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Impact of Integrated Nutrient Management on Growth and Yield Characteristics of Mustard (*Brassica juncea* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The experiment was conducted at the Instructional Farm (SIF) of Chandra Shekhar Azad University of Agriculture and Technology in Kanpur, Uttar Pradesh in the *Rabi* season of 2023-24. A Randomized Block Design was used for statistical analysis, with 10 treatments and 3 replications. The primary

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objectives of this study involved assessing the crop growth and yield attributes, in mustard crops subjected to different treatments. These treatments consisted of various chemical fertilizers, bio fertilizers, and nano fertilizers used in different combinations. Results revealed that, the effect of treatment T_{10} [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}] was found to be best in terms of growth and yield attributes of crop, whereas minimum growth and yield attributes of crop was found under the effect of treatment T_5 [Nano urea @ 60ppm + RD of P&K (60:60)].

Keywords: Biofertilizer; nano urea; nano DAP; RDF.

1. INTRODUCTION

It is crucial for Indian agriculture to become more knowledge intensive to effectively address the challenges posed by a growing population, limited land availability, and diminishing energy resources [1]. The group of oil seed crops has a significant impact on India's agricultural economy, with a total yield of 22.1 million tonnes from an area of 25.4 million hectares. India holds the impressive position of being the fourth largest oilseed economy globally, following the U.S., China, and Brazil. It also ranks as the second biggest importer, after China. According to Jha *et.,* [2], this country contributes significantly to the global oilseeds area, vegetable oils production, and total edible oils consumption. With 13% of the total cultivated area, oil seeds are rather prominent on the agricultural landscape of the nation. They also make a valuable contribution to the Gross National Productivity (GNP), representing about 5% of it. Additionally, oil seeds contribute 10% of the overall value of agricultural products in the country [3].

Mustard, scientifically known as *Brassica juncea* (L.), is a significant oil seed crop that falls under the family "Cruciferae." According to a study by Bhowmik *et. al.* [4], the oil content in mustard seeds can range from 37-49 percent. These seeds are known for their high nutritional value, containing 38-57% erucic acid and 27% oleic acid. The oil cake residue is commonly used as cattle feed and fertilizer, with a nutrient composition of 5.1% nitrogen (N), 1.8% phosphorus pentoxide (P_2O_5), and 1.1% potassium oxide (K_2O). According to Mukherjee [5], this crop has the potential to be grown in the winter *(Rabi)* season because it can adapt well and make use of leftover moisture. The protein content of mustard seed is approximately 30-45%, making it a highly nutritious food. The seed and oil have various culinary uses, such as being used as a condiment in pickles and for adding flavor to curries and vegetables. In northern India, the oil is often used for cooking and frying foods. Additionally, it finds application in the formulation of hair oil, pharmaceuticals, and the production of greases. This substance is commonly employed in the production of soap and it is also utilized in combination with mineral oils to provide lubrication. The oil cakes serve a dual purpose, functioning as both cattle feed and manure. Green stems and leaves provide a nutritious source of fodder for cattle. Mustard oil is commonly utilized in the tanning industry to effectively soften leather, as noted by Singh and Singh [6].

Mustard is a significant oilseed crop. However, its productivity in the state falls short of its full potential. To enhance its yield, a combination of balanced fertilization and effective management practices are necessary. The role of nutrients in supporting plant growth and development cannot be overstated. They play a vital role in facilitating cell growth, cell enlargement, and nutrient transportation throughout different parts of the plant. The mustard plant has a greater demand for macro-nutrients, such as nitrogen, phosphorus, and potassium, in comparison to other nutrients. Understanding the importance of macro- nutrients is essential for assessing the fruit yield and quality of the citrus plant [7]. Nano-fertilizers have been developed to carefully release nutrients in a controlled manner, perfectly matching the specific requirements of the crop. The controlled release mechanism ensures that there is no premature interaction with the soil, water environment, or microorganisms. The plant system therefore effectively absorbs the nutrients once they are released. According to De la Rosa et al*.,* [8], these unique characteristics can improve the crop's nutrient use efficiency. Extensive use of chemical fertilisers has had negative consequences on soil quality, health, and productivity, as well as the pollution of surface and groundwater sources Hazarika et al*.,* [9].

Bio-fertilizers are specialized formulations that harness the power of micro- organisms to convert nutrients from their non-usable state into a form that can be readily absorbed by plants. This transformation occurs through a natural biological process. Bio- fertilizers have been shown to enhance both the quantity and quality of various plants. According to a study conducted by Yosefi et al*.,* [10], the combination of bio-fertilizers and chemical fertilizers has been found to enhance crop productivity and improve nutrient use efficiency.

Bio fertilizers have proven to be highly effective in producing impressive results when compared to chemical fertilizers. This is because each gram of carrier for bio fertilizers contains a minimum of 10 million viable cells of a specific strain [11]. In non-leguminous crops, biofertilizers like Azotobacter play a crucial role as nitrogen-fixing bacteria. Azotobacter has been found to enhance plant growth and increase crop yield in various soil conditions [12]. The bacteria are Gram-negative and exhibits polymorphism, with varying sizes and shapes. The size of these cells can vary, typically measuring between 2-10x1-2.5 µm. Mustard is a crucial oilseed crop that holds great economic importance. It is vital to optimize its production in order to ensure food security and support livelihoods in various regions.

2. MATERIALS AND METHODS

The experiment was conducted at Instructional Farm (SIF), Chandra Shekhar Azad University of Agriculture and Technology in Kanpur, which was served as the experimental site. Kanpur Nagar is a city in central Uttar Pradesh that is at a height of 125.9 meters above sea level on the alluvial tract of the Gangetic plains. Its coordinates are 25° to 28° North latitude and 79° to 80° East longitude. The semi-arid climate and rich alluvial soil characterize this northern zone. About 935 mm of rain falls on the region each year on average. Relative humidity (7 am) is relatively constant at about 80-90% from July to the end of March, gradually declines to about 40-50% by the end of April, and remains at 80% until June, even though temperatures in May and June can reach 44°C to 47°C or higher.

Edaphic condition: Soil samples were collected from different locations of the field before sowing and analyzed for some physio-chemical characteristics in the Laboratory at C.S. Azad University of Agriculture and Technology, Kanpur. The available Nitrogen in soil was 189.12 kg ha^{-1}, which was estimated by the Alkaline permanganate method given by Subbiah and Asija [13] the available Phosphorus was 14.60 kg ha^{-1} estimated by Olsen's method given by Olsen et al., [14]. The available K was 167.31 kg ha^{-1} which was estimated by the Flame photometer method given by Black (1965). The available S was 18.50 kg ha^{-1} which was estimated by the calcium extraction method given by William and Steinberg [15]. The soil of the experimental field was clayey in texture and slightly alkaline in pH (8.12), by using Glass Electrode pH was examined using Piper's [16] technique. The electrical conductivity (EC) of the soil was 0.39 (d S m^{-1}) estimated following method No. 4, USDA Hand Book by Piper (1950). Organic carbon in the soil was 0.42% which was estimated by rapid titration (wet oxidation) method given by Walkley and Black [17].

Treatment details: The experiment was laid out in Randomized Block Design with three replications. There were fourteen treatment combinations (T_1) RDF (120:60:60) + Sulphur @25 kg ha^{-1}, (T_2) RDF (120:60:60) + Azotobacter @2 kg ha^{-1}, (T_3) RDF (120:60:60) + PSB @4 kg ha^{-1}, (T_4) RDF (120:60:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}, (T_5) Nano urea @ 60ppm + RD of P&K (60:60), (T_6) Nano DAP @ 40ppm + RD of N&K (120:60), (T_7) Nano urea @ 60ppm + RD of P&K (60:60) + Azotobacter @2 kg ha^{-1}, (T_8) Nano urea @ 60ppm + RD of P&K (60:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}, (T_9) Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1}, (T_{10}) Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}.

Seed and Sowing: The necessary number of seeds was measured and planted in the furrows. The furrows were created at a row distance of 30 cm and a depth of 3.0-3.5 cm using the desi Plough. The recommended seed dosage of 5 kg per hectare was used for sowing.

Manure and fertilizer application: In the experimental field, well decomposed farmyard manure (FYM) at a rate of 2.4 tons per hectare, as well as vermicompost at a rate of 6 tons per hectare, was applied using the broadcasting method in each plot. These fertilizers were applied at different rates, as per the treatment of the recommended dose of NPKS (120:60:60:25 kg ha^{-1}). The remaining nitrogen was applied as top dressing in two separate split doses. The first top dressing was applied after 35 days after sowing (DAS), followed by the second application at 50 DAS. Application on nano Urea and nano DAP was done according to the treatment combinations 30 and 60 days after sowing.

Biofertilizer application: Biofertilizers Azotobacter and PSB were given by soil method @ 2 kg ha^{-1} and 4 kg ha^{-1} respectively by mixing with the organic manures before sowing of seeds.

3. RESULTS AND DISCUSSION

3.1 Plant Population

The analysis of effect of various treatments has been thoroughly examined and the results have been presented in Table 1. Upon examining the table, it becomes evident that the various treatment combinations had no significant impact on the plant population (plants m^{-2}). At 20 days after sowing (DAS) effect of treatments T_5 [Nano urea @ 60ppm + RD of P&K (60:60)] and T_6 [Nano DAP @ 40ppm + RD of N&K (120:60)] were found to be highest with 11.11 plants m^{-2} area whereas least plant population of 10.97 plants m^2 was found under the effect of treatment T_3 [RDF (120:60:60) + PSB @4 kg ha^{-1}]. Also, at harvest, effect of treatment T_{10} [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}] was found to be highest with 11.08 plants m^{-2} area whereas least plant population of 10.3 plants per m^2 was found under the effect of treatment T_5 [Nano urea @ 60ppm + RD of P&K (60:60)].

3.2 Plant Height (cm)

The data pertaining to plant height (cm) of mustard *(Brassica juncea* L.) at 30, 60, 90 and at harvest is presented in Table 1. The data revealed that, effect of treatment T_{10} [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}] was found best and recorded significantly the highest plant height (cm) i.e., 27.17 cm, 74.74 cm, 98.27 cm and 120.67 cm respectively. whereas, treatment T_5 [Nano urea @ 60ppm + RD of P&K (60:60)] recorded significantly the lowest plant height (cm) i.e., 21.75 cm, 67.16 cm, 93.85 and 108.02 cm respectively.

3.3 Number of leaves plant^{-1}

The data pertaining to number of leaves plant^{-1} of mustard *(Brassica juncea* L.) at 30, 60, 90 and at harvest is presented in Table 2. The data was revealed that, the effect of treatment T_{10} [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}] was found best and recorded significantly the highest number of leaves plant^{-1} i.e., 15.15, 19.89, 22.12 and 19.42 respectively, where- as treatment T_5 [Nano urea @ 60ppm + RD of P&K (60:60)] recorded significantly the lowest number of leaves plant^{-1} i.e., 7.77, 8.11, 15.18 and 7.52 respectively.

3.4 Number of Primary Branches Plant^{-1}

The data pertaining to number of primary branches plant^{-1} of mustard *(Brassica juncea* L.) at 60, 90 and at harvest is presented in the Table 3. The data revealed that, the effect of treatment T_{10} [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}] was found best and recorded significantly the highest number of primary branches plant^{-1} i.e., 5.38, 6.49 and 6.1 respectively, where- as treatment T_5 [Nano urea @ 60ppm + RD of P&K (60:60)] recorded significantly the lowest number of primary branches plant^{-1} i.e., 4.26, 5.64 and 5.08 respectively.

3.5 Number of Secondary Branches Plant^{-1}

The data pertaining to number of secondary branches plant^{-1} of mustard *(Brassica juncea* L.) at 60, 90 and at harvest is presented in Table 4. It was revealed that effect of treatment T_{10} [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}] was found best and recorded significantly the number of secondary branches plant^{-1} i.e., 10.19, 12.28 and 12.0 respectively. Whereas, treatment T_5 [Nano urea @ 60ppm + RD of P&K (60:60)] recorded significantly the lowest number of secondary branches plant^{-1} i.e., 8.24, 10.82 and 10.46 respectively.

3.6. Root Length (cm)

The analysis of effect of various treatments has been thoroughly examined and the results have been presented in Table 5. The root length (cm) per plant of mustard *(Brassica juncea* L.) depicts effect of treatment T_{10} [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}] was found best and recorded significantly the highest root length (cm) i.e.,71.28 cm. The 2nd best treatment i.e., T_4 [RDF (120:60:60) + Azotobacter @2 kg ha^{-1} +

PSB @4 kg ha^{-1}] was found with 70.89 cm root length (cm) where-as treatment T_5 [Nano urea @ 60ppm + RD of P&K (60:60)] recorded significantly the lowest root length (cm) i.e., 57.06 cm. It was also observed that the effect of Treatment T_4 [RDF (120:60:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}] and T_9 [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1}] was found statistically at par with treatment T_{10} [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}].

3.7 Days to 50% Flowering

The data pertaining to was recorded to Days to 50% flowering in presented Table 5**.** The effect of treatment T_{10} [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}] was found best and recorded significantly the lowest Days to 50% flowering i.e., 44.12 days. The 2nd best treatment i.e., T_4 [RDF (120:60:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}] was found with 44.39 days for 50% flowering where-as treatment T_5 [Nano urea @ 60ppm + RD of P&K (60:60)] recorded significantly the highest Days to 50% flowering i.e., 52.72 days. It was also observed that the effect of Treatment T_4 [RDF (120:60:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}] and T_9 [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1}] was found statistically at par with treatment T_{10} [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}].

Table 1. Effect of Integrated Nutrient [Nano fertilizer (nano urea and nano DAP) andbiofertilizer (azotobacter and PSB)] Management on Plant population (plants m^{-2}) and plant height (cm) of mustard

Symbols	Treatments	Plant population (plants m^{-2})		Plant height (cm)			
		20 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest
T1	RDF (120:60:60) + Sulphur @25 kg ha^{-1}	11.02	10.9	25.89	73.02	97.19	117.86
T2	RDF (120:60:60) + Azotobacter @2 kg ha^{-1}	11.01	10.72	24.61	71.3	96.11	115.08
T3	RDF (120:60:60) + PSB @4 kg ha^{-1}	10.97	10.78	25.1	72.51	96.8	117.22
T4	RDF (120:60:60) + Azotobacter @2 kg ha^{-1} +PSB @4 kg ha^{-1}	11.08	11.06	26.91	74.48	98.09	120.29
T5	Nano urea @ 60ppm + RD of P&K (60:60)	11.11	10.3	21.75	67.16	93.85	108.02
T6	Nano DAP @ 40ppm + RDof N&K (120:60)	11.11	10.42	22.54	68.37	94.44	110.16
T7	Nano urea @ 60ppm + RD of P&K (60:60) + Azotobacter @2 kg ha^{-1}	11.05	10.54	23.33	69.58	95.03	112.3
T8	Nano urea @ 60ppm + RDof P&K (60:60) + Azotobacter @2 kg ha^{-1} +PSB @4 kg ha^{-1}	11.06	10.6	23.82	70.09	95.42	112.94
T9	Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1}	11.05	11.02	26.68	74.23	97.88	120
T10	Nano DAP @ 40ppm + RDof N&K (120:60) + Azotobacter @2 kg ha^{-1} +PSB @4 kg ha^{-1}	11.09	11.08	27.17	74.74	98.27	120.67
F-test		**NS**	**NS**	**S**	**S**	**S**	**S**
S.E. (m) (±)		0.22	0.19	0.21	0.24	0.16	0.38
C.D. @ 5%		0.65	0.58	0.63	0.72	0.49	1.12
CV		3.43	3.14	1.49	0.59	0.3	0.57

Table 2. Effect of Integrated Nutrient [Nano fertilizer (nano urea and nano DAP) and biofertilizer (azotobacter and PSB)] Management on number of leaves per plant of mustard

Number of leaves plant^{-1}					
Symbols	**Treatments**	**30 DAS**	**60 DAS**	**90 DAS**	**At harvest**
T_1	RDF (120:60:60) + Sulphur @25 kg ha^{-1}	13.33	17.35	20.56	16.82
T_2	RDF (120:60:60) + Azotobacter @2 kg ha^{-1}	11.81	14.77	19	14.22
T_3	RDF (120:60:60) + PSB @4 kg ha^{-1}	12.07	15.31	19.43	14.77
T_4	RDF (120:60:60) + Azotobacter @2 kg ha^{-1} +PSB @4 kg ha^{-1}	14.95	19.58	21.91	19.04
T_5	Nano urea @ 60ppm + RD of P&K (60:60)	7.77	8.11	15.18	7.52
T_6	Nano DAP @ 40ppm + RDof N&K (120:60)	9.03	10.15	16.31	9.57
T_7	Nano urea @ 60ppm + RD of P&K (60:60) + Azotobacter @2 kg ha^{-1}	10.29	12.19	17.44	11.62
T_8	Nano urea @ 60ppm + RDof P&K (60:60) + Azotobacter @2 kg ha^{-1} +PSB @4 kg ha^{-1}	10.55	12.73	17.87	12.17
T_9	Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1}	14.59	19.39	21.69	18.87
T_{10}	Nano DAP @ 40ppm + RDof N&K (120:60) + Azotobacter @2 kg ha^{-1} +PSB @4 kg ha^{-1}	15.15	19.89	22.12	19.42
F-test		**S**	**S**	**S**	**S**
S.E. (m) (±)		0.21	0.35	0.21	0.34
C.D. @ 5%		0.63	1.03	0.63	1.01
CV		3.79	4.02	1.93	4.1

Table 3. Effect of Integrated Nutrient [Nano fertilizer (nano urea and nano DAP) and biofertilizer (azotobacter and PSB)] Management on number of primary branches per plant of mustard

Number of primary branches plant^{-1}				
Symbols	**Treatments**	**60 DAS**	**90 DAS**	**At harvest**
T1	RDF (120:60:60) + Sulphur @25 kg ha^{-1}	5.07	6.25	5.84
T_2	RDF (120:60:60) + Azotobacter @2 kg ha^{-1}	4.8	6.04	5.63
T_3	RDF (120:60:60) + PSB @4 kg ha^{-1}	4.86	6.08	5.64
T_4	RDF (120:60:60) + Azotobacter @2 kg ha^{-1} +PSB @4 kg ha^{-1}	5.34	6.46	6.08
T_5	Nano urea @ 60ppm + RD of P&K (60:60)	4.26	5.64	5.08
T_6	Nano DAP @ 40ppm + RDof N&K (120:60)	4.32	5.67	5.14
T_7	Nano urea @ 60ppm + RD of P&K (60:60) + Azotobacter @2 kg ha^{-1}	4.53	5.84	5.35
T_8	Nano urea @ 60ppm + RDof P&K (60:60) + Azotobacter @2 kg ha^{-1} +PSB @4 kg ha^{-1}	4.59	5.87	5.41
T_9	Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1}	5.28	6.42	6.04
T_{10}	Nano DAP @ 40ppm + RDof N&K (120:60) + Azotobacter @2 kg ha^{-1} +PSB @4 kg ha^{-1}	5.38	6.49	6.1
F-test		**S**	**S**	**S**
S.E. (m) (±)		0.07	0.05	0.04
C.D. @ 5%		0.22	0.14	0.13
CV		2.61	1.38	1.31

3.8 Days to 50% Maturity

The data pertaining to was recorded to days to 50% maturity in presented Table 5**.** It was found that the effect of treatment T_{10} [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}] was found best and recorded significantly the lowest Days to 50% maturity i.e., 56.56 days. The 2nd best treatment i.e., T_4 [RDF (120:60:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}] was found with 57.01 days for 50% maturity. Whereas, treatment T_5 [Nano urea @ 60ppm + RD of P&K (60:60)] recorded significantly the highest Days to 50% maturity i.e., 69.98 days. It was also observed that the effect of Treatment T_4 [RDF (120:60:60)

+ Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}] and T_9 [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1}] was found statistically at par with treatment T_{10} [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}].

3.9 Number of Siliquas Plant^{-1}

According to the Table 6 data pertaining to the number of siliquas plant^{-1} of mustard *(Brassica juncea* L.) depicts that the effect of treatment T_{10} [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}] was found best and recorded significantly the highest number of siliquas per plant i.e., 117.17. The 2nd best treatment i.e., T_4 [RDF (120:60:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}] was found with 116.84 number of siliquas per plant where-as treatment T_5 [Nano urea @ 60ppm + RD of P&K (60:60)] recorded significantly the minimum number of siliquas per plant i.e., 96.63. It was also observed that the effect of Treatment T_4 [RDF (120:60:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}] and T_9 [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1}] was found statistically at par with treatment T_{10} [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}].

3.10 Length of Siliqua (cm)

The data pertaining to length of siliqua of mustard is presented in the Table 6. It was found that, the effect of treatment T_{10} [Nano DAP @ 40ppm + RD of N&K (120:60) + *Azotobacter* @2 kg ha^{-1} + PSB @4 kg ha^{-1}] was found best and recorded significantly the highest length of siliqua (cm) i.e., 6.80 cm. The 2nd best treatment i.e., T_4 [RDF (120:60:60) + *Azotobacter* @2 kg ha^{-1} + PSB @4 kg ha^{-1}] was found with 6.71 cm length of siliqua (cm) where-as treatment T_5 [Nano urea @ 60ppm + RD of P&K (60:60)] recorded significantly the lowest length of siliqua (cm) i.e., 4.38 cm. It was also observed that the effect of Treatment T_4 [RDF (120:60:60) + *Azotobacter* @2 kg ha^{-1} + PSB @4 kg ha^{-1}] and T_9 [Nano DAP @ 40ppm + RD of N&K (120:60) + *Azotobacter* @2 kg ha^{-1}] was found statistically at par with treatment T_{10} [Nano DAP @ 40ppm + RD of N&K (120:60) + *Azotobacter* @2 kg ha^{-1} + PSB @4 kg ha^{-1}].

3.11 Number of Seeds Siliqua^{-1}

The data pertaining to number of seeds siliqua^{-1} of mustard is presented in the Table 6. It was found that the effect of treatment T_{10} [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}] was found best and recorded significantly the highest number of seeds per siliqua i.e., 20.2. The 2nd best treatment i.e., T_4 [RDF (120:60:60) + Azotobacter @2 kg ha^{-1}+ PSB @4 kg ha^{-1}] was found with 19.81 number of seeds per siliqua where-as treatment T_5 [Nano urea @ 60ppm + RD of P&K (60:60)] recorded significantly the lowest number of seeds per siliqua i.e., 12.95 days. It was also observed that the effect of Treatment T4

Table 4. Effect of Integrated Nutrient [Nano fertilizer (nano urea and nano DAP) and biofertilizer (azotobacter and PSB)] Management on number of secondary branches per plant of mustard

Number of secondary branches plant^{-1}				
Symbols	**Treatments**	**60 DAS**	**90 DAS**	**At harvest**
T_1	RDF (120:60:60) + Sulphur @25 kg ha^{-1}	9.66	11.89	11.64
T_2	RDF (120:60:60) + Azotobacter @2 kg ha^{-1}	9.12	11.55	11.28
T_3	RDF (120:60:60) + PSB @4 kg ha^{-1}	9.26	11.62	11.36
T_4	RDF (120:60:60) + Azotobacter @2 kg ha^{-1} +PSB @4 kg ha^{-1}	10.09	12.25	11.98
T_5	Nano urea @ 60ppm + RD of P&K (60:60)	8.24	10.82	10.46
T_6	Nano DAP @ 40ppm + RDof N&K (120:60)	8.38	10.91	10.54
T_7	Nano urea @ 60ppm + RD of P&K (60:60) + Azotobacter @2 kg ha^{-1}	8.79	11.21	10.92
T_8	Nano urea @ 60ppm + RDof P&K (60:60) + Azotobacter @2 kg ha^{-1} +PSB @4 kg ha^{-1}	8.93	11.28	11
T_9	Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1}	10.05	12.21	11.92
T_{10}	Nano DAP @ 40ppm + RDof N&K (120:60) + Azotobacter @2 kg ha^{-1} +PSB @4 kg ha^{-1}	10.19	12.28	12
F-test		**S**	**S**	**S**
S.E. (m) (±)		0.07	0.09	0.09
C.D. @ 5%		0.22	0.25	0.25
CV		1.36	1.27	1.3

Table 5. Effect of Integrated Nutrient [Nano fertilizer (nano urea and nano DAP) and biofertilizer (azotobacter and PSB)] Management on root length (cm), days to 50% flowering and days to 50% maturity of mustard

Symbols	Treatments	Root length (cm)	Days to 50% flowering	Days to 50% maturity
T_1	RDF (120:60:60) + Sulphur @25 kg ha^{-1}	68.1	46.12	59.86
T_2	RDF (120:60:60) + Azotobacter @2 kg ha^{-1}	64.92	48.12	62.92
T_3	RDF (120:60:60) + PSB @4 kg ha^{-1}	65.76	47.42	62.14
T_4	RDF (120:60:60) + Azotobacter @2 kg ha^{-1} +PSB @4 kg ha^{-1}	70.89	44.39	57.01
T_5	Nano urea @ 60ppm + RD of P&K (60:60)	57.06	52.72	69.98
T_6	Nano DAP @ 40ppm + RDof N&K (120:60)	59.4	51.42	68.26
T_7	Nano urea @ 60ppm + RD of P&K (60:60) + Azotobacter @2 kg ha^{-1}	61.74	50.12	65.98
T_8	Nano urea @ 60ppm + RDof P&K (60:60) + Azotobacter @2 kg ha^{-1} +PSB @4 kg ha^{-1}	62.58	49.42	65.2
T_9	Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1}	70.44	44.82	57.58
T_{10}	Nano DAP @ 40ppm + RDof N&K (120:60) + Azotobacter @2 kg ha^{-1} +PSB @4 kg ha^{-1}	71.28	44.12	56.56
F-test		S	S	S
S.E. (m) (±)		0.44	0.31	0.42
C.D. @ 5%		1.3	0.92	1.25
CV		1.16	1.12	1.16

[RDF (120:60:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}] and T_9 [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1}] was found statistically at par with treatment T_{10} [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}].

3.12. Weight of Seed Plant^{-1} (g)

The data pertaining to weight of seed siliqua^{-1} (g) of mustard *(Brassica juncea* L.) is presented in the Table 6. It depicts that, the effect of treatment T_{10} [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}] was found best and recorded significantly the highest weight of seed per siliqua (g) i.e., 16.37 g. The 2nd best treatment i.e., T_4 [RDF (120:60:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}] was found with 15.63 g weight of seed per siliqua (g) where-as treatment T_5 [Nano urea @ 60ppm + RD of P&K (60:60)] recorded significantly the minimum weight of seed per siliqua (g) i.e., 5.38. It was also observed that the effect of Treatment T_4 [RDF (120:60:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}] and T_9 [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1}] was found statistically at par with treatment T_{10} [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}].

3.13 1000 Seed Weight (g)

The data pertaining to the 1000 seed weight (g) of mustard (*Brassica juncea* L.) is presented in the the Table 6. This depicts that the effect of treatment T_{10} [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @ 2kg ha^{-1} + PSB @4 kg ha^{-1}] was found best and recorded significantly the highest 1000 seed weight (g) i.e., 6.92 g. The 2nd best treatment i.e., T_4 [RDF (120:60:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}] was found with 6.75 g 1000 seed weight (g) where-as treatment T_5 [Nano urea @ 60ppm + RD of P&K (60:60)] recorded significantly the minimum 1000 seed weight (g) i.e., 4.29 g. It was also observed that the effect of Treatment T_4 [RDF (120:60:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}] and T_9 [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1}] was found statistically at par with treatment T_{10} [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}].

Table 6. Effect of Integrated Nutrient [Nano fertilizer (nano urea and nano DAP) and biofertilizer (azotobacter and PSB)] Management on Number of siliquas per plant, Length of siliqua (cm), Number of seeds per siliqua, Weight of seed per plant (g) and 1000 seed weight (g) of mustard

Symbols	Treatments	Number of siliqua plant^{-1}	Length of siliqua (cm)	Number of seeds siliqua^{-1}	Weight of seed plant^{-1} (g)	1000 seed weight (g)
T_1	RDF (120:60:60) + Sulphur @25 kg ha^{-1}	111.73	6.25	18.78	13.25	6.31
T_2	RDF (120:60:60) + Azotobacter @2 kg ha^{-1}	106.29	5.70	17.06	10.34	5.70
T_3	RDF (120:60:60) + PSB @4 kg ha^{-1}	107.51	5.90	17.62	11.24	5.93
T_4	RDF (120:60:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}	116.84	6.71	19.81	15.63	6.75
T_5	Nano urea @ 60ppm + RD of P&K (60:60)	96.63	4.38	12.95	5.38	4.29
T_6	Nano DAP @ 40ppm + RD of N&K (120:60)	100.85	4.77	14.21	6.76	4.71
T_7	Nano urea @ 60ppm + RD of P&K (60:60) + Azotobacter @2 kg ha^{-1}	105.07	5.12	15.37	8.23	5.09
T_8	Nano urea @ 60ppm + RD of P&K (60:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}	102.07	5.32	15.93	8.66	5.32
T_9	Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1}	115.95	6.60	19.94	15.48	6.69
T_{10}	Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}	117.17	6.80	20.2	16.37	6.92
F-test		**S**	**S**	**S**	**S**	**S**
S.E. (m) (±)		0.74	0.53	0.25	0.38	0.09
C.D. @ 5%		2.19	0.74	0.74	1.13	0.27
CV		1.18	2.52	2.52	5.93	2.74

4. CONCLUSION

Treatment T_{10} [Nano DAP @ 40ppm + RD of N&K (120:60) + Azotobacter @2 kg ha^{-1} + PSB @4 kg ha^{-1}] was found to be best in terms of growth and yield attributes. It was found to have best effect in terms of yield attributes.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

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

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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