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Effect of Graded Magnesium Rates on Growth and Productivity of Okra (*Abelmoschus esculentus* L.) in an Acid *Alfisol* of North-West India

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Abstract

Okra (*Abelmoschus esculentus* L.), a dominant vegetable crop of Himachal Pradesh, holds immense significance owing to its high nutritional value. However, the continuous application of primary nutrients, while neglecting secondary nutrients, causes yield reduction in crops. Therefore, optimum crop management practices demand the addition of secondary nutrients, especially Mg, which plays a significant role in enhancing okra growth and production. Therefore, the present study was conducted to evaluate the effect of graded magnesium doses on okra productivity during *kharif*, 2024, with eleven treatments comprising one as GRD and the remaining treatments with varying $MgSO_4$ rates from 0 to 90 kg ha^{-1} in conjunction with RDF and replicated thrice. Various growth parameters and fruit, straw and biological yield of okra were recorded after harvest. The results stated that 70 kg $MgSO_4$ ha^{-1} across the varied doses of Mg showed the most favourable results by enhancing both growth parameters and yield of okra.

Keywords: *Abelmoschus esculentus* L., Nutrients, Mg, Physiology, Yield

India's attainment of self-sufficiency and stability in food production has shifted the focus toward strengthening health security through access to nutritionally balanced diets. Vegetables play a crucial role in a balanced diet by supplying essential vitamins, minerals, and dietary fibre[1]. India is the second largest producer of vegetables in the World, after China. In this context, the North-Western Himalayas, particularly Himachal Pradesh, have achieved self-reliance in vegetable production, emerging as a major vegetable-producing region[2]. Due to diversified and congenial agro-climatic conditions in Himachal Pradesh, a wide range of horticultural commodities, including fruit, vegetable and aromatic plants cultivation, has gained immense importance[3,4]. Okra (*Abelmoschus esculentus* L.) belongs to the *Malvaceae* family, primary grown vegetable in the state due to its high nutritional value and significant economic importance. It is grown in an area of 3.79 thousand ha in Himachal Pradesh with an annual productivity of 16.87 t ha^{-1}, which is higher than the national average productivity of 13.57 t ha^{-1} [5]. As a short-duration crop, its growth and yield are highly responsive to balanced nutrient availability and their management[6,7].

Intensive agriculture, involving high cropping intensity and use of high-yielding varieties, has led

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to increased depletion of macro- and micronutrients from agricultural soils[8]. However, traditional fertiliser management practices have predominantly emphasised the primary nutrients (N, P, and K), resulting in the relative neglect of secondary and micronutrients. Among secondary nutrients, magnesium (Mg) is often referred to as the "forgotten element" due to its comparatively limited attention in fertiliser application practices despite its essential physiological and biochemical functions in plants[9]. In addition, deficiencies of Mg are not perceived as a major constraint to crop production, as symptoms and usually localised or not recognised by the farmers. When these practices are perpetuated over extended periods, such practices can precipitate progressive nutrient depletion and imbalance within the soil–plant continuum. This, in turn, constrains physiological functions, impairs growth dynamics, and ultimately culminates in significant declines in crop productivity. Mg plays a significant role in plant nutrition, human health, and sustainable agriculture. Also, it provides plant defence mechanisms and enhances tolerance to abiotic stresses. Mg is a key constituent of chlorophyll, involved in photosynthesis, enzyme activation, and the efficient translocation of carbohydrates from source to sink, thereby influencing fruit development and overall yield[10]. Also, it plays a critical role in maintaining normal nerve and muscle function, cardiac excitability, neuromuscular conduction, and glucose and insulin metabolism in human sbeings[11]. Therefore, sustaining adequate Mg concentrations in edible agricultural commodities is vital in safeguarding human and animal health.

However, availability of Mg to plants is controlled by several factors, including soil texture, pH, organic carbon content, and climatic conditions. Among these, soil acidity coupled with high rainfall is the most critical constraint, as it reduces exchangeable Mg and accelerates its leaching[12]. Acid soils occupy about 49 m ha in India[13], and their extent in Himachal Pradesh is 1.74 m ha [7]. Therefore, considering the substantial area under acidic conditions in Himachal Pradesh, Mg deficiency can be anticipated as a significant nutritional constraint[14] owing to the inherently low CEC, coupled with continuous cropping and imbalanced replenishment of secondary nutrients. Under such conditions, soils are prominently devoid of basic cations, facilitated by heavy rainfall leading to their leaching, thereby limiting availability and reducing crop production[15]. Therefore, to ensure a sufficient supply of Mg in order to enhance the growth and productivity of okra, it is imperative to standardise appropriate Mg application rates. Accordingly, the present study was undertaken to evaluate the effect of graded Mg levels on the growth and yield of okra with the hypothesis that increased addition of Mg will yield more.

MATERIALS AND METHODS

A field experiment was conducted at the Experimental Farm of the Department of Soil Science, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh. The okra var. *Palam Komal* was raised as a test crop during *kharif*, 2024. The experimental site is situated in the Palam Valley of Kangra district in the mid-hill region of Himachal Pradesh. The region is characterised by a sub-humid temperate climate with distinct seasonal variability, receiving an average annual rainfall of 2500-3000 mm. The experiment was laid out in a Randomised Block Design (RBD) with eleven treatments and three replications. Treatment T_1 comprised the General Recommended Dose (GRD), while treatments T_2 to T_{11} included graded levels of $MgSO_4$, ranging from 0 to 90 kg ha^{-1}. The recommended fertiliser dose for okra (75 kg N, 50 kg P_2O_5, and 55 kg K_2O ha^{-1}) was supplied through urea, single superphosphate, and muriate of potash, respectively. $MgSO_4$ was applied to okra at sowing. FYM was applied @ 100 q ha^{-1} in okra on a wet basis before sowing the crops. N was applied in two splits, with half applied at sowing and the remaining half applied in two equal instalments during the crop growth period, whereas the entire quantities of P and K were applied basally at sowing. All agronomic and cultural practices were uniformly followed throughout the crop growth period. The number of fruits per plant was determined by counting fruits on five randomly selected plants from

each plot, and the mean was calculated. Fruit length and fruit weight were measured from fruits harvested from the same plants (five), and corresponding mean values were computed. The number of plants per meter row was computed by dividing the row length by the row spacing. Fruit and straw yield were recorded on a plot basis and then converted into tonnes per hectare (t ha^{-1}). The biological yield was computed as the sum of fruit and straw yield. The experimental data so generated were subjected to Analysis of Variance (ANOVA) appropriate for a randomised block design, following the procedure outlined by Gomez and Gomez[16]. Statistical analysis was performed using Microsoft Excel.

The soil at the experimental site was silty clay loam in texture with acidic reaction. Baseline soil fertility analysis indicated medium available nitrogen (345 kg ha^{-1}), phosphorus (20.5 kg ha^{-1}), potassium (185 kg ha^{-1}) and sufficient exchangeable magnesium (1.23 c mol (p^+) kg^{-1}).

RESULTS AND DISCUSSION

The number of plants per m row length (Table 1) varied significantly with the graded doses of Mg across the treatments, ranging from 6.24 to 7.20. Application of $MgSO_4$ @ 70 kg ha^{-1} (T_9) coupled with recommended NPK resulted in the highest number of plants per m row length, while its omission (T_2) had the lowest. Treatment T_9 remained statistically at par with the plots treated with $MgSO_4$ @ 40 (6.78), 50 (6.79), 60 (7.06), 80 (7.14) and 90 (7.09) kg ha^{-1}. Treatment T_1, comprising RDF+FYM, also registered 6.56 number of plants with increment of 5.1 per cent compared to the control. The increased number of plants owing to the Mg fertilisation may be credited to the improvement in crop establishment, enhanced chlorophyll synthesis and overall plant vigour. This further enhanced seedling growth, resulting in better survival and establishment. Furthermore, sufficient Mg availability supports energy transfer reactions (ATP formation), phloem loading,

Table 1. Effect of graded Mg application on growth parameters of okra

Treatment	No. of plants per m row length	No. of fruits per plant	Fruit length	Fruit weight
			(cm)	(g)
1. T GRD	6.56	10.92	11.23	9.68
2. T $[MgSO_4]_0$	6.24	9.08	10.23	9.03
3. T $[MgSO_4]_{10}$	6.49	9.08	10.20	9.09
4. T $[MgSO_4]_{20}$	6.51	9.42	10.59	9.18
5. T $[MgSO_4]_{30}$	6.61	9.42	11.08	9.26
6. T $[MgSO_4]_{40}$	6.78	9.75	11.23	9.55
7. T $[MgSO_4]_{50}$	6.79	10.08	11.57	9.64
8. T $[MgSO_4]_{60}$	7.06	10.67	11.42	9.78
9. T $[MgSO_4]_{70}$	7.20	11.33	11.92	9.96
10. T $[MgSO_4]_{80}$	7.14	11.00	11.67	9.94
11. T $[MgSO_4]_{90}$	7.09	11.00	11.50	9.86
SE_m	0.16	0.67	0.82	0.13
LSD ($p \leq 0.05$)	0.46	NS	NS	0.38

and partitioning of photoassimilates toward developing tissues, thereby strengthening root development and improving nutrient uptake efficiency. Collectively, these physiological improvements translate into superior crop stand density and productivity. Similar results were reported by Geng *et al.*[17], who found that the application of Mg to plants significantly improved germination, seed yield, and quality in rapeseed plants. Furthermore, Guo *et al.* [18] demonstrated that balanced Mg nutrition enhanced dry matter production and improved yield components through better source–sink relationships.

The tested treatments had no significant effect on the number of fruits and fruit length in okra. However, slight numerical variations were recorded across the treatments (Table 1). The numerically higher number of fruits per plant (11.33) and fruit length (11.92 cm) were noted in the treatment receiving 70 kg $MgSO_4$ ha^{-1} (T_9), while the lower values were noted in the control. The numerical increment in number of plants and length of fruit over control might be due to improved root growth, enhanced nutrient content and uptake due to magnesium sulphate supplementation. It also activated several enzymes involved in energy transfer and facilitated efficient translocation of photosynthates from source to sink. Similar results of improved growth attributes through Mg fertilisation have been reported in okra by Jassim and Hanshal[19], and in banana by He *et al.*[20] and Shelke *et al.* [21]. Further, Qu *et al.*[22] also reported that magnesium sulphate application results in improved soil nutrient balance and reduced physiological stress, which collectively contribute to significant growth and yield-attributing parameters.

Graded Mg fertilisation significantly influenced the fruit weight of okra (Table 1). Treatment comprising 70 kg $MgSO_4$ ha^{-1} resulted in the highest fruit weight (9.96 g), while the lowest was recorded under control (9.03 g). GRD also registered 7.2 percent rise in okra fruit weight over control. However, treatments receiving 60, 70, 80 and 90 kg $MgSO_4$ ha^{-1} showed statistical parity with GRD. The increase in fruit weight can be explained by the phenomenal contribution of Mg in regulating the metabolism of nitrates, which are utilised by plants in the form of amino acids. This conversion is facilitated by Mg, which thereby helps in overall crop growth and development. Similar were the findings of Wang *et al.*[23] who concluded that Mg fertilisation improved crop yield by enhancing various physiological processes and

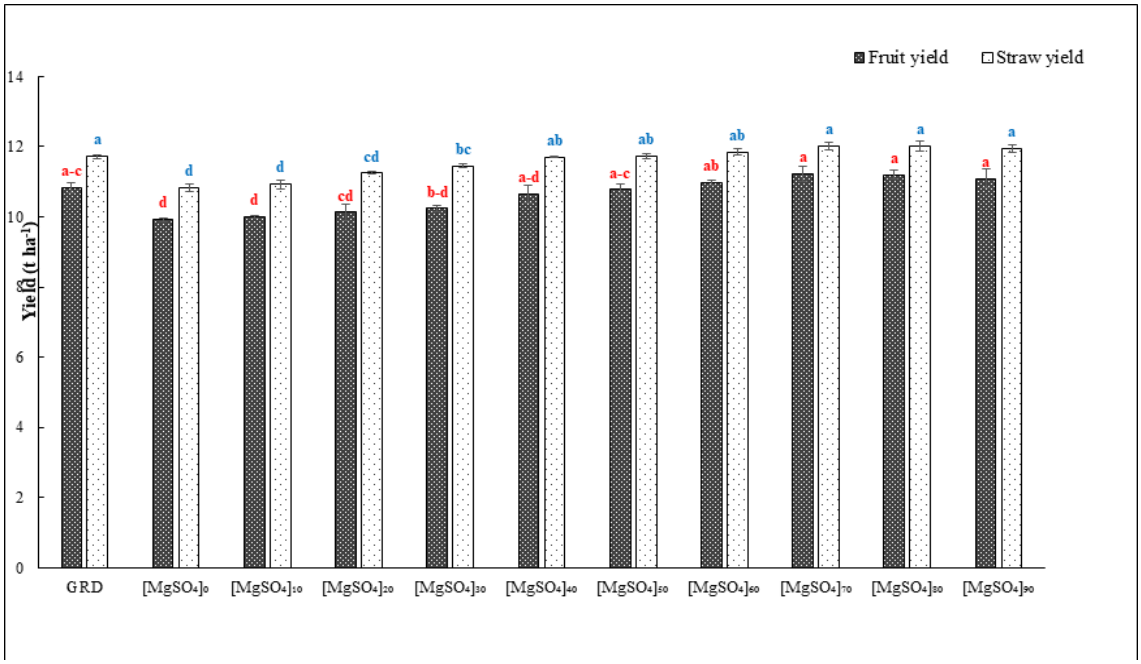


Figure 1. Effect of graded Mg rates on fruit and straw yield of okra.

increasing leaf Mg and sugar content, leading to higher biomass accumulation and higher yield across multiple crops.

The fruit yield of okra (Figure 1) was significantly influenced by Mg fertilisation. The yield varied from 9.92 to 11.22 t ha^{-1}. The plot treated with 70 kg $MgSO_4$ ha^{-1} exhibited the highest yield, with an increase of 13.1 per cent over control. Treatment T_9 was statistically at par with the treatments T_{10} and T_{11}. The Mg-omitted treatment yielded the lowest (9.92 t ha^{-1}). However, the treatment comprising RDF with FYM showed a significant increase of 9.17 per cent over control, albeit the increase was lower than the highest yield obtained from 70 kg $MgSO_4$ ha^{-1}. This increased yield owing to Mg fertilisation can be attributed to improved carbohydrate synthesis and accumulation. The enhanced crop yield upon Mg fertilisation might be due to increased photosynthetic rates and improved carbohydrate accumulation. Moreover, enhanced phloem loading and assimilate partitioning due to Mg application facilitated efficient translocation of photosynthates, thereby enhancing fruit yield[24]. Similar were the findings of Jassim and Hanshal[19]; Şahiv and Karademir[25].

On the other hand, the straw yield (Figure 1) revealed a significant response to magnesium fertilisation. The highest straw yield (12.03 t ha^{-1}) was recorded in the treatment comprising 70 kg $MgSO_4$ ha^{-1}. However, the plots devoid of Mg fertilisation resulted in the lowest straw yield (10.82 t ha^{-1}). Application of 70 kg $MgSO_4$ ha^{-1} showed a rise of 11.18 and 2.65 per cent over control and GRD-treated plots. Recommended NPK+FYM showed higher straw yield compared to control with a respective increase of 8.32 per cent. This can be attributed to the enhancement in photosynthetic activity induced by the application of Mg, thereby resulting in increased biomass production[26]. These findings are in agreement with those reported by Tan *et al.*[27].

The biological yield was significantly influenced by graded Mg rates, and the highest was recorded in the plots treated with 70 kg $MgSO_4$ ha^{-1} (Figure 2). However, Mg-omitted plots resulted in the lowest biological yield. Mg, being an essential component of chlorophyll,

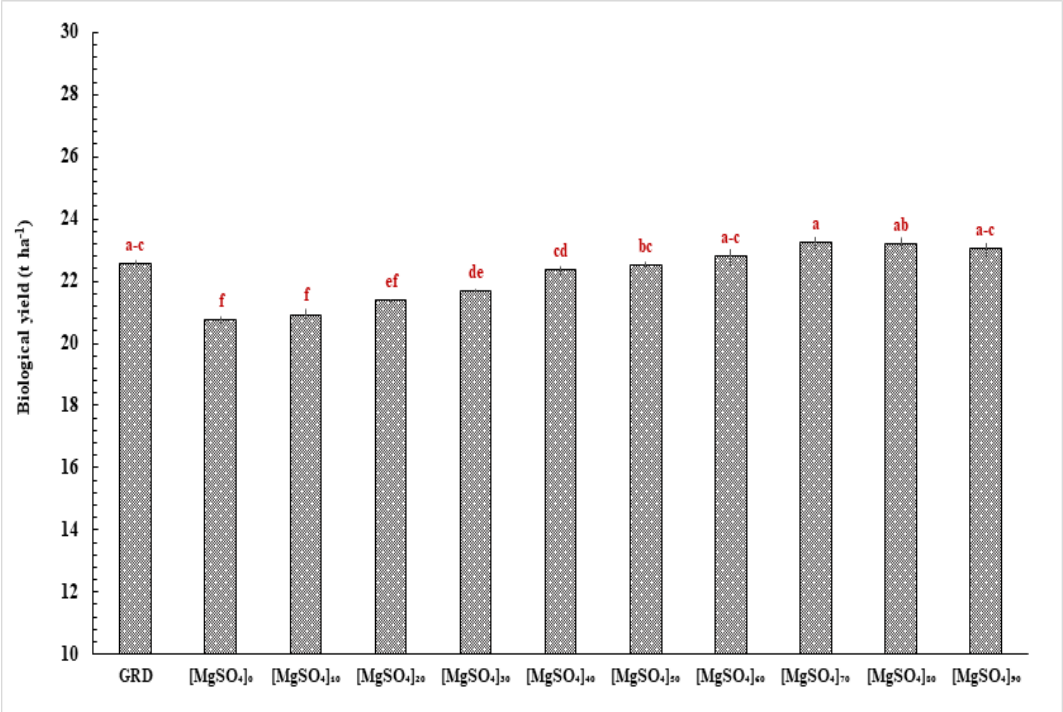


Figure 2. Influence of graded Mg rates on biological yield of okra.

enhances photosynthetic carbon assimilation, enzyme activation, and nutrient transport, all of which improve biomass and yield under Mg-adequate conditions. The results were supported by Pawar *et al.*[28].

CONCLUSION

Application of $MgSO_4$ improved okra growth and productivity in acid soils, indicating a positive role of magnesium nutrition. Growth and yield attributes differences among treatments beyond 30 kg were non-significant and achieved a plateau. However, the higher yield values were noted at 70 kg $MgSO_4$ ha^{-1}; beyond this, additional applications caused yield decline. Also, GRD-treated plots performed better than the control in enhancing crop growth and yield; however, the response was lower than that obtained with the 70 kg $MgSO_4$ ha^{-1}. The results underscore the importance of magnesium in regulating physiological growth processes and improving fruit and straw yields of okra. However, as the present investigation was conducted at a single location, validation across diverse soil types and cropping systems is required to refine magnesium application thresholds.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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AUTHORS CONTRIBUTION

SK: conducted the experiment, analyzed the data and wrote the original manuscript. A, SS, MB and MK: Table formulation, reviewed and edited the manuscript. PK: conceptualized the research programme, methodology, provided resources, reviewed and edited the manuscript