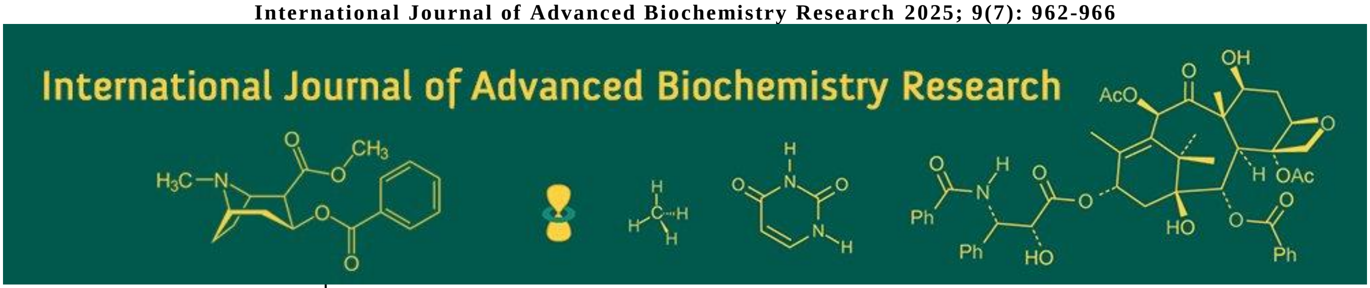

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Optimizing sowing schedule and nutrient strategies for enhanced soil fertility and yield performance of Toria (*Brassica rapa* L.) in the indo-Gangetic region

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Abstract
A field experiment was conducted during the Rabi season of 2024-25 at the Crop Research Farm, Maharishi University of Information Technology, Lucknow (Uttar Pradesh), to evaluate the interactive effects of sowing dates and integrated nutrient management on soil fertility, growth, and yield of *Toria* (*Brassica rapa* L.). The study was laid out in a Factorial Randomized Block Design (FRBD) with three replications, comprising nine treatment combinations involving four sowing dates (25th August, 5th September, 15th September, and 25th September) and five nutrient management regimes: 100% organic, 100% inorganic, 75% organic + 25% inorganic, 50% organic + 50% inorganic, and 25% organic + 75% inorganic. The variety PSC 601 was used as the test crop.
The results indicated that maximum vegetative growth parameters (plant height, leaf number, and biomass accumulation) were observed under higher proportions of organic nutrient application. However, the highest values for yield attributes—including grain yield, straw yield, biological yield, 1000-seed weight, and number of seeds per silique—were recorded under integrated nutrient management treatments combining organic and inorganic sources. Nutrient uptake analysis revealed minimal uptake of nitrogen (N), phosphorus (P), and potassium (K) in treatments receiving either 100% organic or higher proportions of inorganic fertilizers, whereas integrated applications enhanced nutrient absorption significantly.
Among the sowing dates, delayed sowing—particularly on 25th September—resulted in superior performance in terms of growth, yield components, and nutrient uptake. The findings suggest that, under agro-climatic conditions of the eastern Indo-Gangetic region, sowing Toria (PSC 601) on 25th September, coupled with a balanced application of organic and inorganic fertilizers, optimizes soil fertility and crop productivity.

Keywords: *Toria*, *Brassica rapa* L., sowing date, integrated nutrient management, organic fertilizers, inorganic fertilizers, soil fertility, PSC 601, Indo-Gangetic plains

Introduction
Oilseed crops have historically served as the backbone of numerous agricultural economies and continue to play a vital role in global agricultural industries and trade. These crops contribute significantly to the supply of edible oils and are second only to cereals in terms of importance in the global agricultural economy. In addition to their nutritional value—supplying essential fatty acids—oilseeds are used in the production of animal feed and have diverse applications in the pharmaceutical, biofuel, and oleochemical industries (Kumar *et al.*, 2023) [6].
India is one of the leading agricultural producers globally, ranking first in the production of spices, milk, and pulses, and possessing the largest cultivated area under rice, wheat, and cotton. It ranks second in vegetable and fruit production, and third in the production of cereals. The country benefits from a wide array of agro-climatic conditions, ranging from temperate to tropical zones, with 15 agro-climatic zones and 20 agro-ecological regions. India is also the fourth-largest producer of oilseeds globally, contributing approximately 25.60% to the world's total oilseed production.
Among oilseeds, mustard/rapeseed (*Brassica* spp.) ranks third in global importance after palm oil and soybean.

Major oilseed-producing countries include India, Canada, the United States, China, Bangladesh, Iran, Nepal, and Afghanistan (Staff, 2024).

Toria (*Brassica rapa* L. subsp. *dichotoma*), also known by regional names such as turnip rape, field mustard, sarson, tori, laahi, and bird rape, is a significant species within the genus *Brassica*—the largest genus of the oilseed family Brassicaceae. Toria serves multiple purposes: it provides edible oil, leafy vegetables, and high-quality fodder. It is recognized as one of the oldest oilseed crops cultivated by farmers.

Toria is particularly sensitive to water stress during its pre-flowering stage, which can severely impact growth and yield. It requires cool and dry weather throughout the growing season, with a fair supply of soil moisture. However, it does not tolerate excessive water or water-logged conditions. Dry and clear weather at the maturity stage improves both oil content and overall yield (Rahman *et al.*, 2020) [17]. In India, toria is typically cultivated as a Rabi crop, sown between September and October and harvested by February or March. The recommended seed rate is about 1.5 kg per acre. It performs best in sandy loam to clay loam soils, particularly light loams, with neutral pH being optimal for healthy growth and development (Alam *et al.*, 2017; Singh *et al.*, 2023) [17, 8].

Due to the crop's susceptibility to seed shattering at maturity, timely harvesting before pod dehiscence is crucial to minimize yield losses (USDA-ARS, 2018).

Plant nutrition is a critical determinant of crop growth, development, and yield. Essential nutrients, both macro-and micronutrients, must be available for plants to complete their life cycle and perform vital metabolic. Fertilizers—organic or inorganic—play a pivotal role in fulfilling the nutritional needs of crops. Organic fertilizers, such as farmyard manure (FYM), compost, and plant residues, improve soil health and gradually release nutrients. In contrast, inorganic (synthetic) fertilizers offer immediate nutrient availability but may impact soil structure over time if used indiscriminately (Baghdadi *et al.*, 2021) [14].

Optimal performance of toria is influenced by multiple agronomic and environmental factors such as climate, weather conditions, soil properties, sowing time, and nutrient availability. Among these, sowing time is one of the most manageable and influential factors. Early or timely sowing ensures synchronization of the crop's reproductive stages with favorable environmental conditions. Conversely, delayed sowing shortens the silique-filling period, exposes the crop to high terminal temperatures, and reduces seed yield through hastened maturity and drought stress (Alam *et al.*, 2020) [17].

Thus, the selection of an appropriate sowing date and nutrient management strategy is crucial for maximizing the productivity and profitability of toria cultivation. Adopting suitable agronomic practices tailored to regional agro-climatic conditions can significantly enhance yield performance and oil quality.

Materials and Methods

A field experiment was conducted during the Rabi season of 2024-25 at the Research Farm, Department of Agronomy, Maharishi University of Information Technology, Lucknow, Uttar Pradesh, to evaluate the influence of different sowing dates and nutrient management practices on the performance of toria (*Brassica rapa* L.) in terms of growth, yield, and soil fertility. The experimental site, situated in the Indo-Gangetic Plains, is characterized by a subtropical climate. The soil of the experimental field was sandy loam in texture, neutral in reaction, with medium available nitrogen, high phosphorus, and low potassium content. Soil analysis was performed prior to sowing using standard procedures.

The experiment was laid out in a Factorial Randomized Block Design (FRBD) with three replications, comprising four sowing dates (25th August, 5th September, 15th September, and 25th September) and five nutrient management treatments: 100% organic (FYM + vermicompost), 100% inorganic (Recommended Dose of Fertilizers), 75% organic + 25% inorganic, 50% organic + 50% inorganic, and 25% organic + 75% inorganic. The toria variety used was PSC 601, a high-yielding, short-duration cultivar suitable for the Rabi season.

The field was prepared by thorough ploughing and leveling with the help of a power tiller, followed by manual removal of debris and residues. Plots were laid out as per the treatment plan. Sowing was done on the designated dates using line sowing at a spacing of 30 cm between rows and 10 cm between plants, with a seed rate of 1.5 kg per acre. Irrigation was provided based on soil moisture availability and crop requirements. Weed control was managed through manual weeding, with the first weeding done 10 days after germination and the second at 30 days, followed by regular hoeing and weeding as necessary. Harvesting was carried out at the physiological maturity stage, just before pod shattering, to avoid seed loss.

Observations were recorded on various growth and yield parameters, including germination count (plants/m^2), plant height, root length, dry matter accumulation, number of siliques per plant, seeds per silique, 1000-seed weight, biological yield, economic yield (seed and straw), and harvest index. Post-harvest soil samples were analyzed for nutrient status, and plant samples were assessed for nutrient uptake using standard procedures (Lindsay and Norvell, 1978).

The recorded data were statistically analyzed using the analysis of variance (ANOVA) technique as per the method described by Panse and Sukhatme (1985). The standard error of the mean (SEm) was calculated, and the treatment means were compared using the critical difference (CD) at the 5% level of significance to determine statistical significance among the treatments.

Results and Discussion

Effect of Nutrient Management on Growth, Yield, and Nutrient Uptake of Toria

The analysis of variance revealed significant effects of nutrient management on the growth, yield attributes, and nutrient uptake of *Toria* (*Brassica rapa* L.). Among all treatments, the application of 100% inorganic fertilizer (F_2) consistently resulted in superior performance for all measured growth parameters.

The germination count and plant population per square meter were significantly higher in the F_2 treatment, which can be attributed to the immediate solubility and availability of essential nutrients in inorganic fertilizers, thereby ensuring better seedling emergence and establishment. In contrast, the lowest values for these parameters were recorded in F_5 (25% organic + 75% inorganic), indicating suboptimal nutrient release from organic sources during the early growth phase. These findings corroborate the observations of Singh *et al.* (2015), who reported improved seedling vigor under mineral nutrition.

Similarly, plant height and root length were significantly influenced by nutrient levels, with the tallest plants and longest roots recorded under F_2. This can be attributed to the sufficient and balanced supply of nitrogen and phosphorus, essential for vegetative growth and root development. In comparison, limited early nutrient release in organically dominated treatments (especially F_5) may have restricted initial growth due to slower mineralization rates.

The treatment F_2 also led to the maximum dry matter accumulation, reflecting robust vegetative growth and enhanced photosynthetic activity. Yield attributes such as number of seeds per silique and 1000-seed weight also peaked in F_2, likely due to better nutrient availability during the reproductive phase, facilitating higher assimilate translocation to developing seeds. These results are consistent with those reported by Keivanrad and Zandi (2022) [13].

The grain yield, straw yield, and biological yield of toria showed a similar trend. The highest grain yield (1575 kg ha^{-1}) and biological yield were obtained under 100% inorganic nutrient application. The superior yield performance under F_2 is possibly due to enhanced growth parameters and improved reproductive efficiency under optimal nutrient conditions. The harvest index also improved under F_2, indicating efficient biomass partitioning. These results are in line with the findings of Kumar *et al.* (2021) [15], who emphasized the positive impact of balanced nutrient supply on the productivity of *Brassica* crops.

Nutrient uptake analysis revealed that the highest uptake of nitrogen (3.29 kg ha^{-1}), phosphorus (0.64 kg ha^{-1}), and sulphur (1.04 kg ha^{-1}) was recorded under F_2. This corresponds with the higher biomass production and yield components observed in this treatment. In contrast, F_5 resulted in the lowest uptake of all three nutrients. Although organic amendments contribute to long-term soil health, their slower nutrient release can limit early-stage uptake. These findings support the conclusions of Baghdadi *et al.* (2021) [14] and Mookherjee and Malik (2023) [8], who reported delayed nutrient availability from organic sources but emphasized their cumulative long-term benefits.

Effect of Sowing Dates on Growth, Yield, and Nutrient Uptake of Toria

Sowing date exerted a significant influence on all studied parameters of *Toria*. Notably, germination count and plant population improved with delayed sowing, with the highest values observed under 25th September sowing (S_4). This could be attributed to favorable ambient temperatures and soil moisture levels during the later sowing window, which supported better seedling emergence. These findings are consistent with reports by Kumar *et al.* (2022) [12] and Aziz *et al.* (2024) [4].

On the contrary, very early sowing (25th August; S_1) resulted in reduced plant population, possibly due to high soil temperatures and erratic moisture conditions leading to seedling stress and mortality. Moreover, excessively delayed sowing could negatively impact yield due to shortened growth duration and exposure to terminal heat stress during the reproductive phase, as noted by Shamina *et al.* (2024) [5].

Plant height and root length progressively increased with delayed sowing. At 25, 50, and 75 days after sowing (DAS), the longest root lengths were consistently recorded in S_4, indicating vigorous vegetative development under moderate environmental conditions. Additionally, dry matter accumulation was significantly higher in S_4, suggesting enhanced photosynthetic efficiency and carbohydrate assimilation.

In terms of yield components, the highest number of seeds per silique (12.48) and 1000-seed weight (3.38 g) were also recorded in the 25th September sowing treatment. These results suggest that delayed sowing favored optimal flowering and seed development under relatively cooler and stress-free conditions. The cumulative effect of improved growth and reproductive parameters in S_4 translated into the highest grain yield, straw yield, and biological yield among all sowing dates.

The harvest index was also positively influenced by delayed sowing, indicating better partitioning of assimilates to economic yield. Furthermore, nutrient uptake analysis showed that the highest uptake of nitrogen (3.29 kg ha^{-1}), phosphorus (0.64 kg ha^{-1}), and sulphur (1.04 kg ha^{-1}) was achieved under S_4. These results align with the yield data and reflect the better overall physiological performance of the crop under this sowing window.

The interaction between nutrient management and sowing dates played a critical role in the performance of *Toria*. While 100% inorganic fertilization (F_2) ensured superior growth and yield attributes, the combination with 25th September sowing (S_4) proved to be the most productive and efficient in terms of nutrient uptake and yield realization. However, from a sustainability perspective, partial replacement of inorganic inputs with organic amendments (e.g., F_3 or F_4) could be explored in further studies to balance productivity with long-term soil health.

Table 1: Effect of integrated nutrient management and sowing dates on germination percentage of *Toria* (*Brassica rapa* L.)

Treatment	Germination%
Fertilizer	
F1 100% organic	6.75
F2 100% inorganic	6.96
F3 75% organic + 25% inorganic	6.23
F4 50% organic + 50% inorganic	6.44
F5 25% organic + 75% inorganic	6.07
Sem±	0.14
C.D. (5%)	0.28
Sowing date	
S1 25th August	5.97
S2 5th September	6.48
S3 15th September	6.58
S4 25th September	6.92
Sem±	0.18
C.D. (5%)	0.37

Table 2: Influence of nutrient management and sowing windows on plant population per meter row length of *Toria* in Indo-Gangetic plains

Treatment	Plant population (m2)
Fertilizer	
F1 100% organic	7.04
F2 100% inorganic	7.22
F3 75% organic + 25% inorganic	6.76
F4 50% organic + 50% inorganic	6.74
F5 25% organic + 75% inorganic	6.90
Sem±	0.32
C.D. (5%)	NS
Sowing date	
S1 25th August	6.68
S2 5th September	6.96
S3 15th September	6.93
S4 25th September	7.16
Sem±	0.16
C.D. (5%)	NS

Table 3: Impact of integrated nutrient management and sowing schedule on plant height at 25, 50, and 75 DAS in *Toria* crop

Treatment	25 DAS	50 DAS	75 DAS
Fertilizer			
F1 100% organic	19.46	67.11	117.78
F2 100% inorganic	17.90	64.16	114.84
F3 75% organic + 25% inorganic	18.92	63.12	115.81
F4 50% organic + 50% inorganic	19.04	63.91	119.30
F5 25% organic + 75% inorganic	17.98	63.83	116.69
Sem±	0.25	1.04	1.15
C.D. (5%)	0.51	2.10	2.33
Sowing date			
S1 25th August	17.76	60.83	110.42
S2 5th September	19.17	62.61	114.24
S3 15th September	17.97	64.74	119.25
S4 25th September	19.73	69.53	123.62
Sem±	0.38	1.55	1.73
C.D. (5%)	0.77	3.15	3.50

Table 4: Root length dynamics at 25, 50, and 75 DAS as influenced by integrated nutrient management and sowing time in *Toria*

Treatment	25 DAS	50 DAS	75 DAS
Fertilizer			
100% organic	2.82	7.81	13.77
100% inorganic	3.09	7.83	13.57
75% organic + 25% inorganic	2.88	8.17	14.30
50% organic + 50% inorganic	2.85	7.51	14.04
25% organic + 75% inorganic	2.77	7.76	14.53
Sem±	0.11	0.02	0.02
C.D. (5%)	0.22	0.04	0.04
Sowing date			
25th August	2.64	7.34	12.30
5th September	2.73	7.74	13.60
15th September	2.99	7.72	15.10
25th September	3.16	8.48	15.17
Sem±	0.01	0.01	0.01
C.D. (5%)	0.01	0.02	0.02

Table 5: Dry matter accumulation at different crop stages (25, 50, and 75 DAS) of *Toria* under varying nutrient management and sowing dates

Treatment	25 DAS	50 DAS	75 DAS
Fertilizer			
100% organic	33.25	220.16	403.66
100% inorganic	33.98	221.19	407.65
75% organic + 25% inorganic	35.01	219.12	401.67
50% organic + 50% inorganic	33.18	219.94	399.56
25% organic + 75% inorganic	33.18	217.86	406.05
Sem±	0.06	0.30	0.19
C.D. (5%)	0.11	0.61	0.38
Sowing date			
25th August	32.59	209.57	397.45
5th September	33.62	219.09	402.98
15th September	33.38	223.46	404.40
25th September	35.30	226.50	410.04
Sem±	0.03	0.15	0.09
C.D. (5%)	0.06	0.30	0.19

Table 6: Effect of nutrient combinations and sowing dates on number of seeds per silique and 1000-seed weight of *Toria*

Treatment	Numbers of seed silique-1	1000 seed weight (g)
Fertilizer		
100% organic	2.91	66.56
100% inorganic	3.08	68.08
75% organic + 25% inorganic	3.10	61.67
50% organic + 50% inorganic	3.05	63.42
25% organic + 75% inorganic	3.11	63.35
Sem±	0.04	0.53
C.D. (5%)	0.07	1.07
Sowing date		
25th August	2.82	64.57
5th September	3.02	64.58
15th September	3.16	64.65
25th September	3.19	64.67
Sem±	0.05	0.79
C.D. (5%)	0.11	1.61

Table 7: Yield attributes and harvest index of *Toria* as influenced by nutrient management practices and sowing windows

Treatment	Seed yield	Straw yield	Biological yield	Harvest index
Fertilizer				
100% organic	12.99	33.14	46.13	28.18
100% inorganic	13.27	32.69	45.95	28.90
75% organic + 25% inorganic	13.60	33.19	46.79	29.13
50% organic + 50% inorganic	13.09	32.93	46.03	28.41
25% organic + 75% inorganic	13.02	32.75	45.77	28.45
Sem±	0.03	0.04	0.05	0.03
C.D. (5%)	0.07	0.09	0.10	0.06
Sowing date				
25th August	12.51	31.75	44.26	28.54
5th September	12.55	32.32	44.87	27.89
15th September	13.73	33.53	47.26	28.99
25th September	14.00	34.15	48.15	29.03
Sem±	0.02	0.02	0.03	0.01
C.D. (5%)	0.03	0.04	0.05	0.03

Table 8: Nutrient uptake (N, P, and S) in *Toria* under different nutrient management systems and sowing dates in the Indo-Gangetic region

Treatment	Nitrogen	Sulphur	Phosphorus
Fertilizer			
100% organic	76.56	11.38	44.63
100% inorganic	75.79	11.16	44.18
75% organic + 25% inorganic	76.34	10.34	44.49
50% organic + 50% inorganic	74.74	10.85	43.57
25% organic + 75% inorganic	74.44	10.12	43.39
Sem±	1.80	0.42	1.05
C.D. (5%)	3.65	0.85	2.14
Sowing date			
25^{th} August	71.43	10.40	41.62
5^{th} September	72.98	9.89	42.53
15^{th} September	77.35	10.94	45.11
25^{th} September	80.53	11.84	46.95
Sem±	2.70	0.63	1.58
C.D. (5%)	5.47	1.28	3.20

Conclusion

Based on the findings of the present investigation, it can be concluded that integrated nutrient management—the combined use of organic and inorganic fertilizers—positively influenced both the growth and yield performance of *Toria* (*Brassica rapa* L.). While higher doses of organic fertilizers promoted vegetative growth and biomass accumulation, the highest yield attributes such as grain yield, straw yield, biological yield, seed weight, and number of seeds per silique were observed under treatments with a balanced combination of organic and inorganic fertilizers, particularly the 50:50 ratio.

Nutrient uptake analysis further confirmed that purely organic treatments and excessively high inorganic doses resulted in lower uptake of nitrogen, phosphorus, and sulphur. In contrast, integrated nutrient application facilitated better nutrient availability and uptake, thereby enhancing crop performance and promoting more sustainable nutrient use.

Regarding sowing time, delayed sowing significantly improved crop performance, with 25th September emerging as the most suitable date for sowing toria in the Indo-Gangetic plains, especially under the agro-climatic conditions of Lucknow, Uttar Pradesh. This sowing window provided favorable temperature and soil moisture conditions during the critical growth stages, leading to enhanced physiological efficiency, better reproductive development, and ultimately higher yields.

Therefore, the combined use of organic and inorganic fertilizers along with optimal sowing time (25th September) can be recommended as a sustainable agronomic strategy for maximizing yield, improving soil health, and enhancing nutrient use efficiency in *Brassica rapa* cultivation.

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