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EFFECT OF PHOSPHORUS-SULPHUR LEVELS AND ZINC–BORON APPLICATION ON GROWTH AND YIELD OF BLACK GRAM (*VIGNA MUNGO* L.)

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ABSTRACT

A field experiment was conducted during Kharif 2021–22 at the Instructional Farm, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (U.P.) to evaluate the effect of fertility levels (phosphorus and sulphur) and micronutrients (zinc and boron) on growth, yield attributes, yield and economics of black gram (*Vigna mungo* L.). The different treatments consisted of a combination of three fertility levels *viz.* F1 (20 kg P_2O_5 ha⁻¹), F2 (40 kg P_2O_5 ha⁻¹ + 20 kg S ha⁻¹) and F3 (60 kg P_2O_5 ha⁻¹ + 40 kg S ha⁻¹) along with four different micronutrient treatments M0 (control), M1 (Zinc sulphate @ 10 kg ha⁻¹), M2 (boron 0.3% spray) and M3 (Zinc sulphate @ 10 kg ha⁻¹ + Boron spray @ 0.3%). The study revealed that plant population was not significantly affected still various growth parameters such as plant height, dry matter accumulation and number of branches were increased due to the rise in fertility and micronutrient treatment. Both fertility and micronutrients showed a similar trend in the yield components of black gram. The highest pods (62.03) and seeds per pod (8.30) were observed in treatment F3 and M3, respectively which were significantly different from other treatments. F3 recorded the highest seed yield of 998.43 kg/ha and straw yield of 2499.35 kg/ha followed by M3 which recorded seed yield of 996.01 kg/ha and straw yield of 2482.52 kg/ha over the control. Economic analysis revealed that the highest gross return (Rs. 79117/ha) and net return (Rs. 41029 /ha) were obtained from F3M3, with the highest benefit: cost ratio (1.11). Therefore, application of P_2O_5 along with $ZnSO_4$ @10 kg ha⁻¹ and boron 0.3% spray was found most suitable for higher productivity and profitability of black gram under subtropical conditions.
Keywords: Black gram, phosphorus, sulphur, zinc, boron, growth, yield, economics.

Introduction

Black gram (*Vigna mungo* L.) is one of the major pulse crops in India mainly on account of its excellent protein content and its ability to enrich the soil through biological nitrogen fixation. Pulses are essential for food and nutritional security however, the yield of the black gram has been very low so far mainly due to imbalanced fertilization, nutrient depletion and continuous cropping without proper soil management (Kumar *et al.*, 2016; Rani *et al.*, 2021). Therefore, balanced fertilization is not merely a step for better

growth and yield components of the crop but also for getting higher profits. Among the nutrients, phosphorus holds great significance for legumes. It has a direct influence on root development, ATP and energy transfer through the mediation of nodulation and seed formation. A good phosphorus level in plants leads to the growth of green parts, thus the photosynthates produced are easily distributed to the yield components such as the number of pods per plant and the number of seeds per pod (Dewey and Lu, 1959; Kumar *et al.,* 2016). Furthermore, the beneficial effect of phosphorus fertilization in black gram can be correlated with growth and yield by way of enhanced nutrient uptake and growth, as reported by (Rani *et al.* 2021; Verma *et al.* 2023).

Like in all plants, sulphur is very vital in pulses as it helps to make protein through sulphur, containing amino acids (*e.g.,* cysteine and methionine). Sulphur plays a role in enzyme activity, chlorophyll synthesis and even nitrogen use efficiency in legumes (Broughton *et al.,* 2003). Due to sulphur deficiency being increasingly reported in many agricultural soils the application of sulphur fertilizers has become one of the main requirements for raising pulse yields (Blair *et al.*, 2010). Upon the application of sulphur, it has been observed that there is an enhancement in a variety of factors including plant growth, yield components and ultimately grain yield through the improvement of the overall metabolism and reproduction of the plant (Singh *et al.*, 2020). Micronutrients such as zinc (Zn) and boron (B) also have an important role in increasing the yield of pulses. Zinc is a component of several enzymatic reactions and growth regulation therefore, its shortage may lead to reduced plant height, lower branching and consequently, lower yield (Kole *et al.*, 2015). Boron is required for the development of the reproductive organs, pollen viability, pod formation and seed setting, so its sufficient provision ensures the development of better yield characters in legumes (Tomar *et al.*, 2021). The use of Zn combined with B has revealed the positive effects on plant growth, yield components and the final yield through better nutrient utilization and reproductive success (Verma *et al.*, 2023). Black gram yield can be raised through improvement of growth characteristics like plant population, plant height, dry matter accumulation and number of branches which are the major contributors of yield components, *i.e.,* pods per plant, seeds per pod and test weight. Therefore, it becomes imperative to evaluate graded fertility levels of P and S along with Zn and B application for identifying efficient nutrient combinations that will lead to higher productivity and profitability under field conditions (Panse and Sukhatme, 1985). Moreover, economic feasibility is the key factor for the adoption of nutrient recommendations and cost of cultivation, gross return, net return and benefit-cost ratio analyses deliver the practical evidence of farmer-level suitability. Due to this, the present research was conducted to evaluate the effect of P, S fertility levels and Zn, B application on growth, yield attributes, yield and economics of black gram in subtropical conditions.

Materials and Methods

Experimental Site and Soil Sampling

A field experiment was conducted during the Kharif 2022 season at the Students' Instructional Farm, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (U. P.) India which lies under the subtropical climatic condition of the Indo-Gangetic plains agroecosystem. Soil samples for the experiment were collected from the field using a soil auger at two different depths, viz. 0 15 cm and 15 30 cm, randomly. These samples were later pooled and made into composite samples. The physical, chemical properties and fertility level of soil were determined later from these samples. During the study period, the soil turned out to be alkaline and it was very low in organic carbon. At the same time, the nutrient status of the soil revealed that the availability of the main nutrients was from low to medium level. Hence, the soil was tagged as low fertility soil, and the addition of micronutrients would be a good practice for the black gram crop.

Experimental Design and Treatment Details

The research was conducted based on a split plot design with three replications and a total of twelve treatment combinations (3 fertility levels x 4 micronutrient schedules). The main plots were given fertility levels and subplots received the micronutrient treatments.

Fertility levels (Main plot treatments)

➢ F1: 20 kg P_2O_5 ha⁻¹

➢ F2: 40 kg P_2O_5 ha⁻¹ + 20 kg S ha⁻¹

➢ F3: 60 kg P_2O_5 ha⁻¹ + 40 kg S ha⁻¹

Micronutrient treatments (Sub-plot treatments)

➢ M0: Control

➢ M1: Zinc sulphate @ 10 kg ha⁻¹

➢ M2: Boron spray @ 0.3%

➢ M3: Zinc sulphate @ 10 kg ha⁻¹ + Boron spray @ 0.3%

Black gram (*Vigna mungo* L.) variety 'U. Shekhar, 2' was the test crop in the experiment. The crop was sown during Kharif season at the crop spacing of 45 cm x 10 cm, which is the standard practice. Similar practices such as thinning, weed control and irrigation have been maintained in all the plots during the crop season. The crop was harvested at physiological maturity the produce was dried and processed for yield determination.

Plant population

The plant population was determined by the number of plants in a one square meter area from each plot on 20 DAS and at the time of harvest. The number of plants was m^2.

Plant height

Plant height (cm) is the length from the soil surface to the top of the main shoot which was measured by a measuring tape. The height of five randomly selected plants from each plot was taken at 30, 60 days after sowing, and at harvest and the mean was calculated.

Dry matter accumulation

For the dry matter analysis, five plants representative of the respective plots were taken at 30, 60 DAS and at the time of crop harvest. Plants were first air, dried and then oven-dried for a constant weight. Dry matter was expressed as g/plant

Number of branches per plant

The number of branches plant was determined from five randomly selected and tagged plants from each plot at 30 DAS, 60 DAS and at harvest by counting all primary branches. The average value was used for statistical analysis

Yield observations

Yield contributing characters were recorded at maturity from five randomly selected plants from each plot. The number of pods per plant was counted manually from each sampled plant, while the number of seeds per pod was obtained by counting seeds from the representative pods and calculating the average. The test weight (g) was taken as the weight of 1000 seeds taken from the cleaned seed lot of each plot using a digital balance.

Seed yield, straw yield and harvest index

After harvest, the produce from each net plot was separately bundled, dried and threshed. Seed yield and straw yield were recorded and converted to kg/ha.

Economic

An assessment of each treatment was done on the basis of prevailing market prices of inputs and outputs. The cost of cultivation (ha) was worked out by adding the total expenditure on seed, fertilizers, micronutrients, labour and various field operations. The gross return (ha) was derived from the value of seed and straw yield using their respective market prices. The net return (ha^{-1}) was obtained by subtracting the cost of cultivation from the gross return and the benefit: cost (B:C) ratio was calculated as the ratio of gross return to the cost of cultivation.

Statistical analysis

All observations were statistically analyzed using the split-plot design technique. Treatment comparisons were made using the Standard Error of Mean (SEm±) and the significance of treatment differences was tested at 5% probability level (CD at 5%).

Result and Discussions

Growth response

Plant population

The data on Plant population indicated in Table 1 and Figure 1 revealed that the plant population did not vary significantly irrespective of fertility levels or addition of micronutrients in both 20 DAS and harvest time (CD at 5% = NS). However, there was a trend of an increase in population with increase in fertility level. The maximum plant population density in 20 DAS (25.44 m²) and in harvest (21.40 m²) was in F3 (P60 + S40), while the minimum in 20 DAS (24.00 m²) and in harvest (20.45 m²) was in F1 (P20). The maximum plant population density in M3 ($ZnSO_4$ @ 10 kg ha^{-1} + B @ 0.3% spray) was 25.58 m² on 20 DAS and in harvest was 21.67 m². This minimum response of significance suggests that establishment was largely a function of seed quality and environment in plants, whereas levels of nutrients profoundly affected vegetative phases than emergence (Panse and Sukhatme 1985).

Plant Height

The data on Plant Height indicated in Table 2 and Figure 2 revealed that Plant height was greatly enhanced with increased fertility levels and by micronutrient treatments. For the first observation (60 DAS) and at the time of harvest, the tallest plant was in F3 (36.43 cm and 41.53 cm), taller than F1 and similar to F2. Application of micronutrients further enhanced the heights with M3 having the maximum increment at 60 DAS (35.13 cm) and at the time of harvest (40.07 cm) and both were significantly higher than the control (29.43 cm and 33.53 cm). The enhanced heights can be attributed to greater divisions and elongation of cells, better root development activities and better translocation of photosynthates due to higher contents of phosphorus and sulfur. Phosphorus promotes

metabolic processes and sulfur promotes protein and chlorophyll biosynthesis. The role of zinc is in the activation of enzymes and auxin metabolic processes and plays a vital role in stem elongation (Kole *et al.* 2015; Broughton *et al.* 2003).

Dry matter accumulation

The data on Dry matter accumulation indicated in Table 3 and Figure 3 revealed that the dry matter showed a substantial increase with fertility, along with micronutrient applications, starting from 60 DAS. The highest dry matter was recorded in F3 at 60 DAS (8.75g/plant) and at harvest (15.92g/plant), which was significantly higher than F1. For micronutrients, the highest dry matter was recorded in M3 (8.71g/plant at 60 DAS and 15.82g/plant at harvest), which was significantly higher than the control. Higher dry matter accumulation under balanced nutrition indicates improved canopy development and increased photosynthetic efficiency. Adequate phosphorus and sulphur supply improves nutrient uptake and assimilate production, while micronutrients such as zinc and boron assist in metabolic regulation and reproductive efficiency, leading to enhanced biomass production (Singh *et al.* 2020).

Number of branches /plants

The data on the number of branches /plants indicated in Table 4 and Figure 4 revealed that the branching levels were greatly influenced by the fertility of the soil, as well as the micronutrients. At harvest, the highest number of branches per plant was recorded under F3 (13.75), which was significant compared with F1 (10.25) and F2 (12.20). The micronutrients had a significant effect on branching, with M3 producing the highest number of branches (13.13/plant), which was significant compared with the control (10.40). The more vigorous growth due to greater nutrient availability is probably the reason for the higher branching because it allows better utilization of resources. This also translates to more sites where reproduction can occur. Zinc is apparently beneficial in regulating hormone levels, while boron is involved in tissue development; both result in higher branching (Kole *et al.* 2015).

Yield attributes and yield

Yield attributes

The data on the number of branches /plants indicated in Table 5 and Figure 5 revealed that Yield attributes were significantly enhanced by both levels of fertility and the addition of micronutrients. The maximum number of pods per plant (62.03) and seeds per pod (8.30) were recorded in F3, which performed significantly better than F1. Among the micronutrients, the maximum number of pods per plant (61.40) and seeds per pod (8.20) were obtained in M3, which performed significantly better than the control. Test weight did not show any significantly different results (CD at 5% = NS), but numerically, it remained higher in F3 and M3. Both pods and seeds might have benefited by the availability of nutrients at the time of flowering and pod formation, thus enhancing the fertilization and assimilate transport to seeds (Dewey and Lu 1959).

Seed yield, straw yield and harvest index

The data on the Seed yield, straw yield and harvest index indicated in Table 6 and Figure 6 revealed that Seed yield increased with increased fertility. The highest seed yield was produced by F3 (998.43 kg ha^{-1}) and was significantly higher than that of F1 (863.99 kg ha^{-1}) and equivalent to F2 (981.58 kg ha^{-1}). The application of micronutrients increased seed yield by 996.01 kg ha^{-1} in M3 compared with the control of 866.40 kg ha^{-1}. The straw yield was also higher with the increase in fertility. The highest straw yield was produced by F3 (2499.35 kg ha^{-1}) and M3 (2482.52 kg ha^{-1}). The harvest index was not affected. The result indicates that the application of nutrients increased both the economic and biological yield equally. The yield improvement under integrated nutrient management may be due to improved source capacity (biomass and assimilates) and enhanced sink strength (pods and seeds), leading to superior productivity. Such yield-component relationships are consistent with the general understanding of yield as a complex trait regulated by multiple correlated components (Dewey and Lu 1959; Panse and Sukhatme 1985).

Economics

The data on the Economic indicated in Table 7 and Figure 7 revealed that Economic analyses reveal that increased fertility with micronutrient blends increases profits despite the slight rise in cultivation costs. The highest gross return recorded was Rs. 79,117 per hectare, and the highest net return Rs. 41,029 per hectare, both from treatment F3M3, which proves the yield advantage by the combination of P60S40 with ZnSO4 and boron spray. However, the best benefit–cost ratio was only 1.11 when using F2M3, indicating that a medium fertility level supplemented with Zn–B application provides the most efficient economic return under these conditions. Overall, this means that the highest yields may not be given by higher fertility, but possibly the economically

viable approach will depend on optimized input use, which is one of the key parameters for farmer adoption. These findings are in consonance with the work on crop improvement and agronomy regarding the need for balancing productivity with profitability for technology uptake (Singh *et al.* 2020).

Conclusion

The present study clearly indicated that both the levels of fertility and the use of micronutrients significantly influenced the growth and yield performance of black gram. However, the number of plants per unit area was found to be non-significant. Nevertheless, higher fertility levels continued to have a positive effect on some vegetative growth characters such as plant height, dry matter production, and number of branches. In terms of fertility, the highest measure for plant height, dry matter accumulation, branches, pods plant and seeds pod was from F3 (60 kg P_2O_5 ha^{-1}), which finally gave the highest seed yield (998. 43 kg/ha) and straw yield (2499. 35 kg/ha) when compared to the lower fertility level F1. Among all the micronutrient treatments, the combined application of $ZnSO_4$ @10 kg/ha and boron 0. 3% spray (M3) resulted in better growth and yield attributes and hence recorded the highest seed yield (996. 01 kg/ha) when compared to the control. The harvest index remained unchanged significantly, which means that nutrient application led to an increase in both the grain and biomass yield at a similar level. However, an economic analysis revealed that the highest gross return (Rs. 79117/ha) and net return (Rs. 41029/ha) came from the combination of F3M3, i.e., 60 kg P_2O_5 ha^{-1} + $ZnSO_4$ + boron spray. In contrast, the highest benefit: cost ratio (1. 11) was found under F2M3 (60 kg P_2O_5 ha^{-1} + $ZnSO_4$ + boron spray), which implies that the most cost-effective treatment was moderate fertility coupled with micronutrients. indicating that moderate fertility combined with micronutrients was the most cost-effective treatment. Therefore, for maximizing yield and returns, F3M3 may be recommended, whereas for better economic efficiency under farmer conditions, F2M3 can be considered as the best option.

Table 1 : Plant population (m^{-2}) of black gram as influenced by fertility levels and micronutrients

Treatments	Plant population (m^{-2})	
	20 DAS	At harvest
Fertility levels (F)		
F$_1$	24.00	20.45
F$_2$	25.00	21.25
F$_3$	25.44	21.40
SEm±	0.86	0.64
C.D at 5%	NS	NS
Micronutrients (M)		
M$_0$	23.67	20.13
M$_1$	25.00	21.07
M$_2$	25.00	21.27
M$_3$	25.58	21.67
SEm±	0.74	0.54
C.D at 5%	NS	NS

Table 2 : Plant height (cm) of black gram as influenced by fertility levels and micronutrients

Treatments	Plant height (cm)		
	30 DAS	60 DAS	At harvest
Fertility levels (F)			
F$_1$	15.50	29.30	33.40
F$_2$	16.10	34.20	39.00
F$_3$	16.40	36.43	41.53
SEm±	0.48	1.07	1.20
C.D at 5%	NS	3.18	3.58
Micronutrients (M)			
M$_0$	15.40	29.43	33.53
M$_1$	16.20	34.67	39.53
M$_2$	15.90	34.00	38.77
M$_3$	16.50	35.13	40.07
SEm±	0.41	0.76	0.86
C.D at 5%	NS	2.26	2.57

Table 3 : Dry matter accumulation (g plant^{-1}) of black gram as influenced by fertility levels and micronutrients

Treatments	Dry matter accumulation (g plant-1)		
	30 DAS	60 DAS	At harvest
Fertility levels (F)			
F$_1$	1.51	7.60	13.84
F$_2$	1.57	8.62	15.67
F$_3$	1.63	8.75	15.92
SEm±	0.047	0.24	0.46
C.D at 5%	NS	0.73	1.35
Micronutrients (M)			
M$_0$	1.53	7.66	13.94
M$_1$	1.59	8.54	15.53
M$_2$	1.54	8.39	15.27
M$_3$	1.62	8.71	15.82
SEm±	0.030	0.20	0.31
C.D at 5%	NS	0.59	0.92

Table 4 : Number of branches plant^{-1} of black gram as influenced by fertility levels and micronutrients

Treatments	Number of branches plant-1		
Fertility levels (F)	30 DAS	60DAS	At harvest
F$_1$	4.08	9.35	10.25
F$_2$	4.68	11.05	12.20
F$_3$	4.68	12.51	13.75
SEm±	0.07	0.34	0.39
C.D at 5%	0.21	0.99	1.14
Micronutrients (M)			
M$_0$	4.10	9.47	10.40
M$_1$	4.60	11.55	12.73
M$_2$	4.50	10.93	12.00
M$_3$	4.70	11.93	13.13
SEm±	0.07	0.22	0.24
C.D at 5%	0.20	0.67	0.72

Table 6 : Seed yield, straw yield and harvest index of black gram as influenced by fertility levels and micronutrients

Treatments	Seed yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest Index (%)
Fertility levels (F)			
F_1	863.99	2175.94	28.42
F_2	981.58	2463.85	28.48
F_3	998.43	2499.35	28.54
SEm±	18.32	77.92	0.94
C.D at 5%	54.94	233.75	NS
Micronutrients (M)			
M_0	866.40	2200.27	28.25
M_1	974.38	2434.08	28.58
M_2	955.19	2401.98	28.45
M_3	996.01	2482.52	28.63
SEm±	26.05	53.54	0.62
C.D at 5%	77.42	159.08	NS

Table 7 : Economics of black gram as influenced by fertility levels and micronutrients

| Treatment	Treatment combination	Cost of cultivation (Rs. ha^{-1})	Gross return (Rs. ha^{-1})	Net return (Rs. ha^{-1})	Benefit: cost ratio
T_1	$F_1 M_0$	34053	59797	25744	0.76
T_2	$F_1 M_1$	35153	67083	31930	0.91
T_3	$F_1 M_2$	34653	65822	31169	0.90
T_4	$F_1 M_3$	35753	68541	32788	0.92
T_5	$F_2 M_0$	35227	67910	32683	0.93
T_6	$F_2 M_1$	36327	76154	39827	1.10
T_7	$F_2 M_2$	35827	74744	38917	1.09
T_8	$F_2 M_3$	36927	77826	40899	1.11
T_9	$F_3 M_0$	36388	69047	32659	0.90
T_{10}	$F_3 M_1$	37488	77433	39945	1.07
T_{11}	$F_3 M_2$	36988	75994	39006	1.05
T_{12}	$F_3 M_3$	38088	79117	41029	1.08
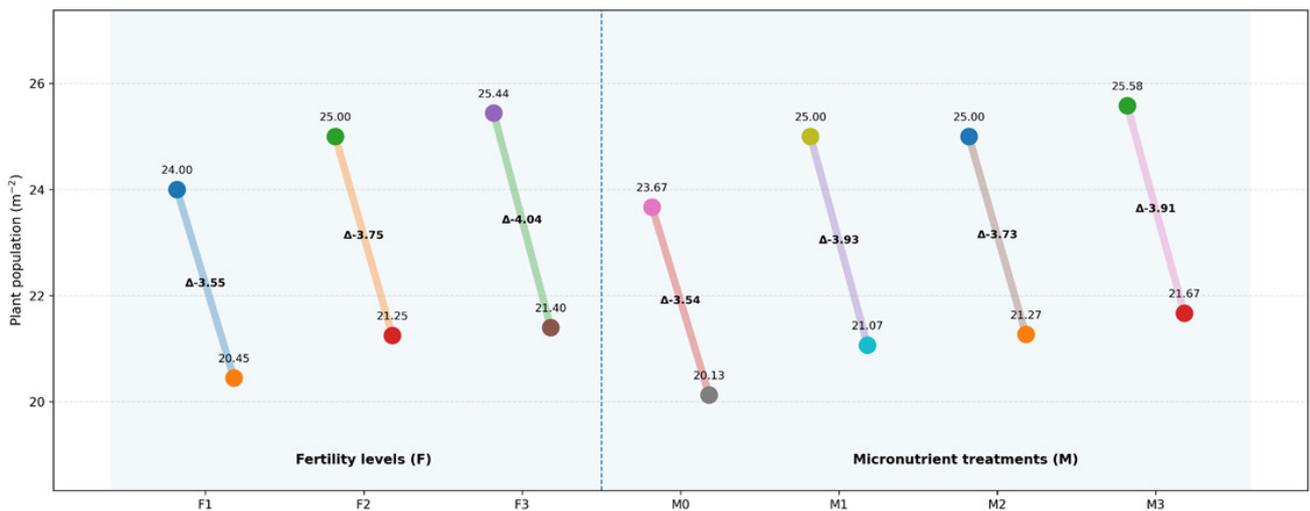
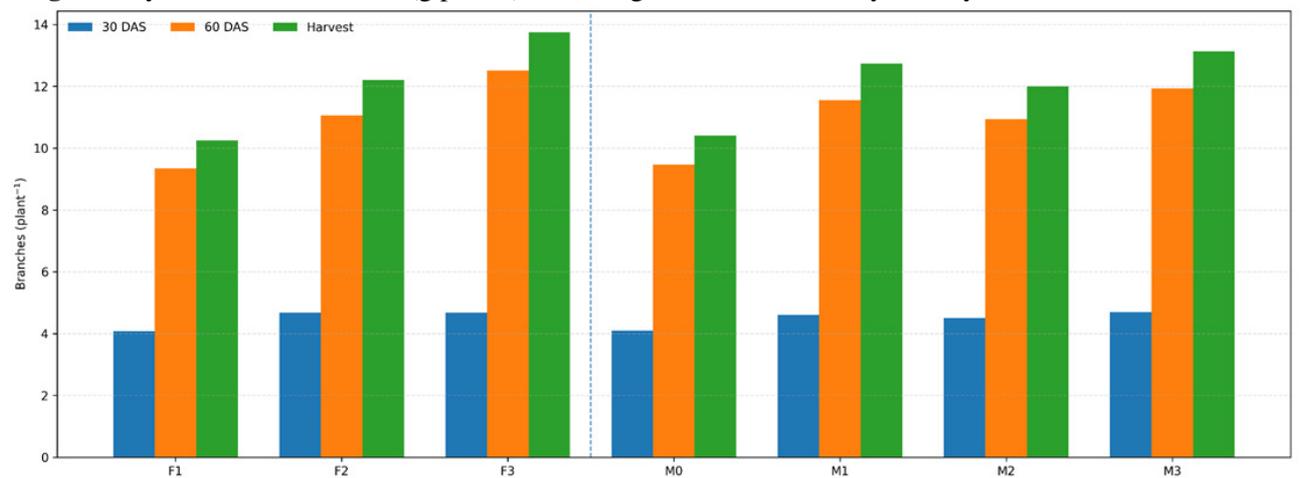**Fig. 1 :** Plant population (m^{-2}) of black gram as influenced by fertility levels and micronutrients
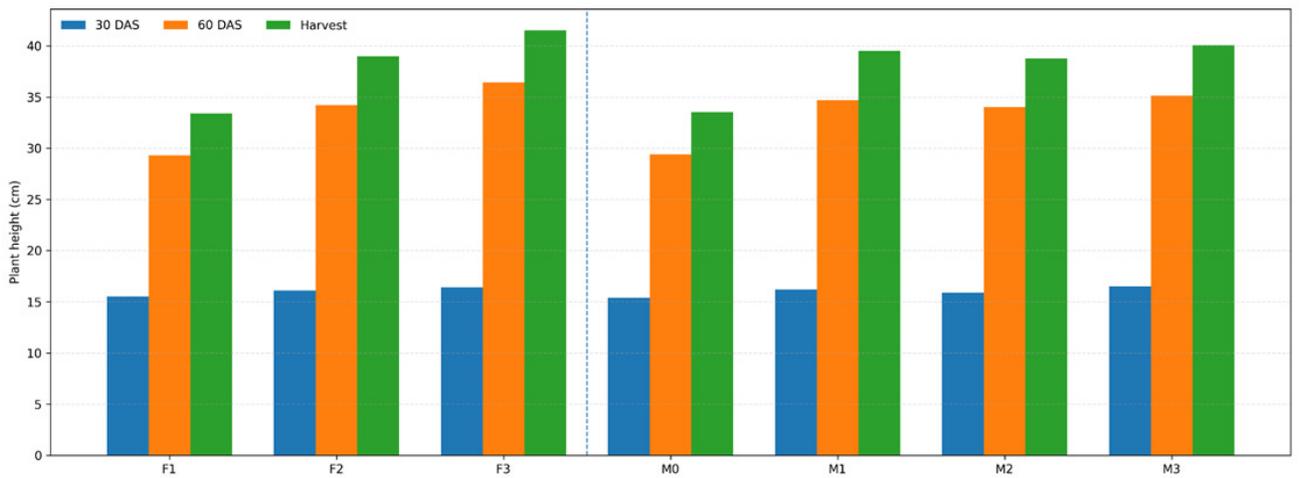
F1 = 20 kg P₂O₅ ha⁻¹; F2 = 40 kg P₂O₅ + 20 kg S ha⁻¹; F3 = 60 kg P₂O₅ + 40 kg S ha⁻¹. M0 = Control; M1 = ZnSO₄ @ 10 kg ha⁻¹; M2 = Boron spray (0.3%); M3 = ZnSO₄ @ 10 kg ha⁻¹ + Boron spray (0.3%). DAS = Days after sowing. Values are treatment means.

Fig. 2 : Plant height (cm) of black gram as influenced by fertility levels and micronutrients
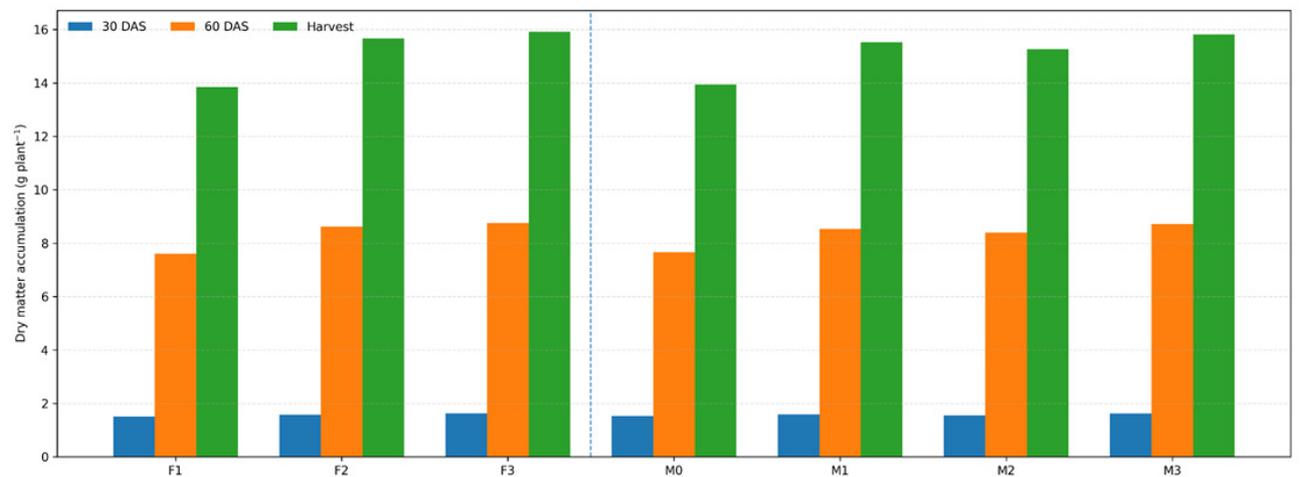
F1 = 20 kg P₂O₅ ha⁻¹; F2 = 40 kg P₂O₅ + 20 kg S ha⁻¹; F3 = 60 kg P₂O₅ + 40 kg S ha⁻¹. M0 = Control; M1 = ZnSO₄ @ 10 kg ha⁻¹; M2 = Boron spray (0.3%); M3 = ZnSO₄ @ 10 kg ha⁻¹ + Boron spray (0.3%). DAS = Days after sowing. Values are treatment means.

Fig. 3 : Dry matter accumulation (g plant⁻¹) of black gram as influenced by fertility levels and micronutrients

F1 = 20 kg P₂O₅ ha⁻¹; F2 = 40 kg P₂O₅ + 20 kg S ha⁻¹; F3 = 60 kg P₂O₅ + 40 kg S ha⁻¹. M0 = Control; M1 = ZnSO₄ @ 10 kg ha⁻¹; M2 = Boron spray (0.3%); M3 = ZnSO₄ @ 10 kg ha⁻¹ + Boron spray (0.3%). DAS = Days after sowing. Values are treatment means.

Fig. 4 : Number of branches plant⁻¹ of black gram as influenced by fertility levels and micronutrients

Effect of phosphorus-sulphur levels and zinc–boron application on growth and yield
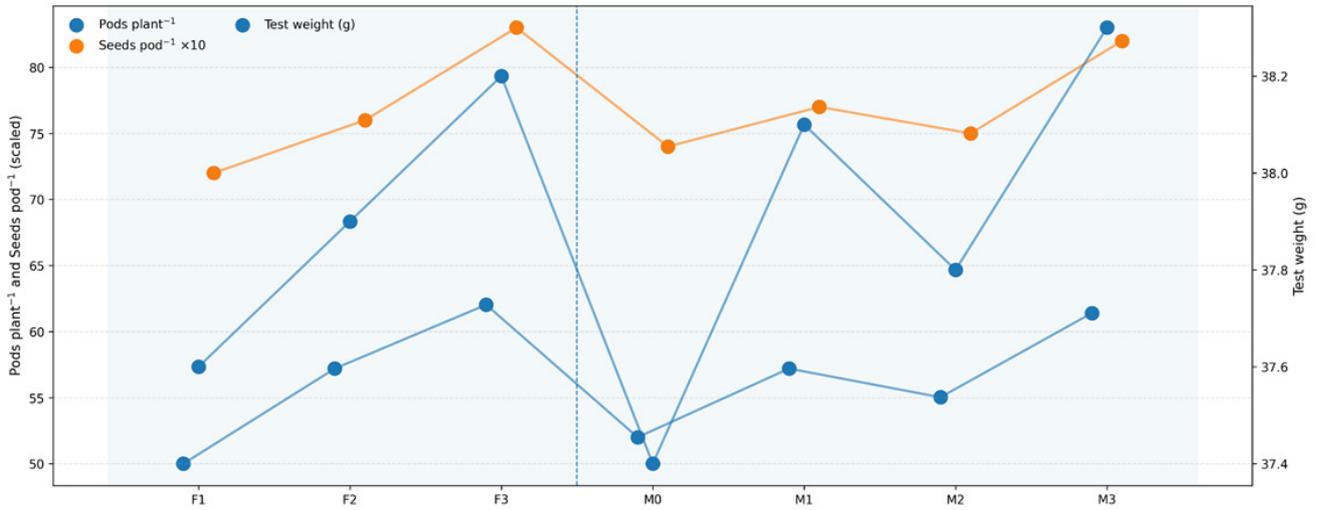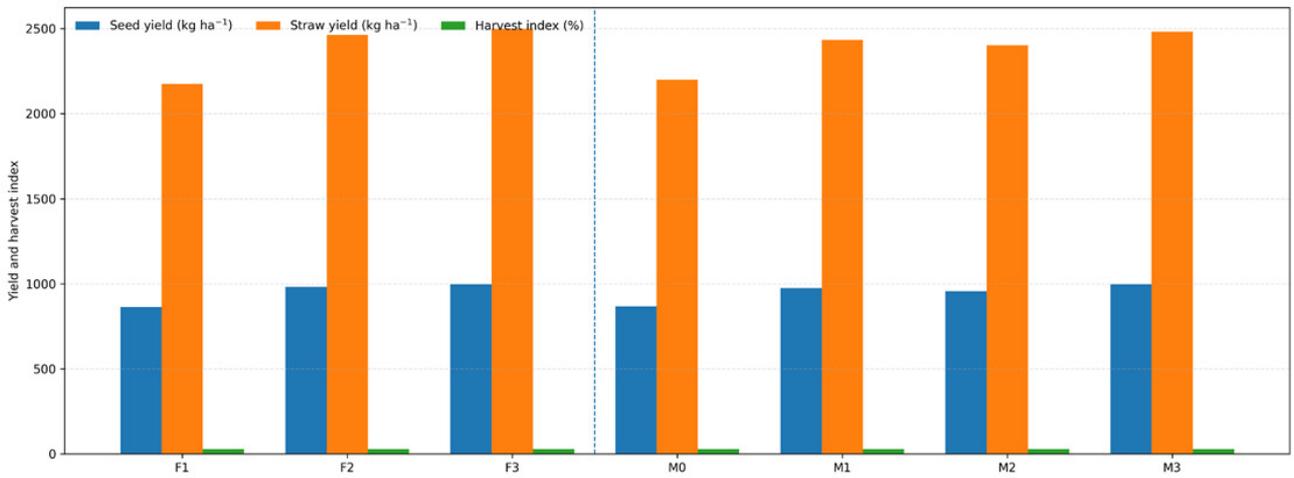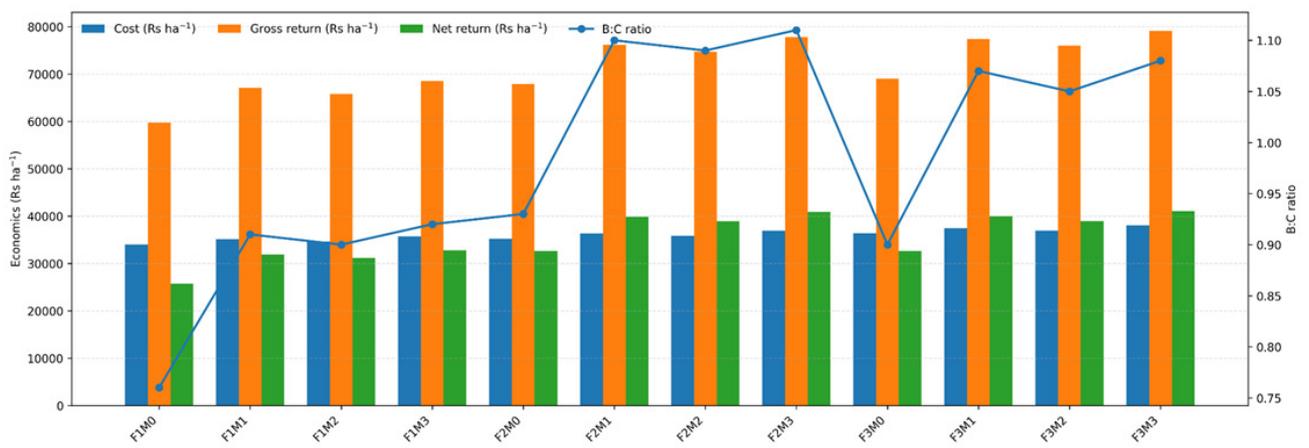of black gram (*Vigna mungo* L.)

Fig. 5 : Yield attributes of black gram as influenced by fertility levels and micronutrients

F1 = 20 kg P₂O₅ ha⁻¹; F2 = 40 kg P₂O₅ + 20 kg S ha⁻¹; F3 = 60 kg P₂O₅ + 40 kg S ha⁻¹. M0 = Control; M1 = ZnSO₄ @ 10 kg ha⁻¹; M2 = Boron spray (0.3%); M3 = ZnSO₄ @ 10 kg ha⁻¹ + Boron spray (0.3%). DAS = Days after sowing. Values are treatment means.

Fig. 6 : Seed yield, straw yield and harvest index of black gram as influenced by fertility levels and micronutrients

F1 = 20 kg P₂O₅ ha⁻¹; F2 = 40 kg P₂O₅ + 20 kg S ha⁻¹; F3 = 60 kg P₂O₅ + 40 kg S ha⁻¹. M0 = Control; M1 = ZnSO₄ @ 10 kg ha⁻¹; M2 = Boron spray (0.3%); M3 = ZnSO₄ @ 10 kg ha⁻¹ + Boron spray (0.3%). DAS = Days after sowing. Values are treatment means. Treatment combinations represent factorial interaction of fertility and micronutrient levels.

Fig. 7 : Economics of black gram as influenced by fertility levels and micronutrients

Acknowledgments

Conflict of Interest

The authors declare that there are no financial, personal or professional conflicts of interest that could have influenced the work reported in this manuscript.

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