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## Effect of planting method and nutrient management practices on growth, yield and profitability of black gram (*Vigna Mungo* L.)

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### ABSTRACT

A field experiment was conducted during the kharif season of 2025 at Adhiparasakthi Agricultural College, Ranipet, Tamil Nadu, to evaluate the effect of planting pattern and nutrient management on growth, physiological traits, yield and economics of black gram (*Vigna mungo* L.) cv. VBN 11. The experiment comprised ten treatment combinations involving line sowing at 30 × 10 cm and broadcasting at 25 kg seed ha<sup>-1</sup> in combination with recommended fertilizer application, foliar nutrient sprays and integrated nutrient management practices, along with corresponding control treatments. The experiment was laid out in a randomized block design with three replications. Planting pattern and nutrient management markedly influenced crop growth, canopy development, biomass accumulation, root growth, yield attributes and economic returns. Line sowing combined with farmyard manure at 12.5 t ha<sup>-1</sup> and 150% of the recommended nitrogen dose applied in splits at 20 and 40 days after sowing recorded taller plants, higher productive branches, higher root length, higher leaf area index, better crop growth rate and higher total dry matter production. At harvest, total dry matter production reached 16.8 g plant<sup>-1</sup>, while seed yield was 1011 kg ha<sup>-1</sup>, with 32.8 pods plant<sup>-1</sup> and 6.6 seeds pod<sup>-1</sup>. The broadcasting treatments recorded lower growth and yield than the corresponding line-sown treatments. Foliar application of 2% TNAU Pulse Wonder under line sowing also performed well, recording a seed yield of 965 kg ha<sup>-1</sup> and comparatively higher economic returns owing to its lower input requirement. The highest net return was obtained with line sowing combined with 2% TNAU Pulse Wonder, whereas the integrated nutrient treatment produced the highest biological productivity. The study indicates that appropriate crop establishment combined with improved nutrient management can enhance growth, resource utilization, yield productivity and economic performance of black gram.

**Keywords:** Black gram, Crop establishment, Foliar nutrition, Nutrient management, Planting pattern, Yield

### Introduction

Pulses are important components of sustainable cropping systems because they provide dietary protein, contribute to soil fertility through biological nitrogen fixation and offer opportunities for diversification of cereal-dominated production systems. Among the short-duration grain legumes, black gram [*Vigna mungo* (L.) Hepper] is an important food legume in India because of its high nutritional value, relatively short duration and suitability for inclusion in diverse cropping sequences. Its ability to fix atmospheric nitrogen through symbiotic association with rhizobia further contributes to its agronomic importance. The continued emphasis on improving pulse productivity in India is also reflected in current national programmes promoting improved production technologies for black gram and other pulses. Despite its importance, black gram productivity is frequently constrained by inadequate crop establishment, sub-optimal plant population, nutrient imbalance and inefficient resource utilization (Swaminathan *et al.*, 2023) [1]. Crop establishment is particularly important in short-duration legumes because early differences in plant distribution can influence canopy development, radiation interception, root competition and reproductive growth. Broadcasting, although simple and widely practised, can result in irregular spatial distribution of plants and greater variation in plant-to-plant competition. In contrast, line sowing provides a more uniform arrangement of plants and can facilitate better interception of radiation, improved aeration and more efficient crop management. Recent studies on black gram have demonstrated that crop geometry and planting management can substantially influence growth, yield attributes and productivity (Bhagavat *et al.*, 2024) [2].

Nutrient management is another major determinant of black gram productivity. Although black gram is a legume capable of biological nitrogen fixation, adequate availability of nitrogen, phosphorus and other nutrients is required during establishment, canopy development and reproductive growth. Integrated use of organic and inorganic nutrient sources can improve nutrient availability and soil physical and biological conditions while supporting crop productivity (Aslam *et al.*, 2010) [3]. Recent field research has shown positive

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responses of black gram to integrated nutrient management involving farmyard manure and inorganic fertilizers, with improvements in yield attributes, grain yield and soil properties (Shashikumar *et al.*, 2013) [4]. Foliar nutrient application provides an additional opportunity to supply nutrients during periods of high crop demand, particularly during flowering and pod development. Foliar application can partially overcome limitations associated with nutrient availability in the root zone and can provide rapidly available nutrients during critical physiological stages. Studies on black gram have reported beneficial effects of foliar nutrition on growth, yield attributes and productivity, while recent work in related pulse crops has also demonstrated the potential of foliar nutrient application for improving physiological performance and yield (Ayyadurai *et al.*, 2024) [5]. The response of black gram to nutrient management, however, cannot be considered independently of plant arrangement. An improved nutrient supply may not be fully expressed when plants are unevenly distributed, whereas an optimum crop geometry can increase the efficiency with which applied nutrients, water and radiation are converted into biomass and seed yield (Basant *et al.*, 2020) [6]. Therefore, the combined evaluation of planting pattern and nutrient management is important for identifying agronomic practices that improve productivity without unnecessarily increasing production costs. Recent studies have emphasized that integrated nutrient management and appropriate sowing or crop establishment practices can improve both productivity and economic returns in black gram.

In this context, the present study was undertaken to evaluate different planting patterns in combination with basal and foliar nutrient management in black gram under the agro-ecological conditions of Tamil Nadu. The study specifically assessed their effects on crop establishment, growth, root development, canopy development, biomass accumulation, yield attributes, seed and stalk yield and economic returns. The objectives were to identify a suitable planting pattern for improving black gram productivity, evaluate the response of the crop to different nutrient and foliar nutrition strategies, and assess the economic performance of the treatment combinations.

## Materials and Methods

### Experimental site and season

A field experiment was conducted during the *kharif* season of 2025 (June–August) at the APAC farm of Adhiparasakthi Agricultural College, Ranipet, Tamil Nadu. The experimental field had a medium black clay loam soil and the initial soil analysis indicated low organic carbon (0.36%) and available nitrogen (155.3 kg ha<sup>-1</sup>), medium available phosphorus (16.2 kg ha<sup>-1</sup>) and potassium (382.0 kg ha<sup>-1</sup>), with a soil pH of 7.4 and electrical conductivity of 0.6 dS m<sup>-1</sup>.

### Experimental material

Black gram variety VBN 11 was used for the experiment. The black gram variety VBN 11, is a medium-duration, determinate type with synchronized maturity and is recommended for Kharif, Rabi and summer seasons and has a reported duration of approximately 70–75 days.

### Experimental design and treatments

The experiment was laid out in a randomized block design with 10 treatments and three replications. Each gross plot measured 4 m × 3 m. The treatments consisted of two planting patterns, viz. line sowing at 30 × 10 cm and broadcasting, combined with different basal and foliar nutrient-management practices.

The treatment combinations were:

- **T1:** Line sowing at 30 × 10 cm + 100% recommended dose of fertilizer (RDF) + 1% urea foliar spray at 30 and 45 DAS.
- **T2:** Line sowing at 30 × 10 cm + 100% RDF + 2% diammonium phosphate (DAP) foliar spray at 30 and 45 DAS.

- **T3:** Line sowing at 30 × 10 cm + 100% RDF + 2% TNAU Pulse Wonder foliar spray at 30 and 45 DAS.
- **T4:** Line sowing at 30 × 10 cm + farmyard manure (FYM) at 12.5 t ha<sup>-1</sup> + 150% recommended dose of nitrogen (RDN), applied in splits at 20 and 40 DAS.
- **T5:** Broadcasting at 25 kg seed ha<sup>-1</sup> + 100% RDF + 1% urea foliar spray at 30 and 45 DAS.
- **T6:** Broadcasting at 25 kg seed ha<sup>-1</sup> + 100% RDF + 2% DAP foliar spray at 30 and 45 DAS.
- **T7:** Broadcasting at 25 kg seed ha<sup>-1</sup> + 100% RDF + 2% TNAU Pulse Wonder foliar spray at 30 and 45 DAS.
- **T8:** Broadcasting at 25 kg seed ha<sup>-1</sup> + FYM at 12.5 t ha<sup>-1</sup> + 150% RDN, applied in splits at 20 and 40 DAS.
- **T9:** Line sowing at 30 × 10 cm without additional nutrient treatment (control).
- **T10:** Broadcasting at 25 kg seed ha<sup>-1</sup> without additional nutrient treatment (control).

### Crop establishment and management

For line sowing, furrows were opened at 30 cm spacing and seed was placed manually at 25 kg seed ha<sup>-1</sup>. Seeds were treated with thiram at 3 g kg<sup>-1</sup> seed and inoculated with *Rhizobium* and *Phosphobacteria* at 600 g ha<sup>-1</sup> each using rice gruel as an adhesive. The seeds were shade-dried before sowing. In line-sown plots, plants were thinned two weeks after emergence to maintain 10 cm spacing between plants. Weeding was carried out at 20 DAS, and plant protection measures were adopted when required. Foliar nutrient applications were made according to the respective treatments at 30 and 45 DAS. The crop was harvested at physiological maturity, indicated by blackening of mature seeds, yellowing and shedding of leaves and maturity of approximately 80% of pods.

### Growth and physiological observations

Plant height was measured from the soil surface to the apical portion of the main stem using five randomly selected plants from each plot. Productive branches were counted on the same tagged plants at successive growth stages. Root length was measured from the collar region to the tip of the primary root in five randomly selected plants from each plot. Root nodules were counted after carefully uprooting and washing the roots. Total dry matter production was determined from sampled plants after oven drying to constant weight. Leaf area index was calculated as the ratio of leaf area to ground area. Crop growth rate was calculated by:

$$CGR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{1}{P}$$

where  $W_1$  and  $W_2$  represent plant dry matter at two successive sampling dates,  $t_1$  and  $t_2$  represent the corresponding time intervals and  $P$  represents the ground area occupied by the crop.

Relative growth rate was calculated according to the change in natural logarithm of plant dry weight over time.

### Yield attributes and yield

Pods plant<sup>-1</sup> were counted from five randomly selected plants before harvest. Seeds pod<sup>-1</sup> were determined from representative pods. Seed yield plant<sup>-1</sup> was calculated from the seed weight obtained from five tagged plants. Seed index was determined by weighing 100 representative seeds. At maturity, the crop from the net plot area was harvested separately for each treatment. After sun drying, total produce was weighed and threshed manually. Clean seed was obtained by threshing and winnowing and expressed as seed yield in kg ha<sup>-1</sup>. Stalk yield was obtained as the difference between biological yield and seed yield. Biological yield was calculated as:

$$\text{Biological yield} = \text{Seed yield} + \text{Stalk yield}$$

Harvest index was calculated as:

$$\text{HI (\%)} = \left( \frac{\text{Seed yield}}{\text{Biological yield}} \right) \times 100$$

### Economics

Cost of cultivation was calculated using the prevailing cost of inputs, labour and other production operations during the experimental season. Gross return was calculated from the value of seed and stalk produce. Net return was calculated as gross return minus cost of cultivation, while benefit ratio was calculated as gross return divided by cost of cultivation.

### Statistical analysis

The observations were subjected to analysis of variance appropriate for a randomized block design. Treatment means were compared using the critical difference at the 5% probability level when the *F*-test was significant. Standard error of the difference [*SE<sub>d</sub>*] and critical difference (CD) values were calculated following standard procedures described by *Snedecor et al. (1967)* [7].

## Results

### Plant growth and development

Plant height was significantly influenced by planting pattern and nutrient management from 45 DAS onwards, whereas the treatment effect at 30 DAS was non-significant. *T<sub>4</sub>* recorded the maximum plant height at 30, 45, 60 DAS and harvest (21.2, 36.3, 51.8 and 59.6 cm, respectively). *T<sub>3</sub>* followed with 20.1, 34.0, 49.0 and 56.4 cm, while *T<sub>8</sub>* recorded 19.3, 33.1, 48.3 and 55.5 cm at the corresponding stages. The minimum plant height at harvest was recorded in *T<sub>10</sub>* (44.9 cm), followed by *T<sub>9</sub>* (47.4 cm). The *SE<sub>d</sub>* values were 0.5, 1.8, 3.2 and 3.5 cm at 30, 45, 60 DAS and harvest, respectively, with corresponding CD values of NS, 3.7, 6.5 and 7.1 cm. Productive branches plant<sup>-1</sup> were also significantly affected by the treatments. *T<sub>4</sub>* recorded the highest number of branches at 45, 60 DAS and harvest (5.9, 6.5 and 6.8 branches plant<sup>-1</sup>, respectively), followed by *T<sub>3</sub>*. *T<sub>10</sub>* recorded the lowest values (4.0, 4.4 and 4.6 branches plant<sup>-1</sup>, respectively). The response demonstrates the combined influence of crop geometry and nutrient availability on vegetative branching. Total dry matter production increased progressively up to 60 DAS in all treatments and declined towards harvest. *T<sub>4</sub>* recorded the highest dry matter production at all stages, with values of 2.8, 12.7, 19.0 and 16.8 g plant<sup>-1</sup> at 30, 45, 60 DAS and harvest, respectively. *T<sub>3</sub>* and *T<sub>8</sub>* followed *T<sub>4</sub>*, whereas *T<sub>10</sub>* recorded the lowest dry matter production values.

**Table 1.** Effect of planting pattern and nutrient management on total dry matter production and relative distribution of dry matter among plant parts in black gram

| Treatment                                                                                                   | Total dry matter (g plant <sup>-1</sup> ) |        |        |         | Relative distribution of measured components (%) |      |                 |
|-------------------------------------------------------------------------------------------------------------|-------------------------------------------|--------|--------|---------|--------------------------------------------------|------|-----------------|
|                                                                                                             | 30 DAS                                    | 45 DAS | 60 DAS | Harvest | Stem                                             | Leaf | Fruiting bodies |
| Line sowing at 30 × 10 cm + 100% RDF + 1% urea foliar spray at 30 and 45 DAS                                | 2.5                                       | 11.2   | 17.0   | 15.2    | 40.0                                             | 38.8 | 21.2            |
| Line sowing at 30 × 10 cm + 100% RDF + 2% DAP foliar spray at 30 and 45 DAS                                 | 2.4                                       | 10.6   | 16.0   | 14.4    | 40.0                                             | 38.4 | 21.6            |
| Line sowing at 30 × 10 cm + 100% RDF + 2% TNAU Pulse Wonder foliar spray at 30 and 45 DAS                   | 2.7                                       | 12.1   | 18.0   | 16.1    | 39.1                                             | 38.3 | 22.6            |
| Line sowing at 30 × 10 cm + FYM @ 12.5 t ha <sup>-1</sup> + 150% RDN in splits at 20 and 40 DAS             | 2.8                                       | 12.7   | 19.0   | 16.8    | 36.4                                             | 35.6 | 28.0            |
| Broadcasting @ 25 kg ha <sup>-1</sup> + 100% RDF + 1% urea foliar spray at 30 and 45 DAS                    | 2.2                                       | 9.9    | 14.6   | 12.9    | 40.4                                             | 37.7 | 21.9            |
| Broadcasting @ 25 kg ha <sup>-1</sup> + 100% RDF + 2% DAP foliar spray at 30 and 45 DAS                     | 2.3                                       | 10.3   | 15.4   | 13.6    | 40.0                                             | 37.8 | 22.2            |
| Broadcasting @ 25 kg ha <sup>-1</sup> + 100% RDF + 2% TNAU Pulse Wonder foliar spray at 30 and 45 DAS       | 2.5                                       | 11.5   | 17.2   | 15.2    | 39.0                                             | 38.1 | 22.9            |
| Broadcasting @ 25 kg ha <sup>-1</sup> + FYM @ 12.5 t ha <sup>-1</sup> + 150% RDN in splits at 20 and 40 DAS | 2.7                                       | 12.3   | 18.5   | 16.3    | 36.8                                             | 35.8 | 27.4            |
| Line sowing at 30 × 10 cm (control)                                                                         | 2.4                                       | 10.7   | 16.5   | 14.5    | 39.8                                             | 37.8 | 22.4            |
| Broadcasting @ 25 kg ha <sup>-1</sup> (control)                                                             | 2.1                                       | 9.5    | 14.0   | 12.2    | 40.0                                             | 37.0 | 23.0            |
| SE(d) ±                                                                                                     | 0.06                                      | 0.14   | 0.25   | 0.35    |                                                  |      |                 |
| CD (P = 0.05)                                                                                               | 0.12                                      | 0.30   | 0.52   | 0.73    |                                                  |      |                 |

(continued on next page)

### Root characteristics and nodulation

Root development was significantly affected by the treatment combinations. Line sowing at  $30 \times 10$  cm + FYM @  $12.5 \text{ t ha}^{-1}$  + 150% RDN in splits at 20 and 40 DAS ( $T_4$ ) recorded the highest root length at 30, 45, 60 DAS and harvest, with values of 12.0, 16.8, 19.8 and  $21.0 \text{ cm plant}^{-1}$ , respectively.  $T_3$  and  $T_8$  followed  $T_4$ , whereas  $T_{10}$  recorded the lowest root length. Root weight showed a non-significant treatment effect during the early stage but differences became more pronounced at later stages.  $T_6$  recorded relatively higher root weight at 45 and 60 DAS, whereas  $T_{10}$  generally recorded lower values. Root nodulation was favourably influenced by the treatment combinations.  $T_4$  recorded the highest number of nodules at the observed stages, with 14.1, 15.5, 8.1 and  $6.1 \text{ nodules plant}^{-1}$ , followed by  $T_3$  and  $T_8$ . The lowest nodulation was generally observed under  $T_{10}$ .

### Leaf area index and crop growth rate

Leaf area index was highest under line sowing at  $30 \times 10$  cm + FYM @  $12.5 \text{ t ha}^{-1}$  + 150% RDN in splits at 20 and 40 DAS ( $T_4$ ) at all observed stages, recording 1.80, 3.60, 3.30 and 1.90 at 30, 45, 60 DAS and harvest, respectively.  $T_3$  and  $T_8$  followed  $T_4$ , while  $T_{10}$  recorded the lowest LAI. Crop growth rate followed a similar pattern during the active growth period.  $T_4$  recorded the highest CGR during 0–30, 30–45 and 45–60 DAS, with values of 3.11, 22.00 and  $14.00 \text{ g m}^{-2} \text{ day}^{-1}$ , respectively. CGR declined during the final period as the crop approached maturity and senescence.

### Yield attributes

The treatment combinations significantly influenced yield attributes. Line sowing at  $30 \times 10$  cm + FYM @  $12.5 \text{ t ha}^{-1}$  + 150% RDN in splits at 20 and 40 DAS ( $T_4$ ) recorded the maximum pods  $\text{plant}^{-1}$  (32.8), seeds  $\text{pod}^{-1}$  (6.6), grain yield  $\text{plant}^{-1}$  (13.2 g) and seed index (6.1 g).  $T_3$  followed  $T_4$  for most yield attributes. The lowest values were generally recorded under  $T_{10}$ , which produced 15.2 pods  $\text{plant}^{-1}$ , 5.7 seeds  $\text{pod}^{-1}$ , 4.9 g grain yield  $\text{plant}^{-1}$  and a seed index of 5.7 g.

**Table 2.** Effect of planting pattern and nutrient management on yield attributes of black gram

| Treatment                                                                                                     | Pods $\text{plant}^{-1}$ | Seeds $\text{pod}^{-1}$ | Grain yield $\text{plant}^{-1}$ (g) | Seed index (g) |
|---------------------------------------------------------------------------------------------------------------|--------------------------|-------------------------|-------------------------------------|----------------|
| Line sowing at $30 \times 10$ cm + 100% RDF + 1% urea foliar spray at 30 and 45 DAS                           | 24.8                     | 6.2                     | 9.1                                 | 5.9            |
| Line sowing at $30 \times 10$ cm + 100% RDF + 2% DAP foliar spray at 30 and 45 DAS                            | 28.4                     | 6.0                     | 10.1                                | 5.9            |
| Line sowing at $30 \times 10$ cm + 100% RDF + 2% TNAU Pulse Wonder foliar spray at 30 and 45 DAS              | 30.0                     | 6.4                     | 11.5                                | 6.0            |
| Line sowing at $30 \times 10$ cm + FYM @ $12.5 \text{ t ha}^{-1}$ + 150% RDN in splits at 20 and 40 DAS       | 32.8                     | 6.6                     | 13.2                                | 6.1            |
| Broadcasting @ $25 \text{ kg ha}^{-1}$ + 100% RDF + 1% urea foliar spray at 30 and 45 DAS                     | 22.0                     | 5.8                     | 7.3                                 | 5.7            |
| Broadcasting @ $25 \text{ kg ha}^{-1}$ + 100% RDF + 2% DAP foliar spray at 30 and 45 DAS                      | 24.0                     | 5.9                     | 8.2                                 | 5.8            |
| Broadcasting @ $25 \text{ kg ha}^{-1}$ + 100% RDF + 2% TNAU Pulse Wonder foliar spray at 30 and 45 DAS        | 26.0                     | 6.1                     | 9.4                                 | 5.9            |
| Broadcasting @ $25 \text{ kg ha}^{-1}$ + FYM @ $12.5 \text{ t ha}^{-1}$ + 150% RDN in splits at 20 and 40 DAS | 27.0                     | 6.3                     | 10.2                                | 6.0            |
| Line sowing at $30 \times 10$ cm (control)                                                                    | 18.0                     | 6.0                     | 6.3                                 | 5.8            |
| Broadcasting @ $25 \text{ kg ha}^{-1}$ (control)                                                              | 15.2                     | 5.7                     | 4.9                                 | 5.7            |
| SE(d) $\pm$                                                                                                   | 0.65                     | 0.12                    | 0.22                                | 0.08           |
| CD ( $P = 0.05$ )                                                                                             | 1.35                     | 0.25                    | 0.45                                | 0.17           |

### Seed yield, stalk yield, biological yield and harvest index

Line sowing at  $30 \times 10$  cm + FYM @  $12.5 \text{ t ha}^{-1}$  + 150% RDN in splits at 20 and 40 DAS ( $T_4$ ) recorded the highest seed yield ( $1011 \text{ kg ha}^{-1}$ ), followed by  $T_3$  ( $965 \text{ kg ha}^{-1}$ ),  $T_8$  ( $935 \text{ kg ha}^{-1}$ ) and  $T_2$  ( $930 \text{ kg ha}^{-1}$ ). Broadcasting @  $25 \text{ kg ha}^{-1}$  (control) ( $T_{10}$ ) recorded the lowest seed yield ( $509 \text{ kg ha}^{-1}$ ). Line sowing at  $30 \times 10$  cm + FYM @  $12.5 \text{ t ha}^{-1}$  + 150% RDN in splits at 20 and 40 DAS ( $T_4$ ) also recorded the highest stalk yield ( $2430 \text{ kg ha}^{-1}$ ), followed by  $T_3$  ( $2360 \text{ kg ha}^{-1}$ ) and

$T_7$  ( $2335 \text{ kg ha}^{-1}$ ).  $T_9$  recorded the lowest stalk yield ( $1970 \text{ kg ha}^{-1}$ ). Biological yield was recorded higher under line sowing at  $30 \times 10$  cm + FYM @  $12.5 \text{ t ha}^{-1}$  + 150% RDN in splits at 20 and 40 DAS ( $T_4$ ) ( $3441 \text{ kg ha}^{-1}$ ), followed by  $T_3$  ( $3325 \text{ kg ha}^{-1}$ ),  $T_8$  ( $3140 \text{ kg ha}^{-1}$ ) and  $T_2$  ( $3210 \text{ kg ha}^{-1}$ ). The higher harvest index was recorded under line sowing at  $30 \times 10$  cm + FYM @  $12.5 \text{ t ha}^{-1}$  + 150% RDN in splits at 20 and 40 DAS ( $T_4$ ) was 29.38%, whereas broadcasting @  $25 \text{ kg ha}^{-1}$  (control) ( $T_{10}$ ) recorded the lowest harvest index of 19.58%.

**Table 3.** Effect of planting pattern and nutrient management on seed yield, stalk yield, biological yield and harvest index of black gram

| Treatment                                                                                                   | Seed yield (kg ha <sup>-1</sup> ) | Stalk yield (kg ha <sup>-1</sup> ) | Biological yield (kg ha <sup>-1</sup> ) | Harvest index (%) |
|-------------------------------------------------------------------------------------------------------------|-----------------------------------|------------------------------------|-----------------------------------------|-------------------|
| Line sowing at 30 × 10 cm + 100% RDF + 1% urea foliar spray at 30 and 45 DAS                                | 827                               | 2310                               | 3137                                    | 26.36             |
| Line sowing at 30 × 10 cm + 100% RDF + 2% DAP foliar spray at 30 and 45 DAS                                 | 930                               | 2280                               | 3210                                    | 28.97             |
| Line sowing at 30 × 10 cm + 100% RDF + 2% TNAU Pulse Wonder foliar spray at 30 and 45 DAS                   | 965                               | 2360                               | 3325                                    | 29.02             |
| Line sowing at 30 × 10 cm + FYM @ 12.5 t ha <sup>-1</sup> + 150% RDN in splits at 20 and 40 DAS             | 1011                              | 2430                               | 3441                                    | 29.38             |
| Broadcasting @ 25 kg ha <sup>-1</sup> + 100% RDF + 1% urea foliar spray at 30 and 45 DAS                    | 671                               | 2210                               | 2881                                    | 23.29             |
| Broadcasting @ 25 kg ha <sup>-1</sup> + 100% RDF + 2% DAP foliar spray at 30 and 45 DAS                     | 803                               | 2250                               | 3053                                    | 26.30             |
| Broadcasting @ 25 kg ha <sup>-1</sup> + 100% RDF + 2% TNAU Pulse Wonder foliar spray at 30 and 45 DAS       | 818                               | 2335                               | 3153                                    | 25.94             |
| Broadcasting @ 25 kg ha <sup>-1</sup> + FYM @ 12.5 t ha <sup>-1</sup> + 150% RDN in splits at 20 and 40 DAS | 935                               | 2205                               | 3140                                    | 29.78             |
| Line sowing at 30 × 10 cm (control)                                                                         | 567                               | 1970                               | 2537                                    | 22.35             |
| Broadcasting @ 25 kg ha <sup>-1</sup> (control)                                                             | 509                               | 2090                               | 2599                                    | 19.58             |
| SE(d) ±                                                                                                     | 43                                | 31.12                              |                                         |                   |
| CD (P = 0.05)                                                                                               | 88                                | 65.24                              |                                         |                   |

### Economics

T4 recorded the highest gross return (₹50,550 ha<sup>-1</sup>) because of its higher seed and stalk yields. However, its higher cost of cultivation (₹27,800 ha<sup>-1</sup>) reduced the resulting economic efficiency. T<sub>3</sub>

recorded the highest net return (₹24,650 ha<sup>-1</sup>) and benefit ratio (2.04), followed by T<sub>2</sub> with a net return of ₹23,100 ha<sup>-1</sup> and B ratio of 1.99. T<sub>10</sub> recorded the lowest net return (₹4,950 ha<sup>-1</sup>) and B ratio (1.24).

**Table 4.** Effect of planting pattern and nutrient management on economics of black gram

| Treatment                                                                                                   | Cost of cultivation (₹ ha <sup>-1</sup> ) | Gross return (₹ ha <sup>-1</sup> ) | Net return (₹ ha <sup>-1</sup> ) | Benefit: cost ratio |
|-------------------------------------------------------------------------------------------------------------|-------------------------------------------|------------------------------------|----------------------------------|---------------------|
| Line sowing at 30 × 10 cm + 100% RDF + 1% urea foliar spray at 30 and 45 DAS                                | 22,500                                    | 41,350                             | 18,850                           | 1.84                |
| Line sowing at 30 × 10 cm + 100% RDF + 2% DAP foliar spray at 30 and 45 DAS                                 | 23,400                                    | 46,500                             | 23,100                           | 1.99                |
| Line sowing at 30 × 10 cm + 100% RDF + 2% TNAU Pulse Wonder foliar spray at 30 and 45 DAS                   | 23,600                                    | 48,250                             | 24,650                           | 2.04                |
| Line sowing at 30 × 10 cm + FYM @ 12.5 t ha <sup>-1</sup> + 150% RDN in splits at 20 and 40 DAS             | 27,800                                    | 50,550                             | 22,750                           | 1.82                |
| Broadcasting @ 25 kg ha <sup>-1</sup> + 100% RDF + 1% urea foliar spray at 30 and 45 DAS                    | 21,800                                    | 33,550                             | 11,750                           | 1.54                |
| Broadcasting @ 25 kg ha <sup>-1</sup> + 100% RDF + 2% DAP foliar spray at 30 and 45 DAS                     | 22,200                                    | 40,150                             | 17,950                           | 1.81                |
| Broadcasting @ 25 kg ha <sup>-1</sup> + 100% RDF + 2% TNAU Pulse Wonder foliar spray at 30 and 45 DAS       | 22,800                                    | 40,900                             | 18,100                           | 1.79                |
| Broadcasting @ 25 kg ha <sup>-1</sup> + FYM @ 12.5 t ha <sup>-1</sup> + 150% RDN in splits at 20 and 40 DAS | 26,800                                    | 46,750                             | 19,950                           | 1.74                |
| Line sowing at 30 × 10 cm (control)                                                                         | 21,000                                    | 28,350                             | 7,350                            | 1.35                |
| Broadcasting @ 25 kg ha <sup>-1</sup> (control)                                                             | 20,500                                    | 25,450                             | 4,950                            | 1.24                |

## Discussion

### Growth response to planting pattern and nutrient management

The results demonstrated that planting pattern combined with nutrient management substantially influenced the growth of black gram. The superiority of  $T_4$  in plant height from 45 DAS onwards indicates that line sowing combined with FYM and split application of 150% RDN provided favourable conditions for sustained vegetative development. Line sowing at  $30 \times 10$  cm provides a more uniform spatial arrangement than broadcasting, potentially reducing local competition for radiation, nutrients and water. The additional contribution of FYM may have improved soil physical condition and nutrient availability, while split nitrogen application supplied nitrogen during periods of active crop demand. Recent research has similarly demonstrated positive re-

sponses of black gram to integrated use of organic and inorganic nutrient sources (Rajeshkumar *et al.*, 2017) [8].

The greater number of productive branches observed under  $T_4$  is agronomically important because branching determines the number of potential reproductive sites. Adequate nutrient availability during vegetative development, combined with improved spatial arrangement under line sowing, probably promoted axillary growth and canopy expansion (Vivekanandan *et al.*, 1972) [9]. Similar improvements in growth and reproductive attributes following appropriate nutrient fortification have been reported in black gram under different agro-ecological conditions.

### Dry matter production and canopy development

The greater total dry matter production under  $T_4$  was consistent with its superior plant height, branching and LAI. Dry matter accumulation increased rapidly up to 60 DAS, coinciding with active canopy development, and subsequently declined towards harvest.

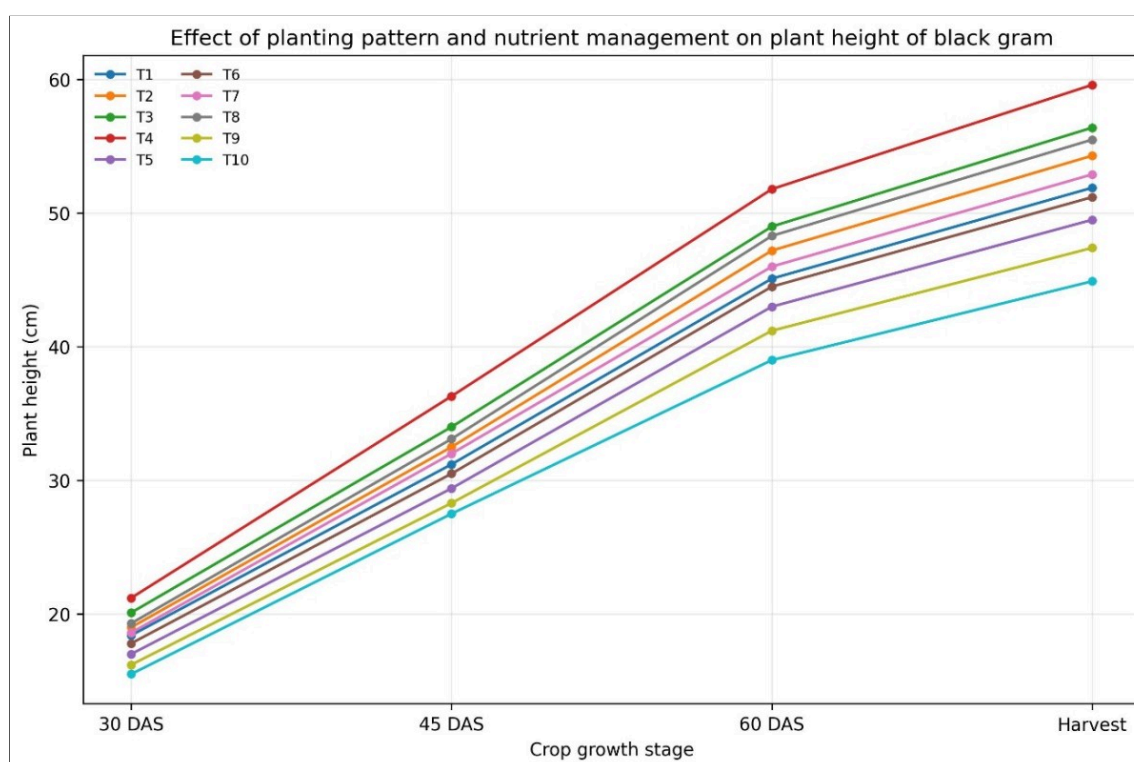


Figure 1. Effect of planting pattern and nutrient management on plant height of black gram

The decline in standing dry matter during the later period is consistent with crop maturation, leaf senescence and redistribution of stored assimilates towards reproductive structures.  $T_4$  recorded the highest TDM throughout the observation period. This indicates that the combined effect of line sowing, organic manure and split nutrient application increased the crop's capacity to accumulate biomass. The greater biomass production is also consistent with the higher LAI and CGR observed under  $T_4$ . Research on black gram has shown that appropriate nutrient management can increase biomass production, LAI, physiological activity and final yield. Thakur *et al.* (2017) [10] reported enhanced biomass production and LAI with optimized nutrient management in black gram, while more recent work has demonstrated the importance of nutrient fortification for improving crop physiological performance and productivity.

### Root growth and nodulation

The superior root length and nodulation under  $T_4$  indicate that improved nutrient management and crop establishment also affected below-ground development. The addition of FYM may further have improved soil structure and moisture retention, creating favourable conditions for root growth. Root nodulation is particularly important in black gram because biological nitrogen fixation contributes to crop nitrogen nutrition. The higher number of nodules under  $T_4$ , followed by  $T_3$  and  $T_8$ , indicates more favourable conditions for symbiotic activity under these treatments. Recent studies have reported improvements in root nodulation and crop productivity in black gram following appropriate nutrient fortification and improved crop management. The response of root growth also helps explain the superior shoot growth under  $T_4$ . An improved root system can increase the effective volume of soil explored by the crop and support nutrient and water acquisition (Verma *et al.*, 2011) [11]. This may have contributed to the greater canopy development and biomass accumulation observed subsequently.

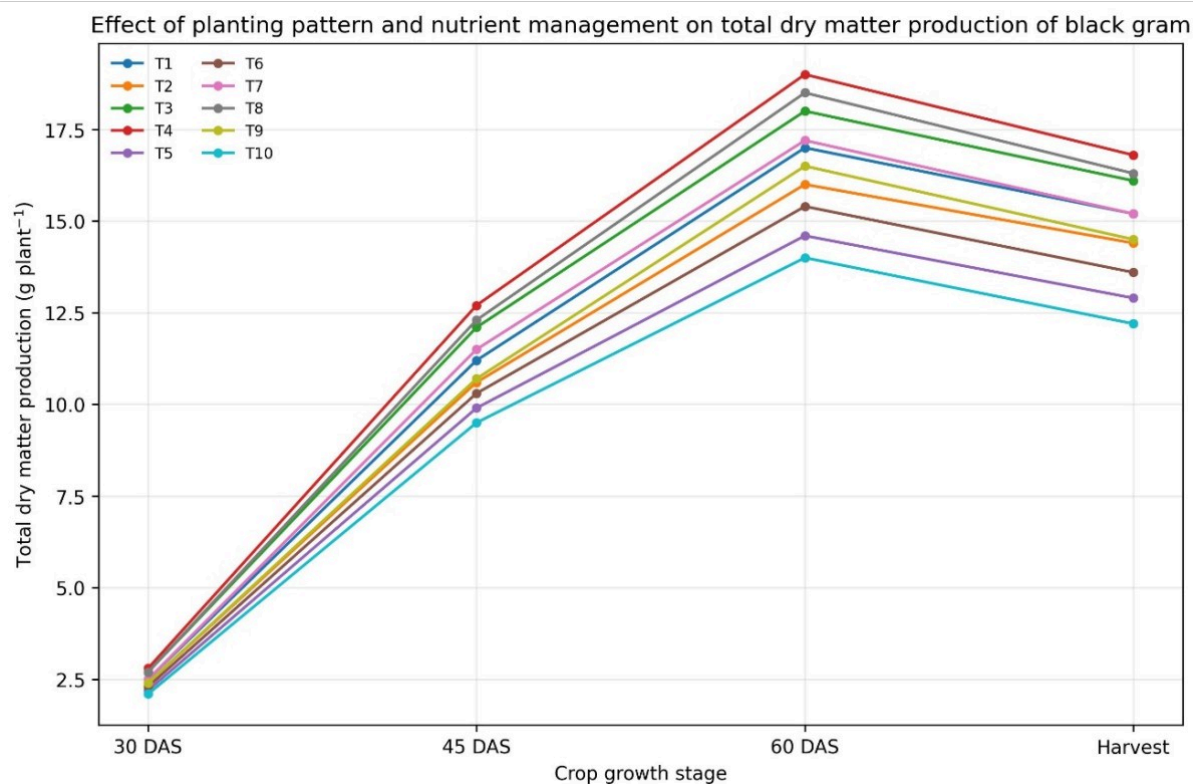


**Figure 2.** Effect of planting pattern and nutrient management on total dry matter production of black gram

#### Leaf area index and crop growth rate

The consistently higher LAI under  $T_4$  indicates greater development of photosynthetically active foliage. The maximum LAI occurred during the period of vigorous vegetative and early reproductive growth

and subsequently declined towards maturity. Such a temporal pattern is expected as leaf production is followed by canopy senescence.

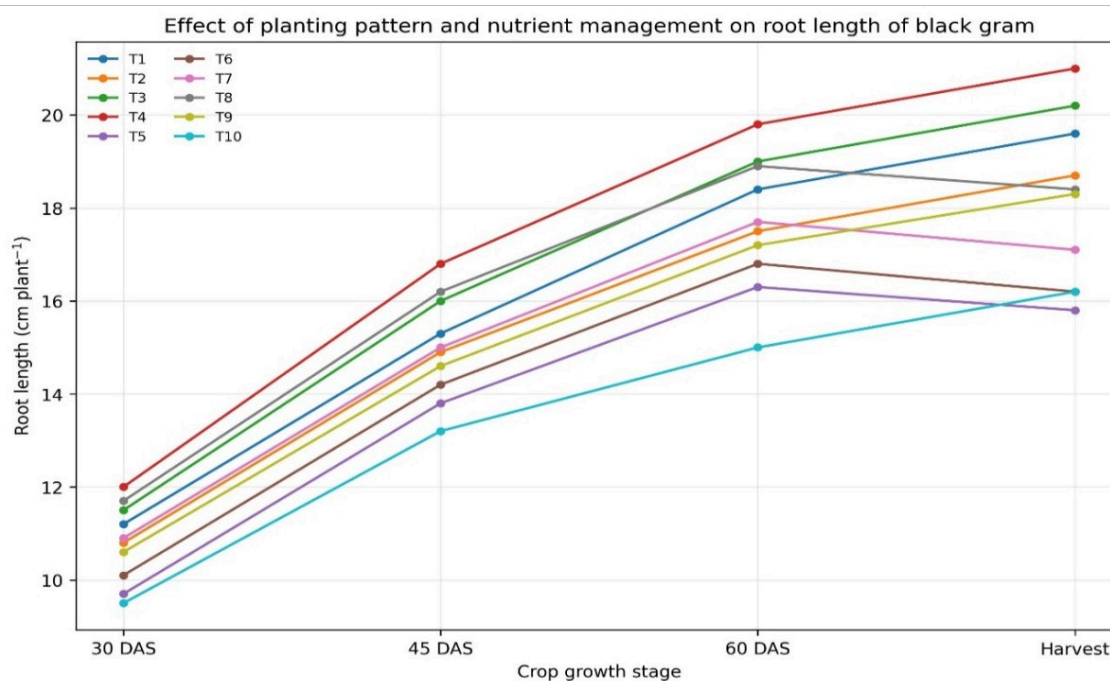


**Figure 3.** Effect of planting pattern and nutrient management on root length of black gram

The high CGR recorded under  $T_4$  (Line sowing at  $30 \times 10$  cm + FYM @  $12.5 \text{ t ha}^{-1}$  + 150% RDN in splits at 20 and 40 DAS) during 30–45 and 45–60 DAS provides further evidence that the treatment promoted rapid biomass accumulation during the critical period of canopy development. CGR integrates the effects of leaf area, radia-

tion interception and photosynthetic activity and therefore provides a useful link between vegetative growth and final yield. Similar reports were observed with Vivekanandan *et al.* (1972) [9] has demonstrated strong associations among nutrient management, LAI, biomass accumulation and productivity.

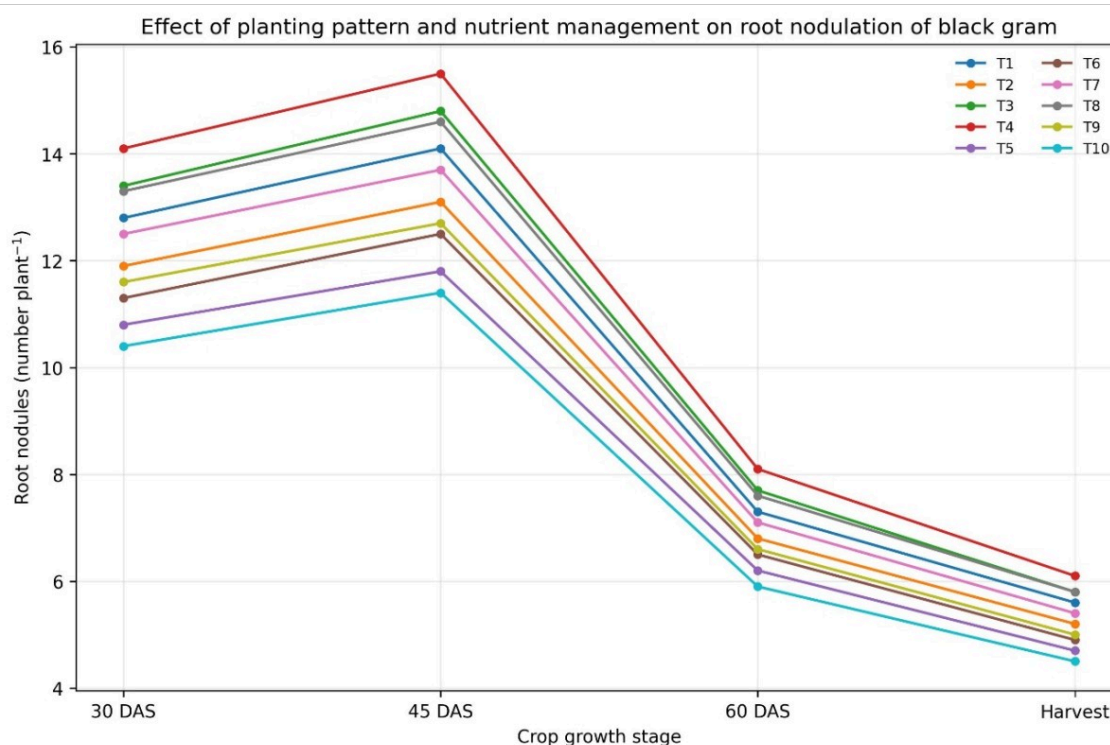


**Figure 4.** Effect of planting pattern and nutrient management on root nodulation of black gram

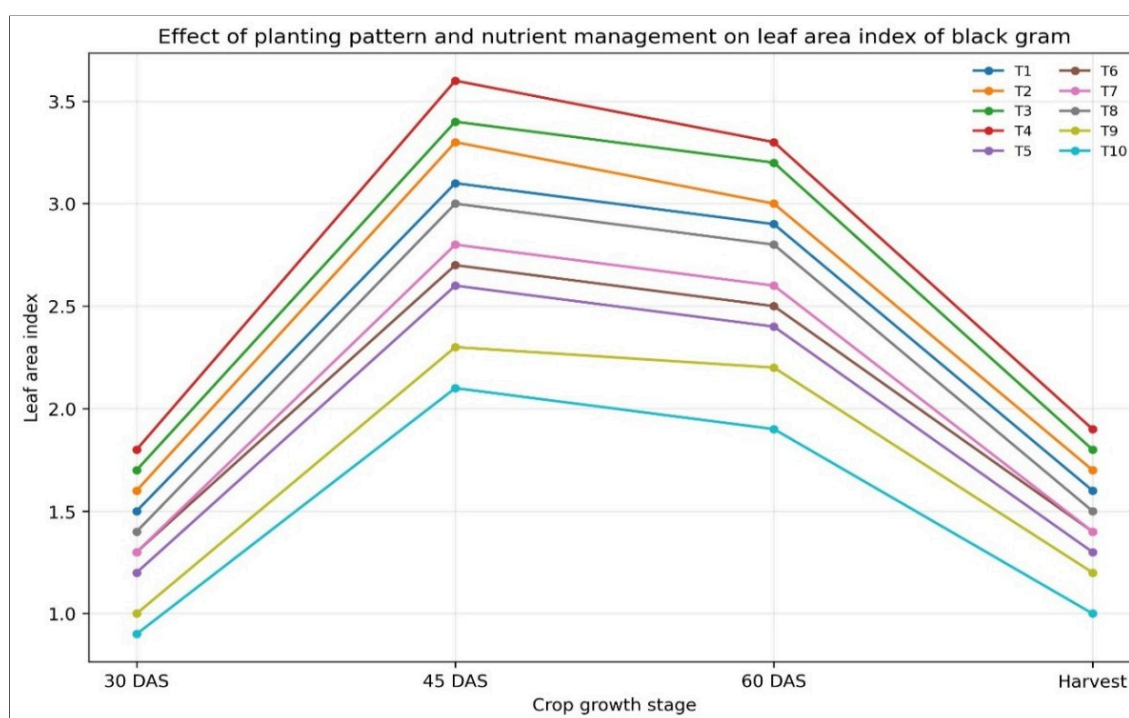


**Figure 5.** Effect of planting pattern and nutrient management on leaf area index of black gram

### Yield attributes and seed yield

The superior yield attributes under  $T_4$  (Line sowing at  $30 \times 10$  cm + FYM @  $12.5 \text{ t ha}^{-1}$  + 150% RDN in splits at 20 and 40 DAS) indicate that the enhanced vegetative growth was successfully translated into reproductive development.  $T_4$  recorded  $32.8 \text{ pods plant}^{-1}$ ,  $6.6 \text{ seeds pod}^{-1}$  and  $13.2 \text{ g seed yield plant}^{-1}$ , compared with only  $15.2 \text{ pods plant}^{-1}$  and  $4.9 \text{ g seed yield plant}^{-1}$  under  $T_{10}$ . The increase in pod formation was likely associated with the greater number of productive branches and improved canopy development. The response of  $T_3$  is particularly relevant as combined line sowing and 100% RDF with 2% TNAU Pulse Wonder foliar application and produced seed yield close to  $T_4$ . This suggests that targeted foliar nutrition during ac-

tive crop development can complement recommended basal fertilization and improve reproductive performance without requiring the higher nutrient and organic-input investment associated with  $T_4$ . Sreemathi *et al.* (2019) [12] reported increased yield attributes and grain yield with combined FYM and inorganic fertilization, while Veeramani (2019) [13] reported improved productivity and profitability under integrated nutrient management.

The maximum seed yield of  $1011 \text{ kg ha}^{-1}$  under  $T_4$  (Line sowing at  $30 \times 10$  cm + FYM @  $12.5 \text{ t ha}^{-1}$  + 150% RDN in splits at 20 and 40 DAS) was approximately twice the yield obtained under  $T_{10}$  ( $509 \text{ kg ha}^{-1}$ ). The response is consistent with the combined improvements in plant height, productive branches, root development, LAI, CGR and yield attributes.

### Stalk yield, biological yield and harvest index

Line sowing at  $30 \times 10$  cm + FYM @  $12.5 \text{ t ha}^{-1}$  + 150% RDN in splits at 20 and 40 DAS ( $T_4$ ) also produced the highest stalk yield and, after correction, the highest biological yield. The greater stalk yield reflects its superior vegetative growth and biomass accumulation. The corrected biological yield of  $T_4$  was  $3441 \text{ kg ha}^{-1}$ , calculated from  $1011 \text{ kg ha}^{-1}$  seed yield plus  $2430 \text{ kg ha}^{-1}$  stalk yield. Using seed yield divided by biological yield,  $T_4$  recorded a harvest index of 29.38%, while  $T_8$  recorded 29.78%. The index values indicate that the high seed yield of  $T_4$  was associated with effective reproductive output, although  $T_8$  had a slightly higher proportion of total above-ground production represented by seed.

### Economic returns

Line sowing at  $30 \times 10$  cm + FYM @  $12.5 \text{ t ha}^{-1}$  + 150% RDN in splits at 20 and 40 DAS ( $T_4$ ) produced the highest gross return because of its superior seed and stalk yields. However,  $T_4$  also incurred the highest cost of cultivation because of FYM at  $12.5 \text{ t ha}^{-1}$  and the higher nitrogen input. Consequently, Line sowing at  $30 \times 10$  cm + 100% RDF + 2% TNAU Pulse Wonder foliar spray at 30 and 45 DAS ( $T_3$ ) produced the highest net return and B:C ratio. The performance of  $T_3$  is economically relevant because it achieved a seed yield of  $965 \text{ kg ha}^{-1}$ , only  $46 \text{ kg ha}^{-1}$  lower than  $T_4$ , but with a substantially lower cost of cultivation. The higher net return and B ratio therefore resulted from a more favourable balance between additional yield and additional input cost. Similar observations have been reported in black gram research where integrated or fortified nutrient treatments improved productivity while the economically optimum treatment depended on the cost of nutrient inputs (Ayyadurai *et al.*, 2024) [5].

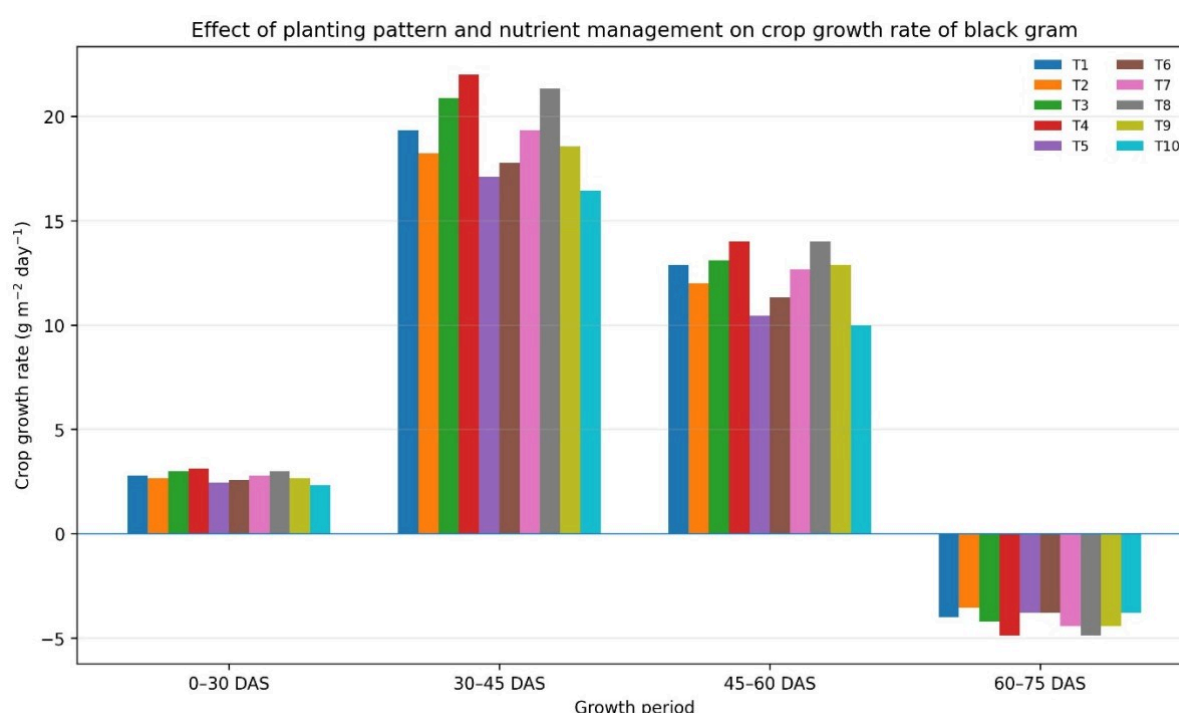


Figure 6. Effect of planting pattern and nutrient management on crop growth rate of black gram

### Conclusion

The field experiment demonstrated that planting pattern combined with appropriate nutrient management substantially influenced growth, root development, canopy development, yield attributes, seed yield and economic returns of black gram. Line sowing at  $30 \times 10$  cm generally provided a more favourable crop environment than broadcasting, particularly when combined with adequate nutrient availability. Among the treatments, line sowing at  $30 \times 10$  cm combined with FYM at  $12.5 \text{ t ha}^{-1}$  and 150% RDN applied in splits at 20 and 40 DAS ( $T_4$ ) produced the highest plant height, productive branches, root length, root nodulation, leaf area index, crop growth rate, yield attributes, seed yield, stalk yield and biological yield. The treatment produced  $1011 \text{ kg ha}^{-1}$  seed yield and  $2430 \text{ kg ha}^{-1}$  stalk yield. After correcting the harvest-index calculation using biological yield as seed yield plus stalk yield,  $T_4$  recorded a harvest index of 29.38%. However, the highest biological productivity did not correspond to the highest economic efficiency. Line sowing at  $30 \times 10$  cm with 100% RDF and 2% TNAU Pulse Wonder foliar spray at 30 and 45 DAS ( $T_3$ ) recorded the highest net return ( $\text{₹}24,650 \text{ ha}^{-1}$ ) and benefit ratio (2.04), indicating a more favourable economic balance between productivity and input expenditure under the price conditions prevailing during the experiment. The study therefore indicates that improved crop establishment together with appropriate nutrient management is

important for enhancing black gram productivity. The results also demonstrate that agronomic and economic responses should be evaluated together when selecting a production practice.

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