**Original Research Article**

**Effect of micronutrients on morpho-physiological parameters of black gram (*Vigna mungo* L.) cv. GAU-4 (Shyamal)**

**ABSTRACT**

|  |
| --- |
| The present study was executed with the prime objective to study the effect of different micronutrients on morpho-physiological parameters of black gram variety GAU-4 (Shyamal). The field trial was carried out in summer 2023 at Department of Plant Physiology, Anand Agricultural University, Anand in randomized block design with eight treatments replicated thrice. The micronutrients were sprayed at 25 and 35 days after sowing. Morphological parameters like plant height and number of trifoliate leaves per plant were recorded highest with ZnSO₄ 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha concentration of micronutrients. Control recorded the lowest plant height and number of trifoliate leaves per plant. ZnSO₄ 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha promoted early flowering and recorded highest stem and total dry weight. Maximum values for leaf area, leaf area index and leaf area ratio was observed with ZnSO₄ 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha at different growth stages. Net assimilation rate and crop growth rate also observed similar trends recording higher values in ZnSO₄ 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha at various crop growth stages. The application of micronutrients is one of the possible way to increase productivity of black gram. |

*Keywords: Micronutrients, ZnSO₄, FeSO4, Boric acid, Sulphur, Foliar spray*

1. INTRODUCTION

Blackgram (*Vigna mungo* L.) is also known as Urad in India. It is an important pulse crop in India. It is an annual pulse crop and mainly grown in rainfed or rice fallow crop. It enriches soil nitrogen by fixing atmospheric nitrogen and has a relatively short duration. Black gram is said to have originated in India, where it is the most widely grown and highly esteemed grain legume. Black gram grain contains about 25% protein, 56% carbohydrate, 2% fat, 4% minerals and 0.4% vitamins (Panigrahi *et al*., 2015). It is well known for its nutritional value, which includes 154 mg calcium, 385 mg phosphorus, 7057 mg iron, 0.254 mg riboflavin and 0.273 mg thiamine per 100 g of black gram. Black gram (*Vigna* *mungo* L.) is an erect, fast growing annual, herbaceous legume reaching 30-100 cm in height. It has a well-developed taproot and its stems are diffusely branched from the base. The leaves are trifoliate with ovate leaflets, 4-10 cm long and 2-7 cm wide. The inflorescence is borne at the extremity of a long (up to 18 cm) peduncle and bears yellow, small, papilionaceous flowers. The fruit is a cylindrical, erect pod, 4-7 cm long. The pod is hairy and has a short-hooked beak. It contains 4-10 ellipsoid black or mottled seeds (Jansen, 2006). Growth parameters like plant height, number of trifoliate leaves, days to 50% of flowering, dry matter accumulation in plant parts, LAI, LAR, NAR, CGR are used to describe and quantify plant growth, biomass accumulation, and partitioning of assimilates. Among the micronutrients; Fe, Zn and B improved the yield appreciably through foliar spray and soil application proved to be economical in different pulses. Foliar application is credited with the advantage of quick and efficient utilization of nutrients, elimination of losses through leaching and fixation and regulating the uptake of nutrient by plants. Foliar application of nutrients using water soluble fertilizers is one of the possible ways to enhance the productivity of pulses like green gram and black gram (Malek *et* *al*., 2018). The increase in seed and haulm yield of black gram due to zinc might be attributed to the reason that, zinc shows beneficial effects on chlorophyll content and so it indirectly influences the photosynthesis and reproduction. Crop yield increase might be due to S (sulphur) availability resulting in better formation of nodule, nitrogenase enzyme, chlorophyll *etc*. and thereby influencing growth and yield components of the crop which ultimately resulting in highest grain and stover yield. Iron (Fe) is a catalytic group of many redox reaction-heme containing cytochrome and non-heme iron-sulphur protein involved in photosynthesis nitrogen fixation and respiration. Boron (B) play important role for structural integrity of cell, cell membrane, cell division and elongation specially in primary and secondary roots and helps in translocation of sugar in plants.

2. methodology

2.1 Experimental site

The experiment is conducted at the farm of college B. A. College of Agriculture, Anand Agricultural University, Anand, India during Summer*,* 2023.

2.2 Experimental Details

The investigation was conducted on GAU-4 black gram variety with ten treatments replicated thrice involving foliar application of micronutrients in a randomized block design. The crop was raised with spacing of 30 x 10 cm by following all the recommended package of practices for better crop growth and production. The data collected from field and laboratory was subjected to statistical analysis as per the procedures of randomized block design (Panse and Sukhatme, 1995).

2.2.1 Treatment details

T1: FeSO4 0.5% (Foliar spray)

T2: ZnSO₄ 0.5% (Foliar spray)

T3: Boric acid 0.2% (Foliar spray)

T4: ZnSO₄ 0.5% + FeSO4 0.5% (Foliar spray

T5: ZnSO₄ 0.5% + FeSO4 0.5% + Boric acid 0.2% (Foliar spray)

T6­: Sulphur @20 kg/ha (Soil application through Bentonite- S)

T7: T5 + T6

T8­: Control

**2.3 Chemical Preparation and Conduct of Experiment**

The micronutrients foliar application of different concentrations like, ZnSO₄ 0.5%, FeSO4 0.5% and Boric acid 0.2% were used from the Department of Plant Physiology, Anand Agricultural University, Anand, Gujarat, India. Micronutrient foliar spray solutions *viz.,* FeSO4 0.5%, ZnSO₄ 0.5% and Boric acid 0.2% were prepared by dissolving 5 gm of FeSO4, 5 gm of ZnSO₄, 2 gmof Boric acid in 1000 ml of water, which gives 0.5% FeSO4, 0.5% ZnSO₄, 0.2% Boric acid solution, respectively. The first foliar spray of micronutrients were given prior to initiation of flowering (at 25 DAS). Second foliar spray was given after 10 days of the first foliar spray *i.e.* 35 DAS. Sulphur @20 kg/ha as soil application at land preparation through Bentonite- S.

#### 2.4 Observations Recorded

##### **2.4.1 Morphological parameters**

The observations on various plant morphological characters, *viz.,* plant height, number of trifoliate leaves per plant and days to 50% of flowering were recorded from a group of five randomly tagged plants in net plot area at 30, 45, 60 DAS and at harvest and average was worked out. For calculating stem and total dry weight of the plant at 30, 45, 60 DAS and at harvest, five plants from each gross plot were uprooted randomly and separated into leaves, stem, and root part which were dried separately in hot air oven at 105 ºC until constant weight was achieved and mean stem and total dry weight was recorded as respective observation per plant.

***2.4.1.1 Plant height (cm)***

The plant height was measured from base of the plant to the tip of fully opened leaf on the main shoot. Measurements were taken from five plants each tagged earlier and were recorded at different intervals at 30, 45, 60 DAS and at harvest and the average height was recorded for analysis.

***2.4.1.2 Number of trifoliate leaves per plant***

Total number of trifoliate leaves in the tagged plants were counted and recorded at different intervals at 30, 45, 60 DAS and at harvest and the average number of trifoliate leaves were calculated.

***2.4.1.3 Days to 50% of flowering***

The date of 50% flower initiation in each treatment were recorded and expressed as days taken for 50% of flowering.

***2.4.1.4 Stem and total dry weight (g)***

Five plants from each gross plot were uprooted randomly at 30, 45, 60 DAS and at harvest and separated into leaves, stem and root parts which were dried separately in hot air oven at 105 ºC until constant weight was achieved and mean stem and total dry weight was recorded as respective observation per plant.

**2.4.2 Physiological Parameters**

***2.4.2.1. Leaf area per plant (cm2)***

Leaf area was measured by using leaf area meter (CI-203) leaves were separated from each of uprooted five randomly selected plants from each plot of black gram (GAU-4) expressed in cm2.

***2.4.2.2 Leaf area index (LAI)***

The observations were recorded in different intervals like 30, 45, 60 days after sowing and at the time of harvest. The LAI is the ratio of leaf area per plant to the land area occupied by the plant and was calculated using the formula (Watson, 1952).

LAI =

***2.4.2.3 Leaf area ratio (LAR) (cm2/g)***

LAR expresses the ratio between the area of leaf lamina to the total plant biomass or the LAR reflects the leafiness of a plant or amount of leaf area formed per unit of biomass which was measured at 30, 45, 60 DAS and at harvest for each treatment and expressed in cm2/g and was calculated using the formula given by Radford (1967),

LAR =

***2.4.2.4 Net assimilation rate (NAR) (g/m2/day)***

NAR is the increase in dry weight per unit leaf area or it is a measure of the index of productive efficiency, which was calculated by the formula as given below and expressed as g/m2/day. It was measured at 30-45, 45-60 DAS and 60 DAS-at harvest for each treatment.

NAR =

Where,

ln A2 – ln A1 = Natural log difference of leaf area at time t2 and t1

W1 = Dry weight of the plant (g) at time t1

W2 = Dry weight of the plant (g) at time t2

t2 - t1 = Time interval in days

***2.4.2.5 Crop growth rate (CGR) (g/m2/day)***

CGR is the ratio of dry matter production per unit ground area per unit time, which was calculated by adopting the formula given by Watson (1952) and expressed as g/m2/day. The observations were recorded in different intervals of 30-45, 45-60 DAS and 60 DAS-at harvest.

CGR =

Where,

W1  = Dry matter production plant-1(g) at time t1

W2  = Dry matter production plant-1(g) at time t2

t2 - t1 = Time interval in days

P = Ground area covered by the plant (m2)

3. results and discussion

**3.1 Morphological Parameters**

**3.1.1 Plant height**

Table 1 provides the evaluation of mean data on black gram’s periodical plant height recorded at 30, 45, 60 DAS as well as at harvest, which showed that plant height increased with increase in the age of crop. Plant height was found non-significant at 30 DAS while, it was found significant at 45, 60 DAS and at harvest. At 45 DAS significantly maximum plant height (23.61 cm) was recorded under treatment T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha) and it was statistically at par with T5. At 60 DAS significantly maximum plant height (31.82 cm) was recorded under treatment T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha) and it was statistically at par with T4 and T5. At harvest, significantly highest plantheight (33.56 cm) was recorded under treatment T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha) and it was statistically at par with treatments T4 and T5. The overall results of the experiment showed that, as crop age increased till harvest, plant height gradually increased. Most effective and increased plant height may be due to adequate amount of micronutrient zinc which activates plant enzymes which are involved in carbohydrate metabolism and also required for the synthesis of growth hormone auxin leading to cell enlargement and increase in normal cell division. These results conform with findings of Rehaman *et al*. (2024) in pigeon pea, Vani *et al*. (2022) in black gram, Kavya *et al*. (2021) in green gram and Malek *et al*. (2018) in black gram.

**Table 1. Effect of micronutrients on plant height (cm) at 30, 45, 60 DAS and at harvest**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Treat. No.** | **Treatment Details** | **Plant height (cm)** | | | |
| **30 DAS** | **45 DAS** | **60 DAS** | **At harvest** |
| T1 | FeSO4 0.5% | 13.40 | 19.50 | 26.43 | 27.46 |
| T2 | ZnSO4 0.5% | 13.42 | 19.92 | 27.54 | 28.83 |
| T3 | Boric acid 0.2% | 13.13 | 19.48 | 26.09 | 27.15 |
| T4 | ZnSO4 0.5% + FeSO4 0.5% | 13.48 | 20.26 | 27.80 | 29.71 |
| T5 | ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% | 13.57 | 22.43 | 27.98 | 29.87 |
| T6 | Sulphur @20 kg/ha | 12.98 | 18.61 | 24.97 | 26.40 |
| T7 | T5 + T6 | 14.44 | 23.61 | 31.82 | 33.56 |
| T8 | Control | 12.18 | 17.73 | 23.80 | 25.56 |
|  | **SEm ±** | 0.76 | 0.99 | 1.35 | 1.45 |
|  | **CD at 5%** | NS | 3.01 | 4.11 | 4.39 |
|  | **CV%** | 9.89 | 8.50 | 8.67 | 8.78 |

**3.1.2 Number of trifoliate leaves per plant**

The number of trifoliate leaves per plant increase as the days of crop stage increase which at the end due to senescence number of leaves were reduced which is represented in Table 2. The results of number of trifoliate leaves during 30 DAS were found non-significant. At 45 DAS, significantly maximum number of trifoliate leavesper plant (19.20) were recorded under treatment T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha) and it was statistically at par with treatments T2, T3, T4 and T5. At 60 DAS, significantly maximum number of trifoliate leavesper plant (22.90) were recorded under treatment T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha) and it was statistically at par with treatments T2, T3, T4 and T5. At harvest, significantly maximum number of trifoliate leavesper plant(21.63) were recorded under treatment T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha) and it was statistically at par with treatments T3 andT5. The application of micronutrients such as Zinc (Zn), Iron (Fe) and Boron (B) lead to a significant increase in the number of trifoliate leaves per plant. The combined application of these micronutrients, especially when supplemented with Sulphur, results in the highest increase in leaf count, demonstrating the synergistic effect of these nutrients on plant growth. This data supports the critical role of micronutrient supplementation in enhancing the vegetative growth of plants. The results obtained from these studies were in accordance with those reported by Rajput *et al*. (2021) in black gram.

**Table 2. Effects of micronutrients on number of trifoliate leaves per plant at 30, 45, 60 DAS and at harvest**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Treat. No.** | **Treatment Details** | **Number of trifoliate leaves per plant** | | | |
| **30 DAS** | **45 DAS** | **60 DAS** | **At harvest** |
| T1 | FeSO4 0.5% | 4.93 | 16.17 | 18.06 | 17.37 |
| T2 | ZnSO4 0.5% | 5.13 | 17.40 | 20.53 | 18.50 |
| T3 | Boric acid 0.2% | 5.15 | 18.00 | 20.94 | 18.77 |
| T4 | ZnSO4 0.5% + FeSO4 0.5% | 5.03 | 16.87 | 19.91 | 15.87 |
| T5 | ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% | 5.34 | 19.10 | 22.34 | 21.43 |
| T6 | Sulphur @20 kg/ha | 4.64 | 14.73 | 17.18 | 15.73 |
| T7 | T5 + T6 | 5.37 | 19.20 | 22.90 | 21.63 |
| T8 | Control | 4.48 | 13.13 | 16.71 | 15.40 |
|  | **SEm ±** | 0.30 | 0.96 | 1.21 | 0.94 |
|  | **CD at 5%** | NS | 2.91 | 3.66 | 2.86 |
|  | **CV%** | 10.23 | 9.87 | 10.54 | 9.04 |

**3.1.3 Days to 50% flowering**

Data (Table 3) on days to 50% of flowering indicated that different concentrations of micronutrients exerted significant effect on the parameter. Significantly highest duration for days to 50% flowering (43.03 days) was recorded under T8 (Control) while shortest time to days to 50% flowering (33.34 days) was recorded in treatment T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha). Boron plays a critical role in the reproductive development of plants, including flower formation and pollen viability. It was also noted that MN mixture II represented maximum number of flowers. (Kannan *et al.*, 2014).

**Table 3. Effect of micronutrients on days to 50% flowering**

|  |  |  |
| --- | --- | --- |
| **Treat. No.** | **Treatment Details** | **Days to 50% flowering** |
| T1 | FeSO4 0.5% | 39.03 |
| T2 | ZnSO4 0.5% | 40.03 |
| T3 | Boric acid 0.2% | 39.33 |
| T4 | ZnSO4 0.5% + FeSO4 0.5% | 36.67 |
| T5 | ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% | 35.34 |
| T6 | Sulphur @20 kg/ha | 42.67 |
| T7 | T5 + T6 | 33.34 |
| T8 | Control | 43.03 |
|  | **SEm ±** | 1.13 |
|  | **CD at 5%** | 3.42 |
|  | **CV%** | 5.05 |

**3.1.4 Stem dry weight (g)**

Table 4 presents the stem dry weight at different crop growth stages, which depicts that stem dry weight At 45 DAS, significantly maximum stem dry weight (2.39 g) was recorded under treatment T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha). Treatment T8 (Control) recorded the lowest stem dry weight (0.76 g) compared to other treatments. At 60 DAS, significantly maximum stem dry weight (3.00 g) was recorded under treatment T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha). Treatment T8 (Control) recorded lowest stem dry weight (1.44 g) compared to other treatments. At harvest, significantly maximum stem dry weight (5.72 g) was recorded under treatment T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha). Treatment T8 (Control) recorded lowest stem dry weight (1.49 g) compared to other treatments. Treatment T7 continuously displayed maximum stem dry weight per plant during all time periods, according to the experiment's overall results. The main cause of this increase in stem dry weight was the higher number of branches per plant that was seen in the micronutrient treatment at every stage. The increase in stem biomass with application of these micronutrients like iron, zinc and boron could be due to its involvement in plant metabolism and promotion of plant growth with better assimilation and translocation. This might be due to micronutrients in general involves in the elongation of stem which results in the greater internodal length and thereby increases the shoot dry weight. These findings were in accordance with the work of Verma *et al.* (2022) in black gram, Raju *et al*. (2019) in black gram and Malek *et al*. (2018) in black gram.

**Table 4. Effect of micronutrients on stem dry weight per plant (g) at 30, 45, 60 DAS and at harvest**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Treat. No.** | **Treatment Details** | **Stem dry weight per plant (g)** | | | |
| **30 DAS** | **45 DAS** | **60 DAS** | **At harvest** |
| T1 | FeSO4 0.5% | 0.68 | 1.33 | 1.61 | 2.41 |
| T2 | ZnSO4 0.5% | 0.69 | 1.34 | 1.92 | 2.66 |
| T3 | Boric acid 0.2% | 0.64 | 1.25 | 2.16 | 2.20 |
| T4 | ZnSO4 0.5% + FeSO4 0.5% | 0.70 | 1.43 | 2.26 | 2.83 |
| T5 | ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% | 0.71 | 1.63 | 2.57 | 3.06 |
| T6 | Sulphur @20 kg/ha | 0.63 | 1.17 | 1.46 | 1.99 |
| T7 | T5 + T6 | 0.79 | 2.39 | 3.00 | 5.72 |
| T8 | Control | 0.62 | 0.76 | 1.44 | 1.49 |
|  | **SEm ±** | 0.04 | 0.07 | 0.14 | 0.21 |
|  | **CD at 5%** | NS | 0.21 | 0.41 | 0.63 |
|  | **CV%** | 9.38 | 8.66 | 11.52 | 12.79 |

**3.1.5 Total dry weight (g)**

Total dry weight in Table 5 At 45 DAS, treatment T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha) has indicated significantly higher total dry weight (4.95 g). While, treatment T8 (Control) reported the lowest total dry weight (1.79 g) as compared to other treatments. At 60 DAS, treatment T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha) reported significantly higher total dry weight (7.65 g). In contrast, treatment T8 (Control) displayed the lowest total dry weight (2.27 g) compared to other treatments. At harvest, treatment T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha) *i.e*. foliar and soil application has found significantly higher total dry weight (12.32 g). The amount of total dry weight production is an indication of the overall efficiency of the utilization of resources and better light interception. The data about total dry weight indicated that it increased continuously from 30 DAS to harvest. At later stage of the growth, dry matter accumulated at increasing rate, which could be attributed to more source activity leading to more dry matter accumulation in leaf and stem. The increase in TDM towards maturity may be due to an indeterminate growth pattern, higher rate of CO2 fixation and RuBP carboxylase activity during crop growth. The association of TDM with grain yield was more correlated at all the stages of crop growth. Similar results were also reported by Verma *et al.* (2022) in black gram, Raju *et al*. (2019) in black gram and Malek *et al*. (2018) in black gram.

**Table 5. Effect of micronutrients on stem dry weight per plant (g) at 30, 45, 60 DAS and at harvest**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Treat. No.** | **Treatment Details** | **Total dry weight per plant (g)** | | | |
| **30 DAS** | **45 DAS** | **60 DAS** | **At harvest** |
| T1 | FeSO4 0.5% | 1.47 | 2.48 | 3.55 | 5.50 |
| T2 | ZnSO4 0.5% | 1.48 | 3.02 | 4.07 | 6.07 |
| T3 | Boric acid 0.2% | 1.44 | 2.39 | 3.64 | 5.81 |
| T4 | ZnSO4 0.5% + FeSO4 0.5% | 1.54 | 3.30 | 4.64 | 7.05 |
| T5 | ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% | 1.57 | 3.49 | 4.73 | 7.73 |
| T6 | Sulphur @20 kg/ha | 1.43 | 2.21 | 3.18 | 5.11 |
| T7 | T5 + T6 | 1.69 | 4.95 | 7.65 | 12.32 |
| T8 | Control | 1.39 | 1.79 | 2.27 | 3.17 |
|  | **SEm ±** | 0.06 | 0.02 | 0.07 | 0.13 |
|  | **CD at 5%** | NS | 0.06 | 0.21 | 0.39 |
|  | **CV%** | 6.98 | 1.13 | 2.85 | 3.35 |

**3.2 Physiological Parameters**

**3.2.1 Leaf area(cm2)**

The data regarding leaf area at 30, 45, 60 DAS as well as at harvest as influenced by micronutrients are presented in Table 6. At 45 DAS significantly maximum (183.32 cm2) leaf area were found in T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + Sulphur @20 kg/ha) *i.e.* combination treatment T5 and T6 where foliar and soil application of micronutrients were given. This treatment is at par with T5 where only foliar application was applied. The treatment with the highest leaf area per plant (227.11 cm2) at 60 DAS was treatment T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + Sulphur @20 kg/ha), which was significantly larger than all other treatments. It remained statistically at par with the treatments T1, T2, T3, T4 and T5. The treatment with the highest leaf area per plant (205.73 cm2) at harvest was of treatment T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + Sulphur @20 kg/ha), which was significantly larger than all other treatments. It remained statistically at par with the treatments T2, T3, T4 and T5. The results of the experiment indicated that treatment T7 consistently exhibited the highest leaf area per plant throughout all stages of the study. The mean leaf area was low at initial stage of crop growth and it was highest at 60 DAS and thereafter it decreased towards maturity of crop due to senescence. Leaves play an important role in the absorption of light radiations and using it in photosynthetic process. Leaf size is influenced by light, moisture and nutrients. This observation aligns with the findings reported by Raut *et al*. (2018) in chickpea, Bhagvat *et al*. (2018) in soyabean and Sritharan *et al*. (2015) in black gram.

**Table 6. Effect of micronutrients on leaf area (cm2) at 30, 45, 60 DAS ant at harvest**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Treat. No.** | **Treatment Details** | **Leaf area (cm2)** | | | |
| **30 DAS** | **45 DAS** | **60 DAS** | **At harvest** |
| T1 | FeSO4 0.5% | 107.04 | 142.67 | 199.44 | 174.27 |
| T2 | ZnSO4 0.5% | 116.67 | 155.04 | 206.69 | 189.22 |
| T3 | Boric acid 0.2% | 107.47 | 149.07 | 203.82 | 176.86 |
| T4 | ZnSO4 0.5% + FeSO4 0.5% | 111.48 | 149.88 | 203.98 | 185.56 |
| T5 | ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% | 117.65 | 165.15 | 223.27 | 194.83 |
| T6 | Sulphur @20 kg/ha | 101.15 | 122.63 | 190.53 | 174.10 |
| T7 | T5 + T6 | 119.32 | 183.32 | 227.11 | 205.73 |
| T8 | Control | 98.40 | 117.77 | 176.34 | 152.03 |
|  | **SEm ±** | 4.70 | 6.96 | 9.71 | 9.57 |
|  | **CD at 5%** | NS | 21.12 | 29.46 | 29.03 |
|  | **CV%** | 7.41 | 8.14 | 8.25 | 9.13 |

**3.2.2 Leaf area index (LAI)**

The data regarding leaf area index at 30, 45, 60 DAS as well as at harvest as influenced by micronutrients are presented in Table 7. At 30 DAS, LAI was found non-significant with treatments but numerically maximum leaf area index(0.40) was recorded under treatment T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha) which, may be due to sulphur application at the time of soil preparation and foliar treatment at 25 DAS shows the effect. At 45 DAS, significantly maximum leaf area index(0.61) was recorded under treatment T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha) and it was statistically at par with treatment T5. At 60 DAS, significantly maximum leaf area index(0.76) was recorded under treatment T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha) and it was statistically at par with treatment T1, T2, T3, T4 and T5. At harvest, significantly maximum leaf area index(0.69) was recorded under treatment T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha) and it was statistically at par with treatment T2, T3, T4 andT5. Treatment T7 continuously showed the most leaf area indexfor all of the investigation period, according to the experiment's results. The LAI declined at 60 DAS due to senescence and abscission of leaves. This finding aligns with the research conducted by Sritharan *et al*. (2015), who observed that the application of micronutrients resulted in increased leaf area index at various stages of black gram growth compared to the control. These results are in conformity with the findings of Kumar *et al.* (2023) in chickpea, Malek *et* *al*. (2018) in black gram, Mondal *et al*. (2012) in green gram and Kumawat *et al*. (2005) in green gram.

**Table 7. Effect of micronutrients on leaf area index at 30, 45, 60 DAS and at harvest**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Treat. No.** | **Treatment Details** | **Leaf area index (LAI)** | | | |
| **30 DAS** | **45 DAS** | **60 DAS** | **At harvest** |
| T1 | FeSO4 0.5% | 0.36 | 0.48 | 0.66 | 0.58 |
| T2 | ZnSO4 0.5% | 0.39 | 0.52 | 0.69 | 0.63 |
| T3 | Boric acid 0.2% | 0.36 | 0.50 | 0.68 | 0.59 |
| T4 | ZnSO4 0.5% + FeSO4 0.5% | 0.37 | 0.50 | 0.68 | 0.62 |
| T5 | ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% | 0.39 | 0.55 | 0.74 | 0.65 |
| T6 | Sulphur @20 kg/ha | 0.34 | 0.41 | 0.64 | 0.58 |
| T7 | T5 + T6 | 0.40 | 0.61 | 0.76 | 0.69 |
| T8 | Control | 0.33 | 0.39 | 0.59 | 0.51 |
|  | **SEm ±** | 0.02 | 0.02 | 0.03 | 0.03 |
|  | **CD at 5%** | NS | 0.07 | 0.10 | 0.10 |
|  | **CV%** | 7.41 | 8.14 | 8.25 | 9.13 |

**3.2.3 Leaf area ratio (LAR) (cm2/g)**

Data pertaining to leaf area ratio at 30, 45, 60 DAS as well as at harvest as influenced by micronutrients presented in Table 8 revealed that LAR was non-significant during 30 DAS. Treatment T8 (Control) had the considerably highest leaf area ratio (66.04 cm2 g­-1) at 45 DAS. In comparison to other treatments, treatment T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha) recorded the lowest leaf area ratio (37.04 cm2 g­-1). Treatment T8 (Control) had the considerably highest leaf area ratio (77.50 cm2 g­-1) at 60 DAS. In comparison to other treatments, treatment T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha) recorded the lowest leaf area ratio (29.73 cm2 g­-1). Treatment T8 (Control) had the considerably highest leaf area ratio (48.28 cm2 g­-1) at harvest. In comparison to other treatments, treatment T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha) recorded the lowest leaf area ratio (16.72 cm2 g­-1). The leaf area ratio (LAR) is a measure of the photosynthetic capacity per unit of respiration and growing tissue, as described by Wallace *et al*. (1972). The findings of the study indicated that the LAR was initially higher during the early stages of the crop's growth, but gradually decreased as it approached maturity.

**Table 8. Effect of micronutrients on leaf area ratio (cm2/g) at 30, 45, 60 DAS and at harvest**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Treat. No.** | **Treatment Details** | **Leaf area ratio (LAR) (cm2 g­-1)** | | | |
| **30 DAS** | **45 DAS** | **60 DAS** | **At harvest** |
| T1 | FeSO4 0.5% | 72.85 | 57.61 | 56.22 | 31.71 |
| T2 | ZnSO4 0.5% | 79.08 | 51.29 | 50.81 | 31.17 |
| T3 | Boric acid 0.2% | 74.70 | 62.41 | 56.00 | 30.45 |
| T4 | ZnSO4 0.5% + FeSO4 0.5% | 73.53 | 45.45 | 43.98 | 26.31 |
| T5 | ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% | 74.82 | 47.35 | 47.22 | 25.33 |
| T6 | Sulphur @20 kg/ha | 71.03 | 55.48 | 59.91 | 34.07 |
| T7 | T5 + T6 | 71.28 | 37.04 | 29.73 | 16.72 |
| T8 | Control | 70.80 | 66.04 | 77.50 | 48.28 |
|  | **SEm ±** | 4.81 | 2.56 | 3.03 | 2.64 |
|  | **CD at 5%** | NS | 7.75 | 9.18 | 8.00 |
|  | **CV%** | 11.33 | 8.38 | 9.95 | 14.97 |

**3.2.4 Net assimilation rate (NAR) (g/m2/day)**

Table 9 containing data regarding net assimilation rate of black gram subjected to micronutrients recorded at 30-45 DAS, 45-60 DAS and at 60 DAS-at harvest revealed that significantly maximum net assimilation rate at 30-45 DAS period significantly impacted the net assimilation rate. Specifically, the application of T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + Sulphur @20 kg/ha) resulted in a higher net assimilation rate(14.65 g m-2 day-1). The effect of micronutrients during the 45-60 DAS period significantly exhibited the net assimilation rate. Specifically, the foliar application of T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha) resulted in a higher net assimilation rate (8.81 g m-2 day-1). The application of micronutrients during the 60 DAS-harvest period significantly exhibited the growth. Specifically, the treatment of T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha) resulted in a higher net assimilation rate (7.20 g m-2 day-1). The average effectiveness of a plant's leaves or the rate at which dry matter accumulates per unit of leaf area is measured by the net assimilation rate or NAR. The NAR reached its peak during 45-60 DAS with the treatment T7. Subsequently, as photosynthates were transported to the reproductive phase net assimilation rate, remained stable or declined. Gregory (1926) defined net assimilation rate as a unit leaf rate, which means the rate of increase in dry weight at any instant based on leaf area, basic with the leaf representing an estimate of the assimilatory area. It was observed in the present study that NAR was declined generally with advancement of the crop maturity. The findings are in accordance with Trivedi *et al*. (2011) in soyabean.

**Table 9. Effect of micronutrients on net assimilation rate at 30-45 DAS, 45-60 DAS and 60 DAS-at harvest**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Treat. No.** | **Treatment Details** | **Net assimilation rate (g m-2 day-1)** | | |
| **30-45 DAS** | **45-60 DAS** | **60 DAS-harvest** |
| T1 | FeSO4 0.5% | 5.43 | 4.21 | 3.48 |
| T2 | ZnSO4 0.5% | 7.65 | 3.88 | 3.38 |
| T3 | Boric acid 0.2% | 4.95 | 4.78 | 3.81 |
| T4 | ZnSO4 0.5% + FeSO4 0.5% | 9.02 | 5.14 | 4.14 |
| T5 | ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% | 9.13 | 4.27 | 4.84 |
| T6 | Sulphur @20 kg/ha | 4.69 | 4.19 | 3.55 |
| T7 | T5 + T6 | 14.65 | 8.81 | 7.20 |
| T8 | Control | 2.46 | 2.27 | 1.88 |
|  | **SEm ±** | 0.35 | 0.27 | 0.37 |
|  | **CD at 5%** | 1.07 | 0.81 | 1.14 |
|  | **CV%** | 8.46 | 9.88 | 16.07 |

**3.2.5 Crop growth rate (CGR) (g/m2/day)**

Table 10 provides information on crop growth rate at 30-45 DAS, 45-60 DAS and 60 DAS-at harvest on account of micronutrients. The application of micronutrients during the 30-45 DAS period significantly impacted the crop growth rate. Specifically, the application of T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha) resulted in a higher crop growth rate (7.24 g m-2 day-1). The application of micronutrients during the 45-60 DAS period significantly impacted the crop growth rate. Specifically, the application of T7 (ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha) resulted in a higher crop growth rate (6.00 g m-2 day-1). The administration of micronutrients resulted in a substantial difference between the crop growth rates at 60 DAS and harvest. The crop growth rate (5.19 g m-2 day-1) was considerably higher when treatment given ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha. For calculating the effectiveness of agricultural production, the crop growth rate (CGR) is a helpful parameter. It is a measure of light interception and are affected by variables including leaf area index (LAI), photosynthetic rate, and leaf angle. Crop growth increased to peak at 60 DAS and then remained stable due to photosynthate transport towards the reproductive phase. Crop production is determined by CGR as a function of light interception by the leaf area of a crop. Further findings suggested by Kumar *et al.* (2023) in chickpea, Kavya *et al*. (2021) in green gram, Sritharan *et al*. (2015) in black gram, Mondal *et al*. (2012) in green gram and Kumawat *et al*. (2005) in green gram.

**Table 10. Effect of micronutrients on crop growth rate at 30-45 DAS, 45-60 DAS and 90 DAS-at harvest**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Treat. No.** | **Treatment Details** | **Crop growth rate (g m-2 day-1)** | | |
| **30-45 DAS** | **45-60 DAS** | **60 DAS-harvest** |
| T1 | FeSO4 0.5% | 2.24 | 2.38 | 2.17 |
| T2 | ZnSO4 0.5% | 3.44 | 2.32 | 2.23 |
| T3 | Boric acid 0.2% | 2.10 | 2.78 | 2.41 |
| T4 | ZnSO4 0.5% + FeSO4 0.5% | 3.90 | 2.99 | 2.68 |
| T5 | ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% | 4.26 | 2.75 | 3.34 |
| T6 | Sulphur @20 kg/ha | 1.74 | 2.15 | 2.14 |
| T7 | T5 + T6 | 7.24 | 6.00 | 5.19 |
| T8 | Control | 0.88 | 1.09 | 0.99 |
|  | **SEm ±** | 0.15 | 0.16 | 0.20 |
|  | **CD at 5%** | 0.44 | 0.49 | 0.61 |
|  | **CV%** | 7.80 | 10.07 | 13.27 |

**4. CONCLUSION**

The results of the present experiment showed that foliar spray of micronutrients ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha performed well in morphological parameters like plant height, number of trifoliate leaves per plant, days to 50% of flowering, stem dry weight and total dry weight. ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha (T7) recorded better results on physiological traits (leaf area, LAI, LAR, CGR and NAR). In summary, farmers aiming to higher yield were recommended to use of combine micronutrients ZnSO4 0.5% + FeSO4 0.5% + Boric acid 0.2% + sulphur @20 kg/ha. The application of micronutrients is one of the possible way to increase productivity of black gram.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1.

2.

3.

**REFERENCES**

1. Panigrahi KK, Mohanty A, Pradhan J, Baisakh B, Kar M. Analysis of combining ability and genetic parameters for yield and other quantitative traits black gram (*Vigna mungo* L.). Legume Genomics and Genetics. 2015;6(1):1-11.
2. Jansen PCM. *Vigna* *mungo* (L.) Hepper. Record from Protabase. Brink, M., & Belay, G. (Editors). PROTA (Plant Resources of Tropical Africa), Wageningen, Netherland. 2006.
3. Malek MZ, Bhadane RS, Patel DB, Tadvi SN. Effect of micro-nutrients on morpho-physiological, biochemical parameters and yield in black gram (*Vigna* *mungo* L.). International Journal of Chemical Studies. 2018;6(3):2418-2421.
4. Panse VG, Sukhatme PV. Statistical methods for agricultural workers. New Delhi: ICAR.1995.
5. Watson DJ. The physiological basis of variation in yield. In Advances in Agronomy. 1952;4:101-145.
6. Radford PJ. Growth analysis formulae‐their use and abuse*.* Crop Sci. 1967;7(3):171-175.
7. Rehaman HMA, Navi L, Lohitthaswa HC, Dayanandanaik S, Devika A. Effect of agronomic biofortification of Zn and Fe on growth, yield and economics of pigeonpea. Asian of Journal of Soil Science and Plant Nutrition. 2024;10(2):280-287.
8. Vani TT, Raman R, Kandasamy S, Balaji E. Response of micronutrients on growth parameters of irrigated blackgram (*Vigna* *mungo* L.). The Pharma Innovation. 2022;11(9):1899-1901.
9. Rajput D, Kumar M, Kumar S, Yadav R. Effect of micronutrient application on growth, yield attributes, grain and biological yield of urdbean (*Vigna* *mungo* L.). Journal of Plant Development Sciences. 2021;13(1):19-24.
10. Kavya P, Singh S, Hinduja N, Tiwari D, Sruthi S. Effect of foliar application on micronutrients on growth and yield of greengram (*Vigna radiata* L.). Legume Research-An International Journal. 2021;44(12):460-1464.
11. Kannan P, Arunachlam P, Prabukumar G, Prabhaharan J. Response of Blackgram (*Vigna mungo* L.) to Multi-Micronutrient Mixtures under Rainfed Alfisol. Journal of the Indian Socienty of Soil Science. 2014;62(2):154-160.
12. Verma A, Khan MA, Singh AK, Singh BV, Kumar A, Singh S, Gupta H. Performance of black gram (*Vigna mungo* L.) as influenced through the application of Zn, B and Mo. Agriculture Association of Textile Chemical and Critical Reviews Journal. 2022:21-26.
13. Raju RS, Rani YA, Sreekanth B, Jyothula DPB. Influence of boron molybdenum and nickle on total dry matter, partitioning and yield of black gram (*Vigna mungo* L. Hepper). International Journal of Current Microbiology and Applied Sciences. 2019;8(12):512-521.
14. Malek MZ, Bhadane RS, Patel DB, Tadvi SN. Dry matter partitioning in black gram (*Vigna mungo* L.) influenced by micronutrients application. International Journal of Chemical Studies. 2018;6(3):2422-2425.
15. Kumar R, Saren BK, Patel SK. Effect of foliar application of zinc and boron on growth attributes and yield of chickpea (*Cicer* *arietinum* L.) varieties. International Journal of Plant and Soil Science. 2023;35(21):958-965.
16. Raut DA, Deotale RD, Blessena A, Hivare VS, Pise SE, Yelore SA. Morpho-physiological traits and yield in chick pea as influenced by application of ascorbic acid and zinc sulphate. Journal of Soils and Crops. 2019;29(2):312-318.
17. Bhagwat GJ, Waghmare PK, Gokhale DN, Bhalerao GA. Study on Growth and Yield of Soybean (*Glycine* *max* L.) Crop as Influenced by Micronutrient Application. International Journal of Current Microbiology and Applied Sciences. 2018;6:1852-1859.
18. Sritharan N, Rajavel M, Senthilkumar R. Physiological approaches: yield improvement in blackgram. Legume Research. 2015;38(1):91-95.
19. Mondal C, Bandopadhyay P, Alipatra A, Banerjee H. Performance of different irrigation regimes and boron levels in mungbean (*Vigna radiata* L.). Journal of Food Legumes. 2012;25(1):37-40.
20. Kumawat RN, Rathode PS, Talwar HS. Effect of sulphur and iron on crop growth attributes in summer green gram. Indian Journal of Plant Physiology. 2005;10(1):86-89.
21. Wallace DH, Ozbun JL, Munger HM. Physiological genetics of crop yield. Advances in Agronomy. Academic Press.1972;24:97-146.
22. Gregory FG. The effect of climatic conditions on the growth of barley. Annals of Botany. 1926;40(157):1-26.
23. Trivedi AK, Hemantaranjan A, Pandey SK. Iron and sulphur application may improve growth and yield of soyabean. Indian Journal of Plant physiology 2011;16(3-4):309-313.