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Impact of Foliar Application of Macro and Micro Nutrients on Growth and Physiological Traits of Rice (*Oryza sativa* L.) Grown under Rainfed Condition

Vikas Yadav[1], A.H. Khan[2], Akanksha Singh[3], Ajay Kumar[4], Manoj Kumar[1], Sonam Arya[1], Yadvendra Pal Singh[5]

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ABSTRACT

Background: Foliar application of macro and micronutrients plays a vital role in improving plant growth and physiological processes, especially in rainfed conditions where nutrient availability is limited. Rice (*Oryza sativa* L.), a staple crop, requires an adequate supply of essential nutrients for optimal growth and productivity. This study aimed to evaluate the impact of foliar application of macro and micronutrients on the growth and physiological traits of rice grown under rainfed conditions.

Methods: Research was carried out at the Student's instructional farm, Acharya Narendra Deva University of Agriculture and Technology, Ayodhya, India, during the *Kharif* season usingrandomized block design with nine treatments and three replications on the rice variety *Sahbhagi Dhan*. Treatments included foliar application of KCl (0.5%, 1.0%), $MgSO_4$ (1.0%, 2.0%), boric acid (0.3%, 0.6%) and salicylic acid (0.25%, 0.5%), applied twice during the vegetative and grain filling stages. Data were recorded on growth parameters such as plant height, number of tillers plant^{-1} and dry weight plant^{-1}, as well as physiological traits including relative water content, chlorophyll, proline, catalase and peroxidase content at 30, 60 and 90 days after transplanting.

Result: Study showed that foliar application of macro and micronutrients significantly influenced the growth and physiological traits of rice. Among the treatments, 1.0% $MgSO_4$ led to the most notable improvements. Statistical analysis confirmed the significance of foliar nutrients application for several traits at the 5% probability level. The findings suggest that foliar nutrient application enhances rice yield by supporting plant metabolic processes and enzyme activation, ultimately improving vegetative growth and productivity.

Key words: Foliar application, Growth parameters, Macro, Micro nutrients, Physiological traits, Rainfed, Rice.

INTRODUCTION

Rice (*Oryza sativa* L.) is a member of the Poaceae family and is one of the most widely cultivated crops worldwide. It serves as a staple food for over three billion people, contributing between 50% and 80% of their daily caloric intake (Khush, 2005). It originates from the tropical and subtropical regions of Southeast Asia and Africa. These areas account for 90% of global rice production and consumption. The *Oryza* genus includes 24 species, with *Oryza sativa* and *Oryza glaberrima* being the only cultivated ones. Rice is grown in tropical, subtropical, semiarid and temperate regions worldwide.

Water plays a crucial role in agriculture and food production, yet it remains a scarce resource (Wang *et al.,* 2012). Water deficit stress significantly reduces agricultural yields globally, posing a major challenge to sustainable farming. Drought impacts nearly 23 million hectares of rainfed rice worldwide (Serraj *et al.,* 2011). Water deficit may arise at any stage, from early growth to flowering and grain filling. The severity of stress varies based on the duration and frequency of water shortage (Wade *et al.,* 1999). Drought stress limits leaf expansion, tillering and midday photosynthesis while reducing photosynthesis and leaf area through early senescence (Nooden, 1988) all these factors contribute to reduced grain yield under drought conditions. Research has demonstrated that zero tillage rice, wheat (crop establishment methods) recorded significantly higher plant height, tillers hill^{-1}, leaf area, RWC,

[1]School of Agricultural and Environmental Sciences, Shobhit Institute of Engineering and Technology, Meerut-250 110, Uttar Pradesh, India.
[2]Department of Crop Physiology, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya-224 229, Uttar Pradesh, India.
[3]Department of Agriculture, Mangalayatan University, Aligarh-202 146, Uttar Pradesh, India.
[4]Faculty of Agriculture Sciences, Shri Khushal Das University, Hanumangarh-335 801, Rajasthan, India.
[5]Department of Soil Science and Agriculture Chemistry, Lovely Professional University, Phagwara-144 002, Punjab, India.

Corresponding Author: Yadvendra Pal Singh, Department of Soil Science and Agriculture Chemistry, Lovely Professional University, Phagwara-144 002, Punjab, India.
Email: yadvendrapalsingh@gmail.com

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total chlorophyll content and protein content as compared to other crop establishmentmethods (Bhangare *et al.,* 2025). Additionally, water deficit triggers the production of reactive oxygen species (ROS), causing lipid peroxidation, protein denaturation and nucleic acid damage, which disrupts metabolism and further lowers grain yield.

Essential mineral nutrients are categorized into macronutrients and micronutrients based on their relative concentrations within plant structures.Foliar application of micronutrients is highly effective when roots are unable to absorb or supply essential nutrients (Babaeian *et al.,* 2011). Several studies have shown that combined application of macro- and micro nutrients under rainfed systems improves yield-contributing traits such as leaf area index, chlorophyll content and dry matter production in rice (Singh *et al.,* 2020). Research has demonstrated that foliar application of nutrients plays an important role in changing growth and physiological characteristics of field crops (Sathishkumar *et al.,* 2020). Research has demonstrated that foliar micronutrient application in wheat crop significantly enhances plant growth and physiological traits (Ali, 2012). Studies indicate that foliar application of nutrients is more effective than soil applied nutrients, as it provides a quicker remedy for deficiencies when soil-applied micronutrients act too slowly (Kazemi, 2013). The results of the study revealed that the 14 days age of seedling with the foliar application of 0.5% $ZnSO_4$ + 0.5% $FeSO_4$ at 20 and 30 DAT resulted in maximum plant height, no. of tillers/m^2 and highest grain and straw yield (Sai Vikram *et al.,* 2022). Magnesium has long been illustrious for its essential role in chlorophyll formation and photosynthesis. Magnesium deficiency cause negatively impacts on essential physiological and biochemical processes in plants, resulting the reduced growth, yield and quality of the crops (Tang *et al.,* 2012). Boron is an essential micronutrient necessary for optimal plant growth and yield (Soomro *et al.,* 2011). Boron plays a crucial role in various plant functions, including cell division, meristem elongation, membrane stability, cell wall formation, leaf expansion, water balance, ion absorption, sugar transport, Auxin and carbohydrate metabolism. Its deficiency may negatively impact on these essential processes (Da Rocha Pinho *et al.,* 2015). Foliar application has demonstrated economically prosperous mainly cereal crops. Boron deficiency affects the reproductive more than biomass yield. Salicylic acid plays acrucial role in preventing oxidative damage in plants by detoxifying superoxide radicals (Bowler *et al.,* 1992). Plants treated with salicylic acid exhibited higher photosynthetic rates and water use efficiency while showing reduced stomatal conductance and transpiration rates (Khan *et al.,* 2010). Recognizing the significance of macronutrients and micronutrients in plant nutrition and enzyme activation, this study investigates the impact of integrated foliar application of potassium, magnesium, salicylic acid and boron on the structural and physiological traits of rice (*Oryza sativa* L. cv. Sahbhagi Dhan) to enhance crop yield.

MATERIALS AND METHODS

The experiment was performed at students' instructional farm of Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, India. Soil at the experimental site had neutral pH (7.5) and the experiment was laid down in randomized block design with three replicationsunder rainfed condition. Rice variety *i.e.* Sahbhagidhan were sown in well puddled bed to raise the nursery. 21 days old seedlings transplanted (2 $hill^{-1}$ and 3 cm depth) at 20 × 15 cm spacing in 3 × 4 m^2 plots, replicated thrice in well prepared field. Fertilized with nitrogen, phosphorus, potassium, zinc@ 120:60:60:20 kg ha^{-1} using Urea, SSP and MOP. Full Phosphorus, Potassium, Zinc and ½ Nitrogen as basal while remaining nitrogen split at tillering and panicle initiation. Foliar sprays of KCl (0.5%, 1.0%), $MgSO_4$ (1.0%, 2.0%), Boric acid (0.3%, 0.6%) and Salicylic acid (0.25%, 0.5%) were applied two times at vegetative (15 DAT) andmilky stage (70 DAT). Growth parameters *i.e.* plant height, number of tillers $plant^{-1}$, dry weight $plant^{-1}$ was determined by oven-drying the harvested plant samples at 65±5°C to a constant weight and weighing them using an electronic balance (Hunt, 1978) and physiological traits such as relative water content was estimated through the method described by Turner and Beg (1981), chlorophyll content was assessed with the help of plant efficiency analyzer (Model X 55/M-PEA), Bates *et al.* (1973) spectrophotometric methods were used to determine the proline content of leaves,Peroxidase activity was calculated using the Curnow and Galston (1959) method, whereas catalase activity was evaluated colorimetrically (Sinha, 1972). All the observations were recorded at 30, 60 and 90days after transplanting of crop. Various data recorded on growth and physiological traits were subjected to statistical analysis by Fisher method of analysis of variance (Fisher, 1925).

RESULTS AND DISCUSSION

Growth parameters

Data pertaining to plant height (Table 1) as affected by nutrients, recorded at different growth stages show that progressively increased with the age of the plant. It is evident from the data that spraying of all the nutrients registered higher plant height as compared to control at all observation stages. These inferences are in accordance with Rawashdeh and Sala (2013) who reported that foliar application of Fe and B significantly increased plant height as compared to control treatment.

The data on tillers $plant^{-1}$ (Table 1) showed that at 30 DAT, 1% $MgSO_4$, 0.3% boric acid and both salicylic acid doses significantly enhanced tiller formation, indicating early vegetative growth stimulation. At 60 and 90 DAT, all treatments except 0.5% KCl continued to improve tillering, with 1% $MgSO_4$ showing the strongest effect, followed by salicylic acid and boric acid. This reflects the essential role of Mg in photosynthesis, B in cell division and salicylic

acid in stress regulation. Similar results were observed by Rawashdeh and Sala (2013) with Fe and B foliar sprays.

The data on dry weight plant^{-1} (Table 2) revealed a progressive increase with plant age, reflecting the cumulative effect of nutrient uptake and biomass accumulation. At 30 DAT, foliar application of 1% $MgSO_4$ and both doses of salicylic acid (0.25% and 0.5%) significantly enhanced plant dry weight over the control, indicating their early positive influence on physiological and metabolic activity. At 60 and 90 DAT, all nutrient treatments, except 0.5% KCl, significantly improved dry matter accumulation. The most pronounced effect was observed with 1% $MgSO_4$, followed by 0.25% and 0.5% salicylic acid, suggesting a consistent role of Mg in enhancing photosynthesis and assimilate partitioning. The minimal impact of 0.5% KCl could be due to suboptimal potassium uptake or physiological imbalances caused by stress concentration. These findings are consistent with Asad and Rafique (2002), who reported similar improvements in wheat dry matter due to foliar nutrient application. Additionally, Sankaranarayanan *et al.* (2010) demonstrated that foliar spraying of 0.5% $MgSO_4$ at multiple growth stages significantly enhanced dry weight by up to 30% in crops, further supporting the beneficial role of Mg nutrition in promoting biomass production and overall plant vigor.

Physiological traits

The analysis of physiological traits (Table 2) indicated a decline in relative water content (RWC) with plant age; however, all foliar treatments significantly enhanced RWC over the control at each stage. The highest RWC was observed at 30 DAT with 1% $MgSO_4$, followed by 0.25% salicylic acid and 1% KCl, suggesting improved cellular hydration and stress tolerance. The lowest RWC was recorded with 0.5% KCl, likely due to osmotic imbalance. These findings align with Elgamaal *et al.* (2013), who reported that salicylic acid enhances RWC under varying irrigation conditions, supporting its role in maintaining water status under stress.

The data on chlorophyll content (Table 3) revealed that foliar application of all nutrients, except 0.5% KCl, significantly enhanced chlorophyll levels at all growth

Table 1: Impact of foliar applied macro and micro nutrients on plant height and number of tillers plant^{-1}of rice at different growth stages.

Treatment	Plant height (cm)			No of tillers plant^{-1}		
	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
T_1- Control	57.52	84.46	88.36	4.74	5.96	6.23
T_2- 0.5% KCl	60.45	87.95	91.66	4.91	6.47	6.95
T_3- 1.0% KCl	60.28	87.62	90.89	5.12	8.98	9.48
T_4- 1.0% $MgSO_4$	62.16	89.37	92.32	6.68	9.56	9.99
T_5- 2.0% $MgSO_4$	61.22	88.76	91.71	5.22	7.58	7.98
T_6- 0.3% Boric acid	59.64	87.12	90.45	5.51	8.05	8.47
T_7- 0.6% Boric acid	59.06	86.53	89.85	5.06	7.12	7.51
T_8- 0.25% Salicylic acid	60.85	88.15	91.07	6.29	9.15	9.69
T_9- 0.5% Salicylic acid	60.05	87.45	90.75	5.94	8.72	9.11
SEm±	2.86	3.89	3.70	0.27	0.36	0.27
CD at 5%	NS	NS	NS	0.80	1.08	0.83

KCl- Potassium chloride; $MgSO_4$- Magnesium sulfate; NS- Non-significant, DAT- Days after transplanting.

Table 2: Impact of foliar applied macro and micronutrients on dry weight plant^{-1} and relative water content of rice at different growth stages.

Treatment	Dry weight plant^{-1} (g)			Relative water content (%)		
	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
T_1- Control	4.57	13.83	18.64	87.77	85.55	81.88
T_2- 0.5% KCl	4.73	15.01	20.79	91.89	89.67	85.31
T_3- 1.0% KCl	4.93	20.84	28.36	93.12	90.95	86.62
T_4- 1.0% $MgSO_4$	6.44	22.18	29.89	93.85	91.84	87.25
T_5- 2.0% $MgSO_4$	5.03	17.59	23.87	92.24	90.11	85.82
T_6- 0.3% Boric acid	5.31	18.68	25.34	92.55	90.32	86.11
T_7- 0.6% Boric acid	4.87	16.52	22.47	92.11	89.91	85.59
T_8- 0.25% Salicylic acid	6.06	21.23	28.99	93.42	91.37	86.93
T_9- 0.5% Salicylic acid	5.72	20.23	27.25	92.88	90.81	86.41
SEm±	0.26	0.83	0.83	1.06	1.04	0.93
CD at 5%	0.78	2.51	2.49	3.20	3.12	2.81

KCl- Potassium chloride; $MgSO_4$- Magnesium sulfate; NS- Non-significant, DAT- Days after transplanting.

stages compared to the control. The most pronounced effect was observed with 0.5% salicylic acid, followed by 1% $MgSO_4$ and 0.3% boric acid, indicating their positive influence on chlorophyll biosynthesis and leaf health. Salicylic acid likely promoted chloroplast stability and delayed senescence, while Mg and B played key roles in chlorophyll formation and membrane integrity. These findings align with Rawashdeh and Sala (2014), who reported that application of Fe and B, individually or combined, significantly increased chlorophyll content by improving micronutrient availability and photosynthetic efficiency.

The data on proline content (Table 3) indicated a progressive increase with plant age, reflecting its role in stress adaptation. At 30 DAT, no clear trend was observed across treatments, likely due to the timing of foliar nutrient application. However, at 60 and 90 DAT, all treatments except 0.5% KCl significantly enhanced proline accumulation compared to control. The highest proline content was recorded with 1% $MgSO_4$, followed by 0.25% and 0.5% salicylic acid, suggesting their role in osmoprotection and stress signaling. Minimum proline was observed with 0.5% KCl, indicating its limited effect on stress tolerance. These results support the role of Mg and salicylic acid in enhancing plant resilience.

The data on catalase activity (Table 4) showed an increasing trend with plant age, highlighting enhanced antioxidant defense during later stages. At 30 DAT, no distinct pattern was observed, possibly due to the early stage of enzyme activation. However, at 60 and 90 DAT, all treatments except 0.5% KCl significantly increased catalase activity compared to control. The most pronounced effect was observed with 1% $MgSO_4$, followed by 0.25% and 0.5% salicylic acid, indicating their role in boosting the antioxidative defense system. The lowest catalase activity was recorded with 0.5% KCl. These findings align with Tewari *et al.* (2004), who reported enhanced antioxidant enzyme activity in maize with Mg application.

The data on peroxidase activity (Table 4) showed a steady increase with crop age, indicating enhanced antioxidant defense over time. At 30 and 60 DAT, all foliar

Table 3: Impact of foliar applied macro and micronutrients on chlorophyll and proline content in rice plant at different growth stages.

Treatment	Chlorophyll content (SPAD Value)			Proline content (µg g^{-1})		
	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
T_1- Control	8.42	11.32	7.98	266.45	292.47	329.53
T_2- 0.5% KCl	9.36	12.58	8.11	267.76	298.84	334.46
T_3- 1.0% KCl	10.16	13.12	9.86	284.73	352.37	388.35
T_4- 1.0% $MgSO_4$	11.55	14.91	11.15	291.36	369.45	403.26
T_5- 2.0% $MgSO_4$	10.61	13.37	10.23	244.38	336.74	369.73
T_6- 0.3% Boric acid	11.41	14.48	11.13	245.12	341.32	375.24
T_7- 0.6% Boric acid	10.16	12.86	9.97	243.89	335.97	368.12
T_8- 0.25% Salicylic acid	11.13	15.64	10.92	285.08	358.76	394.37
T_9- 0.5% Salicylic acid	10.61	13.11	10.28	246.21	341.92	375.95
SEm±	0.46	0.46	0.45	11.25	10.41	5.98
CD at 5%	1.39	1.38	1.35	33.75	31.22	17.94

KCl- Potassium chloride; $MgSO_4$- Magnesium sulfate; NS- Non-significant, DAT- Days after transplanting.

Table 4: Impact of foliar applied macro and micronutrients on catalase and peroxidase content in rice plantat different growth stages.

Treatment	Catalase content (Unit g^{-1} fresh weight $min.^{-1}$)			Peroxidase content (Unit g^{-1} fresh weight $min.^{-1}$)		
	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
T_1- Control	311.18	400.05	489.15	244.35	292.46	358.76
T_2- 0.5% KCl	312.23	408.37	506.58	251.48	300.06	357.53
T_3- 1.0% KCl	334.28	431.27	542.26	266.73	315.18	372.07
T_4- 1.0% $MgSO_4$	345.68	447.12	560.12	274.82	323.21	379.11
T_5- 2.0% $MgSO_4$	332.37	428.24	538.31	260.34	308.45	366.23
T_6- 0.3% Boric acid	332.88	428.89	538.67	260.97	309.12	367.08
T_7- 0.6% Boric acid	332.14	427.86	538.11	260.04	308.78	366.62
T_8- 0.25% Salicylic acid	334.65	432.57	543.25	267.35	315.89	372.86
T_9- 0.5% Salicylic acid	333.51	429.13	540.17	266.51	314.88	371.98
SEm±	5.95	7.14	11.22	4.96	5.82	3.21
CD at 5%	17.85	21.41	33.65	14.87	10.5	9.64

KCl- Potassium chloride; $MgSO_4$- Magnesium sulfate; NS- Non-significant, DAT- Days after transplanting.

treatments significantly increased peroxidase activity over the control. At 90 DAT, the highest activity was observed with 1% $MgSO_4$, followed by 1% KCl, 0.25% and 0.5% salicylic acid, while the lowest was recorded with 0.5% KCl. The superior effect of $MgSO_4$ and salicylic acid suggests their role in activating oxidative stress defense mechanisms. These results support Vicent and Plasencia (2011), who noted that salicylic acid regulates key antioxidant enzymes like peroxidase and catalase under stress conditions.

CONCLUSION

The present study concludes that foliar application of 1.0% $MgSO_4$ significantly improved key growth parameters such as plant height, dry weight and number of tillers in rice under rainfed conditions. Relative water content (RWC) was enhanced with 0.5-1.0% KCl, 1.0-2.0% $MgSO_4$, 0.3-0.6% boric acid and 0.25-0.5% salicylic acid, with 1.0% $MgSO_4$ showing the most consistent effect. Chlorophyll content was notably increased with similar treatments, particularly 1.0% KCl, $MgSO_4$, boric acid and salicylic acid at effective doses. Furthermore, foliar nutrients significantly improved physiological parameters such as proline, catalase and peroxidase activities, which are critical for stress resilience. The results highlight the synergistic role of macro and micronutrient foliar sprays in promoting growth and physiological efficiency, ultimately contributing to better performance of rice under moisturelimited rainfed conditions. These findings support the strategic use of nutrients to enhance stress adaptation and crop productivity.

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Disclaimers

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Informed consent

All experimental procedures related to the present research were conducted in accordance with the guidelines of Acharya Narendra Deva University of Agriculture and Technology and were approved by the relevant committee. Necessary permissions were obtained to ensure compliance with research standards.

Conflict of interest

Regarding the publishing of this work, the authors state that they have no any conflicts of interest.

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