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Effect of foliar nutrition on yield, and water use efficiency of *Rabi Sorghum (Sorghum bicolor L.)* in semi-arid conditions

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Abstract

A field investigation entitled "Effect of foliar application of nutrients on growth, yield and water use efficiency of Rabi sorghum" was conducted during the Rabi season of 2023-24 under the Sorghum Improvement Project at the Instructional Farm, MPKV, Rahuri, Maharashtra. The experiment was laid out in a Randomized Block Design (RBD) with nine treatments viz., T₁: Absolute control; T₂: GRDF (80:40:40 kg N:P₂O₅:K₂O ha⁻¹ + 5 ton FYM ha⁻¹); T₃: GRDF (50% N through urea at basal) + one foliar spray of nano urea @ 4 ml L⁻¹ at Panicle Initiation (PI) stage; T₄: GRDF (50% N through urea at basal) + one foliar spray of nano urea @ 4 ml L⁻¹ at Flag Leaf (FL) stage; T₅: GRDF (50% N through urea at basal) + two foliar sprays of nano urea @ 4 ml L⁻¹ at PI and FL stages; T₆: GRDF + two foliar sprays of NaCl @ 1% at PI and FL stages; T₇: GRDF + two foliar sprays of Phule Micro Grade II @ 1% at PI and FL stages; T₈: GRDF + two foliar sprays of Potassium Nitrate (13:0:45) @ 1% at PI and FL stages; T₉: Protective irrigation at PI and FL stages. The highest panicle length (21.20 cm) and panicle weight (86.40 g) were recorded in T₇ (GRDF + two foliar sprays of Phule Micro Grade II @ 1% at PI and FL stages), which also showed maximum panicle density (2303.99 panicles m⁻²) and grain weight (40.32 g). Grain yield was significantly higher in T₇ (2793 kg ha⁻¹), followed by T₈ (2418 kg ha⁻¹). Water use efficiency (WUE) was highest in T₇ (11.04 kg ha⁻¹ mm), demonstrating the effectiveness of micronutrient-based foliar sprays in improving sorghum productivity and resource efficiency in semi-arid conditions.

Keywords: Rabi, sorghum, foliar spray, micronutrient, water use efficiency

Introduction

Sorghum (*Sorghum bicolor* L.) is a valuable cereal crop cultivated extensively in arid and semi-arid regions, providing essential resources such as food, feed, stover, and fuel to millions of impoverished farm families and their livestock. Its grains contain approximately 10-12% protein, 3% fat, and 70% carbohydrates. In India, *Sorghum bicolor* is primarily used for food, feed, and forage. The crop is cultivated on 5.79 million hectares across the country, with Maharashtra, Karnataka, and Andhra Pradesh being the leading states in production India (Anonymous-2014) [4]. Maharashtra alone accounts for 22.9% of India's total sorghum production, making it a crucial component of the agricultural economy in the region.

Sorghum's biological drought tolerance makes it a primary dryland cereal crop, particularly suitable for cultivation under rainfed conditions where water availability significantly limits yields (Rosenow *et al.*, 1983) [8]. The cultivation of kharif sorghum is concentrated in the semi-arid Deccan Plateau of India, which is characterized by low rainfall and challenging growing conditions. Despite its adaptability, sorghum production is often constrained by poor crop establishment and limited nutrient availability.

Key yield-contributing characters in sorghum include panicle length, the number of grains per panicle, and grain weight. These factors play a critical role in determining the crop's overall productivity. Improving these attributes requires a balanced supply of essential nutrients such as iron (Fe), zinc (Zn), copper (Cu), and manganese (Mn), which are vital for plant metabolic processes including photosynthesis, respiration, and enzyme activity (Puig and Penarrubia, 2009) [7].

However, deficiencies of these micronutrients are prevalent in arid and semi-arid soils, leading to reduced yields and delayed crop maturity. Traditional soil-based nutrient applications often result in low efficiency due to losses through leaching and volatilization.

Foliar application of nutrients has emerged as a promising alternative to address these deficiencies. This technique allows for direct nutrient absorption through the plant canopy, ensuring rapid correction of deficiencies and enhanced nutrient use efficiency. Studies have shown that foliar sprays of micronutrients significantly improve growth parameters and yield attributes in crops like sorghum. For instance, micronutrient supplementation can enhance panicle development, grain filling, and overall biomass production, leading to higher grain yields.

The present study was conducted to evaluate the effect of foliar nutrition on yield-contributing factors, yield and water use efficiency of Rabi sorghum. By focusing on critical growth and yield parameters, the research aims to provide insights into optimizing nutrient management practices for improving sorghum productivity in semi-arid regions. Therefore the research experiment was planned on “Effect of Foliar Nutrition on Yield, and Water Use Efficiency of Rabi Sorghum in Semi-Arid Conditions” during *Kharif* 2023 at Interfaculty Department of Irrigation Water Management, PGI, MPKV, Rahuri.

Materials and Methods

The field experiment entitled, “Effect of Foliar Nutrition on Yield, and Water Use Efficiency of Rabi Sorghum (*Sorghum bicolor* L.) in Semi-Arid Conditions” was conducted during the Rabi season of 2023-24 under the Sorghum Improvement Project at the Instructional Farm of the Inter-Faculty Department of Irrigation Water Management, Post Graduate Institute, MPKV, Rahuri, Maharashtra. Geographically, the experimental site is located between 19°51' and 19°64' N latitude and 76°32' and 76°10' E longitude, at an altitude ranging from 491 to 537 meters above mean sea level. The site lies on the eastern side of the Western Ghats and falls under a rain-shadow area. The soil of the experimental plot was slightly alkaline (pH 8.2), medium in organic carbon (0.58%), non-calcareous, clayey in texture, low in available nitrogen (163.00 kg ha⁻¹), medium in available phosphorus (15.00 kg ha⁻¹), and very high in available potassium (314.00 kg ha⁻¹). Agro-climatically, the location is categorized as a drought-prone area of Maharashtra, with annual mean maximum temperatures ranging from 39-42°C and mean minimum temperatures within the same range. The experiment was laid out in a Randomized Block Design (RBD) with nine treatments comprising various foliar sprays of water-soluble fertilizers. The treatments were: T₁: Absolute control; T₂: GRDF (80:40:40 kg N: P₂O₅: K₂O ha⁻¹ + 5 ton FYM ha⁻¹); T₃: GRDF (50% N through urea at basal) + one foliar spray of nano urea @ (4ml liter⁻¹ water) at Panicle initiation (PI) stage; T₄: GRDF (50% N through urea at basal) + one foliar spray of nano urea @ (4ml liter⁻¹ water) at flag leaf (FL) stage; T₅: GRDF (50% N through urea at basal) + one foliar spray of nano urea @ (4ml liter⁻¹ water) at PI and FL stage; T₆: GRDF + Two foliar spray of NaCl @ 1% at PI and FL stage; T₇: GRDF + Two foliar spray of Phule micro grade II @ 1% at PI and FL stage; T₈: GRDF + Two foliar spray of Potassium nitrate (13:0:45) @ 1% at PI and FL stage; T₉: Protective irrigation at Panicle initiation (PI) and flag leaf (FL). A recommended dose of P₂O₅ and K₂O was applied in treatments T₃ to T₉. The first foliar sprays of Phule Micro Grade II and nano urea were applied on the 45th day

(Panicle Initiation stage), while the second spray was administered on the 55th day (Flag Leaf stage). Sowing of sorghum breeder seeds of the variety "Phule Suchitra" was completed on 17th September 2023 at a spacing of 45 cm x 15 cm using the dibbling method.

The recommended fertilizer dose for sorghum is 80:40:40 kg N:P₂O₅:K₂O ha⁻¹. In treatments involving drip irrigation, the irrigation schedule was based on climatological approaches. Irrigation was provided on alternate days for all drip-irrigated treatments. Reference crop evapotranspiration (ET₀) was estimated using the FAO-56 recommended Penman-Monteith method. The depth of irrigation water to be applied was calculated using the formula:

$$ET_c = ET_r \times K_c$$

Where,

ET_c = Evapo-transpiration of crop (mm two days⁻¹)

ET_r = Reference Evapo-Transpiration

K_c = Crop coefficient

The water use efficiency in different treatment was calculated by formula

$$WUE = \frac{Y}{\text{water applied}}$$

Where,

WUE = Water use efficiency (kg ha⁻¹ mm)

Y = Yield (kg ha⁻¹)

The observations were recorded periodically to study the growth attributes

Results and Discussion

A. Yield Attributing Characters

The data regarding the yield-attributing characters as influenced by different treatments are presented in Table 1. Panicle length (cm), panicle weight (g), number of panicles m⁻², weight of grains per panicle (g), thousand grain weight (g), and total yield of fodder and grain were obtained during the investigation.

a. Panicle Length (cm) and Panicle Weight (g)

The data on panicle length and panicle weight are presented in Table 4.10. Regarding panicle length, the significantly longest panicle was recorded in treatment T₇ (GRDF + two foliar sprays of Phule Micro Grade II @ 1% at PI and FL stages), with a length of 21.20 cm. This was statistically at par with treatment T₈ (GRDF + two foliar sprays of Potassium Nitrate (13:0:45) @ 1% at PI and FL stages) at 19.13 cm and treatment T₂ (GRDF (80:40:40 kg N: P₂O₅: K₂O ha⁻¹ + 5 tons FYM ha⁻¹)) at 18.84 cm. For panicle weight, treatment T₇ showed the significantly highest panicle weight at 86.40 g per panicle, which was at par with treatment T₈ (77.96 g) and treatment T₂ (76.81 g).

The significantly higher panicle length and weight observed in treatment T₇ may be attributed to the micronutrients present in the foliar application, such as zinc and boron, which enhanced reproductive growth, resulting in longer and heavier panicles. These micronutrients play a critical role in enzyme function and hormonal activity in plants, promoting panicle development and grain filling. Similar results were reported by Munagilwar *et al.* (2020). In contrast, treatment T₁ (absolute control) exhibited the shortest and lightest panicles, indicating that a lack of additional nutrient inputs severely limits reproductive growth.

b. Number of Panicles m⁻² and Weight of Grains per Panicle (g)

T: The data on the number of panicles m⁻² and weight of grains per panicle are presented in Table 4.11. The maximum number of panicles per square meter was recorded in treatment T₇ (GRDF + two foliar sprays of Phule Micro Grade II @ 1% at PI and FL stages) at 2303.99, followed by treatment T₈ (2027.96) and treatment T₂ (2048.37). For the weight of grains per panicle, treatment T₇ recorded the significantly highest weight (40.32 g), which was statistically at par with treatments T₈ (36.38 g) and T₂ (35.85 g). The significantly higher number of panicles and grain weight per panicle in treatment T₇ can be attributed to enhanced nutrient availability during critical growth stages. Improved grain filling due to the foliar application of micronutrients likely contributed to the increased grain weight. In contrast, treatment T₁ (absolute control) recorded the lowest grain weight per panicle, demonstrating that nutrient-deficient plants produce fewer and smaller grains due to limited photosynthesis and poor nutrient allocation. These findings align with the results of Dafen *et al.* (1999).

c. Thousand Grain Weight (g)

The data on the thousand grain weight (g) of sorghum as influenced by different treatments are presented in Table 4.12. Treatment T₇ (GRDF + two foliar sprays of Phule Micro Grade II @ 1% at PI and FL stages) had the significantly highest thousand grain weight at 33.42 g, followed by treatment T₈ (33.11 g) and treatment T₂ (32.19 g). The higher thousand grain weights observed in treatments T₇ and T₈ reflect the effectiveness of these treatments in promoting grain development. Although the differences in thousand grain weight were not statistically significant among treatments, the trend indicates that nutrient availability influences grain size.

The potassium and urea feeding during growth stages might have enhanced the accumulation of assimilates in the grains, resulting in heavier grains, as reported by Amal *et al.* (2011). Treatment T₁ (absolute control) recorded the significantly lowest thousand grain weight (25.64 g) due to the lack of proper nutrition, further emphasizing the importance of nutrient inputs in improving grain size and weight.

Table 1: Mean Yield contributing characters i.e. Panicle length, panicle weight (gram panicle⁻¹), Number of panicle (m²), weight of grain panicle⁻¹ and thousand seed weight (g) of sorghum crop as influenced by different foliar application treatments

Tr. No.	Treatments	Panicle Length	Panicle Weight (g) panicle ⁻¹	Number of panicle (m ²)	Weight of grain panicle ⁻¹	Thousand seed weight (g)
T ₁	Absolute control	15.05	61.35	1635.96	28.63	25.64
T ₂	GRDF(80:40:40 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹ +5 ton FYM ha ⁻¹)	18.84	76.81	2048.37	35.85	32.19
T ₃	GRDF (50% N through urea at basal) + one foliar spray of nano urea @ (4 ml liter ⁻¹ water) at Panicle initiation (PI) stage	15.97	65.08	1735.48	30.37	29.15
T ₄	GRDF (50% N through urea at basal) + one foliar spray of nano urea @ (4 ml liter ⁻¹ water) at flag leaf (FL) stage	16.45	67.06	1788.15	31.29	29.80
T ₅	GRDF (50% N through urea at basal) + one foliar spray of nano urea @ (4 ml liter ⁻¹ water) at PI and FL stage	18.23	74.29	1981.16	34.67	30.92
T ₆	GRDF +Two foliar spray of NaCl @ 1% at PI and FL stage	15.62	63.66	1697.72	29.71	27.37
T ₇	GRDF + Two foliar spray of Phule micro grade II @ 1% at PI and FL stage	21.20	86.40	2303.99	40.32	33.42
T ₈	GRDF + Two foliar spray of Potassium nitrate (13:0:45) @ 1% at PI and FL stage	19.13	77.96	2027.96	36.38	33.11
T ₉	Protective irrigation at PL and FL	16.84	68.65	1830.79	32.04	30.74
	S. E. (m) ±	0.92	3.75	141.44	2.47	2.31
	C.D. at 5 %	2.76	11.29	NS	5.13	7.20
	General Mean	17.48	71.25	1900	33.25	30.25

d. Yield Studies

The data regarding grain, straw, total biological yield, and harvest index are presented in Table 2. The mean values for grain yield, fodder yield, total biological yield, and harvest index were 2187 kg ha⁻¹, 4289 kg ha⁻¹, 6464 kg ha⁻¹, and 33.80%, respectively. Significantly higher grain yield was observed in treatment T₇ (GRDF + Two foliar sprays of Phule micro grade II @ 1% at PI and FL stage) with a yield of 2793 kg ha⁻¹. This was statistically at par with treatment T₈ (GRDF + Two foliar sprays of Potassium nitrate (13:0:45) @ 1% at PI and FL stage), which recorded a yield of 5139 kg ha⁻¹, and treatment T₂ (GRDF 80:40:40 kg N:P₂O₅:K₂O ha⁻¹ + 5 tons FYM ha⁻¹), which recorded a yield of 2418 kg ha⁻¹.

The foliar application of nutrients, particularly in treatment T₇, significantly improved grain yield, straw yield, and total biological yield in sorghum compared to other treatments. The role of micronutrients in promoting both vegetative and reproductive growth was evident, leading to enhanced productivity. This improvement is likely due to the sustained availability of macro- and micronutrients during the later growth stages of sorghum. These results align with the findings of Alston (1979) [2]. Conversely, T₁ (Absolute Control) recorded significantly lower yields, highlighting the adverse effects of

nutrient deficiency.

e. Harvest Index (%)

The harvest index (HI) of Rabi sorghum, as influenced by treatments and foliar sprays, is presented in Table 2. The mean harvest index of Rabi sorghum was 33.80%. The highest HI was recorded in treatment T₇ (GRDF + Two foliar sprays of Phule micro grade II @ 1% at PI and FL stage), with a value of 33.80%. This was statistically at par with treatment T₈ (GRDF + Two foliar sprays of Potassium nitrate (13:0:45) @ 1% at PI and FL stage) at 33.80% and treatment T₂ (GRDF 80:40:40 kg N:P₂O₅:K₂O ha⁻¹ + 5 tons FYM ha⁻¹) at 33.75%.

The differences in harvest index among treatments were not statistically significant. The HI represents the proportion of total biomass allocated to grain production. Treatment T₇ exhibited the highest HI, indicating efficient biomass partitioning toward grain production, supported by a balanced nutrient supply that enhanced grain filling. These findings are consistent with the studies of Singh *et al.* (2012) and Singh *et al.* (2013). In contrast, the lowest HI was recorded in treatment T₉ (Protective irrigation) at 28.01%, reflecting inefficient biomass allocation to grain.

Table 2: Grain yield, straw yield, biological yield, harvest index as influenced by different foliar application treatments

Tr. No.	Treatments	Yield (kg ha ⁻¹)			Harvest Index (%)	Yield increase over control
		Grain yield	Straw Yield	Biological Yield		
T ₁	Absolute control	1623	3732	5355	31.18	--
T ₂	GRDF (80:40:40 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹ +5 ton FYM ha ⁻¹)	2418	5924	8342	33.75	48.98
T ₃	GRDF (50% N through urea at basal) +one foliar spray of nano urea @ (4 ml liter ⁻¹ water) at Panicle initiation (PI) stage	2016	4757	6773	32.02	24.21
T ₄	GRDF (50% N through urea at basal) + one foliar spray of nano urea @ (4 ml liter ⁻¹ water) at flag leaf (FL) stage	2033	4777	6810	32..80	25.26
T ₅	GRDF (50% N through urea at basal) + one foliar spray of nano urea (4 ml liter ⁻¹ water) at PI and FL stage	2390	5712	8102	32.99	47.25
T ₆	GRDF +Two foliar spray of NaCl @ 1% at PI and FL stage	1888	4380	6268	31.80	16.32
T ₇	GRDF + Two foliar spray of Phule micro grade II @ 1% at PI and FL stage	2793	6982	9775	33.80	72.08
T ₈	GRDF + Two foliar spray of Potassium nitrate (13:0:45) @ 1% at PI and FL stage	2624	6507	9131	33.01	51.26
T ₉	Protective irrigation at PL and FL	2061	4905	6966	28.01	26.68
	S. E. (m) ±	114	352	297	--	--
	C.D. at 5 %	385	1067	905	--	--
	General Mean	2187	4324	7502	33.80	--

B. Water Productivity of Sorghum

The data presented in Table 3 show that the average effective rainfall during the crop growth period was 252.2 mm for treatments T₁ to T₉. For treatment T₉, which involved protective irrigation at the panicle initiation (PI) and flag leaf (FL) stages, an additional 120 mm of water was applied, resulting in a total water application of 372.2 mm. Treatment T₇ (GRDF + Two foliar sprays of Phule micro grade II @ 1% at PI and FL stage) recorded the highest water use efficiency (WUE) at 11.04 kg ha⁻¹ mm, demonstrating the efficient utilization of nutrients from water-soluble fertilizers. Water use efficiency can be improved either by increasing the numerator (crop yield) or decreasing the denominator (total water applied). The numerator, which

represents plant production, depends on factors such as enhanced photosynthesis and reduced losses from pests and diseases. Consequently, WUE can be influenced by pest and disease management and the availability and uptake of nutrients. The data in Table 3 further revealed that treatment T₇ achieved the maximum WUE, followed by treatment T₈ (GRDF + Two foliar sprays of Potassium nitrate (13:0:45) @ 1% at PI and FL stage) with 10.40 kg ha⁻¹ mm and treatment T₂ (GRDF 80:40:40 kg N:P₂O₅:K₂O ha⁻¹ + 5 tons FYM ha⁻¹) with 9.73 kg ha⁻¹ mm. The lowest WUE was recorded in treatment T₉ (Protective irrigation) at 5.56 kg ha⁻¹ mm, highlighting the inefficiency of this treatment in maximizing yield relative to water applied.

Table 3: Water use efficiency of sorghum crop as influenced by different treatments

Tr. no.	Treatments	Effective Rainfall (mm)	Irrigation Water (mm)	Total water applied (mm)	Yield of sorghum (kg ha ⁻¹)	WUE (kg ha ⁻¹ mm)
T ₁	Absolute control	252.2	-	252.2	1623	6.43
T ₂	GRDF (80:40:40kg N:P ₂ O ₅ :K ₂ O ha ⁻¹ +5 ton FYM ha ⁻¹)	252.2	-	252.2	2418	9.58
T ₃	GRDF (50% N through urea at basal) + one foliar spray of nano urea @ (4 ml litre ⁻¹ water) at Panicle initiation (PI) stage	252.2	-	252.2	2016	7.96
T ₄	GRDF (50% N through urea at basal) + one foliar spray of nano urea @ (4 ml litre ⁻¹ water) at flag leaf (FL) stage	252.2	-	252.2	2033	8.03
T ₅	GRDF (50% N through urea at basal) + one foliar spray of nano urea @ (4 ml litre ⁻¹ water) at PI and FL stage	252.2	-	252.2	2390	9.46
T ₆	GRDF +Two foliar spray of NaCl@ 1% at PI and FL stage	252.2	-	252.2	1888	7.42
T ₇	GRDF + Two foliar spray of Phule micro grade II @ 1% at PI and FL stage	252.2	-	252.2	2793	11.04
T ₈	GRDF + Two foliar spray of Potassium nitrate (13:0:45) @ 1% at PI and FL stage	252.2	-	252.2	2624	10.40
T ₉	Protective irrigation at Panicle initiation (PI) and flag leaf (FL)	252.2	120	372.2	2061	5.56

Conclusion

The findings from the one-year investigation suggest that the treatment involving GRDF + two foliar sprays of Phule Micro Grade II @ 1% at Panicle Initiation and Flag Leaf stages (T₇) consistently delivered the highest growth parameters, yield-contributing factors, grain yield (2793 kg ha⁻¹), and water use efficiency (11.04 kg ha⁻¹ mm). This underscores the effectiveness of micronutrient-rich foliar applications in enhancing sorghum productivity under semi-arid conditions. Additionally, the treatments T₈ (GRDF + two foliar sprays of Potassium Nitrate (13:0:45) @ 1%) and T₂ (GRDF with 80:40:40 kg N:P₂O₅:K₂O ha⁻¹ + 5 ton FYM ha⁻¹) demonstrated competitive results, offering viable alternatives for sustainable nutrient management. These findings advocate for the

integration of foliar nutrient sprays into existing agronomic practices to optimize sorghum production while addressing water resource challenges.

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Conflict of Interest

The authors declare there are no conflict of interest relevant to this article.

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