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RESEARCH ARTICLE

Impact of multi-nutrient foliar fertilization on yield and nutrient uptake of green gram

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Abstract

Green gram and other pulse crops are particularly vulnerable to nutrient deficiencies, particularly in specific soil types or when intensive farming methods are used. Applying multiple nutrients guarantees that the plants get the components they need for optimum growth and development. Multi-nutrient applications, particularly foliar spraying can greatly increase green gram yield, growth and nutrient uptake; improving crop productivity as well as possibly increasing net returns. To develop a foliar multi-nutrient schedule for enhancing the productivity and nutrient uptake of green gram under irrigated conditions, the experimental trials were conducted in the Rabi season of 2019–2021 (two years) using a randomized block design (RBD) that was replicated three times at the Regional Research Station (RRS), Tamil Nadu Agricultural University, Paiyur of Krishnagiri district, Tamil Nadu. The RRS Farm comprises of Lithic Haplustepts soils from the Vannapatti series, which are characterized by non-calcareous sandy loam. In the experimental trial, green gram (var. VBN 4) was grown as test crop and TNAU-Water Soluble Fertilizers with or without combination of liquid multi-micronutrient (LMMN) and humic acid (HA) sprayed twice at vegetative and flowering stages. Among the different combination of foliar spray, applying TNAU-WSF (Tamil Nadu Agricultural University water soluble fertilizer) @ 2 % with LMMN @ 1 % and HA @ 1 % recorded higher SPAD value, photosynthetic rate, transpiration rate and nutrient uptake that enhanced significantly higher green gram yield (1102 kg/ha) and achieved a 32 % higher compared to application of 2 % DAP spray.

Key words: green gram; HA; LMMN; photosynthetic rate; TNAU-WSF; uptake

Introduction

One of the most significant edible legume crops, the mung bean (*Vigna radiata* L.) is produced on more than 6 Mha globally, making up around 8.5 % of the entire worldwide pulse land area. It is the primary form in the dietary requirements consumed by numerous Asian families. The mung bean is extensively cultivated in the warmer parts of Canada and the United States, drier regions of southern Europe and various Asian countries including China, India, Bangladesh, Pakistan and other Southeast Asian nations (1). It has been a staple food in China and India for a long time, where diets predominantly consist of cereals. The mung bean has a balanced nutritional profile that includes large amounts of bioactive substances, minerals, vitamins, dietary fiber and protein (20 - 25 %). The mung bean contributes 10 % to the global pulse production, cultivated on around 4.5 Mha, yielding a total of 2.5 Mt with an average productivity of 548 kg/ha (2). In Tamilisdu, approximately 1.95 lakh ha are dedicated to green gram, producing 0.89 lakh t at a productivity rate of 444 kg/ha (3).

The primary method by which plants absorb macro- and micronutrients is through their roots; nevertheless, reduced root uptake can frequently happen because of nutrient availability limitations. The absorption and transport of nutrients applied topically are supported by a substantial body of evidence (4). One of the biggest challenges faced by crop production systems currently is to enhance foliar absorption and fertilizer use efficiency. Numerous limitations, including biotic and abiotic factors, contribute to the low production of green gram. Low yields are often attributed to factors such as inadequate nutrient availability and management practices, as well as the limited yield potential of existing varieties, particularly insufficient soil moisture in the initial growth phases (5). Moreover, nutritional stress brought on by a deficiency of nutrients throughout the crucial phases of crop growth results in low agricultural production and yield (6).

A reduction in the percentage of fallen flowers in the green gram and an increase in crop output were linked to foliar application of nutrients and growth regulators during the pre-flowering and flowering stages (7). Foliar nutrition is

acknowledged as a crucial way of fertilization since it often reaches the cells through the stomata or leaf cuticle, facilitating easy and rapid uptake of nutrients (8). The advantages include fixing, preventing leaching losses, using nutrients quickly and efficiently and raising the yield and plant nutrient uptake of irrigated green gram (9). Nutrient components are required in comparatively tiny amounts for proper plant shape and production; their absence can greatly disrupt the physiological and metabolic functions of the plant (10). In finger millet, applying a foliar spray of $ZnSO_4$ (0.5 %) combined with $FeSO_4$ (1 %) and citric acid (0.1 %) twice during the vegetative stage and once during the blooming stages combined with NPK soil application resulted in greater grain by 39 % over the recommended fertilizer dosage (11). Nutrient applications to the soil are frequently insufficient to fulfill the increasing crop demand, especially for short-duration crops like green gram. One effective approach to boost the productivity of pulses such as green gram is to apply nutrients foliarly using a water-soluble fertilizer. Through foliar application, plants can directly absorb nutrients through their leaves, avoiding the soil and possibly getting around restrictions on nutrient uptake or availability (12). Therefore, to improve the productivity and nutrient uptake of irrigated green gram, a recent study was carried out to evolve multi-nutrient foliar schedule and growth hormones.

Materials and Methods

Fieldwork was carried out for two years (2019-2021) at the Regional Research Station in Paiyur, Krishnagiri district. The station is 490 m above MSL and is situated at 12.21° N latitude and 78.18° E longitude. To improve the productivity and uptake of green gram under irrigated conditions, a foliar multi-nutrient schedule was developed through three replications of a RBD experiment. The non-calcareous sandy loam Lithic Haplustepts soils of the Vannapatti soil series comprised the soils of RRS Farm. The original soils had neutral soil reaction and non-saline character, low Soil Organic Carbon (SOC;4.3 g/kg) and available N (212 kg/ha), high available K status (307 kg/ha) and medium content (13.8 kg/ha) of available P (13, 14) (Table 1). The levels of DTPA-extractable Fe, Mn and Cu were adequate, whereas Zn was found to be deficient. In this site, green gram (var. VBN 4) was grown with following treatments viz., T_1 - N: P: K (19:19:19) TNAU-WSF @ 2 %, T_2 - TNAU-WSF @ 2 % + HA @ 1 %, T_3 - LMMN @ 1 %, T_4-LMMN @ 1 % + HA @ 1 %, T_5 - TNAU-WSF @ 2 % + LMMN @ 1 %, T_6- TNAU-WSF @ 2 % + LMMN @ 1 % + HA @ 1 %, T_7- DAP @ 2 % - Check and T_8- Absolute control. Recommended dose of fertilizer (RDF) for green gram applied to soil @ 25:50:25 kg N: P_2O_5: K_2O per ha (as per TNAU Crop Production Guide) and foliar spray done at vegetative and flowering stage during morning hours.

Table 1. Physical, chemical properties and available nutrients of initial soil samples

Available Nutrients*	(kg/ha)	Physical & Chemical properties*	
N	212	pH	7.66
P	13.8	EC	0.45 (dS m^{-1})
K	307	SOC	4.3 g/kg
S	9.3 ppm	Bulk density	1.42 Mg m^{-3}

*Mean of three soil samples

Observations on growth and physiological attributes

Among the five randomly selected and tagged observation plants, data on plant height, crop growth rate (CGR), photosynthetic rate and transpiration rate were recorded during the growth and harvest stages. Besides, dry matter production was recorded. Additionally, yield-related characteristics such as the number of seeds per pod, the number of pods per plant and the weight of 1000 grains were noted for the observation plants. The pod yield and haulm yield per ha were computed based on the pod and haulm yields obtained from the net plot area of 20 m^2. For statistical significance, the yield and soil parameters were measured through an ANOVA analysis and mentioned p-values (15).

Results and Discussion

Effects of multinutrient foliar fertilization on growth and physiological attributes

A higher plant height of 61.5 cm was obtained by applying TNAU-WSF @ 2 % + LMMN @ 1 % + HA @ 1 %. This result was statistically comparable to the TNAU-WSF @ 2 % + LMMN @ 1 % applied treatment. The reaction of green gram to Zn treatment in Zn-deficient soil and its role in auxin synthesis, which enhances the elongation phase of plant development, were the causes of the rise in plant height that resulted from the addition of multi-micronutrients (16). After closely monitoring CGR for 30 to 60 days, foliar application of TNAU-WSF @ 2 % + LMMN @ 1 % + HA @ 1 % observed higher CGR (22 g/m^2/day). Evidence suggested that foliar spray may facilitate plants' rapid uptake of nutrients by plants, leading to improved expression of growth traits. A naturally occurring organic substance, humic acid, improves soil qualities, increases nutrient uptake and encourages root development, all of which are critical for plant health and growth (17). Better expression of growth qualities may have resulted from increased nutrient availability and uptake, which in turn may have promoted photosynthesis and photosynthate translocation from source to growing plant parts (18). Increased photosynthetic and metabolic activity, enhanced cell division and improved cell elongation were the causes of the improved vegetative growth brought about by the foliar application of Zn and B. Foliar application of KNO_3 increased plant growth by promoting the physiological processes of nitrate metabolism, osmoregulation, photosynthesis, stomatal conductance and protein synthesis (19).

TNAU-WSF @ 2 % + LMMN @ 1 % + HA @ 1 % produced a higher SPAD value of 54.8, which was comparable to the results of TNAU-WSF @ 2 % + LMMN @ 1 % and LMMN @ 1 % + HA @ 1 % applied treatments. This positive effect may be attributed to its contents particularly CCC, K and Fe, which enhances the enzyme activity involved in chlorophyll synthesis and helps protect the chloroplasts by maintaining osmotic water balance (20). Micronutrients like Zn are critical for enzymes involved in numerous metabolic processes, required for the synthesis of chlorophyll and aid in the development of starch, which helps seed formation. Comparably, Mn contributes to the synthesis of naturally occurring antifungal chemicals in plants, which aid in the battle against disease infection. In addition to being a crucial part of the haemoglobin (Hb) molecule, Fe is necessary for preserving chlorophyll. It participates in the enzymatic activity

and in plant tissue, growth may have biological effects (19). Applying of 0.5 % $FeSO_4$ foliar spray during the blooming and peg formation stages of groundnut markedly increased the chlorophyll content compared to other treatments. The current investigation clearly demonstrates the superiority of Fe in enhancing the SPAD value.

The photosynthetic rate, a key indicator of photosynthetic efficiency and productivity in green gram, was significantly higher with the foliar application of TNAU-WSF @ 2 % + LMMN @ 1 % + HA @ 1 %, reaching 36.0 µmol CO_2 of photosynthetic rate m^2 s^{-1} (Table 2). This rate was comparable to that of the TNAU-WSF @ 2 % + LMMN @ 1 % treatment, which recorded 32.8 µmol CO_2 m^2 s^{-1}. The improved photosynthetic rate with the TNAU-WSF @ 2 % + LMMN @ 1 % + HA @ 1 % treatment is likely due to the beneficial effects of its multi-nutrient components. Fe may have an additional influence on photosynthetic rate because it acts as a catalyst to generate aminolevulinic acid (ALA), the first step in the synthesis of chlorophyll. Evidence reported that foliar spray of micronutrients increased photosynthetic rate in Bt cotton by 13.4 % as compared to the control and 1 % TNAU Horse gram wonder increased photosynthetic rate by 18.8 % (12). The application of both P and S together demonstrated a synergistic effect on black gram seed output. This effect was likely caused by the influence of balanced nutrition on photosynthesis (20).

Effects of multi-nutrient foliar fertilization on yield attributes and yield

Foliar application of TNAU-WSF @ 2 % + LMMN @ 1 % + HA @ 1 % statistically on par with TNAU-WSF @ 2 % + LMMN @ 1 % (T_5) and LMMN @ 1 % + HA @ 1 % (T_4) resulted in a higher number of pods per plant and increased individual seed weight. The primary factor influencing yield in pulses is the quantity of pods produced by each plant. When nutrients are applied topically, they become available quickly, speeding up physiological processes that ultimately increase plant growth and pod count (21). Foliar application of macro- and micronutrients maintained optimal bio-physiological conditions, enhancing the number of flower buds and ensuring their retention compared to the control group (22). Using 19:19:19 topically significantly increased the amount of fruit produced by each plant (16). More pods were seen per plant because of B's beneficial influence on increasing the fruit setting % through improving pollen viability, germination and tube elongation (23). Applying nutrients through foliar feeding improved the source-sink relationship, reducing competition for nutrients within the plant. The weight of each individual pod was significantly impacted by the foliar application of macro- and micronutrients (9). Applying nutrients through foliar feeding boosts water and nutrient absorption, leading to improved photosynthesis and assimilate partitioning to the edible portions. Higher B levels were linked to improved water absorption, fruits production and metabolite translocation to sink tissues (22). Higher individual pod weight in pulses was also influenced by Zn 's beneficial effects of translocation.

Among the foliar nutrients tested, applying TNAU-WSF @ 2 % combined with LMMN @ 1 % and HA @ 1 % resulted in the highest grain yield of 1102 kg/ha (Table 3). This yield was statistically like that achieved with TNAU-WSF @ 2 % + LMMN @ 1 % and it represented a 32 % increase compared to the DAP @ 2 % spray. The control plot yielded significantly less, to 764 kg/ha. The enhanced yield from these treatments was primarily due to a significantly greater number of pods per plant and increased 1000-grain weight compared to other treatments. Current findings are comparable with previous observations (24) in green gram. Regarding dry matter production, TNAU-WSF @ 2 % + LMMN @ 1 % + HA @ 1 % resulted in a significantly greater dry matter production (2323 kg/ha) and a 32 % increase in comparison. To influence growth, yield and quality, multi-micronutrients are critical for plant health because they serve as catalysts in vital processes like photosynthesis, enzyme activity and nutrient uptake. The foliar application of water-soluble fertilizers resulted in a notable increase in the production of dry matter in chickpea (25). The uptake of nutrients was considerably impacted by the foliar application of water-soluble fertilizers. Increased food intake boosted physiological processes such protein synthesis, nitrate metabolism, photosynthesis, chlorophyll production and glucose synthesis, which in turn

Table 2. Effect of multi-nutrient foliar application on biometric characters and physiological attributes of green gram

Treatments	Plant height (cm)	CGR (g/m^2/day) (30-60 DAS)	SPAD Value	Photosynthetic rate (µmol CO_2 m^{-2} s^{-1})	Transpiration rate (mmol m^{-2} s^{-1})
T_1 - TNAU WSF @ 2 %	56.7	16.5	47.5	26.0	6.6
T_2 - TNAU WSF @ 2 % + HA @ 1%	56.8	17.3	48.6	27.6	9.1
T_3 - LMMN @ 1 %	57.3	19.2	49.7	30.2	9.5
T_4 - LMMN @1 % + HA @1%	59.3	20.1	51.4	31.0	10.3
T_5 - TNAU WSF@ 2 % + LMMN @1 %	61.1	19.2	53.1	32.8	12.1
T_6 - TNAU WSF @ 2 % + LMMN @1 % + HA@1 %	61.5	22.0	54.8	36.0	15.2
T_7 - DAP @ 2 %	56.4	17.5	49.8	29.9	6.9
T_8 - Control	54.8	16.3	43.5	26.0	5.3
SEm ±	*0.91*	*0.59*	*1.14*	*1.50*	*0.45*
CD (p<0.05)	*2.77*	*1.79*	*3.45*	*4.56*	*1.37*

Table 3. Effect of multi-nutrient foliar application on yield attributes and yields of green gram

Treatment	No. of pods/plant	No. of seeds/ pod	Test weigh (g)	DMP (kg/ha)	Grain yield (kg/ha)
T_1 - TNAU WSF @ 2 %	25.1	10.3	4.0	1620	856
T_2 - TNAU WSF @ 2 % + HA @ 1%	25.9	10.5	4.1	1740	864
T_3 - LMMN @ 1 %	26.3	10.4	4.1	1847	877
T_4 - LMMN @1 % + HA@1 %	27.1	10.5	4.2	1976	939
T_5 - TNAU WSF@ 2 % + LMMN @1 %	27.8	10.9	4.5	2126	1040
T_6 - TNAU WSF @ 2 %+ LMMN @1 %+HA@1 %	28.5	12.0	4.6	2323	1102
T_7 - DAP @ 2 %	25.6	10.0	4.1	1774	837
T_8 - Absolute control	24.7	9.1	3.7	1450	764
SEd	*0.54*	*0.32*	*0.13*	*51.3*	*24.7*
CD (p<0.05)	*1.63*	*0.96*	*0.40*	*156*	*75.0*

leads to higher DMP. The topical application of Solubor similarly resulted in an increased DMP. B has a significant impact on cell membrane permeability, which improves the transit of sugars as well as carbs and ultimately raises DMP (18). Effects of multi-nutrient foliar fertilization on nutrient uptake

The study revealed that foliar fertilization with a combination of nutrients significantly enhanced the uptake of total N, k and P in green gram plants. The maximum nutrient uptake were observed in the treatment of TNAU-WSF @ 2 % + LMMN @ 1 % + HA @ 1 % and recorded 97, 9.2 and 95 kg/ha of total N, P and K respectively. This treatment was comparable to TNAU-WSF @ 2 % + LMMN @ 1% (Fig. 1). Grain had higher amounts of N, P and K. The observed trend may be attributed to the significant movement of N from vegetative tissues to reproductive organs after flowering. The results clearly demonstrated that the different treatments had a substantial effect on the uptake of N, P and K by the grain. Different applications of macro- and micronutrients had a substantial impact on the increased P uptake by green gram crop. The comparable findings were revealed that cowpea considerably enhanced its total P uptake when sprayed with 2 % DAP as opposed to 2 % KCl and water. The increased availability of K through leaves resulting from foliar K treatment may have caused an uptake of K in the green gram crop (25). Foliar application is recognized for its ability to facilitate rapid and effective nutrient usage, eliminate losses from leaching and fixation and control plant nutrient uptake (10). It was determined that foliar application of essential nutrients to plants, such as K and N, is just as effective as soil application. In addition, foliar spraying of green gram with 1 % urea and 1 % DAP prior to blooming resulted in a 40 % higher yield than foliar spraying without any treatment. One potential solution to prevent such fertilizer loss is foliar spray of fertilizers (17).

Conclusion

The combination of soil application and foliar spray of macro- and micronutrients to ensure the sustainable green gram productivity and corrected multi-nutrient deficiency in the plant and soil. Foliar nutrients typically reach cells through stomata or the leaf cuticle, allowing for quick and simple nutrient utilization and it is acknowledged as a crucial fertilization technique. The field experiments were conducted at Regional Research Station, Paiyur of Krishnagiri district identified best multi-nutrient formulation, alleviated deficiency and increased the nutrient uptake as well as yield of green gram. The foliar formulation of TNAU-WSF @ 2 % + LMMN @ 1 % + HA @ 1 % sprayed during the vegetative and flowering stages increased grain yield by 32 % compared to DAP spray @ 2.0 %. In addition, it improved crop growth, chlorophyll content and improved the efficiency of macro- and micronutrients. Growers can apply nutrients as foliar sprays at both the vegetative and blooming stages of the plant to maximize production in green gram, which will contribute to sustainability and profitability.

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Authors' contributions

MV contributed to the conceptualization and analysis of the study, including writing the original draft manuscript. RS and PK carried out data analysis. VA, TB, KM and VS conducted the literature search, advised on data processing and interpretation of the results. Each author examined the manuscript and participated in the data analysis. All authors have read and agreed to the published version of the manuscript.

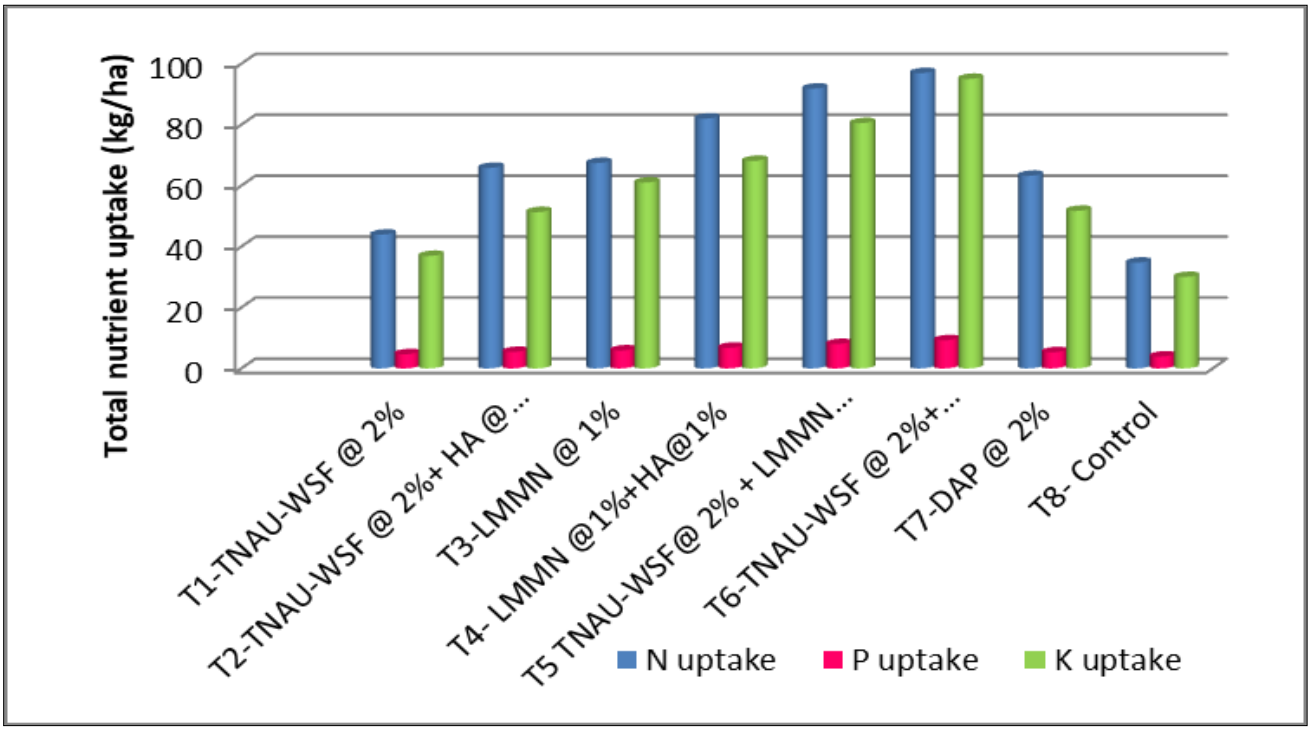

Fig. 1. Effect of multi-nutrient foliar application on nutrient uptake of green gram.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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