**Impact of Nutrient Management on Soil Properties in Indian Mustard (Brassica juncea L.) Cultivation**

**Abstract**

A field study was carried out during the rabi (winter) seasons of 2022–23 and 2023–24 at the Instructional Farm of Banda University of Agriculture & Technology, Banda, to evaluate the impact of integrated nutrient management on soil fertility in Indian mustard (Brassica juncea L.). The experiment employed a split-plot design, with four fertility levels (50%, 75%, 100%, and 125% of the recommended NPKS) assigned to the main plots, and four sub-plot treatments involving different combinations of micronutrients (Zn and B) and enriched vermicompost. Each treatment was replicated three times. Results showed that application of 100% and 125% of the recommended NPKS significantly increased the post-harvest availability of nitrogen, phosphorus, potassium, sulphur, and zinc compared to lower application rates. Among the sub-plot treatments, the combinations of 2.5 kg Zn + 0.5 kg B + 500 kg enriched vermicompost (S3) and 5 kg Zn + 1 kg B + 250 kg enriched vermicompost (S4) consistently enhanced nutrient availability in the soil. However, the interaction effects between fertility levels and micronutrient-organic combinations were found to be statistically non-significant for all measured nutrients. The study concludes that integrated nutrient management, especially using either 100% or 125% of the recommended NPKS along with micronutrients and organic amendments, effectively improves soil fertility and supports sustainable mustard production under semi-arid conditions.

**Keywords-** Indian mustard, Nutrient management, Soil fertility, Enriched vermicompost, Micronutrients (Zn and B)

**Introduction**

Oilseeds represent the second most important agricultural commodity in India after cereals, playing a vital role in the nation's farming sector. They account for around 13% of the total cultivated area, contribute approximately 3% to the gross national product, and make up about 10% of the overall value of agricultural commodities **(DA & FW, 2022).** These crops are primarily grown for their oil-rich seeds, which are used in cooking, various industries, and in the production of products such as soap, cosmetics, and biodiesel. The major oilseed-producing states include Madhya Pradesh, Rajasthan, Chhattisgarh, Uttar Pradesh, Maharashtra, Bihar, Odisha, Jharkhand, Nagaland, Karnataka, and Assam, together contributing over 95% of the area and production (NFSM, 2018).

Among these crops, Indian mustard (*Brassica juncea* L.) is a key oilseed plant from the *Brassicaceae* family, responsible for about one-third of India’s total oilseed output. It is the third most produced oilseed in the country, after soybean and groundnut, and contributes around 28% to the national oilseed production. Mustard oil is widely consumed as a cooking medium and enhances both mineral and caloric intake for humans and livestock. It is also used in various industrial applications, while the leftover oilcake serves as animal feed and fertilizer. Additionally, mustard greens are consumed as vegetables and used as green fodder. Indian mustard is cultivated across a wide range of agro-climatic zones—from the northeastern and northwestern hills to southern regions—under both irrigated and rainfed conditions, and in various soil types, including saline lands. It adapts well to different farming systems, including early and late sowing and mixed cropping. The oil content of Indian mustard ranges from 37% to 49%, and the composition includes 38–57% erucic acid, 4.7–13% linolenic acid, 27% oleic acid, and 10–12% linoleic acid **(Kumar *et al.,* 2019).**This crop holds significant importance in India’s agricultural economy by supporting food security and serving as a key income source for farmers. India ranks as the third-largest producer of rapeseed-mustard globally. These crops are grown on approximately 6.78 million hectares, yielding 9.25 million tons of oilseeds, with an average productivity of 1,349 kg per hectare, resulting in about 1.8 million tons of oil. In Uttar Pradesh alone, mustard is cultivated on 0.753 million hectares, producing 1.11 million tons with a yield of 1,290 kg/ha, accounting for 9.5% of the country’s total rapeseed-mustard output. In the Bundelkhand region of Uttar Pradesh, mustard is grown on roughly 70,975 hectares, yielding 71,367 tons at a productivity level of 1,010 kg/ha **(Anonymous, 2019).** Despite its importance, the yield levels in many parts of the state remain considerably below the crop's potential.

 Improving productivity in Indian mustard cultivation can be achieved through balanced fertilization and effective soil management practices, with particular emphasis on the application of sulfur, boron, and zinc in semi-arid soils. The depletion of organic matter further worsens nutrient deficiencies, and a two-thirds reduction in organic content reflects a significant drop in nutrient availability **(Roy *et al.,* 2013; Haque *et al.,* 2014; Rabbani *et al.,* 2023).** In the Bundelkhand region, soil fertility is generally poor due to the lack of essential nutrients such as nitrogen (N), phosphorus (P), potassium (K), sulfur (S), zinc (Zn), and boron (B), largely caused by soil erosion and high surface runoff. Fertilizer application plays a key role in increasing mustard yields, as the crop is nutrient-demanding and energy-intensive. Achieving optimal production requires precise nutrient management alongside the preservation of soil health. Successful cultivation also involves addressing pest and disease control, managing irrigation efficiently, and maintaining overall soil fertility. Sustainable agricultural practices, including crop rotation and integrated pest management (IPM), are commonly used to promote healthy plant growth and ensure consistent and productive mustard harvests. Indian mustard (*Brassica juncea* L.) is a major oilseed crop in India, playing a crucial role in the production of edible oil and supporting the livelihoods of rural communities. Cultivated across various agro-climatic regions, especially in semi-arid areas, the crop’s success is heavily influenced by soil fertility, which is often compromised due to intensive farming practices. Being a nutrient-demanding crop, mustard places considerable pressure on soil nutrient reserves, making efficient nutrient management essential for sustainable cultivation. Over time, soil fertility has declined due to factors such as unbalanced fertilizer application, continuous cropping, erosion, and reduced organic matter content. This has led to widespread deficiencies of key nutrients like nitrogen (N), phosphorus (P), potassium (K), sulfur (S), zinc (Zn), and boron (B), particularly in erosion-prone areas like Bundelkhand. Balanced nutrient management, involving the appropriate use of both macro- and micronutrients, is critical for improving soil conditions and boosting crop yields.

Proper nutrient management not only enhances mustard growth and productivity but also positively affects important soil characteristics, including pH levels, organic carbon content, microbial activity, nutrient retention, available N,P,K, and Zn in soil. The adoption of sustainable practices such as integrated nutrient management (INM), organic amendments, and enriched vermicompost can help rehabilitate degraded soils and promote long-term agricultural productivity. This research focuses on examining how different nutrient management strategies influence the soil properties under Indian mustard cultivation, with the goal of enhancing soil health and crop performance in nutrient-deficient environments.

**Materials and Methods**

The field experiment was carried out during the *rabi* (winter) seasons of 2022–23 and 2023–24 at the Integrated Farming System (IFS) unit, Instructional Farm, of Banda University of Agriculture & Technology, Banda. The objective was to evaluate the most effective nutrient management practices for improving soil properties under Indian mustard cultivation. The research site is located in the Central Plateau and Hill Region, which falls under Agro-Climatic Zone VIII. The study followed a split-plot design with three replications. The main plots were assigned four levels of fertility treatments: 50%, 75%, 100%, and 125% of the recommended NPKS (RNPKS) doses. Sub-plots received four different combinations of micronutrients and enriched vermicompost:

1. 2.5 kg Zn + 0.5 kg B
2. 5 kg Zn + 1 kg B
3. 2.5 kg Zn + 0.5 kg B + 500 kg enriched vermicompost
4. 5 kg Zn + 1 kg B + 250 kg enriched vermicompost

This created a total of 16 treatment combinations, such as 50% RNPKS + 2.5 kg Zn + 0.5 kg B, 75% RNPKS + 5 kg Zn + 1 kg B, 100% RNPKS + 2.5 kg Zn + 0.5 kg B + 500 kg vermicompost, and so on up to 125% RNPKS + 5 kg Zn + 1 kg B + 250 kg vermicompost. The experimental soil was characterized as clay loam with low levels of organic carbon and limited availability of nitrogen, phosphorus, zinc, and sulfur, while potassium was moderately available. The Indian mustard variety 'Giriraj (DRMRIJ-31)' was used as the test crop, and seeds were manually sown at a rate of 3 kg/ha.

The standard recommended fertilizer dose for Indian mustard—90 kg nitrogen (N), 45 kg phosphorus (P₂O₅), 30 kg potassium (K₂O), and 25 kg sulfur (S)—was applied using urea, di-ammonium phosphate (DAP), muriate of potash (MOP), and sulfur bentonite. Micronutrients zinc and boron were supplied using zinc sulfate monohydrate and disodium octaborate tetrahydrate, respectively. Enriched vermicompost was prepared by treating 500 kg of compost with 1 liter each of Azotobacter, NPK consortia, phosphate-solubilizing bacteria (PSB), potassium-mobilizing bacteria (PMB), and zinc-solubilizing bacteria (ZSB). In both cropping seasons, half of the nitrogen was applied at the time of sowing along with the full basal doses of phosphorus, potassium, and sulfur, as per the treatment plans. The remaining half of the nitrogen was top-dressed during the first irrigation. Zinc, boron, and enriched vermicompost were applied based on the specific treatment combinations in each plot.

**Result and Discussion**

**Available Nitrogen**

The data in Table 1 indicate noticeable differences in soil nitrogen availability. Among the main plot treatments, applying 125% of the recommended NPKS dose (M4) led to the highest levels of available nitrogen across both years, while the lowest levels were recorded under the 50% RNPKS treatment (M1). Notably, both the 125% (M4) and 100% (M3) RNPKS treatments performed similarly and significantly outperformed the other treatments in enhancing nitrogen availability.
Sub-plot treatments also showed a significant influence on nitrogen levels. The highest nitrogen availability was observed in plots treated with 2.5 kg Zn + 0.5 kg B + 500 kg enriched vermicompost (S3) and 5 kg Zn + 1 kg B + 250 kg enriched vermicompost (S4), with both treatments statistically similar in performance. However, the interaction between main plot and sub-plot treatments had no significant effect on available nitrogen during either year.

**Available Phosphorus**
As shown in Table 1, phosphorus availability varied among treatments. The 125% RNPKS application (M4) again resulted in the highest phosphorus content in both years, while the 50% RNPKS treatment (M1) yielded the lowest. Treatments M4 and M3 (100% RNPKS) were statistically comparable and significantly better than other treatments.
Sub-plot treatments using S3 and S4 combinations also significantly enhanced phosphorus availability, with both treatments being statistically at par. No significant interaction was found between main plot and sub-plot treatments for phosphorus availability.

**Available Potassium**
Table 2 shows differences in potassium levels across treatments. The highest potassium availability was observed with the 125% RNPKS treatment (M4), followed by 100% RNPKS (M3), both of which were statistically similar and significantly higher than the other treatments. The lowest potassium levels were found under the 50% RNPKS treatment (M1).
Among sub-plot treatments, both S3 and S4 significantly increased potassium content in the soil, with no significant difference between them. As with other nutrients, the interaction effect between main and sub-plot treatments was not significant.

**Available Sulphur**
Table 2 also highlights variations in sulphur availability. The application of 125% RNPKS (M4) yielded the highest sulphur content, while the 50% RNPKS (M1) treatment resulted in the lowest. Treatments M4 and M3 were statistically at par and significantly superior to other levels in enhancing sulphur availability. For sub-plot treatments, the use of 2.5 kg Zn + 0.5 kg B + 500 kg enriched vermicompost (S3) and 5 kg Zn + 1 kg B + 250 kg enriched vermicompost (S4) led to the highest levels of available sulphur, with both treatments performing similarly. No significant interaction was observed between main plot and sub-plot treatments in terms of sulphur levels.

**Available Zinc**
According to Table 2, available zinc content in the soil was higher in the second year compared to the first. Among the main plot treatments, 125% RNPKS (M4) had the highest zinc availability, closely followed by 100% RNPKS (M3); both treatments were statistically at par. The lowest zinc levels were recorded in the 50% RNPKS (M1) treatment.In the sub-plots, the highest zinc availability was again found in S3 and S4 treatments, which were statistically similar. However, no significant interaction effect was noted between main and sub-plot treatments for zinc availability in either year.

The integrated use of nitrogen, phosphorus, potassium, and sulfur significantly enhanced both plant development and yield, while also improving the availability of nutrients in the soil. Supplying these macronutrients through chemical fertilizers like urea, DAP, and MOP helped sustain adequate levels of available NPKS in the soil after harvest. When micronutrients were applied in combination with vermicompost, the available nitrogen content increased further, likely due to the gradual mineralization of nitrogen from the organic material—an effect less pronounced with chemical fertilizers alone. According to **Saha *et al.* (2010),** varying fertility levels had a significant impact on nutrient uptake by mustard plants and also led to improvements in soil organic carbon and the availability of nitrogen, phosphorus, and potassium. Generally, nitrogen application enhances phosphorus absorption, while phosphorus fertilizers improve the uptake of multiple nutrients including nitrogen and potassium. Urea, as a commonly used nitrogen source, is efficiently absorbed and hydrolyzed in the cytosol of most plants, often boosting the synthesis of storage nitrogen compounds such as amino acids and proteins. This process supports better nutrient utilization and contributes to increased nutrient availability in the soil.In the experiment, plots treated with 125% of the recommended NPKS dose, as well as those with 100% of the recommended dose, showed higher concentrations of available nitrogen, phosphorus, potassium, sulfur, and zinc during both years of study. The direct application of NPKS fertilizers not only raises nutrient levels in the soil but also improves their availability for plant uptake. These fertilizers stimulate microbial activity, which aids in the decomposition of organic matter and subsequent nutrient release. Additionally, they can adjust soil pH, especially improving phosphorus availability, and reduce the soil’s tendency to fix nutrients like phosphorus and potassium, making more of these elements accessible to plants.The observed increases in post-harvest soil nutrients—specifically nitrogen, phosphorus, potassium, sulfur, and zinc—were largely attributed to the nutrient input from inorganic fertilizers. These outcomes are consistent with the findings of previous studies by **Azami *et al.* (2008), Mortvedt (1991), Takkar (1991), Takkar and Bansal (1987), Tomar *et al.* (2018), and Singh *et al.* (2018, 2021).**

**Table 1 Effect of main plot and sub plot treatments on Available N and Available P of post-harvest soil of Indian mustard**

|  |  |  |
| --- | --- | --- |
| **Treatment** | **Available N (kg ha-1)** | **Available P (kg ha-1)** |
|  | **2022-23** | **2023-24** | **2022-23** | **2023-24** |
| **Main plot treatments** |
| M1 – 50% RNPKS | 216.08 | 214.99 | 14.32 | 14.03 |
| M2- 75% RNPKS | 217.55 | 216.83 | 14.79 | 14.15 |
| M3-100% RNPKS | 219.60 | 221.53 | 15.83 | 16.06 |
| M4- 125%NPKS | 221.88 | 222.86 | 16.32 | 16.85 |
| SEM± for MPT | 0.88 | 1.18 | 0.23 | 0.32 |
| C.D.(0.05) | 2.01 | 3.02 | 0.81 | 0.87 |
| **Sub plot treatments** |
| S1-2.5 kg Zn + 0.5 kg B  | 213.96 | 214.53 | 14.10 | 14.71 |
| S2-5 kg Zn + 1 kg B | 216.08 | 216.45 | 14.57 | 14.93 |
| S3-2.5 kg Zn + 0.5 kg B + 500 kg enriched vermicompost  | 220.45 | 221.44 | 16.97 | 17.10 |
| S4-5 kg Zn + 1 kg B + 250 kg enriched vermicompost  | 218.64 | 219.41 | 16.53 | 16.96 |
| SEM± for SPT | 1.05 | 1.36 | 0.32 | 0.36 |
| C.D.(0.05) | 2.37 | 2.80 | 0.93 | 1.04 |
| Interaction(MXS) | NS | NS | NS | NS |

**Table 2 Effect of main plot and sub plot treatments on Available P, Available S and Available Zn of post-harvest soil of Indian mustard**

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatment** | **Available K****(kg ha-1)** | **Available S** **(kg ha-1)** | **Available Zn****(PPM)** |
|  | **2022-23** | **2023-24** | **2022-23** | **2023-24** | **2022-23** | **2023-24** |
| **Main plot treatments** |  |  |
| M1 – 50% RNPKS | 285.12 | 284.81 | 11.32 | 10.03 | 0.66 | 0.68 |
| M2- 75% RNPKS | 287.29 | 286.45 | 12.79 | 12.00 | 0.68 | 0.69 |
| M3-100% RNPKS | 290.73 | 292.59 | 13.83 | 14.33 | 0.72 | 0.74 |
| M4- 125% RNPKS | 292.12 | 294.98 | 14.32 | 14.82 | 0.74 | 0.75 |
| SEM± for MPT | 1.03 | 1.16 | 0.23 | 0.26 | 0.01 | 0.02 |
| C.D.(0.05) | 3.40 | 4.58 | 0.81 | 0.91 | 0.03 | 0.04 |
| **Sub plot treatments** |
| S1-2.5 kg Zn + 0.5 kg B  | 284.23 | 284.92 | 10.04 | 10.53 | 0.69 | 0.70 |
| S2-5 kg Zn + 1 kg B | 285.63 | 286.29 | 11.03 | 11.63 | 0.70 | 0.71 |
| S3-2.5 kg Zn + 0.5 kg B + 500 kg enriched vermicompost  | 291.57 | 292.43 | 13.97 | 14.27 | 0.74 | 0.76 |
| S4-5 kg Zn + 1 kg B + 250 kg enriched vermicompost  | 290.83 | 291.69 | 13.53 | 13.93 | 0.73 | 0.75 |
| SEM± for SPT | 2.14 | 2.19 | 0.32 | 0.33 | 0.01 | 0.01 |
| C.D.(0.05) | 4.50 | 5.09 | 0.93 | 0.96 | 0.02 | 0.03 |
| Interaction(MXS) | NS | NS | NS | NS | NS | NS |

**CONCLUSION**

It can be concluded that the treatment combination of either 125% or 100% of the recommended NPKS along with 2.5 kg Zn, 0.5 kg B, and 500 kg of enriched vermicompost resulted in the most favorable improvements in soil properties, particularly in terms of available nitrogen, phosphorus, potassium, sulphur, and zinc under Indian mustard cultivation.

**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 this manuscript.

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