E-ISSN: 2618-0618
P-ISSN: 2618-060X

NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; 9(1): 121-124
Received: 21-11-2025
Accepted: 24-12-2025

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Effect of time of foliar application of magnesium fertilization on forage yield of pearl millet

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DOI: https://www.doi.org/10.33545/2618060X.2026.v9.i1b.4609

Abstract
A pot culture experiment was conducted during the Kharif season at the Livestock Farm Complex of Veterinary College and Research Institute, Tirunelveli, Tamil Nadu, India to evaluate the effect of magnesium sulphate ($MgSO_4$) on growth, biomass, and yield of fodder pearl millet (*Pennisetum glaucum* L.). Five treatments with triplicate included were T_1: Control, T_2: 100% recommended dose of fertilizer (RDF), T_3: RDF + Foliar spray of $MgSO_4$ at 20 days after sowing (DAS), T_4: RDF + Foliar spray of $MgSO_4$ at 35 DAS, and T_5: RDF + Foliar spray of $MgSO_4$ at 20 and 35 DAS. Foliar application of Mg as magnesium sulphate at 20 DAS significantly improved vegetative growth and yield parameters. Leaf length found increased by 51% (79.33 cm vs 52.60 cm in control), stem weight by 75% (57.02 g vs 32.66 g), leaf weight by 82% (52.30 g vs 28.80 g), total plant weight by 46% (103.68 g vs 71.01 g), and plant biomass by 46% (34.56 t/ha vs 23.67 t/ha). Leaf-stem ratio also improved from 0.88 to 0.92. Mg applications at later stages of plant growth or twice were found less effective on the growth and yield of fodder pearl millet. The study demonstrated that application of Mg as foliar spray with RDF enhanced vegetative growth and biomass accumulation in fodder pearl millet under pot culture conditions as well as the time of application.

Keywords: Fodder pearl millet, magnesium sulphate, growth, biomass, time of application

Introduction
Fodder pearl millet (*Pennisetum glaucum* L.) is an important forage crop in semi-arid and arid regions due to its shorter duration, drought tolerance, rapid growth, and high biomass production (Patel *et al*., 2017; Gupta *et al*., 2018) [4, 9]. As it provides good quality green fodder, suitability for silage and dry hay with high nutritional quality, widely used for livestock feed (Singh *et al*., 2020a) [14]. However, productivity of fodder pearl millet is often limited by nutrient deficiencies, particularly magnesium (Mg), that plays a critical role in chlorophyll formation, enzyme activation, carbohydrate partitioning, and photosynthate translocation (Marschner, 2012; Senbayram *et al*., 2015) [6, 12].

Although nitrogen (N), phosphorus (P), and potassium (K) fertilizers are applied routinely to optimize growth, the use of micronutrients is often ignored, especially with Mg its role is unnoticed, in spite of its essentiality in its crop's vegetative growth and biomass accumulation, which are critical for fodder crops (Wang *et al*., 2019) [17]. Mg deficiency in soils, especially slightly acidic, sandy-loam soils common in southern India, can lead to reduced leaf area, stunted growth, and lower dry matter yield (Guo *et al*., 2019; Zheng *et al*., 2020) [2, 18].

Studies indicate that Mg fertilization improves the physiological factors of crops *viz*., leaf expansion, stem elongation, and biomass in cereals and forage crops (Bolton & Penny, 2009; Ntshangase *et al*., 2022) [1, 8]. However, the time and its method of Mg application either as soil or foliar application during early vegetative, mid-vegetative, or split applications could determine and can significantly influence the efficiency of Mg uptake and utilization. Pot culture experiments provide a controlled environment to assess nutrient dynamics and growth responses.

This study aimed to evaluate the effect of magnesium sulphate ($MgSO_4$) applied at 20 and 35 days after sowing (DAS) as foliar spray, individually and in combination with the recommended dose of fertilizer (RDF), on the growth, tillering, leaf characteristics, biomass, and dry matter yield of fodder pearl millet.

Materials and Methods

The present study was conducted as a pot culture experiment during the Kharif season twice during 2025 at the Livestock farm Complex of Veterinary College and Research Institute (VC&RI), Tirunelveli, Tamil Nadu, India with the Latitude of 8.73°N, Longitude of 77.70°E, and Altitude of 84 m above mean sea level. The experiment aimed to evaluate the effect of foliar application of magnesium sulphate ($MgSO_4$) on the growth, yield, and biomass of fodder pearl millet (*Pennisetum glaucum L.*). The soil used for the experimental study was collected from the institute farm and classified as sandy loam with slightly acidic pH (6.2). The initial soil properties included organic carbon 0.25%, available nitrogen 148 kg/ha, available phosphorus 10.5 kg/ha, available potassium 180 kg/ha, and extractable magnesium 20.5 mg/kg. Soil pH was measured in a 1:2.5 soil-water suspension using a pH meter, soil organic carbon by Walkley-Black method, soil available nitrogen by Kjeldahl method, soil available phosphorus by Olsen method, soil available potassium by flame photometer, and soil magnesium content by atomic absorption spectrophotometry.

The experiment was laid out in a Completely Randomized Design (CRD) with five treatments and replicated thrice. T_1: Control, T_2: 100% recommended dose of fertilizer (RDF), T_3: RDF + Foliar spray of $MgSO_4$ at 20 days after sowing (DAS), T_4: RDF + Foliar spray of $MgSO_4$ at 35 DAS, and T_5: RDF + Foliar spray of $MgSO_4$ at 20 and 35 DAS. Each pot was filled with 25 kg of soil and planted with uniform seeds of fodder pearl millet variety CO 8. Standard agronomic practices as recommended from crop production guide of Tamil Nadu Agricultural University were followed throughout the crop growth period, and pots were maintained with moisture at field capacity by regular watering. Calculated quantities of farm yard manure, nitrogen, phosphorous and potassium were applied as per the standard recommendation of farm yard manure at the rate of 12.5 tonnes per hectare and 25: 20: 12 kg/ha of NPK. NPK were applied in the soil in the form of urea, single super phosphate and Muriate of Potash and magnesium as magnesium sulphate at the rate of 2.5% as foliar application. Foliar application of magnesium as magnesium sulphate were done on 20 and 35 days after sowing as per the treatment schedule i.e at early vegetative phase and late vegetative phase. The crop was harvested at 50 days after sowing for green fodder estimation.

Growth parameters, such as plant height, number of tillers, and leaf length, were recorded at harvest. Stem, leaf, and total plant weight were measured as fresh weight, and plant biomass and dry biomass were calculated per hectare. The leaf-stem ratio was determined by dividing leaf weight by stem weight. Data were subjected to analysis of variance (ANOVA), and treatment differences were compared using the Critical Difference (CD) at 5% significance level.

Results and Discussion

Plant Height

The foliar application of magnesium sulphate significantly influenced the plant height of fodder pearl millet (Table 1). Among the treatments, 100% Recommended Dose of Fertilizer (RDF) combined with $MgSO_4$ applied as foliar spray at 20 and 35 DAS resulted in the tallest plants measuring 146.37 cm. in comparison to control (127.70 cm), the plant height was found 14.7% higher. The treatment with foliar application of $MgSO_4$ at 20 DAS once with RDF were slightly shorter (129.33 cm), yet showed an appreciable increase in height compared to the control but on par with T_5, indicating that foliar application of Mg at the early vegetative phase supports initial vegetative growth and carried throughout the crop growth period. Magnesium is a central component of chlorophyll and is vital for photosynthesis and enzyme activation, which promotes cell elongation and overall plant stature (Marschner and Römheld,1997; Khan *et al*., 2016) [7, 11]. The results suggest that foliar Mg enhances vegetative growth, and timing plays a critical role, with early application favouring better height development.

Number of Tillers

The number of tillers per plant also responded positively to Mg foliar sprays (Table 1). The highest number of tillers (6.27 per plant) was observed in treatments receiving $MgSO_4$ at 20 DAS as foliar spray with RDF (T_3), resulting in an increase of 14.6% over the control (T_1) with 5.47 tillers. Treatments with Mg applied on leaves at 35 DAS or at both 20 and 35 DAS with RDF also produced more tillers than control and RDF alone, although the increases were slightly lower than early Mg application but statistically significant. Prasad and Srivastava, 2017 suggested that tillering is closely associated with meristematic activity, that can be enhanced by micro nutrients, in this experiment with magnesium as foliar spray, resulting in in carbohydrate partitioning and enzyme activation. These results indicate that Mg as foliar application can stimulate tiller initiation, thereby contributing to higher potential biomass production as a result of synergistic effect of nutrient absorption of macro and micronutrients.

Leaf Length

Leaf length showed a marked improvement by Mg supplementation (Table 1). The longest leaves (79.33 cm) were observed with foliar Mg applied at 20 DAS with RDF (T_3), displaying an increase of 50.9% over control (T_1) with 52.60 cm. Treatments with Mg applied at 35 DAS (T_4) and applied twice with (RDF) (T_5) also increased leaf length, but the effect was less significantly marked than foliar application of Mg with RDF (T_3). The results highlight the importance of magnesium in promoting leaf expansion when applied during early vegetative stages. The enhancement in leaf length contributes directly to the photosynthetic surface area, which is crucial for energy capture and biomass accumulation as suggested by Singh and Kumar, 2018.

Stem and Leaf Weight

The foliar application of Mg significantly influenced the fresh weight of both stem and leaf components (figure 1). Mg applied on leaves as foliar spray at 20 DAS with RDF (T_3) resulted in the stems (57.02 g per plant) and leaves (52.30 g per plant) of significant weight than other treatments, representing increases of 74.7% and 81.7%, respectively, over control treatment. Mg supplementation as foliar spray at the early vegetative phase enhanced carbohydrate transport from leaves to the stem, improving structural growth. The application of Mg at 20 and 35 DAS twice with RDF (T_5) produced significantly lower stem and leaf weights than 35 DAS alone with RDF (T_4), indicating that time of application of magnesium is critical for optimal growth and biomass production. This corroborates with the findings of Siddiqui *et al*., 2019 [13].

Total Plant Weight

The cumulative effect of Mg application with RDF on plant weight was evident (Table 1). The highest total plant weight (103.68 g per plant) was recorded in plants receiving Mg as foliar spray at 20 DAS with RDF (T_3), showing an increase of

46% than the control (T_1). The increase in total biomass is a directly proportional to vegetative parameters such as improved leaf length, tiller number, and stem and leaf weight. Treatments with foliar application of Mg at 35 DAS (T_4) and at both 20 and 35 DAS (T_5) also showed substantial gains compared to control but significantly evident, though slightly lower than the foliar application of magnesium at early vegetative phase. The results confirms that magnesium not only enhances individual plant components but also contributes to overall plant biomass (Hu *et al*., 2021, Wang *et al*., 2018) [5, 16].

Green and Dry Biomass

Green biomass yield responded significantly to Mg foliar application (Table 1). The maximum green biomass (34.56 t ha^{-1}) was observed with foliar application of Mg applied at 20 DAS with RDF (T_3), an increase of 46% over control (T_1) (23.67 t ha^{-1}). Similarly, dry biomass of pearl millet was found higher with 22.88 t ha^{-1} in the treatment foliar application of Mg applied at 20 DAS with RDF (T_3), resulting in an increase of 29.5% than control (T_1). Foliar application of Mg at 35 DAS (T_4) and at 20 DAS and 35 DAS (T_5) with RDF also resulted in significantly lesser on improved biomass, than with the treatment (T_2). Magnesium plays a pivotal role in photosynthesis and carbohydrate translocation, which directly contributes to biomass accumulation (Gupta *et al*., 2019; Sharma *et al*., 2021) [3]. These results suggest that foliar Mg can significantly enhance fodder yield, especially when applied during early vegetative growth along with RDF. Here the application of magnesium as foliar spray supplements the interaction of macro and micro nutrients thereby enhancing the nutrient absorption from the soil for better growth and development of pearl millet (Rengel, 2015) [10].

Leaf-Stem Ratio

The leaf-stem ratio, an important indicator of fodder quality, was slightly higher in Mg supplemented treatments (Fig. 1) with the maximum ratio of 0.92 recorded in the treatment (T_3) i.e magnesium applied as foliar spray at 20 DAS along with RDF Mg treatment compared to 0.88 in control. Leaf stem ration is an indicator for the proportion of the quantity of leaves to stems. A higher leaf proportion indicates the improvement in forage palatability and nutrient content, making it more suitable for livestock feeding. Foliar application of Mg at the vegetative phase i.e at 20 DAS (early vegetative phase) supports leaf growth than stem, thereby enhancing the leaf-stem ratio and improving overall fodder quality. Enhanced leaf production under Mg fertilization improves forage quality, as leaves contain higher protein and lower fibre compared to stems (Singh *et al*., 2020b) [15], which was evident from the physical appearance of leaves that were glossy, fibrous and greenish in comparison to treatments that received RDF alone and control

Time of application of magnesium

The experiment demonstrated that magnesium plays an important role in improved plant biomass along with RDF. The experiment clearly shown that foliar application of Mg at 20 DAS is more effective than later application or twice at 20 and 35 DAS along with RDF in promoting vegetative growth, tiller production, leaf and stem development, and biomass production. Application of magnesium at early vegetative phase ensured sufficient amount of nutrients for uptake by the crops. Early application is essential for supporting the photosynthetic efficiency, carbohydrate accumulation, and assimilate partitioning to leaves and stems (Guo *et al*., 2019; Senbayram *et al*., 2015) [2, 12]. These findings are consistent with the results of prior studies on cereals and forage crops, suggesting that Mg fertilization, especially when synchronized with crop nutrient demand, optimizes growth and yield (Bolton & Penny, 2009; Wang *et al*., 2019; Römheld & Marschner, 1991) [1, 11, 17].

Conclusion

The present study demonstrated that application of magnesium sulphate ($MgSO_4$) at 20 days after sowing (DAS) in combination with 100% recommended dose of fertilizer (RDF) significantly enhanced the growth, tiller production, leaf expansion, stem and leaf weight, total plant weight, biomass accumulation, and leaf-stem ratio in fodder pearl millet (*Pennisetum glaucum* L.) under pot culture conditions. Application of Mg as foliar spray at 20 DAS along with RDF was more effective than later application (35 DAS) or application twice at 20 and 35 DAS with RDF, signifying that the critical requirement of magnesium occurs during the early vegetative growth stage. Integration of Mg with standard recommendation of NPK fertilization enhances both forage yield and quality, improving fodder productivity in semi-arid regions.

Table 1: Effect of treatments on the mean growth, yield parameters and yield of fodder pearl millet

Treatments	Plant height (cm)	No. of tillers	Leaf length(cm)	Plant weight (g/plant)	Green biomass (t/ha)	Dry Biomass (t/ha)
Control (T_1)	127.70	5.47	52.60	71.01	23.67	17.64
100% Recommended dose of fertilizer (T_2)	150.93	5.87	64.93	85.86	28.62	19.46
100% Recommended dose of fertilizer+ Application of Magnesium sulphate at 20 days after sowing (T_3)	129.33	6.27	79.33	103.68	34.56	22.88
100% Recommended dose of fertilizer+ Application of Magnesium sulphate at 35 days after sowing (T_4)	144.83	6.20	69.87	88.86	29.62	19.09
100% Recommended dose of fertilizer+ Application of Magnesium sulphate at 20 and 35 days after sowing (T_5)	146.37	5.93	72.20	90.27	30.09	18.23
S.Em±	16.78	0.71	7.13	7.91	3.22	2.14
CD	31.55	1.34	12.99	13.88	6.09	3.76

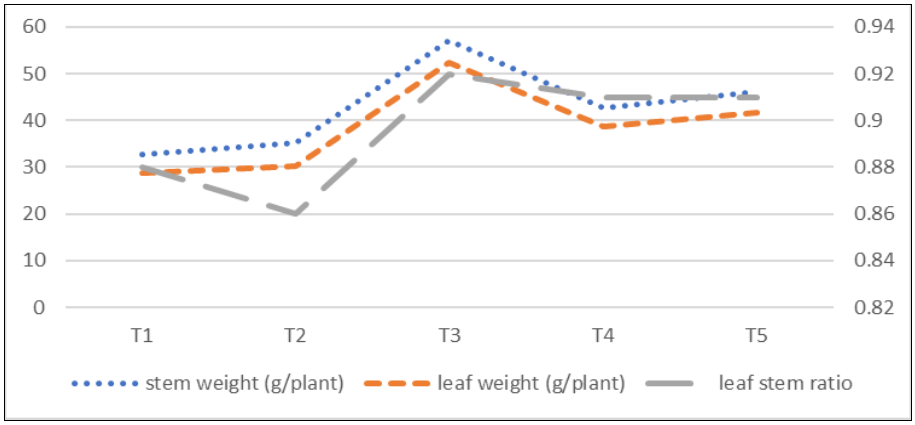

Fig 1: Effect of treatments on stem weight, leaf weight and leaf stem ratio of fodder pearl millet

Acknowledgement

The authors acknowledge Tamil Nadu Veterinary and Animal Sciences University, Chennai and Veterinary College and Research Institute, Tirunelveli for their support and facilities provided for this research work.

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