechanisms of accumulation, translocation and utilization of nutrients [10]. Similar results of differences in plant height due to cultivars was also recorded by Mishra *et al.* (2015) [11].

b) Drymatter (g $plant^{-1}$)

Significantly highest drymatter among the fertilizer levels was recorded with 150% RDF and it was comparable to 100% RDF (126.6 g $plant^{-1}$) followed by 50% RDF (118.5 g $plant^{-1}$). Lowest drymatter was recorded in control (99.9 g $plant^{-1}$). The increment in drymatter with fertilizer application (50, 100 & 150% RDF) was 15.7-24.5% over the control treatment. This was due to application of major nutrients (NPK) which resulted in improved synthesis of amino acids, protein, growth promoting substances and their involvement in energy transfer reactions likely had caused increase in plant height and leaf area which ultimately resulted in improved drymatter[12, 13]. Similar results were published by Nayak *et al.* (2023) [14].

Among the cultivars, significantly highest drymatter was recorded with M 35-1 (121.1 g $plant^{-1}$) and it was on par with CSV 216R (119.2 g $plant^{-1}$). Lowest performance was seen with the CSH 15R (117.7 g $plant^{-1}$). This was due to the fact that cultivars inherently vary in traits like plant height, stem girth, leaf to stem ratio, panicle development and nutrient uptake capacity all of which impact biomass partitioning to drymatter. Similar results were recorded by Singh *et al.* (2012) [15].

c) Days to 50% flowering and maturity (DTF & DTM)

Control recorded the least DTF (73.9) and DTM (122.6) and it was on par with 50% RDF (75.3 & 123.6, respectively). Highest DTF (77.7) and DTM (126.6) were recorded with 150% RDF and it was comparable to 100% RDF. Delay in DTF and DTM was due to application of higher levels of nitrogen, which have resulted in increase in the vegetative growth and delayed the reproductive period [16].

With respect to cultivars, significantly least DTF (74.5) and DTM (120.0) were recorded in hybrid CSH 15R followed by CSV 216R (75.5 & 125.6, respectively) and M 35-1 (77.3 & 127.8, respectively). Variation in phenology of cultivars was also reported by Rao *et al.* (2013) [17] and Mishra *et al.* (2015) [11].

B. Yield parameters and Yield (Table 2 & Fig 1)

a) Number of panicles m^{-2} (No.)

Number of panicles m^{-2} was not significantly influenced neither by the fertilizer levels nor by the sorghum cultivars and their interaction. Numerically though application of 150% RDF resulted in higher number of panicles m^{-2} (14.4), whereas lowest recorded in control (12.7).

Table 1: Growth parameters of sorghum as affected by fertilizer levels and cultivars

Treatment	Growth parameters			
	Plant height (cm)	Dry weight (g plant^{-1})	Days to 50% flowering	Days to maturity
Main plot: Fertilizer levels (Based on RDF)				
F_1: 0% (control)	170.2	99.9	73.9	122.6
F_2: 50%	191.3	118.5	75.3	123.6
F_3: 100%	203.7	126.6	76.1	125.1
F_4: 150%	210.9	132.3	77.7	126.6
S.Em±	2.94	2.25	0.70	0.79
CD (P=0.05)	10.17	7.78	2.41	2.73
Sub plot: Cultivars				
V_1: M 35-1	207.4	121.1	77.3	127.8
V_2: CSV 216R	191.0	119.2	75.5	125.6
V_3: CSH 15R	183.7	117.7	74.5	120.0
S.Em±	2.91	0.84	0.61	0.74
CD (P=0.05)	8.72	2.53	1.82	2.20

b) Number of grains panicle^{-1} (No.)

Number of grains panicle^{-1} was significantly influenced only by the fertilizer levels, whereas cultivars of sorghum and interaction effects were non-significant. Among the fertilizer levels, highest number of grains panicle^{-1} (940.7) was found with 150% RDF and it was comparable to 100% RDF (913.3) followed by 50% RDF (856.3). Increment in grains per panicle were 10.8%, 16.3% and 18.8% with nutrient application (50, 100 & 150% RDF, respectively) over the control treatment (764.1). This might be due to higher sink at higher level of nutrition manifested into increase in grains panicle^{-1}. Higher nitrogen application enhances nitrogen availability during the vegetative growth stage, which supports increased photosynthetic activity [18]. This leads to improved carbohydrate production, better partitioning and more efficient translocation of photo-assimilates to the grain, ultimately resulting in a higher number of grains per panicle. Similar line of work in sorghum was published by Sujathamma *et al*. (2015) [19].

With respect to cultivars, numerically hybrid CSH 15R recorded more number of grains per panicle (880.4) followed by CSV 216R (866.4) and M 35-1 (859.0).

c) Test weight (g)

Test weight was not significantly influenced by the fertilizer levels. However among the cultivars, significantly highest test weight was recorded in the CSH 15R (31.3 g) followed by CSV 216R (29.6 g) and M 35-1 (29.2 g). Genetic differences among the sorghum genotypes significantly contribute to test weight variation as demonstrated by Dahlberg (2002) [20], who documented considerable seed morphology and size diversity across sorghum germplasm accessions, indicating that genotype-specific traits strongly influence grain density and weight.

d) Grain yield (t ha^{-1})

Significantly the highest grain yield (3.68 t ha^{-1}) among the fertilizer levels was attained with 150% RDF and this was on par with 100% RDF (3.57 t ha^{-1}) followed by 50% RDF (3.07 t ha^{-1}). The increment in grain yield with nutrient application (50, 100 & 150% RDF) was 30.0%, 38.9% and 40.7%, respectively, when compared to the control treatment (2.18 t ha^{-1}). Bekunda *et al*. (2015) [21] reported that the two most limiting nutrients to food production are nitrogen and phosphorus and application of these nutrients improves the yield. A meta-analysis study in sorghum-cropping system in Africa concluded that application of N and P fertilizer resulted in 98.0% yield improvement [22].

With respect to the cultivars, hybrid CSH 15R recorded highest grain yield (3.27 t ha^{-1}) and it was on par with CSV 216R (3.12 t ha^{-1}), which was closely followed by M 35-1 (2.99 t ha^{-1}). Variation in yield due to cultivars was also reported by Gangaiah *et al*. (2020) [23].

e) Straw yield (t ha^{-1})

Among the fertility levels, significantly highest straw yield was reported in 150% RDF (8.59 t ha^{-1}) and it was on par with 100% RDF (8.18 t ha^{-1}) followed by 50% RDF (7.42 t ha^{-1}). Straw yield increased by 18.6%, 26.2% and 29.7% with the application of 50%, 100% and 150% RDF, respectively, compared to the control treatment, which recorded a straw yield of 6.04 t ha^{-1}. This was due to the role of nitrogen in protein synthesis, chlorophyll production, increasing leaf area and enhancing photosynthetic capacity [24]. Phosphorus is essential for energy transfer (ATP), nucleic acid synthesis (DNA/RNA) and early tissue development supporting processes such as cell division and elongation [25]. Together, these nutrients accelerate vegetative biomass accumulation, which in sorghum results in increased straw yield. Patel *et al*. (2018) [26] and Raut *et al*. (2016) [27] also recorded similar findings.

Among the cultivars, significantly highest straw yield was recorded with the cultivars M 35-1 (7.94 t ha^{-1}) followed by CSV 216R (7.47 t ha^{-1}) and CSH 15R (7.26 t ha^{-1}). Similar variations in straw yield was also reported by Satish *et al*. (2017) [28].

f) Biological yield (t ha^{-1})

Significantly among the fertility levels, highest straw yield was reported in 150% RDF (12.27 t ha^{-1}) and it was on parity with 100% RDF (11.74 t ha^{-1}) followed by 50% RDF (10.49 t ha^{-1}). Control treatment (0% RDF) recorded a biological yield of 8.22 t ha^{-1}. The availability of mineral nutrients is a key determinant of plant growth, yield and biomass production which determines the biological yield. Nutrient deficiencies reduce these parameters, while adequate supply enhances them [29].

In case of cultivars, significantly highest biological yield was recorded with the cultivars M 35-1 (10.93 t ha^{-1}) followed by CSV 216R (10.59 t ha^{-1}) and CSH 15R (10.53 t ha^{-1}). Biological yield reflects the combined production of grain and straw. Variations in grain and straw yield among the cultivars influenced their overall biological yield.

g) Harvest index

Among the fertility levels, significantly highest harvest index was recorded with 100% RDF (30.4) and it was on par with 150% RDF (30.0) followed by 50% RDF (29.3), whereas lowest HI was recorded in the control treatment (26.5). There was an increase in HI by 12.8% with 100% RDF, compared to the control. Optimal nitrogen and phosphorus levels significantly increased grain yield and harvest index in sorghum by enhancing assimilate partitioning towards the panicle, rather than vegetative organs [30].

Between the cultivars, significantly highest HI (30.8) was recorded with CSH 15R and it was on par with CSV 216R (29.2), whereas lowest HI was recorded in M 35-1 (27.1). Mishra *et al.* (2017) [31] also reported variations in HI among the cultivars.

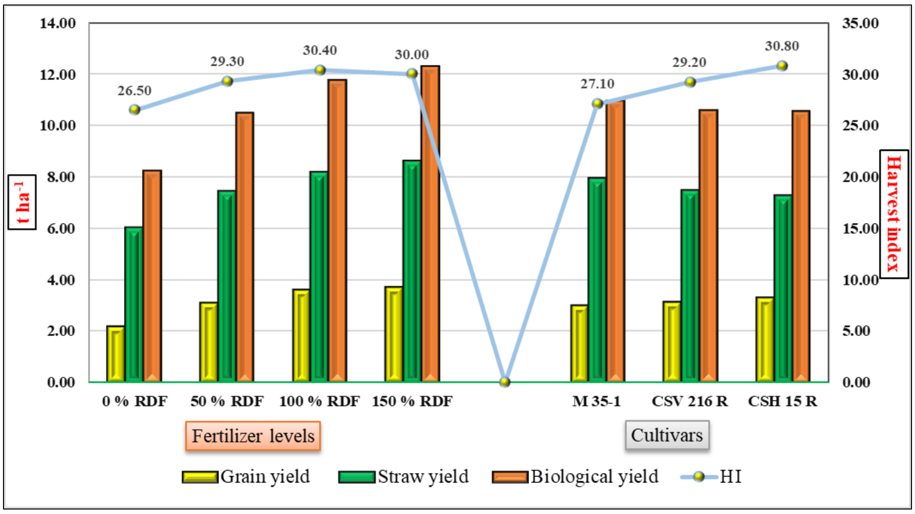

Fig 1: Yield and harvest index of sorghum as affected by fertilizer levels (based on RDF) and its cultivars

Table 2: Yield parameters and yield of sorghum as affected by fertilizer levels and cultivars

Treatment	Yield parameters and yield						
	Panicles m^{-2} (No.)	Grains panicle^{-1} (No.)	Test weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index
Main plot: Fertilizer levels (Based on RDF)							
F_1:0% (control)	12.7	764.1	28.4	2.18	6.04	8.22	26.5
F_2: 50%	13.8	856.3	29.1	3.07	7.42	10.49	29.3
F_3: 100%	14.1	913.3	31.1	3.57	8.18	11.74	30.4
F_4: 150s%	14.4	940.7	31.5	3.68	8.59	12.27	30.0
S.Em±	0.37	15.06	0.83	0.101	0.188	0.232	0.73
CD (P=0.05)	NS	52.13	NS	0.350	0.651	0.802	2.53
Sub plot: Cultivars							
V_1: M 35-1	13.8	859.0	29.2	2.99	7.94	10.93	27.1
V_2: CSV 216R	13.6	866.4	29.6	3.12	7.47	10.59	29.2
V_3: CSH 15R	13.9	880.4	31.3	3.27	7.26	10.53	30.8
S.Em+	0.33	11.51	0.51	0.065	0.088	0.111	0.50
CD (P=0.05)	NS	NS	1.52	0.195	0.264	0.333	1.49
Interaction	NS	NS	NS	NS	NS	NS	NS

Conclusions

The study clearly demonstrated that fertilizer levels exert a strong influence on the growth, phenology and productivity of sorghum. Application of 150% RDF consistently enhanced plant growth, biomass accumulation and yield attributes, resulting in the highest grain, straw and biological yields. However, yields obtained with 150% RDF were statistically comparable to those under 100% RDF for several parameters, indicating that 100% RDF remains an efficient and economically viable option. Higher fertilizer levels also prolonged the crop duration due to delayed flowering and maturity. Among the cultivars, M 35-1 exhibited superior vegetative growth and biomass production, while the hybrid CSH 15R proved more productive in terms of grain yield and harvest index, coupled with earlier phenological development. Overall, the results highlight that nutrient management at 100 and 150% RDF, along with the selection of high-yielding cultivars such as CSH 15R, can substantially improve sorghum productivity.

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