



## Soybean Physiology and Yield Response to Seed Rate and Sowing Method

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### Authors' contributions

This work was carried out in collaboration among all authors. Authors RSR, GKK and ASG designed the study, author DG, SS, RV and VJ performed the statistical analysis, author SN, ASG and RS wrote the protocol, and author SMK and RSR wrote the first draft of the manuscript. Authors AK and DG managed the analyses of the study. Author SMK managed the literature searches. All authors read and approved the final manuscript.

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### ABSTRACT

The soybean crop is highly sensitive to climate change associated events viz., global warming, drought, and water-logging at the time of highly sensitive flowering and grain filling stage, causing a shortfall in production and supply of quality seed to the country. Under prevailing high-density planting, at the seed rate of 70 kg ha<sup>-1</sup> and flatbed sowing method, plant growth is restricted due to limitation of radiation and nutrients. Hence, the seed rate and sowing method need revision in an era of climate change. Therefore, we hypothesized that adopting a lower seed rate under ridges and furrow sowing would improve seed yield and quality over the prevailing seed rate of 70 kg ha<sup>-1</sup> and flatbed sowing method. In order to test our hypothesis, an experiment was conducted to study the effect of various seed rates and sowing methods on growth and productivity of soybean. Studies revealed that a seed rate of 70 kg ha<sup>-1</sup> shows superiority in terms of seed yield (3873.70 kg

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ha<sup>-1</sup>) which was at par with 60 kg ha<sup>-1</sup> (3359.40 kg ha<sup>-1</sup>). Lower seed rate of 60 kg ha<sup>-1</sup> was superior in terms of seed yield per plant (8.99 g plant<sup>-1</sup>), biological yield (6310 kg ha<sup>-1</sup>), Harvest index (35.69%), dry matter accumulation in pods at 61 DAS (1.74 g). Ridges and furrow sowing method was found superior for biological yield (26.33 g plant<sup>-1</sup>) and (6958.90 kg ha<sup>-1</sup>), dry matter accumulation in pods at 61 DAS (1.84 g), Leaf Area Duration at 71 DAS (19535.00 cm<sup>2</sup>.days). Interaction studies revealed that 60 kg ha<sup>-1</sup> seed rate with ridge and furrow stand superior in terms of seed yield per plant 10.65 g plant<sup>-1</sup> which was attributed to maximum harvest index (29.58%), dry matter accumulation in pod at 61 DAS (2.13 g), Leaf Area Duration at 71-81 DAS (22069.00 cm<sup>2</sup>.days). In contrary, highest seed yield(4018.89 kg ha<sup>-1</sup>) was observed for seed rate of 70 kg ha<sup>-1</sup> with flat bed sowing. Hence it can be concluded that, under low productive environment the efficient dry matter accumulation, leaf area development and number of branches under low density planting will not compensate for the higher plant stand induced yield increment due to high density planting. Therefore, higher seed rate of 70 kg/ha with ridge and furrow sowing will be recommended to the farmers to get higher yield of soybean under rainfed and low productive environment.

**Keywords:** Seed rate; sowing method; planting density; physiology; dry matter accumulation; leaf area index; soybean.

## 1. INTRODUCTION

Soybean plays a vital role in the agricultural economy of India. The low productivity of crops is due to several constraints, including soil moisture stress at critical growth stages and biotic interferences to crop growth [1]. The seed rate is an important factor in determining the optimum plant population, leading to a potential seed yield expression. Research on spatial distribution adequacy in soybean in a cultivation area motivated by increased grain yield per agricultural unit has been of interest in recent years because soybean crops have an ability (*Glycine max* [L.] Merrill.) to adapt to various types of cultivation a characteristic known as phenotypic plasticity [2]. To avoid the risk of less plant population, farmers practice sowing at a high seed rate and narrow spacing of plants and rows. Higher seed rate causes poor plant growth due to competition for nutrients, light, and space, leading to fewer branches and increased dependency on the main stem [3]. Thus, a reduced seed rate may help in maintaining the optimum plant population. In soybean, number of branches and leaves per plant are characteristics that change in each cultivar, but plants appear quite sensitive when considering changes in population density [4,5,6], so the best arrangement should enable high agricultural productivity [5]. Different seed rates, tillage, and drainage methods may have a high impact on the morpho-physiological traits that influence productivity. High-yielding varieties of soybean will give potential yield only when the optimum environmental condition will be provided. In general, aside from cultivar selection and

adequate fertility, manipulation of soybean planting date, seeding rate, weed control are major agronomic factors that are routinely studied as they can significantly influence yield potential and economic return. The soybean yield is also limited due to excessive or deficit rainfall at critical stages of growth. Therefore, it was hypothesized that appropriate land configurations like ridges and furrow systems increase crop yield due to increased rainfall infiltration into the soil profile, which become available to the crop during the prolonged monsoonal break. The excessive moisture or water logging conditions during monsoon season create unfavorable conditions for growth, such as reducing porosity, soil aeration, root growth, hampered nodulation, reduced nutrient uptake, and devastatingly affecting the physiological condition of a plant leading to reduction in crop productivity and poor seed quality [7,8]. Manipulation of the sowing method leads to easy and uniform germination, growth, and development of the plant. Among all legumes, soybean is most sensitive to soil moisture. The loss in yield can be minimized if the optimum amount of water is stored in the soil. This problem of poor yield, seed quality causes a huge gap in the demand and supply of soybean in the country. To resolve this problem, our group hypothesized that by reducing the seed rate sowing in ridges and furrows will stabilize the crop yield and seed quality of soybean by strengthening the physiological efficiency of soybean and maximize the use of environmental resources under rainfed and low productive environment. Keeping all these facts in mind, the present study was carried out with the focal objective of investigating the effects of various

seed rates, sowing method, and its interaction on physiology, growth, dry matter accumulation, and yield of soybean.

## 2. MATERIALS AND METHODS

Soybean variety JS 20-98 an indeterminate soybean variety of medium maturity group was sown in Experimental Research Farm, Seed technology Research Unit, JNKVV, Jabalpur during *Kharif* 2019 in Factorial Randomized Block Design with three levels of seed rate viz., 70 kg ha<sup>-1</sup>, 60 kg ha<sup>-1</sup> and 50 kg ha<sup>-1</sup> and two levels of sowing method viz., Ridge and furrow, Flatbed sowing method with four replications. The plot area was 10 m<sup>2</sup> with six rows of Five-meters row length, and row-row distance is 40cm. In 70 kg ha<sup>-1</sup> seed rate, 70 g seeds plot<sup>-1</sup> with 113 seeds row<sup>-1</sup> with 4.4 cm plant-plant distance was maintained. In 60 kg ha<sup>-1</sup> seed rate plant-plant distance is 5.2 cm with 96 seeds row<sup>-1</sup> and 60 g seeds plot<sup>-1</sup> was sown. In 50 kg ha<sup>-1</sup> seed rate, plant-plant distance is 6.2cm with 80 seed row<sup>-1</sup> and 50 g seeds plot<sup>-1</sup> was sown and maintained. Nitrogen, Phosphorus and Potassium were added at 20:60:40 kg ha<sup>-1</sup>. Sampling was done at the fixed intervals of growth for obtaining primary data for computation of physiological growth determinants at 21 DAS, 31 DAS, 41 DAS, 51 DAS, 61 DAS, 71 DAS and at the maturity stage. Three plants were randomly selected from each treatment per replication for growth analysis and dry matter accumulation studies. Data were recorded on morphological observation and yield traits, dry matter analysis, growth and physiological parameters. Leaf Area Index (LAI), Leaf Area Duration (LAD), Specific Leaf Area (SLA) and Biomass duration (BMD) was also observed at 31,41,51, 61 and 71 Days after sowing. Two way ANOVA and Tukey multiple range test was done with the SAS 2.0 statistical software.

## 3. RESULTS AND DISCUSSION

### 3.1 Plant Height as affected by Seed Rate, Sowing Method and Its Interaction

Due to seed rate, significant difference was observed for plant height at 41 DAS, 51 DAS, 61 DAS, 71 DAS and at harvest. Highest plant height at all stages was observed for 70 kg ha<sup>-1</sup> and 60 kg ha<sup>-1</sup>. Lowest was being observed for 50 kg ha<sup>-1</sup>. With respect to sowing method, non-significant difference was observed ( $p < 0.05$ ). With respect to interaction effect of seed rate and sowing methods, significant difference was

observed with highest plant height was observed for 60 kg ha<sup>-1</sup> seed rate with flat bed sowing method (83.03 m) which was at par with 60 kg ha<sup>-1</sup> seed rate with ridges and furrow sowing method (81.71 m) (Table 2).

### 3.2 Seed Rate, Sowing Method and Its Interaction Effect on Seed Yield and Yield Component

Non-significant difference ( $P < 0.05$ ) due to seed rate, sowing method and its interactions was observed for number of nodes at harvest, number of effective nodes at harvest, number of pods plant<sup>-1</sup>, pod length, pod width and pod girth. The seed rate of 50 kg ha<sup>-1</sup> cause's production of a greater number of branches (7.26) as compared to 70 kg ha<sup>-1</sup> (5.52) and 60 kg ha<sup>-1</sup> (5.85). The interaction effect shows that 50 kg ha<sup>-1</sup> seed rate with ridge and furrows sowing method produced more branches (8.18). The increment of 31.52% on the number of branches plant<sup>-1</sup> was observed due to 50 kg ha<sup>-1</sup> over control (70 kg ha<sup>-1</sup>) (Table 3). The seed rate of 60 kg ha<sup>-1</sup> shows superiority in seed yield plant<sup>-1</sup> (8.99 g) which was at par with 70 kg ha<sup>-1</sup> (7.76 g). A minimal increment of 15.85% was observed on seed yield due to 60 kg ha<sup>-1</sup> over control. Interaction studies and analysis revealed a significant difference with highest seed yield per plant was observed for 60 kg ha<sup>-1</sup> seed rate with ridge and furrow sowing method (10.65g plant<sup>-1</sup>) (Table 3). The seed yield ha<sup>-1</sup> was found to be maximum for the seed rate of 70 kg ha<sup>-1</sup> at par with 60 kg ha<sup>-1</sup> (3359.4 kg ha<sup>-1</sup>) compared to lower seed rate of 50 kg ha<sup>-1</sup> (2555.3 kg ha<sup>-1</sup>). Non-significant difference was observed for sowing method on seed yield (kg ha<sup>-1</sup>). Interaction studies revealed that highest seed yield (4018.89 kg ha<sup>-1</sup>) was observed for 70 kg ha<sup>-1</sup> under flat bed sowing method. A significant difference was observed for biological yield for seed rate, sowing method and interaction. Lower seed rate of 50 kg ha<sup>-1</sup> shows maximum biological yield per plant (26.83 g plant<sup>-1</sup>) which was at par with 60 kg ha<sup>-1</sup> (25.00 g plant<sup>-1</sup>). Higher biological yield kg ha<sup>-1</sup> was observed for 50 kg ha<sup>-1</sup> (7225.00 kg ha<sup>-1</sup>) which was at par with 60 kg ha<sup>-1</sup> (6310.00 kg ha<sup>-1</sup>) (Table 3). Highest biological yield plant<sup>-1</sup> was observed for ridge and furrow sowing method 26.33 g plant<sup>-1</sup> and 6958.9 kg ha<sup>-1</sup>, respectively. With respect to harvest index significant difference was observed for seed rate, with highest harvest index (35.69%) for 60 kg ha<sup>-1</sup> was observed which was at par with 70 kg ha<sup>-1</sup> (32.11%).

**Table 1. Results of the Two-way ANOVA and Tukey multiple range tests for the comparative effects of seed rate and sowing method on the seed yield, yield components, dry matter accumulation, physiological growth determinants**

| Source of variation       | No. of Branches at harvest | Plant height at harvest | Seed yield (g plant <sup>-1</sup> ) | Seed yield (Kg ha <sup>-1</sup> ) | Biological yield (g plant <sup>-1</sup> ) | Biological yield (Kg ha <sup>-1</sup> ) | Harvest index (%) | Pod dry weight at 61 DAS | LAI at 31 DAS | LAI at 41 DAS | LAD at 71 DAS | BMD At 61 DAS |
|---------------------------|----------------------------|-------------------------|-------------------------------------|-----------------------------------|---|---|-------------------|--------------------------|---------------|---------------|---------------|---------------|
| Seed rate                 | 6.75 **                    | 15.23 ***               | 4.16*                               | 10.05 **                          | 5.49*                                     | 5.33*                                   | 7.09**            | 4.21*                    | 4.44 *        | 5.33 *        | 2.46 ns       | 1.01 ns       |
| Sowing method             | 0.10 ns                    | 2.41 ns                 | 4.27 ns                             | 0.38 ns                           | 8.85**                                    | 8.06 **                                 | 0.14 ns           | 15.18**                  | 1.84 ns       | 1.90 ns       | 9.62 **       | 5.16 *        |
| Seed rate X sowing method | 5.17 *                     | 13.78 ***               | 9.26**                              | 2.45 ns                           | 4.67*                                     | 4.38*                                   | 4.67 *            | 3.47 ns                  | 0.66 ns       | 0.53 ns       | 4.78 *        | 7.53 **       |

LAI=Leaf Area Index; LAD=Leaf Area Duration; BMD=Biomass Duration;

\*F-values. ns: not significant F ratio ( $p < 0.05$ ); \*, \*\* and \*\*\* (indicate significant at  $P < 0.05, 0.01$  and  $0.001$ , respectively)**Table 2. Effect of seed rate, sowing methods and its interaction on plant height at 31 DAS, 41 DAS, 51 DAS, 61 DAS, 71 DAS and at harvest of soybean**

| Treatment                        | Plant height 31 DAS | Plant height 41 DAS | Plant height 51 DAS | Plant height 61 DAS | Plant height 71 DAS | Plant height at harvest |
|----------------------------------|---------------------|---------------------|---------------------|---------------------|---------------------|-------------------------|
| <b>Seed rate</b>                 |                     |                     |                     |                     |                     |                         |
| 70 kg ha <sup>-1</sup>           | 55.22 <sup>a</sup>  | 63.53 <sup>a</sup>  | 72.86 <sup>a</sup>  | 76.66 <sup>a</sup>  | 78.46 <sup>a</sup>  | 80.84 <sup>a</sup>      |
| 60 kg ha <sup>-1</sup>           | 54.18 <sup>a</sup>  | 63.78 <sup>a</sup>  | 70.94 <sup>a</sup>  | 76.87 <sup>a</sup>  | 79.97 <sup>a</sup>  | 82.37 <sup>a</sup>      |
| 50 kg ha <sup>-1</sup>           | 54.55 <sup>a</sup>  | 58.20 <sup>b</sup>  | 64.23 <sup>b</sup>  | 70.90 <sup>b</sup>  | 73.57 <sup>b</sup>  | 76.77 <sup>b</sup>      |
| <b>Sowing method</b>             |                     |                     |                     |                     |                     |                         |
| RF                               | 54.42 <sup>a</sup>  | 61.31 <sup>a</sup>  | 69.66 <sup>a</sup>  | 74.93 <sup>a</sup>  | 78.02 <sup>a</sup>  | 80.66 <sup>a</sup>      |
| FB                               | 54.89 <sup>a</sup>  | 62.37 <sup>a</sup>  | 69.02 <sup>a</sup>  | 74.69 <sup>a</sup>  | 76.65 <sup>a</sup>  | 79.33 <sup>a</sup>      |
| <b>Seed rate x Sowing method</b> |                     |                     |                     |                     |                     |                         |
| 70 kg ha <sup>-1</sup> + RF      | 52.97 <sup>b</sup>  | 59.34 <sup>bc</sup> | 73.28 <sup>a</sup>  | 75.56 <sup>ab</sup> | 77.86 <sup>ab</sup> | 79.66 <sup>a</sup>      |
| 60 kg ha <sup>-1</sup> + RF      | 53.99 <sup>ab</sup> | 63.33 <sup>ab</sup> | 69.20 <sup>ab</sup> | 76.40 <sup>ab</sup> | 79.49 <sup>a</sup>  | 81.71 <sup>a</sup>      |
| 50 kg ha <sup>-1</sup> + RF      | 56.29 <sup>ab</sup> | 61.25 <sup>b</sup>  | 66.50 <sup>ab</sup> | 72.83 <sup>ab</sup> | 76.72 <sup>ab</sup> | 80.60 <sup>a</sup>      |
| 70 kg ha <sup>-1</sup> + FB      | 57.47 <sup>a</sup>  | 67.71 <sup>a</sup>  | 72.43 <sup>a</sup>  | 77.76 <sup>a</sup>  | 79.06 <sup>a</sup>  | 82.02 <sup>a</sup>      |
| 60 kg ha <sup>-1</sup> + FB      | 54.37 <sup>ab</sup> | 64.23 <sup>ab</sup> | 72.67 <sup>a</sup>  | 77.35 <sup>a</sup>  | 80.45 <sup>a</sup>  | 83.03 <sup>a</sup>      |
| 50 kg ha <sup>-1</sup> + FB      | 52.81 <sup>b</sup>  | 55.16 <sup>c</sup>  | 61.95 <sup>b</sup>  | 68.96 <sup>b</sup>  | 70.42 <sup>b</sup>  | 72.94 <sup>b</sup>      |

DAS: Days after sowing RF: Ridge &amp; Furrow sowing method FB: Flatbed sowing method

Table 3. Effect of seed rate, sowing method and its interaction on seed yield and yield components of soybean

| Treatment                        | No. of Branches at harvest | No of seeds pod <sup>-1</sup> | Seed yield            |                       | Biological yield      |                       | Harvest Index (%)   |
|----------------------------------|----------------------------|-------------------------------|-----------------------|-----------------------|-----------------------|-----------------------|---------------------|
|                                  |                            |                               | g plant <sup>-1</sup> | Kg ha <sup>-1</sup>   | g plant <sup>-1</sup> | kg ha <sup>-1</sup>   |                     |
| <b>Seed rate</b>                 |                            |                               |                       |                       |                       |                       |                     |
| 70 kg ha <sup>-1</sup>           | 5.52 <sup>b</sup>          | 2.92 <sup>a</sup>             | 7.76 <sup>b</sup>     | 3873.7 <sup>a</sup>   | 24.17 <sup>b</sup>    | 5855.0 <sup>a</sup>   | 32.11 <sup>ab</sup> |
| 60 kg ha <sup>-1</sup>           | 5.85 <sup>b</sup>          | 2.95 <sup>a</sup>             | 8.99 <sup>a</sup>     | 3359.4 <sup>a</sup>   | 25.00 <sup>ab</sup>   | 6310.0 <sup>ab</sup>  | 35.69 <sup>a</sup>  |
| 50 kg ha <sup>-1</sup>           | 7.26 <sup>a</sup>          | 2.96 <sup>a</sup>             | 7.73 <sup>b</sup>     | 2555.3 <sup>b</sup>   | 26.83 <sup>a</sup>    | 7225.0 <sup>a</sup>   | 28.91 <sup>b</sup>  |
| <b>Sowing method</b>             |                            |                               |                       |                       |                       |                       |                     |
| RF                               | 6.272 <sup>a</sup>         | 2.81 <sup>a</sup>             | 8.58 <sup>a</sup>     | 3337.4 <sup>a</sup>   | 26.33 <sup>a</sup>    | 6958.9 <sup>a</sup>   | 32.51 <sup>a</sup>  |
| FB                               | 6.142 <sup>a</sup>         | 3.07 <sup>b</sup>             | 7.74 <sup>a</sup>     | 3188.2 <sup>a</sup>   | 24.33 <sup>b</sup>    | 5967.8 <sup>b</sup>   | 31.96 <sup>a</sup>  |
| <b>Seed rate x Sowing method</b> |                            |                               |                       |                       |                       |                       |                     |
| 70 kg ha <sup>-1</sup> +RF       | 4.83 <sup>b</sup>          | 2.84 <sup>a</sup>             | 7.55 <sup>b</sup>     | 3728.48 <sup>ab</sup> | 25.00 <sup>ab</sup>   | 6256.67 <sup>ab</sup> | 30.12 <sup>b</sup>  |
| 60 kg ha <sup>-1</sup> + RF      | 5.80 <sup>ab</sup>         | 2.79 <sup>a</sup>             | 10.65 <sup>a</sup>    | 3811.26 <sup>ab</sup> | 27.33 <sup>a</sup>    | 7480.00 <sup>a</sup>  | 39.03 <sup>a</sup>  |
| 50 kg ha <sup>-1</sup> + RF      | 8.18 <sup>a</sup>          | 2.81 <sup>a</sup>             | 7.55 <sup>b</sup>     | 2472.37 <sup>b</sup>  | 26.67 <sup>ab</sup>   | 7140.00 <sup>ab</sup> | 28.37 <sup>b</sup>  |
| 70 kg ha <sup>-1</sup> + FB      | 6.20 <sup>ab</sup>         | 3.00 <sup>a</sup>             | 7.97 <sup>b</sup>     | 4018.89 <sup>a</sup>  | 23.33 <sup>ab</sup>   | 5453.33 <sup>ab</sup> | 34.10 <sup>ab</sup> |
| 60 kg ha <sup>-1</sup> FB        | 5.89 <sup>ab</sup>         | 3.11 <sup>a</sup>             | 7.33 <sup>b</sup>     | 2907.47 <sup>ab</sup> | 22.67 <sup>b</sup>    | 5140.00 <sup>b</sup>  | 32.35 <sup>ab</sup> |
| 50 kg ha <sup>-1</sup> + FB      | 6.33 <sup>ab</sup>         | 3.11 <sup>a</sup>             | 7.92 <sup>b</sup>     | 2638.13 <sup>ab</sup> | 27.00 <sup>a</sup>    | 7310.00 <sup>a</sup>  | 29.45 <sup>b</sup>  |

RF: Ridge &amp; Furrow sowing method FB: Flatbed sowing method

**Table 4. Effect of seed rate, sowing method and its interaction on Dry Matter Accumulation in leaves, Stem and Pods in soybean**

| Treatment                        | DM accumulation in leaves at 21 DAS | DM accumulation in leaves at 41 DAS | DM accumulation in Stem at 21 DAS | DM accumulation in Stem at 51 DAS | DM accumulation in Pod at 61 DAS |
|----------------------------------|-------------------------------------|-------------------------------------|-----------------------------------|-----------------------------------|----------------------------------|
| <b>Seed rate</b>                 |                                     |                                     |                                   |                                   |                                  |
| 70 kg ha <sup>-1</sup>           | 0.66 <sup>a</sup>                   | 0.88 <sup>b</sup>                   | 1.09 <sup>a</sup>                 | 2.36 <sup>a</sup>                 | 1.67 <sup>a</sup>                |
| 60 kg ha <sup>-1</sup>           | 0.47 <sup>b</sup>                   | 0.96 <sup>b</sup>                   | 1.10 <sup>a</sup>                 | 2.45 <sup>a</sup>                 | 1.74 <sup>a</sup>                |
| 50 kg ha <sup>-1</sup>           | 0.41 <sup>b</sup>                   | 1.12 <sup>a</sup>                   | 1.07 <sup>a</sup>                 | 2.37 <sup>a</sup>                 | 1.22 <sup>b</sup>                |
| <b>Sowing method</b>             |                                     |                                     |                                   |                                   |                                  |
| RF                               | 0.52 <sup>a</sup>                   | 0.94 <sup>a</sup>                   | 0.99 <sup>b</sup>                 | 2.63 <sup>a</sup>                 | 1.85 <sup>a</sup>                |
| FB                               | 0.51 <sup>a</sup>                   | 1.04 <sup>a</sup>                   | 1.19 <sup>a</sup>                 | 2.16 <sup>a</sup>                 | 1.24 <sup>b</sup>                |
| <b>Seed rate x Sowing method</b> |                                     |                                     |                                   |                                   |                                  |
| 70 kg ha <sup>-1</sup> + RF      | 0.70 <sup>a</sup>                   | 0.87 <sup>ab</sup>                  | 0.98 <sup>a</sup>                 | 2.74 <sup>a</sup>                 | 1.75 <sup>a</sup>                |
| 60 kg ha <sup>-1</sup> + RF      | 0.40 <sup>a</sup>                   | 0.81 <sup>b</sup>                   | 1.12 <sup>a</sup>                 | 2.57 <sup>a</sup>                 | 2.13 <sup>a</sup>                |
| 50 kg ha <sup>-1</sup> + RF      | 0.46 <sup>a</sup>                   | 1.13 <sup>a</sup>                   | 0.89 <sup>a</sup>                 | 2.57 <sup>a</sup>                 | 1.68 <sup>ab</sup>               |
| 70 kg ha <sup>-1</sup> + FB      | 0.62 <sup>a</sup>                   | 0.89 <sup>ab</sup>                  | 1.22 <sup>a</sup>                 | 2.16 <sup>a</sup>                 | 1.73 <sup>a</sup>                |
| 60 kg ha <sup>-1</sup> + FB      | 0.54 <sup>a</sup>                   | 1.12 <sup>ab</sup>                  | 1.08 <sup>a</sup>                 | 2.15 <sup>a</sup>                 | 1.22 <sup>ab</sup>               |
| 50 kg ha <sup>-1</sup> + FB      | 0.37 <sup>a</sup>                   | 1.11 <sup>ab</sup>                  | 1.26 <sup>a</sup>                 | 2.17 <sup>a</sup>                 | 0.76 <sup>b</sup>                |

DM: Dry matter; DAS: Days after sowing RF: Ridge & Furrow sowing method FB: Flatbed sowing method

**Table 5. Effect of seed rate, sowing method and its interaction on physiological growth attributes of soybean**

| Treatment                        | LAI at 31 DAS      | LAI at 41 DAS      | LAD at 31 DAS        | LAD at 71 DAS       | SLA at 31 DAS       | BMD at 61 DAS        |
|----------------------------------|--------------------|--------------------|----------------------|---------------------|---------------------|----------------------|
| <b>Seed rate</b>                 |                    |                    |                      |                     |                     |                      |
| 70 kg ha <sup>-1</sup>           | 1.59 <sup>ab</sup> | 2.93 <sup>b</sup>  | 4311.1 <sup>a</sup>  | 16790 <sup>a</sup>  | 529.61 <sup>b</sup> | 125.34 <sup>a</sup>  |
| 60 kg ha <sup>-1</sup>           | 1.65 <sup>b</sup>  | 4.11 <sup>ab</sup> | 4348.2 <sup>a</sup>  | 19539 <sup>a</sup>  | 654.51 <sup>a</sup> | 119.84 <sup>a</sup>  |
| 50 kg ha <sup>-1</sup>           | 1.78 <sup>a</sup>  | 5.05 <sup>a</sup>  | 4704.1 <sup>a</sup>  | 17182 <sup>a</sup>  | 669.12 <sup>a</sup> | 127.07 <sup>a</sup>  |
| <b>Sowing method</b>             |                    |                    |                      |                     |                     |                      |
| RF                               | 1.52 <sup>a</sup>  | 3.66 <sup>a</sup>  | 4145.4 <sup>b</sup>  | 19535 <sup>a</sup>  | 609.80 <sup>a</sup> | 129.02 <sup>a</sup>  |
| FB                               | 1.66 <sup>a</sup>  | 4.40 <sup>a</sup>  | 4763.5 <sup>a</sup>  | 16139 <sup>b</sup>  | 609.70 <sup>a</sup> | 119.15 <sup>b</sup>  |
| <b>Seed rate x Sowing method</b> |                    |                    |                      |                     |                     |                      |
| 70 kg ha <sup>-1</sup> + RF      | 1.44 <sup>a</sup>  | 2.93 <sup>a</sup>  | 3978.53 <sup>a</sup> | 16128 <sup>ab</sup> | 521.41 <sup>a</sup> | 118.58 <sup>ab</sup> |
| 60 kg ha <sup>-1</sup> + RF      | 1.38 <sup>a</sup>  | 3.67 <sup>a</sup>  | 3881.82 <sup>a</sup> | 22069 <sup>a</sup>  | 627.24 <sup>a</sup> | 128.62 <sup>ab</sup> |
| 50 kg ha <sup>-1</sup> + RF      | 1.75 <sup>a</sup>  | 4.39 <sup>a</sup>  | 4575.93 <sup>a</sup> | 20406 <sup>ab</sup> | 680.44 <sup>a</sup> | 139.87 <sup>a</sup>  |
| 70 kg ha <sup>-1</sup> + FB      | 1.74 <sup>a</sup>  | 2.93 <sup>a</sup>  | 4643.68 <sup>a</sup> | 17452 <sup>ab</sup> | 537.81 <sup>a</sup> | 132.10 <sup>ab</sup> |
| 60 kg ha <sup>-1</sup> + FB      | 1.43 <sup>a</sup>  | 4.55 <sup>a</sup>  | 4814.61 <sup>a</sup> | 17007 <sup>ab</sup> | 681.78 <sup>a</sup> | 111.07 <sup>b</sup>  |
| 50 kg ha <sup>-1</sup> + FB      | 1.81 <sup>a</sup>  | 5.71 <sup>a</sup>  | 4832.32 <sup>a</sup> | 13958 <sup>b</sup>  | 657.80 <sup>a</sup> | 114.27 <sup>ab</sup> |

LAI: Leaf Area Index, LAD: Leaf Area Duration, SLA: Specific Leaf Area, BMD: Biomass duration, RF: Ridge & Furrow sowing method, FB: Flatbed sowing method

### 3.3 Effect of Seed Rate and Sowing Method on Dry Matter Accumulation in Leaves, Stem and Pods in Soybean

Significant difference was observed for dry matter accumulation in leaves. Dry matter accumulation in leaves at 41 DAS was higher for 50 kg ha<sup>-1</sup> (1.12 g) while, dry matter accumulation in pods is highest for 60 kg ha<sup>-1</sup>

(1.74 g), which was at par with 70 kg ha<sup>-1</sup> (1.67 g). Dry matter accumulation in pods at 61 DAS is highest for ridge and furrow sowing method (1.85 g). Interaction studies revealed the highest dry matter accumulation (2.13 g) was observed for 60 kg ha<sup>-1</sup> in pod at 61 DAS, which was at par with 70 kg ha<sup>-1</sup> + ridge and furrow (1.75 g) and 70 kg ha<sup>-1</sup> seed rate + flat bed sowing method (1.73 g) (Table 4).

### 3.4 Effect of Seed Rate and Sowing Method on Physiological Growth Determinants in Soybean

Significant difference was observed for LAI at 31 DAS and 41 DAS with statistical no effect of sowing method and its interaction of LAI. Highest leaf area index was observed for lower seed rate of 50 kg ha<sup>-1</sup> at 31 DAS (1.78) and 41 DAS (5.05) (Table 5). Non-significant difference was observed for Leaf Area Duration due to seed rate but significantly affected by sowing method at 31 DAS, and 71 DAS with significant difference was observed for interaction between seed rate and sowing method. Highest Leaf area duration at 71 DAS was observed for Ridge and furrow sowing method (19535.00 cm<sup>2</sup> days) (Table 5). Interaction studies revealed highest Leaf Area Duration at 71 DAS for 60 kg ha<sup>-1</sup> seed rate with Ridge and furrow sowing method (22069.00 cm<sup>2</sup>.days). Nonsignificant difference was observed for Specific leaf area and Specific leaf weight at all duration except at 31 DAS for seed rate. Highest specific leaf area at 31 DAS was observed for 50 kg ha<sup>-1</sup> (669.12 cm<sup>2</sup> g<sup>-1</sup>) which was at par with 60 kg ha<sup>-1</sup> (654.51 cm<sup>2</sup> g<sup>-1</sup>). In contrast, for SLW non significant difference was observed at all the growth stages for seed rate, sowing method, and interaction. Nonsignificant difference for Crop Growth Rate (CGR), Net Assimilation Rate (NAR) and Relative Growth Rate (RGR) was observed for both the two factors and its interactions. Nonsignificant difference was observed for Biomass Duration (BMD) at all the stages for seed rate but a significant difference at 61 DAS was observed for sowing method and interactions of both factors. Biomass duration is the prevalence of biomass over time, reflecting the retention of biomass and higher dry matter accumulation capacity in plants. Highest Biomass Duration (129.02 g.days) was observed for ridge and furrow sowing method with superior interaction effect was observed for 50 kg ha<sup>-1</sup> seed rate with ridge and furrow sowing method (Table 5).

Plant height is one of the important growth parameters of any crop as it determines or modifies the yield contributing characters. In terms of seed rate, 60 kg ha<sup>-1</sup> was found to be superior over 50 kg ha<sup>-1</sup>. This confirms result found by De Bruin and Pederson (2008) who observed a 6 cm increase in the Final population from 258600 to 402700 plants. The minimal decrement of 0.16 % on plant height was observed due to 60 kg ha<sup>-1</sup> over control (70 kg ha<sup>-1</sup>). In terms of seed rate and sowing method

interaction, 60 kg ha<sup>-1</sup> seed rate with flatbed sowing method showed a 2.99% increment over control (70 kg ha<sup>-1</sup> seed rate with flatbed sowing method). Our result conforms with Autkar et al. [9] who reported that in ridges and furrow sowing, plant height was significantly superior to conventional flat bed sowing in increasing plant height due to better growth (CGR). Hamid et al. [10] also experimented on 40 kg ha<sup>-1</sup>, 60 kg ha<sup>-1</sup>, 80kg ha<sup>-1</sup>, and 100 kg ha<sup>-1</sup> seed rates and reported that plant height increased with an increase in seed rate.

The range of the number of branches plant<sup>-1</sup> was found to be 4.83 – 8.18. In terms of seed rate, 50 kg ha<sup>-1</sup> was found to be superior over 60 kg ha<sup>-1</sup>. The minimal increment of 31.52% on the number of branches plant<sup>-1</sup> was observed due to 50 kg ha<sup>-1</sup> over control (70 kg ha<sup>-1</sup>). In terms of seed rate and sowing method interaction, 50 kg ha<sup>-1</sup> seed rate with ridges and furrows sowing method showed 31.94% increment over control (70 kg ha<sup>-1</sup> seed rate with flatbed sowing method). The finding is in conformity with Rahman et al., [11] who justified that narrow spacing planting of crops increases plant density which decreased the number of branches plant<sup>-1</sup> because limited carbon will be available, which does not support more branching. Cox and Churney [12] also obtained a 20% reduction in the number of branches per plant by increasing sowing density from 321000 to 421000 plants ha<sup>-1</sup>. Higher plant density provides more competition for natural resources essential for vegetative growth and lesser grain formation. Our result confirms with Furuhashi et al. [13] who reported that a higher number of branches per plant was found in Soybean under ridge & furrow bed cultivation system. The number of branches plant<sup>-1</sup>, growth and yield attributes were highest in ridge sowing followed by broad bed & furrow and flat sowing [14]. Characters such as number of seeds per pod are not significantly influenced by seeding density as this characters are mostly influenced by genetic factors [6].

Seed yield per plant is the final expression of a plant's physiological and metabolic activities and a product of cumulative action of all factors contributing to better growth viz., no. of pods plant<sup>-1</sup>, no. of seeds pod<sup>-1</sup>, no. of branches plant<sup>-1</sup> and seed index. The range of seed yield (g plant<sup>-1</sup>) was found to be 7.33 – 10.65 g plant<sup>-1</sup>. In terms of seed rate, 60 kg ha<sup>-1</sup> was found to be superior over 50 kg ha<sup>-1</sup>. The minimal increment of 15.85% on seed yield (g plant<sup>-1</sup>) was observed due to 60 kg ha<sup>-1</sup> over control. In terms of the sowing method, ridges and furrows showed a

9.79% increment in seed yield ( $\text{g plant}^{-1}$ ) over control. In terms of seed rate and sowing method interaction,  $60 \text{ kg ha}^{-1}$  seed rate with ridges and furrows sowing method showed a 33.63% increment of seed yield ( $\text{g plant}^{-1}$ ) over control ( $70 \text{ kg ha}^{-1}$  seed rate with flatbed sowing method). Optimum seed rate is most important for the maximum yield of the crop. If more seed rate is used, the plant population will be more and there will be competition among plants for water, nutrient and sunlight resulting in low quality and low yield. Under lower plant population, radiation and light penetration over the canopy is efficient, leading to higher radiation use, photochemical reaction, photosynthetic rate, chloroplast development, Rubisco counter per area leading to efficient expression of seed yield. Several studies on Soybean indicated that a decrease in plant density produce greater growth of the individual plant [15,12,16] and consequently more leaf area, branches, pods and seeds per plant [17,18,12]. On the contrary, non-significant difference has been observed for seed yield per hectare between seed rate of  $70 \text{ kg/ha}$  and  $60 \text{ kg/ha}$  which is in consistent with results of De Bruin and Pederson [4], who reported that changes in the final population did not reflect any change in final soybean productivity. Under a low productive environment, efficient growth of single plant and yield components due to lower seed rate might not compensate for the higher final plant stand in lower planting density. Interaction studies revealed that highest seed yield  $4018.89 \text{ kg ha}^{-1}$  was observed for  $70 \text{ kg ha}^{-1}$  under flat bed sowing method. The result is in contradiction with an expression of maximum seed yield  $\text{plant}^{-1}$  for  $60 \text{ kg ha}^{-1}$  seed rate. Higher biological yield  $\text{kg ha}^{-1}$  was observed for  $50 \text{ kg ha}^{-1}$  which was at par with  $60 \text{ kg ha}^{-1}$ . The increment in biological yield under lower plant density might be due to higher radiation and light intensity interception over the canopy leading to higher leaf area, number of branches  $\text{plant}^{-1}$ , harvest index consequently causing higher biological yield. Interaction studies revealed that,  $60 \text{ kg ha}^{-1}$  seed rate with ridges and furrow sowing method showed a 29.58% increment of HI over control ( $70 \text{ kg ha}^{-1}$ ) with flat bed sowing method, which conforms with Basediya et al. [19] who reported that HI were found to be higher in ridge and furrow system as compared to flat bed sowing method. Higher HI under lower plant density might be due to maximum pods  $\text{plant}^{-1}$  and seed yield  $\text{plant}^{-1}$  due to exposure of plants to radiation and light leading to higher leaf area, more electron transport rate, photosynthetic activity,

with efficient partitioning of photo assimilates towards pods or sink leading to higher Harvest index.

Higher dry matter accumulation in leaves and pods under a lower seed rate might be due to higher light penetration in lower layers of the canopy. Therefore, optimum plant density produces optimum leaf area index and duration, leading to high radiation use, light capture, consequently leading to higher dry matter accumulation in pods and leaves. Leaf area index explains the ratio of leaf surface area to the ground area occupied by crop. It is the practical means of trapping solar energy and converting it into photoassimilates for growth and maintenance respiration. The leaf weight per plant decreases while the leaf area index (LAI) increases with plant population density [20]. The range of average LAI was found to be 2.53 – 3.47. In terms of seed rate,  $50 \text{ kg ha}^{-1}$  was found to be superior over  $60 \text{ kg ha}^{-1}$ . The minimal increment of 18.21% on LAI was observed due to  $50 \text{ kg ha}^{-1}$  over control ( $70 \text{ kg ha}^{-1}$ ). In terms of seed rate and sowing method interaction,  $50 \text{ kg ha}^{-1}$  seed rate with ridges and furrows sowing method showed 12.66% increment of LAI over control ( $70 \text{ kg ha}^{-1}$  seed rate with flatbed sowing method). Our result is consistent with Gudge [21], who reported that seed rates significantly influenced physiological parameters like crop growth rate, leaf area, leaf area index, chlorophyll content and rainwater use efficiency at most of the crop growth stages. The leaf area duration is an important factor that indicates an active period of leaf growth and leaves survival period, which is a significant factor in contributing to photo-assimilate production. More times the leaves remain active, they will produce more photosynthates. If this food material is properly translocated to the developing sinks, it will enhance economic productivity. Chauhan et al. [22] reported that the LAD measured at 30-45 days after sowing (DAS) had a positive and significant association with dry matter accumulation at 50% flowering. The range of average LAD was found to be 11393.05 – 14188.64  $\text{cm}^2 \cdot \text{days}$ . In terms of seed rate,  $60 \text{ kg ha}^{-1}$  was found to be superior over  $50 \text{ kg ha}^{-1}$  and  $70 \text{ kg ha}^{-1}$ . The minimal increment of 14.05% on LAD was observed due to  $60 \text{ kg ha}^{-1}$  over control. In terms of the sowing method, ridges and furrows showed a 5.62% increment on LAD over the flatbed sowing method. In terms of seed rate and sowing method interaction,  $60 \text{ kg ha}^{-1}$  seed rate with ridges and furrows sowing method showed a 17.12% increment of LAD over control

(70 kg ha<sup>-1</sup> seed rate with flatbed sowing method). This reduction in leaf area duration under high seed rate might be due to light and radiation limitation leading to premature senescence induced yellowing of leaves. Biomass duration is the prevalence of biomass over time, reflecting the retention of biomass and higher dry matter accumulation capacity. High Biomass duration under lower planting density and ridge and furrow sowing method might be attributed to better land configuration which conserve moisture under ridges with lesser effect of saturated moisture on the roots better light penetration due to optimal plant density. Our result conforms with Gudge [21], who reported that seed rates significantly influenced physiological parameters like Crop growth rate at most of the growth stages. The reduction in LAD under high seed rate might be attributed to light and radiation limitation leading to premature senescence-induced yellowing of leaves.

#### 4. CONCLUSION

The lower seed rate of 60 kg/ha significantly enhances plant height, harvest index, seed yield per plant, dry matter accumulation in pod at 61 DAS and LAI at 41 DAS. Seed productivity per hectare was highest for the seed rate of 70 kg/ha at par with 60 kg/ha. Ridge and Furrow sowing method significantly enhance biological yield, dry matter accumulation in pod, LAD and BMD. Interaction studies revealed the superior performance of 60 kg/ha and ridge and furrow sowing method for seed yield per plant, biological yield per plant and kg/ha, harvest index, dry matter accumulation in pod and LAD at 71 DAS. Seed yield per hectare is highest for 70 kg/ha seed rate with a flat bed sowing method which was at par with 60 kg/ha seed rate with ridge and furrow sowing method. Despite higher seed yield per plant, lower seed rate might not compensate for the yield loss over large area due to lack of plant population over higher seed rate. Hence, a higher seed rate of 70 kg/ha with ridge and furrow sowing will be recommended to the farmers to get a higher yield of soybean under a rainfed and low productive environment.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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