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Foliar application of water-soluble fertilizer improved growth and yield of summer barnyard millet (*Echinochloa frumentacea* L.)

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Abstract

Barnyard millet (*Echinochloa frumentacea* L.) is a climate-resilient, nutrient-rich small millet, but systematic information on its response to foliar nutrition under summer irrigated conditions is limited. A field experiment was conducted during summer 2025 at Shirol Farm, Regional Sugarcane and Jaggery Research Station, Kolhapur, Maharashtra on silty loam soil (pH 7.82, low N, medium P, high K). The experiment was laid out in Randomized Block Design with 10 treatments and 3 replications, using variety *Phule Bharti-1* sown at 60 x 10 cm. Treatments comprised absolute control (water spray), 100% RDF (60:30:30 NPK kg ha⁻¹), and 50% and 75% RDF in combination with foliar sprays of water-soluble fertilizers 19:19:19 and KNO₃ @ 1% and 2% at tillering (30 DAS) and flowering (50 DAS). Results revealed significant influence of nutrient management on growth and yield. Application of 100% RDF (T₂) recorded the highest plant height (145.27 cm), number of tillers (7.60 running m⁻¹), dry matter accumulation (59.36 g plant⁻¹), leaf area (284.77 dm² plant⁻¹), grain yield (23.46 q ha⁻¹) and straw yield (32.77 q ha⁻¹). However, it was statistically at par with T₆ - 75% RDF + 2% foliar spray of 19:19:19 at tillering and flowering, which recorded 140.37 cm plant height, 7.43 tillers m⁻¹, 56.15 g dry matter, 270.23 dm² leaf area, 22.00 q ha⁻¹ grain yield and 31.40 q ha⁻¹ straw yield. The lowest values were observed in absolute control. Among foliar sources, 19:19:19 was found superior to KNO₃. It can be concluded that foliar application of 2% 19:19:19 at tillering and flowering stages can successfully compensate 25% of recommended dose of fertilizers and sustain growth and productivity of summer barnyard millet.

Keywords: Barnyard millet, foliar application, water-soluble fertilizer, 19:19:19, KNO₃, growth, yield

Introduction

Millets are widely recognized as nutritious cereals owing to their superior content of proteins, vitamins, minerals and dietary fibre compared to major staples like rice and wheat. Their gluten-free nature and low glycemic index make them particularly suitable for individuals suffering from diabetes or celiac disease, thereby positioning millets as functional foods in modern diets (Bravo, 1998) [5]. India is the global leader in millet production, contributing about 42.75% of the world's total output, and has recently promoted millets through national and international initiatives such as the "National Year of Millets 2018" and the "International Year of Millets 2023" (Senthamil *et al.*, 2021) [21]. Among small millets, barnyard millet (*Echinochloa frumentacea* L.) is a resilient and nutrient-dense nutri-cereal grown predominantly in marginal and rainfed environments of India (DMI, MoAFW, 2026) [1]. It combines short duration with a remarkable ability to withstand adverse climatic and edaphic conditions, making it a strategic crop for climate-resilient farming systems (Sood *et al.*, 2015) [28]. Nutritionally, barnyard millet grains are rich in carbohydrates, protein, essential amino acids, dietary fibre, minerals and bioactive phytochemicals such as phytates, polyphenols and tannins, which contribute to antioxidant activity and help in managing metabolic and age-related health disorders (Singh *et al.*, 2010; Saleh *et al.*, 2013; Chandel *et al.*, 2014) [25, 19, 7].

Water-soluble fertilizers (WSF) have emerged as an important input for improving crop productivity because they dissolve completely in water and can be applied efficiently through fertigation or foliar spraying. The availability and effectiveness of macro- and micronutrients

applied to the soil are often constrained by soil environmental factors, leading to losses through leaching, fixation and other processes (Latha and Nadanassababady, 2003; Arif *et al.*, 2006) [12, 2]. In contrast, foliar application of nutrients can markedly enhance nutrient use efficiency; in sandy loam soils, foliar-applied fertilizers have been reported to be several-fold (up to 20 times) more effective than soil-applied fertilizers (Nadergholi *et al.*, 2011) [13]. Foliar feeding delivers nutrients directly to leaves, allowing rapid absorption through stomata and cuticle, faster correction of acute deficiencies, improved translocation to developing plant parts, reduction in nutrient losses, and overall improvement in crop growth, yield and quality (Jamal *et al.*, 2007) [11].

The increasing cost of conventional fertilizers such as urea, SSP and MOP has restricted many farmers from applying recommended doses, leading to sub-optimal nutrient supply and unsatisfactory yields. Under such conditions, integrating judicious basal soil application with targeted foliar sprays of WSF offers a promising strategy to enhance nutrient use efficiency and reduce the cost per unit yield (Senthilkumar and Gokul, 2020) [20]. Studies in different crops indicate that combined soil and foliar nutrition can increase grain yield substantially, sometimes by more than 30%, by synchronizing nutrient availability with critical growth stages (Elayaraja and Angayarkanni, 2005; Nadergholi *et al.*, 2011) [10, 13]. However, systematic information on the response of barnyard millet to foliar nutrient sprays, particularly under summer irrigated conditions where the crop shows high yield potential, remains limited. This research gap is critical because barnyard millet is expanding beyond its traditional rainfed niches into irrigated plains. Optimizing foliar nutrient strategies for barnyard millet under such conditions could simultaneously improve grain yield, enhance grain nutritional quality, and strengthen farm economics in smallholder production systems. Therefore, the present investigation was undertaken to evaluate the impact of foliar application of water-soluble fertilizers on growth and yield of summer barnyard millet under irrigated conditions.

Martials and Methods

A field experiment was conducted during the summer season of 2025 at Shirol Farm, Regional Sugarcane and Jaggery research Station (RS&JRS), Kolhapur to study the response of summer barnyard millet (*Echinochloa frumentacea* L.) to foliar application of various water-soluble fertilizers. The soil of experimental site was silty loam in texture, slightly alkaline (pH 7.82), with an electrical conductivity of (0.25 dSm⁻¹) and low organic carbon (0.64%) and low amount of available nitrogen (205.91 kg ha⁻¹), medium available phosphorus (12.01 kg ha⁻¹) and high level of available potassium (292.18 kg ha⁻¹). The total rainfall received during the period of field experiment was 102.7 mm in 7 rainy days. The minimum temperature varied from 10.7°C to 22.2°C, whereas the maximum temperature ranged between 30.3°C and 38.8°C during the experimental period. The irrigation was given for ten times as per crop requirement throughout the growing days. The experiment was conducted in a Randomized Block Design (RBD) comprising ten treatments with three replications. The barnyard millet variety *Phule Bharti-1* was directly sown in rows on ridges at a spacing of 60 cm × 10 cm. The ten treatments viz. absolute control (water spray) at tillering (30 DAS) and flowering (50 DAS) (T₁), RDF (60:30:30 NPK kg ha⁻¹) (T₂), 50% RDF (30:15:15 NPK kg ha⁻¹) fb 1% foliar spray of 19:19:19 at tillering (30 DAS) and flowering (50 DAS) (T₃), 50% RDF (30:15:15 NPK kg ha⁻¹) fb 2% foliar spray of 19:19:19 at tillering (30 DAS) and flowering (50 DAS) (T₄), 75% RDF

(45:23:23 NPK kg ha⁻¹) fb 1% foliar spray of 19:19:19 at tillering (30 DAS) and flowering (50 DAS) (T₅), 75% RDF (45:23:23 NPK kg ha⁻¹) fb 2% foliar spray of 19:19:19 at tillering (30 DAS) and flowering (50 DAS) (T₆), 50% RDF (30:15:15 NPK kg ha⁻¹) fb 1% foliar spray of KNO₃ at tillering (30 DAS) and flowering (50 DAS) (T₇), 50% RDF (30:15:15 NPK kg ha⁻¹) fb 2% foliar spray of KNO₃ at tillering (30 DAS) and flowering (50 DAS) (T₈), 75% RDF (45:23:23 NPK kg ha⁻¹) fb 1% foliar spray of KNO₃ at tillering (30 DAS) and flowering (50 DAS) (T₉) and 75% RDF (45:23:23 NPK kg ha⁻¹) fb 2% foliar spray of KNO₃ at tillering (30 DAS) and flowering (50 DAS) (T₁₀). The recommended dose of fertilizers was supplied through urea, single super phosphate (SSP), and muriate of potash (MOP). Foliar application of water-soluble fertilizers was carried out at concentrations of 1% and 2% at two critical growth stages, namely tillering stage (30 DAS) and flowering stage (50 DAS). Water soluble fertilizer 19:19:19 and potassium nitrate (KNO₃) were employed as sources of foliar nutrition. For growth observations plant height, number of tillers, leaf area, and dry matter accumulation were recorded periodically from five randomly selected and tagged plants within the net plot area. Grain and straw yields were determined after harvest, grains and straw from each treatment net plot were harvested, threshed, cleaned, sun-dried, and weighed to record the final air-dry grain and straw weight, which was subsequently expressed on a hectare basis.

Results and Discussion

Growth parameters of summer barnyard millet as influenced by various treatments: The effect of different treatments on growth parameters such as plant height, number of tillers, dry matter accumulation, and leaf area is summarized in Table 1 and illustrated in Fig. 1.

Plant height

Plant height is an important indicator of plant vigour and overall growth, exhibited significant variation in barnyard millet under different fertilizer application. Among all the treatments, RDF (60:30:30 NPK kg ha⁻¹) (145.27 cm) recorded the highest taller plant at harvest. But it was statically at par with treatment 75% RDF (45:23:23 NPK kg ha⁻¹) fb 2% foliar spray of 19:19:19 at tillering (30 DAS) and flowering (50 DAS) (140.37 cm). The increase in plant height might be attributed to the enhanced availability and uptake of essential nutrients, particularly nitrogen, which promotes cell division, cell elongation, chlorophyll synthesis, and photosynthetic activity, resulting in vigorous vegetative growth through the sequential foliar sprays of 19:19:19 and provided balanced and adequate nutrients through fertilizer. Similar findings were reported by Warpe *et al.* (2022) [30], Biradar *et al.* (2023) [4], Sowmyalatha *et al.* (2023) [27], Shukla *et al.* (2023) [24], Parjane *et al.* (2024_a) [14], Deshmukh *et al.* (2025_a) [8] and Pawar *et al.* (2025) [16].

Number of tillers running per meter

The treatment RDF (60:30:30 NPK kg ha⁻¹) (7.60) recorded the maximum number of tillers running per meter and 75% RDF (45:23:23 NPK kg ha⁻¹) fb 2% foliar spray of 19:19:19 at tillering (30 DAS) and flowering (50 DAS) stage (7.43) was at par with 100% RDF. This could be attributed to improved crop growth, enhanced nutrient availability and efficient utilization of nutrients supplied through fertilizers and foliar application, which promoted vegetative development. The increased number of tillers might be associated with an adequate nutrient supply, as tiller production in barnyard millet is highly responsive to nutrient availability. Similar findings were reported by Prashanth *et al.*

(2019) ^[17], Senthil Kumar and Gokul (2020), Senthamil (2022) ^[22], Shukla *et al.* (2023) ^[24], Triveni *et al.* (2023) ^[29], Parjane *et al.* (2024_a) ^[14], Deshmukh *et al.* (2025_a) ^[8] and Pawar *et al.* (2025) ^[16].

Dry matter accumulation per plant

The treatment RDF (60:30:30 NPK kg ha⁻¹) (59.36 g) recorded the highest dry matter accumulation per plant significantly superior to remaining treatment. But it was at par with 75% RDF (45:23:23 NPK kg ha⁻¹) *fb* 2% foliar spray of 19:19:19 at tillering (30 DAS) and flowering (50 DAS) stage (T₆) (56.15 g). The improved crop growth may be attributed to enhanced nutrient availability and efficient absorption through foliar application of water-soluble fertilizers, which resulted in greater nutrient uptake and ultimately promoted higher biomass production and dry matter accumulation. Similar result was obtained by Suruthi *et al.* (2019), Senthil Kumar and Gokul (2020), Warpe *et al.* (2022) ^[30], Shukla *et al.* (2023) ^[24], Triveni *et al.* (2023) ^[29], Parjane *et al.* (2024_a) ^[14], Deshmukh *et al.* (2025_a) ^[8] and Pawar *et al.* (2025) ^[16].

Leaf area per plant

The treatment RDF (60:30:30 NPK kg ha⁻¹) (T₂) (284.77 dm²) recorded the highest leaf area per plant at harvest. It was statically at par with treatment 75% RDF (45:23:23 NPK kg ha⁻¹) *fb* 2% foliar spray of 19:19:19 at tillering (30 DAS) and flowering (50 DAS) stage (T₆) (270.23 dm²). It could be due to sequential foliar nutrient application, as leaves play a vital role in the process of photosynthesis, through which plants synthesize carbohydrates

required for their growth and development. Moreover, leaves contain stomatal openings that facilitate the absorption of moisture and foliar-applied nutrients, thereby enhancing the overall growth and development of the plant. Similar result was obtained by Sharifi *et al.* (2018) ^[23], Somarowthu and Umesha (2021) ^[26], Warpe *et al.* (2022) ^[30], Xess and Singh (2023) ^[31], Parjane *et al.* (2024_a) ^[14] and Pawar *et al.* (2025) ^[16].

Yield of summer barnyard millet as influenced by various treatments

The data pertaining to grain yield and straw yield influenced by different treatments are presented in Table 1 and illustrated in Fig 2. The RDF (60:30:30 NPK kg ha⁻¹) recorded the highest grain yield (23.46 q ha⁻¹) and straw yield (32.77 q ha⁻¹) overall the remaining treatment and it was found statistically at par with 75% RDF (45:23:23 NPK kg ha⁻¹) *fb* 2% foliar spray of 19:19:19 at tillering (30 DAS) and flowering (50 DAS) stage noted the grain yield (22.00 q ha⁻¹) and straw yield (31.40 q ha⁻¹). This might be attributed to the balanced and adequate nutrient supply ensured by the full recommended dose of fertilizers and also foliar spray of 19:19:19 with 75% RDF could have compensated the nutrient requirement in progressive crop development stages which ultimately enhances overall plant growth and development which leads to higher yield. Similar findings are reported by Bulbule *et al.* (2018) ^[6], Reddy *et al.* (2018) ^[18], Prashanth *et al.* (2019) ^[17], Sowmyalatha *et al.* (2023) ^[27], Yadav *et al.* (2023) ^[32], Parjane *et al.* (2024_b) ^[15], Deshmukh *et al.* (2025_b) ^[9] and Ban *et al.* (2026) ^[3].

Table 1: Growth and yield of summer barnyard millet at harvest as influenced by the various treatments

Treatments		Plant height (cm)	Number of tillers running per meter	Dry matter accumulation per plant (g)	Leaf area per plant (dm ²)	Grain Yield (q ha ⁻¹)	Straw Yield (q ha ⁻¹)
T ₁	Absolute control (water spray) at tillering (30 DAS) and flowering (50 DAS) stage.	118.73	6.00	36.61	176.80	10.10	17.38
T ₂	RDF (60:30:30 NPK kg ha ⁻¹)	145.27	7.60	59.36	284.77	23.46	32.77
T ₃	50% RDF (30:15:15 NPK kg ha ⁻¹) <i>fb</i> 1% foliar spray of 19:19:19 at tillering (30 DAS) and flowering (50 DAS) stage.	125.93	6.73	47.06	209.83	14.10	22.85
T ₄	50% RDF (30:15:15 NPK kg ha ⁻¹) <i>fb</i> 2% foliar spray of 19:19:19 at tillering (30 DAS) and flowering (50 DAS) stage.	129.80	7.00	47.18	219.62	16.28	25.76
T ₅	75% RDF (45:23:23 NPK kg ha ⁻¹) <i>fb</i> 1% foliar spray of 19:19:19 at tillering (30 DAS) and flowering (50 DAS) stage.	132.13	7.20	50.29	232.50	19.46	27.70
T ₆	75% RDF (45:23:23 NPK kg ha ⁻¹) <i>fb</i> 2% foliar spray of 19:19:19 at tillering (30 DAS) and flowering (50 DAS) stage.	140.37	7.43	56.15	270.23	22.00	31.40
T ₇	50% RDF (30:15:15 NPK kg ha ⁻¹) <i>fb</i> 1% foliar spray of KNO ₃ at tillering (30 DAS) and flowering (50 DAS) stage.	123.43	6.63	45.39	200.37	13.92	21.65
T ₈	50% RDF (30:15:15 NPK kg ha ⁻¹) <i>fb</i> 2% foliar spray of KNO ₃ at tillering (30 DAS) and flowering (50 DAS) stage.	128.67	6.93	48.86	210.42	15.36	24.09
T ₉	75% RDF (45:23:23 NPK kg ha ⁻¹) <i>fb</i> 1% foliar spray of KNO ₃ at tillering (30 DAS) and flowering (50 DAS) stage.	131.43	7.17	49.43	227.00	18.11	26.37
T ₁₀	75% RDF (45:23:23 NPK kg ha ⁻¹) <i>fb</i> 2% foliar spray of KNO ₃ at tillering (30 DAS) and flowering (50 DAS) stage.	133.53	7.23	52.25	250.13	20.52	29.50
S.Em±		3.95	0.10	2.36	9.32		0.81
C. D. (p = 0.05)		11.73	0.31	7.00	27.68		2.42
General Mean		130.93	6.99	49.26	228.17		17.33

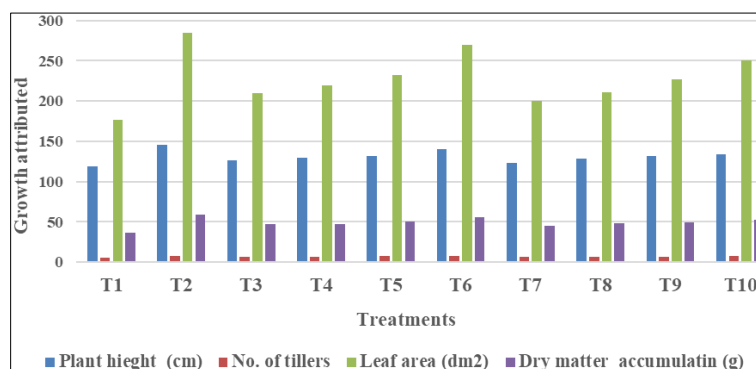


Fig 1: Effect of different treatments on growth attributed of summer barnyard millet

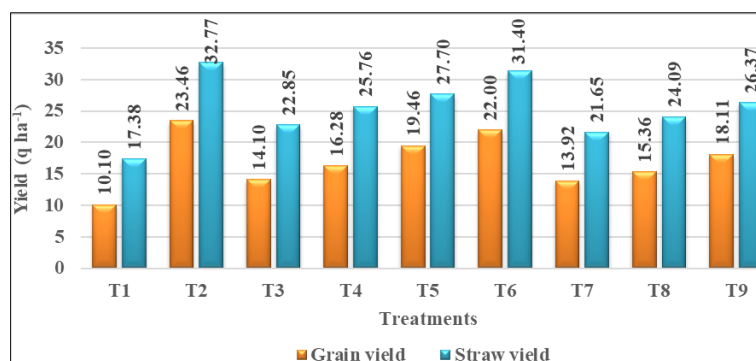


Fig 2: Effect of different treatment on grain and straw yield of summer barnyard Millet

Conclusion

The study demonstrated that while 100% RDF (60:30:30 NPK kg ha⁻¹) produced maximum growth and yield in summer barnyard millet, the application of 75% RDF (45:23:23 NPK kg ha⁻¹) followed by 2% foliar spray of 19:19:19 at tillering (30 DAS) and flowering (50 DAS) was equally effective and is the most viable alternative. This treatment enhanced nutrient availability, uptake and translocation at critical growth stages, leading to improved vegetative growth, dry matter production and ultimately grain and straw yield. It also offers the advantage of saving 25% basal fertilizer, reducing nutrient losses and input cost while maintaining yield levels. Therefore, for higher productivity and resource-use efficiency of summer barnyard millet cv. *Phule Bharti-1* under irrigated conditions of Western Maharashtra, application of 75% RDF + 2% foliar spray of 19:19:19 at 30 and 50 DAS is recommended.

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Disclaimers

All opinions and conclusions in this article are those of the authors and do not necessarily reflect the views of their institutions. The authors are solely responsible for the accuracy and completeness of the content and disclaim any liability for direct or indirect losses arising from its use.

Conflict of Interest

The authors declare no conflicts of interest, and no external funding or sponsorship influenced the study design, data collection, analysis, publication decision, or manuscript preparation.

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