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EFFECT OF NUTRIENT MANAGEMENT AND CROP ESTABLISHMENT TECHNIQUE ON PRODUCTIVITY AND ECONOMICS OF INDIAN MUSTARD IN LATERITE SOIL OF WEST BENGAL, INDIA

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ABSTRACT

Mustard holds a significant position as one of the key rabi oilseed crops in India, encompassing an expansive 6.51 million hectares of cultivated land and yielding an impressive 7.67 million metric tons of production, albeit with a somewhat modest productivity rate of 1179 kilograms per hectare. This lower productivity is primarily attributed to suboptimal fertilizer application and the cultivation of mustard on marginal lands. Within the spectrum of seven edible oilseeds cultivated in India, rapeseed mustard stands out, contributing a substantial 28.6 percent to the overall oilseeds production. It secures the second position, trailing only behind groundnut, which commands a 27.8 percent share in India's oilseed economy. The existing disparity between oilseed production and demand continues to expand, underscoring the need for increased production to attain self-sufficiency. One potential avenue to bolster productivity and meet future demand lies in the adoption of the System of Mustard Intensification (SMI). During the rabi seasons of 2018-2019 and 2019-2020, a meticulous field experiment unfolded at the Agricultural Farm, Palli Siksha Bhavana, Visva-Bharati, Sriniketan. The study delved into the impact of crop establishment methods and nutrient management on Indian mustard, specifically the "Divya 33" variety. Employing a split-plot design with three replications, the experiment encompassed two distinct crop establishment techniques: drilling and transplanting. Additionally, it encompassed four distinct nutrient management strategies, denoted by their respective N:P_2O_5:K_2O ratios -60:30:30, 70:35:35, 80:40:40 and 90:45:45 (in kilograms per hectare). The findings unveiled notable disparities between these approaches. In the realm of crop establishment techniques, the transplanting method emerged as the frontrunner, yielding superior results in various parameters. Notably, it contributed to greater plant height, expanded leaf area, a higher count of leaves per plant, an augmented crop growth rate, and increased dry matter accumulation when compared to the conventional drilling method. Furthermore, the transplanting method spurred higher branch formation per plant, increased siliquae production per plant and a greater number of seeds per siliqua, resulting in higher seed and stover yields in contrast to the drilling approach. Turning our attention to nutrient management, the application of 90 kilograms of nitrogen (N), 45 kilograms of phosphorus (P_2O_5), and 45 kilograms of potassium (K_2O) per hectare proved to be particularly advantageous. This nutrient management regimen exerted a positive and favorable influence across a spectrum of growth and yield parameters, ultimately culminating in the attainment of maximum seed yield at 1480 kilograms per hectare and a robust stover yield of 3049 kilograms per hectare for the mustard crop. In conclusion, the results of this study strongly advocate for the adoption of the transplanting method for crop establishment, paired with a nutrient management strategy involving 90 kilograms of N, 45 kilograms of P_2O_5 and 45 kilograms of K_2O per hectare. This synergistic approach holds the potential to significantly enhance mustard crop productivity, particularly in the lateritic soil conditions prevalent in West Bengal.

Key words : Nutrient management, Mustard, SMI, Transplanting, Lateritic soil.

Introduction

Mustard (*Brassica* spp.) is globally recognized as one of the most pivotal oilseed crops, thriving in cool season conditions. This versatile crop exhibits a unique sensitivity to both temperature and light, a trait noted by Cao *et al.* (2021). Its popularity as an edible oil in rural

India cannot be overstated, as it plays a vital role in enhancing the flavor of numerous culinary delights. Moreover, mustard serves as a valuable raw material across various industries, finding applications in the production of soap, paints, varnishes, hair oils, lubricants, textile auxiliaries, pharmaceuticals and more. The significance of mustard in both the human diet and industrial sectors is paramount, contributing to improved nutrition, food security and income generation.

Oilseed crops, including mustard, offer tremendous promise by enriching human diets, combating malnutrition, alleviating food insecurity, and fostering economic opportunities (Rao and Annadana, 2017). They serve as versatile resources with diverse applications, crucially supporting global food security endeavors in terms of both quantity and quality. Vegetable oils, a product of oilseeds, should feature prominently in a balanced and healthy diet. They are abundant sources of unsaturated fatty acids, essential fatty acids such as linolenic and alpha-linolenic acids, vitamin E and importantly, they contain no dietary cholesterol (Saini *et al.*, 2021). Canada holds the distinction of being the largest producer of oilseed brassica, commanding a significant share of the global market, closely followed by China. India, while ranking third in terms of both cultivated area and production volume after Canada and China is the fifth-largest in terms of yield per hectare, trailing behind Germany, France, Canada and China (Tiwari and Singh, 2024). India's oilseed cultivation encompasses approximately 19% of the global area, contributing around 2.7% of global production. The country stands as a prominent oilseed producer and boasts the fifth-largest vegetable oil economy worldwide, with a substantial presence in oilseeds, oils, and oil meal production, as well as edible oil consumption, accounting for 7.4% of the global total. Within the Indian agricultural landscape, oilseeds represent the second most vital sector after cereals, growing at an impressive rate of 4.1% per annum over the last three decades. Among these oilseeds, the brassica family commands a significant share, encompassing 23.5% of the total oilseed area and contributing 24.2% to the overall production in the country (Mahto *et al.*, 2024). Despite ranking as the third-largest producer (11.3%) of oilseed brassica globally, following Canada and China, India still relies on imports to meet 57% of its domestic edible oil demand, consequently securing the seventh position among the world's largest importers of edible oils (Jat *et al.*, 2019). Key mustard-producing states in India include Rajasthan, Madhya Pradesh, Haryana, Uttar Pradesh, West Bengal, and Gujarat. In West Bengal, mustard cultivation occupies an area of 0.62 million hectares, resulting in a production of 0.79 million metric tons and a productivity rate of 1279 kilograms per hectare (2020-21). It is worth noting that mustard's productivity in West Bengal lags behind the national average. Several factors contribute to this, with the most prominent ones being cultivation in residual moisture conditions, the crop's sensitivity to light and temperature and the suboptimal adoption of good agronomic practices, such as selecting the optimum sowing date and planting geometry. The choice of plant population and sowing date significantly influences mustard yield and related parameters. Delayed sowing, often necessitated by various factors, adversely impacts yield due to its detrimental effects on plant growth, flowering duration, seed formation, and overall productivity. Late-sown mustard also faces a shorter growing period, as it contends with higher temperatures during the critical reproductive phase, resulting in diminished yields (Bazzaz *et al.*, 2020). In a general context, it has been consistently observed that mustard crops sown after the 30th of October tend to exhibit lower yields due to inherent limitations in their genetic potential. The competitive performance of rapeseed-mustard plants is closely linked to factors such as plant density per unit area and the overall fertility status of the soil. Ensuring a uniform distribution of crop plants across the field proves essential as it optimizes the efficient utilization of nutrients and moisture, while also effectively suppressing weed growth, ultimately resulting in higher yields. One of the primary reasons behind the forceful late sowing of mustard crops is the delayed harvesting of *kharif* crops. Consequently, adopting the early crop establishment technique through transplanting can be a more favorable alternative to minimize yield losses in mustard cultivation. The transplantation method not only aids in increasing crop intensity but also reduces the duration of the crop in the field by at least a fortnight, all without compromising on productivity. This approach offers a significant advantage to farmers who intend to cultivate mustard immediately after harvesting paddy or other *kharif* crops. Farmers can readily adopt this method to compensate for the 12-15-day nursery period required for mustard seedlings (Hedayetullah *et al.*, 2016). While it's true that transplanting the crop may involve higher initial costs compared to conventional drilling, it eliminates the need for subsequent thinning of the crop, which can also incur labor expenses. Transplanted crops boast precise and uniform plant populations, delivering time efficiency advantages following the harvest of *kharif* crops (Gautam *et al.*, 2023). A critical factor contributing to the subdued productivity of cultivated lands is the gradual decline in soil fertility. To counteract this issue and enhance both yield and seed quality, the judicious and balanced application of plant nutrients becomes imperative. Nitrogen (N) assumes particular significance in this regard, as it plays a pivotal role in determining mustard crop growth, protein content, methionine levels, dry matter accumulation, and overall yield. Phosphorus (P) and potassium (K) are known to exhibit enhanced utilization in the presence of nitrogen, with P notably influencing efficient crop establishment, winter hardiness and yield in oilseeds. However, it's worth noting that a substantial number of Indian soils are deficient in phosphorus, necessitating focused attention on its supplementation to maintain soil fertility. When applied in conjunction with N and K, phosphorus significantly boosts mustard yields. Potassium (K) also holds a vital position in augmenting the productivity and quality of various crops. Its influence extends to processes such as photosynthesis, water use efficiency, plant disease resistance, drought and cold tolerance, as well as the balance between protein and carbohydrate synthesis and oil deposition. Therefore, when transplanted mustard is coupled with a well-balanced fertilization strategy, it has the potential to substantially improve productivity in lateritic soils.

Materials and Methods

Description of the study area

The field study was conducted during the rabi seasons of 2018-19 and 2019-20 at the Agricultural Farm of Palli Siksha Bhavana, Visva-Bharati University, nestled in the Birbhum district of West Bengal. This location is situated at an elevation of approximately 58.9 meters above mean sea level and falls within the geographical coordinates of 23°39' North latitude and 85°67' East longitude (Fig. 1). The soil composition within the experimental field was characterized as sandy-loam, with a notable predominance of sand and a relatively lower proportion of clay. Specifically, the soil makeup consisted of 61.5% sand, 12.5% silt, and 26.0% clay. In terms of soil properties, the soil displayed a slightly acidic nature and fell within the category of moderately fertile soils. The soil organic carbon content was measured at 0.50%, indicating a modest presence of organic matter. Furthermore, the soil analysis revealed an availability of 135.5 kilograms per hectare of nitrogen, which could be classified as a moderate level. Phosphorus content in the soil was recorded at 11.90 kilograms per hectare, designating it as a medium level. Additionally, the soil exhibited a medium availability of potassium, with a measurement of 161.50 kilograms per hectare. This comprehensive soil profile information serves as a valuable foundation for understanding the agricultural conditions in which the *rabi* season experiments were conducted at the mentioned location.

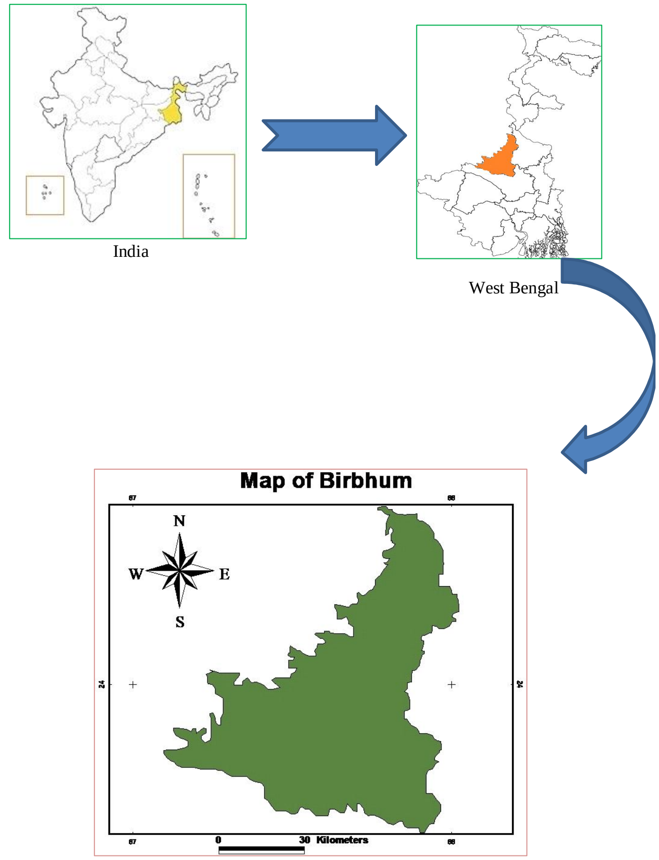

Fig. 1 : Map of the study area.

Climatically, Sriniketan is situated within the transitional zone between sub-humid and semi-arid tropics, resulting in a climate that exhibits moderate variability. Throughout the year, Sriniketan experiences diverse weather conditions. In May, the hottest month, the mean maximum and minimum temperatures range from approximately 42°C to 44°C, signifying warm and sometimes extreme heat. Conversely, during the coldest month, January, the mean monthly minimum temperature drops considerably to as low as 9.2°C. The monsoon typically arrives in the third week of June, ushering in a period of significant rainfall. Annually, Sriniketan receives an average rainfall of about 1190 millimeters, with approximately 80% of this precipitation concentrated within a relatively brief span of three months, spanning from mid-June to mid-September. The remaining 20% of the annual rainfall is distributed across the months of October through May. To provide a more specific context, the total rainfall received during the cropping period amounted to 74.1 millimeters, occurring over five rainy days in the 2018-19 season. In the subsequent year, during the 2019-20 season, the total rainfall for the cropping

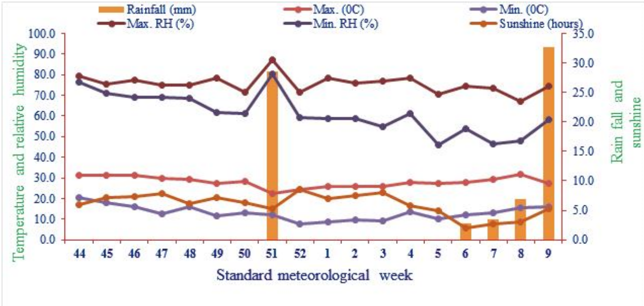

Fig. 2 : Meteorological observation during crop season during 2018-19.

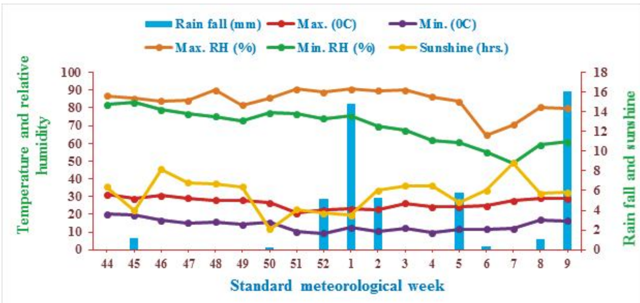

Fig. 3 : Meteorological observation during crop season during 2019-20.

period was recorded at 50 millimeters, also distributed across five rainy days. It's important to note that a day with rainfall equal to or exceeding 2.5 millimeters has been considered as a rainy day. For a more comprehensive understanding of the local weather conditions, detailed weather parameters can be found in Figs. 2 and 3, offering valuable insights into the climatic dynamics in the region.

Crop husbandry

The mustard variety 'Divya 33' was transplanted at spacing 50cm × 50cm, and spacing for drilling was 40 cm × 25 cm. The seed rate for drilling sowing was 3 kg ha^{-1} for conventional method and 250 g ha^{-1} for transplanting method. In first year of experiment, mustard was transplanted on 11^{th} November, 2018 and harvested on 4^{th} March, 2019 whereas drilling sowing on 14^{th} November, 2018 and on 6^{th} March, 2019 whereas in second year of experiment mustard transplanted on 13^{th} November, 2019 and harvested on 4^{th} March, 2020; drilling sowing on 22^{nd} November, 2019 and harvested on 7^{th} March, 2020. The experimental design employed for this study adhered to a split-plot design (SPD) framework. The primary plot treatments revolved around two distinct crop establishment methods: drilling and transplanting of the mustard crop. Within the sub-plots, four varying nutrient management strategies were implemented, encompassing the following $N:P_2O_5:K_2O$ ratios per hectare - 60:30:30, 70:35:35, 80:40:40 and 90:45:45. To provide more detail on the fertilizer application methodology, the full dosage of P_2O_5 was administered as a basal application, with half of the K_2O and N doses applied alongside it. For the transplanting method, this involved placement in holes created by a dedicated hole-making implement, while for drilling, it was carried out in a row-based placement. Subsequently, two rounds of top-dressing were carried out: the first at 30 days after transplanting (DAT) and 45 days after sowing (DAS), constituting a quarter of the N dosage. The second top-dressing session occurred at 45 DAT and 60 DAS, consisting of a quarter of the N dosage along with half of the K_2O. The fertilizers used in the experiment included urea for nitrogen, single super phosphate (SSP) for phosphorus, and muriate of potash (MOP) for potassium. Regarding irrigation, a total of four irrigations were systematically applied during the mustard crop's growth period. Irrigation was triggered when visual symptoms of wilting were detected in the young leaves, ensuring that the crop received adequate moisture to support its healthy development.

Data collection

In each experimental plot, a systematic sampling approach was adopted to assess various key parameters of the mustard crop. Specifically, five plants were randomly selected from the sampling row within each plot, and these plants were duly tagged for subsequent data collection. The recorded observations included plant height, the number of primary branches per plant, the number of siliquae (seed pods) per plant, and the count of seeds per siliqua. The remaining plants within the sampling row of each plot were reserved for the purpose of conducting a series of morphological and physiological assessments. These observations were conducted at 30-day intervals following either transplanting or sowing, and the assessments continued until the crop reached maturity and was ready for harvest. To determine seed yield characteristics, a seed counter was employed to accurately count 1000 seeds from the mustard crop. The weight of these 1000 seeds was subsequently measured using an electronic balance. Harvesting of the crop was carried out manually, utilizing sickles to cut the plants. This process commenced after leaving a border area around the plot to ensure accurate measurements. To determine the final yield values, net plots were demarcated initially from the portion of the plot that had been designated for recording seed yield. The harvested mustard plants were then subjected to a drying period, typically lasting 3 to 4 days, to reduce their moisture content to approximately 14%. The weight of the harvested plants, after sun drying and before threshing, was meticulously recorded. After threshing, the seeds were carefully separated from the plant material, cleaned, and subjected to additional sun drying. The weight of both the seeds and the remaining plant material, referred to as stover, were documented. Ultimately, the seed and stover yields were calculated in kilograms per hectare (kg ha^{-1}), with stover yield derived by subtracting the seed weight from the total weight of the harvested plants. This rigorous methodology ensured accurate and comprehensive data collection for the study's analysis. Harvest index was calculated using the formula as under:

$$\text{Harvest index (\%)} = \frac{\text{Seed yield}}{\text{Biological yield}} \times 100$$

Economics

Net return (ha^{-1}) is calculated by subtracting cost of cultivation from the gross return of each treatment. Net return (` $ha^{-1}$) = Gross return (` ha^{-1}) – Cost of cultivation (` ha^{-1}).

Benefit: Cost ratio was calculated by dividing gross return with total cost of cultivation.

$$\text{B: C ratio} = \frac{\text{Gross return per ha}}{\text{Cost of cultivation per ha}}$$

Statistical analysis

The data collected from the experiment underwent thorough analysis using the Analysis of Variance (ANOVA) technique. Subsequently, any significant differences in means were meticulously adjusted through the application of a multiple comparison test, as outlined by Gomez and Gomez in 1984. To assess the significance of various sources of variance, the error mean square was subjected to Fisher and Snedecor's 'F' test, employing a probability level of 0.05. Critical differences at the 5% significance level were determined by consulting Fisher and Yates' tables. Additionally, standard error of the mean (SEm ±) values were computed, along with the determination of the least significant difference (LSD), which served as a reliable metric for comparing the differences between treatment means. Beyond this, the study encompassed a correlation and regression analysis, focusing on establishing relationships between grain yield and other key yield attributing parameters. These analytical techniques were employed to derive comprehensive insights from the data and provide a robust foundation for drawing meaningful conclusions from the study.

Results

Plant height

Plant height is a crucial growth parameter that plays a significant role in influencing various yield-related characteristics in crops. In the context of mustard cultivation, the choice of crop establishment technique has been observed to exert a notable impact on plant height throughout different growth stages, as illustrated in Table 1. Notably, plants subjected to the transplanting method consistently exhibited greater height compared to those established through the drilling method. Furthermore, the application of different N, P, K doses through chemical fertilization demonstrated a discernible effect on plant height, as evident in Table 1. Among these various nutrient management approaches, it was observed that the tallest plants were recorded when treated with a combination of 90 kilograms of N, 45 kilograms of P_2O_5 and 45 kilograms of K_2O per hectare. This treatment outperformed other combinations, including 80 kilograms of N, 40 kilograms of P_2O_5, and 40 kilograms of K_2O per hectare; 70 kilograms of N, 35 kilograms of P_2O_5 and 35 kilograms of K_2O per hectare; and 60 kilograms of N, 30 kilograms of P_2O_5 and 30 kilograms of K_2O per hectare. These findings underscore the importance of both crop establishment techniques and nutrient management strategies in influencing plant height, a critical factor in determining overall crop performance and yield potential in mustard cultivation.

Dry matter accumulation

The data analysis revealed a consistent and progressive increase in dry matter accumulation throughout the observation period and this accumulation was significantly influenced by the choice of crop establishment technique, as detailed in Table 1. Notably, the results indicated that the highest aerial dry matter accumulation was consistently observed when mustard crops were established using the transplanting method, surpassing those established via drilling at all stages of growth. Furthermore, it was evident that mustard crops treated with 90 kilograms of N, 45 kilograms of P_2O_5, and 45 kilograms of K_2O per hectare exhibited the maximum dry matter accumulation. This treatment outperformed others, including the combination of 80 kilograms of N, 40 kilograms of P_2O_5 and 40 kilograms of K_2O per hectare, as well as 70 kilograms of N, 35 kilograms of P_2O_5 and 35 kilograms of K_2O per hectare. Conversely, the mustard crops receiving 60 kilograms of N, 30 kilograms of P_2O_5 and 30 kilograms of K_2O per hectare consistently exhibited the lowest levels of dry matter accumulation at all growth stages. These findings underscore the significant impact of both crop establishment techniques and nutrient management strategies on the dry matter accumulation in mustard crops. The choice of these factors plays a critical role in

Table 1 : Effect of crop establishment method and nutrient management on growth parameters of mustard crop at different growth stages (pooled data).

Treatments	Plant height (cm)			Dry matter accumulation (g plant^{-1})			Number of leaves plant^{-1}	
	30 DAT/DAS	60 DAT/DAS	90 DAT/DAS	30 DAT/DAS	60 DAT/DAS	90 DAT/DAS	30 DAT/DAS	60 DAT/DAS
Crop establishment								
Drilling	30.2	165	175	2.56	19.2	35.0	7.4	24.0
Transplanting	37.5	189	201	8.39	53.9	98.1	10.3	38.4
SEm (±)	0.7	1.6	2.1	0.17	0.95	1.48	0.21	0.53
LSD(p=0.05)	4.0	9.8	12.9	1.04	5.77	9.00	1.29	3.23
Nutrient management (N: P_2O_5: K_2O kg ha^{-1})								
60:30:30	29.4	150	162	4.11	22.2	43.8	8.3	24.0
70:35:35	33.5	178	188	4.82	32.0	63.7	8.3	28.9
80:40:40	33.9	184	196	5.89	41.3	75.9	8.6	32.8
90:45:45	38.6	196	206	7.07	50.6	82.8	10.2	38.9
SEm (±)	0.6	1.7	2.2	0.13	1.17	1.34	0.25	0.58
LSD p=0.05)	1.8	5.2	6.8	0.41	3.62	4.12	0.77	1.78

determining the overall biomass production and plant development during the growth phase of mustard cultivation.

Number of leaves plant^{-1}

The impact of crop establishment techniques was notably significant in influencing the number of leaves per plant at various growth stages during the experimental year, as presented in Table 1. The results elucidated a consistent trend wherein the number of leaves per plant in the mustard crop exhibited a gradual increase from 30 to 60 days after transplanting/sowing (DAT/DAS). However, it's noteworthy that by the 90 DAT mark, the transplanted mustard crop displayed no leaves, while the drilling method of crop establishment exhibited only a minimal number of leaves. In addition to the establishment technique, nutrient management emerged as a pivotal factor in regulating the number of leaves per plant in the mustard crop under scrutiny, as outlined in Table 1. Notably, different doses of chemical fertilizers demonstrated a significant influence on this parameter. The highest number of leaves per plant was observed in the presence of chemical fertilizers with an N:P2O5:K2O ratio of 90:45:45 kilograms per hectare, followed by ratios of 80:40:40 kilograms per hectare, 70:35:35 kilograms per hectare and 60:30:30 kilograms per hectare, consistently across all growth stages. These findings emphasize the interplay between crop establishment techniques and nutrient management practices in shaping the number of leaves per plant in mustard crops. It highlights the importance of carefully calibrated nutrient applications in optimizing leaf development and overall crop vigor during different growth phases.

Yield attributes

The influence of crop establishment techniques was strikingly evident in the recorded parameters of the mustard crop. Specifically, the highest number of primary branches per plant (8.1), number of siliquae per plant (595), and number of seeds per siliqua (14) were consistently observed in crops grown using the transplanting method of crop establishment, surpassing those established via drilling, as detailed in Table 2. The percentage increase in these attributes—number of branches per plant, number of siliquae per plant, and number of seeds per siliqua—achieved with the transplanting method over drilling was substantial, standing at 30.6%, 95.1% and 9.4%, respectively. Moreover, the results underscore the significant impact of nutrient management strategies on these parameters. Mustard crops treated with 90 kilograms of N, 45 kilograms of P_2O_5 and 45 kilograms of K_2O per hectare consistently exhibited a higher number of primary branches per plant (7.9), an increased number of siliquae per plant (619), and a greater number of seeds per siliqua (14.9). These outcomes outperformed those obtained with other fertilizer combinations, including 80:40:40 kilograms per hectare, 70:35:35 kilograms per hectare and 60:30:30

Table 2 : Effect of crop establishment method and nutrient management on yield parameters, yield and economics of mustard crop (pooled data).

Treatments	Number of primary branches plant^{-1}	Number of siliquae plant^{-1}	Number of seeds siliqua^{-1}	Test weight (g)	Seed yield (kg ha^{-1})	Stick yield (kg ha^{-1})	Net return (` ha^{-1})	B:C ratio
Crop establishment								
Drilling	6.2	305	12.8	5.9	837	1981	14507	1.62
Transplanting	8.1	595	14.0	7.1	1494	3068	44310	2.91
SEm (±)	0.3	14.3	0.1	0.2	22	87	1016	0.04
LSD (p=0.05)	1.7	87.2	0.9	1.2	134	531	6181	0.27
Nutrient management (N: P_2O_5: K_2O kg ha^{-1})								
60:30:30	6.4	331	11.7	5.3	792	1808	13299	1.59
70:35:35	7.0	383	12.9	6.1	1115	2372	27345	2.20
80:40:40	7.3	468	14.2	7.0	1276	2869	34208	2.47
90:45:45	7.9	619	14.9	7.6	1480	3049	42782	2.80
SEm (±)	0.2	11.1	0.2	0.2	27	57	1206	0.05
LSD (p=0.05)	0.7	34.1	0.6	0.7	83	176	3717	0.16

kilograms per hectare. These findings underscore the substantial influence of both crop establishment techniques and nutrient management strategies on primary branch development, siliqua formation, and seed production in mustard crops. The careful selection of these agricultural practices can significantly impact crop productivity and yield potential.

Test weight (g)

The 1000-seed weight observed in the experiment exhibited a range from 5.0 to 7.9 grams, and this variation was independent of the specific crop establishment technique and nutrient management strategies employed, as detailed in Table 2. In terms of the impact of crop establishment techniques, the transplanting method of crop establishment yielded the highest test weight, measuring 5.9 grams, in contrast to the drilling method, which resulted in a test weight of 7.1 grams. Regarding nutrient management, the application of 90 kilograms of N, 45 kilograms of P_2O_5 and 45 kilograms of K_2O per hectare yielded the maximum test weight, reaching 7.6 grams. This value was significantly higher than the test weights achieved with other fertilizer combinations, including 80 kilograms of N, 40 kilograms of P_2O_5 and 40 kilograms of K_2O per hectare (7.0 grams), as well as 70 kilograms of N, 35 kilograms of P_2O_5 and 35 kilograms of K_2O per hectare (6.1 grams). Conversely, the lowest test weight, measuring 5.3 grams, was recorded in the case of crops treated with 60 kilograms of N, 30 kilograms of P_2O_5, and 30 kilograms of K_2O per hectare. These findings underscore the notable influence of both crop establishment techniques and nutrient management strategies on the test weight of 1000 mustard seeds. The careful selection and optimization of these factors can significantly impact the weight and quality of mustard seeds, thereby affecting overall crop yield and quality.

Seed and stover yield

The results of the study highlighted the significant impact of the transplanting method of crop establishment on seed and stover yield, as depicted in Table 2. Specifically, the highest seed yield, amounting to 1494 kilograms per hectare (kg ha^{-1}) was recorded in crops grown using the transplanting method, surpassing those established through drilling, which yielded 837 kg ha^{-1}. This represented a substantial percentage increase of 78.5% in seed yield with the transplanting method compared to drilling. Furthermore, when considering the influence of nutrient management strategies, crops treated with 90 kilograms of N, 45 kilograms of P_2O_5 and 45 kilograms of K_2O per hectare exhibited significantly higher seed yield, totaling 1480 kg ha^{-1}. In contrast, those subjected to 80 kilograms of N, 40 kilograms of P_2O_5, and 40 kilograms of K_2O per hectare yielded 1276 kg ha^{-1}, while crops treated with 70 kilograms of N, 35 kilograms of P_2O_5 and 35 kilograms of K_2O per hectare yielded 1115 kg ha^{-1}. This corresponded to percentage increases in seed yield of 86.9%, 61.1% and 40.8%, respectively, when compared to crops receiving 60 kilograms of N, 30 kilograms of P_2O_5 and 30 kilograms of K_2O per hectare.

Similarly, the highest stover yield, totaling 3068 kg ha^{-1}, was achieved with the transplanting method of crop establishment, while the lowest stover yield, measuring 1968 kg ha^{-1}, was recorded with the drilling technique. Crops treated with 90 kilograms of N, 45 kilograms of P_2O_5, and 45 kilograms of K_2O per hectare also exhibited significantly higher stover yield, reaching 3049 kg ha^{-1}, compared to 80 kilograms of N, 40 kilograms of P_2O_5, and 40 kilograms of K_2O per hectare (2869 kg ha^{-1}), and 70 kilograms of N, 35 kilograms of P_2O_5, and 35 kilograms of K_2O per hectare (2372 kg ha^{-1}). These findings underscore the pivotal role of both crop establishment techniques and nutrient management strategies in influencing seed and stover yields in mustard crops, with the potential to significantly enhance overall crop productivity and resource utilization.

Simple regression between seed yield and yield attributes of mustard

The analysis revealed significant positive associations between several key parameters and the seed yield of mustard, as depicted in Figs. 4, 5, 6, 7, 8, 9 and 10. Branches per plant, siliquae per plant, number of seeds per siliqua, seed weight per plant (in grams), test weight (in grams), harvest index (in percentage), and stover yield (in kilograms per hectare) all exhibited noteworthy correlations with seed yield (Figs. 4, 5, 6, 7, 8, 9 and 10).

The increase in seed yield displayed a linear relationship with these correlated factors. Specifically,

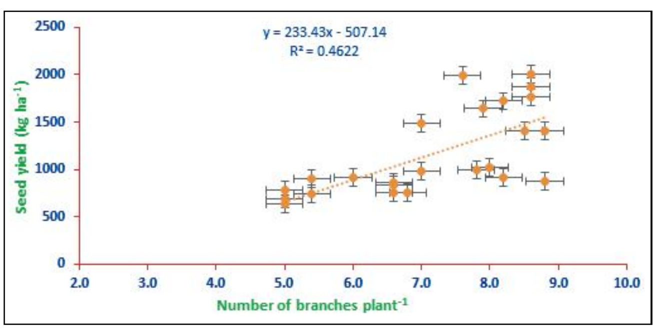

Fig. 4 : Relationship between seed yield and number of branches plant^{-1}.

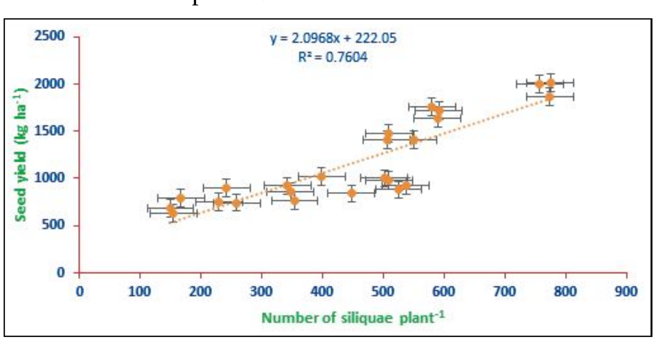

Fig. 5 : Relationship between seed yield and number of siliquae plant^{-1}.

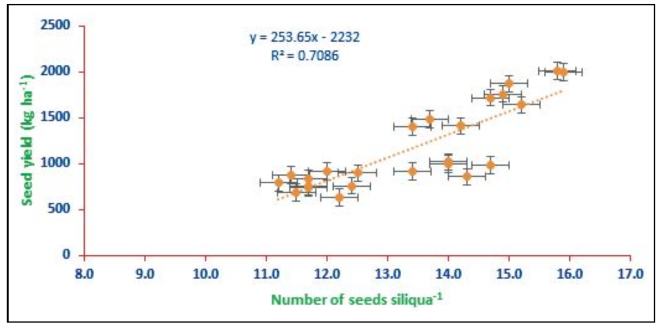

Fig. 6 : Relationship between seed yield and number of seeds siliqua^{-1}.

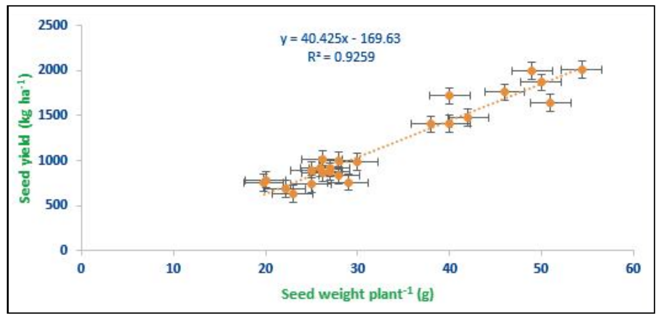

Fig. 7 : Relationship between seed yield and seed weight plant^{-1}.

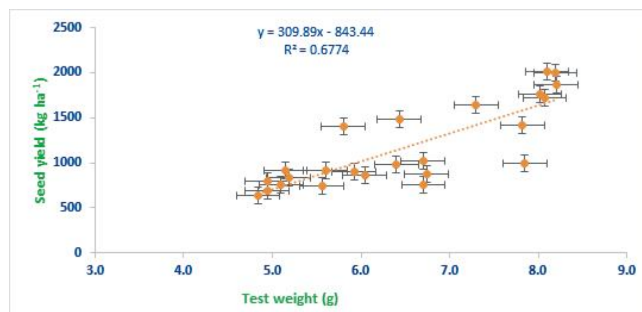

Fig. 8 : Relationship between seed yield and test weight plant^{-1}.

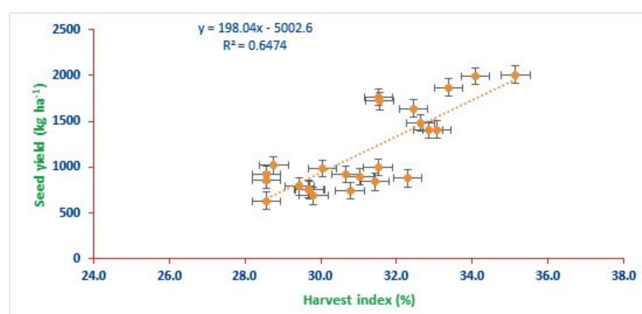

Fig. 9 : Relationship between seed yield and harvest index.

stover yield, accounting for a remarkable 96.92% of the variability, had a particularly strong influence on seed yield (Fig. 10). Similarly, the number of branches per plant explained 46.22% of the variability (Fig. 4), the number of siliquae per plant elucidated 76.02% of the variability (Fig. 5), the number of seeds per siliqua explained 70.86% of the variability (Fig. 6), seed weight per plant accounted

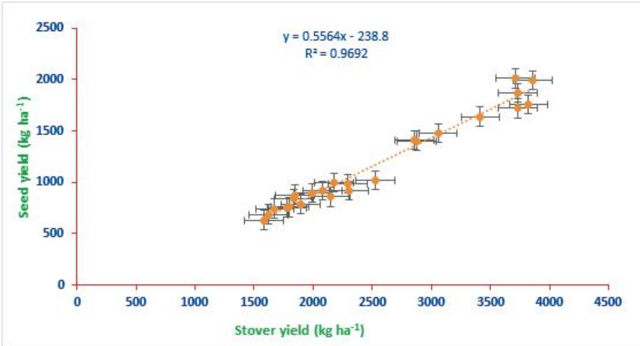

Fig. 10 : Relationship between seed yield and stover yield.

for 92.59% of the variability (Fig. 7), test weight elucidated 67.59% of the variability (Fig. 8) and harvest index accounted for 64.99% of the variability in seed yield (Fig. 9). These findings highlight the direct and substantial impact of increasing stover yield, branches per plant, siliquae per plant, number of seeds per siliqua, seed weight per plant (in grams), test weight (in grams) and harvest index (in percentage) on enhancing the seed yield of mustard crops. This knowledge underscores the importance of optimizing these factors to maximize mustard crop productivity effectively.

Discussion

Effect of crop establishment

The findings from this study underscore the viability of adopting the transplanting method for crop establishment, particularly in situations of late harvesting of *kharif* paddy and in lateritic soil environments, as a means to enhance mustard productivity. Plant height is a crucial growth parameter that plays a significant role in influencing various yield-contributing characteristics. The favorable plant height observed with the transplanting method of crop establishment may be attributed to the early transplanting of mustard seedlings, which occurred approximately 14 days earlier than drilling sowing. This early transplanting, combined with favorable weather conditions, likely contributed to the advantageous plant height observed. These results align with those reported by Chaudhary *et al*. (2017). Additionally, the transplanting method resulted in higher dry matter accumulation compared to the drilling method (Table 1). The prolonged maturity period observed in the transplanted crop, in comparison to conventional drilling, may be attributed to increased dry matter production and more robust growth. In contrast, drilling-sown crops exhibited lower dry matter accumulation, possibly due to lower root dry weight. This reduction in root dry weight may have been influenced by the delayed sowing of the crop, leading to shorter growth durations in higher temperatures during the latter phases of crop growth. The productivity of a crop is highly dependent on the number of leaves and the persistence of a high leaf area. Leaf area index typically increases after germination and reaches its peak before gradually declining due to leaf senescence. The increase in the number of leaves, as observed in the transplanted crop (Table 1), can be attributed to the higher plant height and vigorous growth resulting from the early establishment of the mustard crop under optimal weather conditions. Conversely, the delayed sowing in the drilling method led to a reduction in leaf area, likely due to the shorter crop duration and increased temperatures during the later stages of growth. The transplanting method of crop establishment also led to the highest number of primary branches per plant (Table 2). This outcome may be attributed to the early establishment of seedlings in the main field, with branching occurring primarily from the basal part of the main shoot in transplanted crops. Similar findings have been reported by Chaudhary *et al*. (2016) and Tyagi *et al*. (2017). Furthermore, the transplanted crops exhibited a significantly higher number of siliquae per plant compared to conventionally sown crops using the drilling method. This increased number of siliquae can be attributed to the greater number of branches in the transplanted crop, which, in turn, was largely influenced by the increased branching from the basal part of the main shoot in transplanted crops. These results align with previous findings by Kaur *et al*. (2024) and Chaudhary *et al*. (2016). The number of siliquae per plant is closely linked to the number of branches per plant. Conventional sowing through drilling resulted in a significant reduction in the average number of seeds per siliqua (Table 2). In contrast, the transplanting method of crop establishment recorded the maximum number of seeds per siliqua. This difference may be attributed to the vigorous growth of the transplanted crop and the greater supply of photosynthate to a larger number of sinks. The transplanted crop accumulated significantly more dry matter than the conventionally sown crop. This difference may be attributed to the higher root density observed in the transplanted crop, possibly due to increased soil nutrient and water uptake. The reduction in seed yield observed in the drilling-sown crop may be linked to decreased dry matter production, which could result from a decrease in photosynthetic rates, leading to reduced assimilate production for siliquae growth and seed filling. Additionally, the transplanted crop exhibited a longer reproductive period, resulting in better early crop yields. Conversely, delayed sowing led to a drastic reduction in yield due to a shorter reproductive period, as reported by Sharma *et al*. (2022). Higher seed and stover yields under the transplanting system for mustard have also been reported by Patel *et al*. (2023), Chaudhary *et al*. (2017), and Singh *et al*. (2019). These findings collectively highlight the potential benefits of adopting the transplanting method of crop establishment to optimize mustard crop productivity, particularly in lateritic soil environments and under conditions of late *kharif* paddy harvesting.

Effect of nutrient management

Achieving a balanced application of nutrients is a crucial aspect of crop production, not only for attaining higher yields but also for maintaining soil health. In this context, the balanced application of 90 kg N, 45 kg P_2O_5, and 45 kg K_2O per hectare proved to be highly effective, resulting in the maximum plant height compared to other nutrient management treatments. This positive outcome can be attributed to the initial low soil nitrogen (N) status, which was supplemented with additional N, stimulating meristematic activity, cell multiplication, cell elongation, and ultimately leading to increased plant height. Similar results were reported by de Bang *et al*. (2021) for mustard. A similar trend was observed in the case of phosphorus (P) and potassium (K) application. Increasing levels of P significantly contributed to greater plant height, consistent with findings from Cheema *et al*. (2012). The same effect was seen for K. The higher doses of N, P and K also led to significantly increased numbers of leaves and larger leaf areas per plant. This increase in leaf numbers and surface area was likely due to the enhanced uptake of N, P and K, resulting in improved plant height and an expanded photosynthetic surface area. Furthermore, the higher doses of N, P, and K contributed to greater dry matter accumulation in plants, which can be attributed to the increased uptake of these essential nutrients. This, in turn, accelerated the photosynthetic rate, leading to greater carbohydrate production. Similar results were observed by Damian *et al*. (2017) in Indian mustard for dry matter production. The same trend was observed for P and K, with higher levels of these nutrients resulting in increased dry matter accumulation. These findings align with those reported by Kapadia *et al.* (2021) and Kumar and Yadav (2007) in Indian mustard. The number of branches per plant also increased with higher levels of N, P and K application. The positive effects of higher N doses can be attributed to their direct role in the formation of protoplasm and chlorophyll molecules in leaf cells, thereby increasing the photosynthetically active leaf area. This increased availability of photosynthates was reflected in profuse branching. Similar findings were reported by Marimuthu *et al.* (2024) and Labudda *et al.* (2022). Higher nitrogen application at recorded doses had a positive impact on various yield attributes. The number of siliques per plant, number of seeds per siliqua, and test weight of seeds were all highest at the 90:45:45 kg NPK per hectare application rate (Table 2). The favorable effects of increasing N levels on various yield attributes can be attributed to the increased production of vegetative parts, with a corresponding increase in photosynthate production, and a proportional allocation of assimilates for reproductive growth. Additionally, higher N doses were responsible for more efficient utilization of P and K, further enhancing both vegetative and reproductive growth. These findings are consistent with the research of Sharifi *et al*. (2024) and Barłóg *et al.* (2022). Similar positive responses were observed in yield attributes with varying levels of P and K. Both phosphorus and potassium had a beneficial effect on yield attributes, as also reported by Mozaffari *et al*. (2012) and Kumar *et al*. (2016) in mustard. The application of 90 kg N, 45 kg P_2O_5 and 45 kg K_2O per hectare resulted in higher growth attributes, along with improved yield attributes, ultimately leading to increased seed and stover yields in mustard. This positive effect of N, P, and K application on mustard seed yield has been corroborated by previous studies such as those conducted by Ray (2023), Mozaffari *et al*. (2012) and Kumar *et al*. (2016). Additionally, the harvest index increased with the increasing levels of NPK application. The application of 90 kg N, 45 kg P_2O_5 and 45 kg K_2O per hectare also recorded the highest test weight compared to other nutrient management levels. This can be attributed to the positive effects of nutrient management on overall yield. These results are in line with the findings of Kumar *et al*. (2016).

Conclusion

Sustainable crop production will obviously require optimum crop stand and enhanced flows of nutrients to crops. This in turn will involve supply of optimum supply nutrient from reserves in soils and addition of nutrient in balanced ratio. The transplanting method of crop establishment not only compensate late harvesting of *kharif* paddy but also advantageous in respect to growth, productivity and profitability. In the same time balanced application of 90 kg N, 45 kg P_2O_5 and 45 kg K_2O ha^{-1} was best treatment for maximum crop growth, yield, net return and B: C ratio of mustard. From the present study it may be concluded that transplanting method of crop establishment technique with 90 kg N, 45 kg P_2O_5 and 45 kg K_2O ha^{-1} may be promote for improving the productivity and profitability of the mustard crop in lateritic soil.

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