Archives of Current Research International

Volume 25, Issue 10, Page 292-304, 2025; Article no.ACRI.145970
ISSN: 2454-7077

Influence of Irrigation Scheduling and Foliar Application of Phosphorus, Sulphur, and Boron on Quality Characteristic and Soil Nutrient Availability of Indian Mustard (*Brassica juncea* L.)

Pradeep Kumar [a++*], Sanjeev Kumar [a#], M. Z. Siddiqui [a#], Naushad Khan [a#], Sarvesh Kumar [b#], Anil Kumar [c#], Rajat Yadav [a++], Janardan Prasad Bagri [a++] and Kumari Pooja [a++]

[a] Department of Agronomy, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, 208002, India.
[b] Department of Soil Conservation & Water Management, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, 208002, India.
[c] Department of Soil Science & Agricultural Chemistry, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, 208002, India.

Authors' contributions

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

Article Information

DOI: https://doi.org/10.9734/acri/2025/v25i101568

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/145970

[++] Research Scholar;
[#] Professor;
**Corresponding author: E-mail: pradeepkumar25299@gmail.com;*

Cite as: *Pradeep Kumar, Sanjeev Kumar, M. Z. Siddiqui, Naushad Khan, Sarvesh Kumar, Anil Kumar, Rajat Yadav, Janardan Prasad Bagri, and Kumari Pooja. 2025. "Influence of Irrigation Scheduling and Foliar Application of Phosphorus, Sulphur, and Boron on Quality Characteristic and Soil Nutrient Availability of Indian Mustard (Brassica Juncea L.)". Archives of Current Research International 25 (10):292–304. https://doi.org/10.9734/acri/2025/v25i101568.*

Original Research Article

Received: 28/08/2025
Published: 20/10/2025

ABSTRACT

A field experiment was conducted at the Students Instructional Farm, Department of Agronomy, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur (U.P.) during the two consecutive *Rabi* seasons of 2023 and 2024 to evaluate the effects of irrigation scheduling and foliar application of phosphorus, sulphur, and boron on Indian mustard (*Brassica juncea* L.). The trial was arranged in a split plot design with two factors main plot: (Irrigation levels 03) *i.e.* I_1 (no irrigation), I_2 (one irrigation at pre-flowering), and I_3 (two irrigations at pre-flowering and siliqua development). and sub-plots: (Nutrient management practices 05) *i.e.* T_1 (RDF 120:60:40 NPK), T_2 (RDF+ foliar application of sulphur @ 2% at 30 DAS and 45 DAS), T_3 (RDF+ foliar application of boron @ 0.2% at 30 DAS and 45 DAS), T_4 (RDF+ foliar application of sulphur @ 2% + foliar application of boron @ 0.2% at 30 DAS and 45 DAS) and T_5 (RDF + foliar application of sulphur @ 2% + foliar application of boron @ 0.2% + foliar application of nano phosphorus @ 0.5% at 30 DAS and 45 DAS). Mustard variety *Azad Mahak* was sown on November 2nd, 2023, and November 4th, 2024. Harvesting was carried out on March 26th, 2024, and March 29th, 2025 respectively. Requisite soil and crop parameters were determined by standard methods. Results indicate that I_3 irrigation and T_5 treatment improved soil available P, N and K contents. It was observed that combined I_3 irrigation and T_5 nutrient management enhanced crop performance hence maximum oil content, sulphur, phosphorus, boron and nitrogen contents of grains were obtained, particularly with adequate nutrient management, hence are recommended for profitable mustard farming.

Keywords: RDF; phosphorus; sulphur; boron; irrigation scheduling; Brassica juncea; mustard; oil; foliar application.

1. INTRODUCTION

Mustard (*Brassica juncea*) is an economically important oilseed crop grown primarily during the Rabi (winter) season in India. It belongs to the Brassicaceae family and is widely cultivated for its seeds, which are a rich source of edible oil, as well as for its tender leaves, which are consumed as greens. Indian mustard is adapted to a range of agro-climatic conditions and is grown in both irrigated and rainfed fields, making it a versatile crop for diverse regions such as Rajasthan, Uttar Pradesh, Haryana, Madhya Pradesh, and Gujarat.

The crop matures within 100–120 days and is commonly included in crop rotations with cereals, pulses, and other vegetables. Mustard plants have small yellow flowers, hairy leaves, and produce seeds high in oil content (up to 45%). The oil extracted is widely used in cooking, especially in northern India, and the remaining oil cake serves as valuable animal feed and organic manure. Apart from culinary uses, mustard oil is also utilized in traditional medicine, and the plant is noted for its biofumigant properties that can suppress soil-borne pests. Mustard cultivation supports smallholder farmers by providing an important source of income and contributes significantly to the edible oil pool of the country.

Irrigation had been reported to enhance the growth and yield characteristic of mustard. Phogat *et al.* (2009) in their studies found that the growth yield attributes and yield of mustard increased significantly with increases in the number of irrigations. The applications of three irrigations, significantly increased seed yield by 15.5% & and 52.8% after two and one irrigations, respectively. This can be attributed to an enhancement of nutrients supply with in the soil due to higher soil moisture.

In another study, the application of higher amount of inorganic sulphur led optimal seed and oil yield of Indian mustard (Patel *et al.,* 2011) other than increase in the seed and oil contents. (Ahmad and Abdin, 2000) found sequestered in the storage proteins cruciferin and napin, while (Hassan *et al.*, 2007) obtained in the secondary metabolite glucosinolate (GSL) sinigrin, gluconapin and progoitrin. There studies showed that Sulphur application largely influenced chlorophyll synthesis, carbohydrate as well as protein metabolism.

The role of phosphorus (P) is critical in plant metabolism which plays an important role in energy transfer, respiration, and photosynthesis. It is a key structural component of nucleic acids, co-enzymes, phosphoproteins, and phospholipids. Phosphorus fertilization is a major input in crop production (Blackshaw *et al.,* 2004). It participates in metabolic activities as a constituent of nucleoprotein and nucleotides and plays a key role in the formation of energy rich bond like adenosine diphosphate (ADP) and adenosine triphosphate (ATP). Favourable response of mustard to applied P was reported by (Gangwal *et al.,* 2011) and (Solanki *et al.,* 2016). In areas where mustard is traditionally grown without P, poor growth and low yields are common features. Further, it improves seed size, stimulates proper seed filling, and increases oil content. Phosphorus (P) promotes root development and enlargement seed germination, cell wall division, flowering, fruiting, synthesis of fat, starch and in fact most biochemical activities (Singh and Singh, 2012). Phosphorus fertilization is of prime importance for normal growth and development of plants because of its vital role in chlorophyll synthesis, photosynthesis, and various physiological and metabolic processes of the plant (Mehta *et al*., 2005).

Boron is known to improve seed protein content, plant physiological functions support rapid plant growth, and increases seed yield and oil content (Allen and Morgan 2009). Excessive application of of boron may result to appreciable reduction in seed yield and quality (Cheema *et al.,* 2001).

2. MATERIALS AND METHODS

A field experiment was conducted during two consecutive *rabi* season of 2023 and 2024 at Student's Instructional Farm of Chandra Shekhar Azad University of Agriculture and Technology, Kanpur. The Kanpur Nagar is a city in central Uttar Pradesh situated at 125.9 meters above sea level on the alluvial tract of the Gangetic plains. It is coordinated at 25° - 28° North latitude and 79°- 80° East longitude. This northern zone is characterized by the semi-arid climate and rich alluvial soils. About 935 mm of rainfalls is received each year on average. The soil of experiment plot was sandy loam in texture having 0.45% organic carbon, 189.12 kg ha^{-1} available N, 14.60 kg ha^{-1} available P, 167.31 kg ha^{-1} K, 18.5 kg ha^{-1} available sulphur and 0.22 – 2.2 kg ha^{-1} available boron. in both the years. The experiment was laid-out as a split plot design with 2 factors and 3 replications. Main plot: Irrigation levels (03) *i.e.* I_1: Control (No Irrigation), I_2: One irrigation at pre-flowering, I_3: Two irrigations at pre-flowering and siliqua development. Sub Plot: T_1: RDF (120:60:40 NPK), T_2: RDF+ foliar application of sulphur@ 2% at 30 DAS and 45 DAS, T_3: RDF+ foliar application of boron@ 0.2% at 30 DAS and 45 DAS, T_4: RDF+ foliar application of sulphur@ 2% + foliar application of boron@ 0.2% at 30 DAS and 45 DAS, T_5: RDF+ foliar application of sulphur@ 2% + foliar application of boron@ 0.2% + foliar application of nano phosphorus@ 0.5% at 30 DAS and 45 DAS. The recommended dose of fertilizer (NPK: 120:60:40 Kg ha^{-1} was applied uniformly in each plot. While foliar application of phosphorus, sulphur, and boron at 30 DAS and 45 DAS were applied in respective plots. Seeds of mustard variety Azad Mahak were shown on the 2nd and 4th of November 2023 and 2024, respectively. The crops were harvested at full ripe stage on the 26th of March and 29th of March of each experimental year.

3. RESULTS AND DISCUSSION

Oil content in grains (%): The percentage oil content of the mustard seeds at different treatments are presented in Table 1. The pooled analysis of data on oil content indicates that irrigation levels I_3 (Two irrigation at pre-flowering and siliqua development) had maximum oil content (39.67 %). Lowest oil content was recorded (38.38 %) under the treatment I_1 Control (No irrigation).

The pooled analysis of data on oil content showed that different nutrient management practices contributed to the recorded maximum percent of oil content (39.88 %) under the treatment T_5 (RDF + foliar application of sulphur @ 2% + foliar application of boron @ 0.2% + foliar application of nano phosphorus @ 0.5% at 30 DAS and 45 DAS and followed by values for T_4, T_2 and T_3. However, the lowest oil content recorded was 38.29 % under treatment T_1 (RDF 120:60:40). similar results were obtained by Meena and Sumeriya (2003) and Khourang *et al*., (2012), Malhi *et. al.* (2007).

Sulphur content in grain (%): The percentage sulphur content of the grains is presented in Table 1. Which showed pooled analysis data for sulphur content in grains was maximum (0.55 %) for irrigation levels I_3 (Two irrigation at pre-flowering and siliqua development). followed by I_2 (One Irrigation at pre-flowering). and lowest sulphur content in grain was recorded (0.47 %) under the treatment I_1 Control (No irrigation).

Table 1. Effect of irrigation scheduling and foliar application of phosphorus, sulphur, and boron on qualitative characteristics of in mustard grains harvested in 2023 and 2024

Qualitative studies									
Treatments	**Oil content (%)**			**Sulphur content in grain (%)**			**Boron content in grain (mg kg^{-1})**		
	2023	**2024**	**Pooled**	**2023**	**2024**	**Pooled**	**2023**	**2024**	**Pooled**
Irrigation levels									
I_1: Control (No irrigation)	37.10	39.66	38.38	0.46	0.47	0.47	41.59	44.86	43.22
I_2: One irrigation at pre-flowering	38.28	40.88	39.58	0.53	0.55	0.54	53.40	57.12	55.26
I_3: Two irrigations at pre-flowering and siliqua development	38.34	41.01	39.67	0.54	0.57	0.55	53.54	57.25	55.40
S.E. (m) (±)	0.11	0.17	0.10	0.003	0.003	0.002	0.29	0.35	0.23
CD at 0.05 %	0.43	0.68	0.33	0.01	0.01	0.01	1.13	1.36	0.73
Phosphorus, Sulphur, and Boron levels (T)									
T_1: RDF (120:60:40 NPK)	37.10	39.48	38.29	0.48	0.49	0.48	43.88	47.24	45.56
T_2: RDF+ foliar application of sulphur @ 2% at 30 DAS and 45 DAS	37.97	40.59	39.28	0.51	0.53	0.52	49.50	53.08	51.29
T_3: RDF+ foliar application of boron @ 0.2% at 30 DAS and 45 DAS	37.72	40.22	38.97	0.49	0.51	0.50	46.61	50.07	48.34
T_4: RDF+ foliar application of sulphur @ 2% + foliar application of boron @ 0.2% at 30 DAS and 45 DAS	38.25	41.01	39.63	0.53	0.55	0.54	52.31	55.98	54.14
T_5: RDF + foliar application of sulphur @ 2% + foliar application of boron @ 0.2% + foliar application of nano phosphorus @ 0.5% at 30 DAS and 45 DAS	38.49	41.27	39.88	0.54	0.57	0.55	55.25	59.00	57.13
S.E. (m) (±)	0.27	0.37	0.23	0.01	0.01	0.01	0.88	1.07	0.69
CD at 0.05 %	0.78	1.09	0.75	0.02	0.02	0.02	2.57	3.11	2.25
Interaction Effect (*I* × *T*)									
S.E. (m) (±)	0.47	0.65	0.40	0.01	0.01	0.01	1.52	1.85	1.20
CD at 0.05 %	NS	NS	NS	NS	NS	NS	NS	NS	NS

The pooled analysis data on sulphur content in grains also showed that the contents were influenced by different nutrient management practices as higher percent of sulphur content (0.55%) in grains was recorded in grains was recorded from treatment T_5 (RDF + foliar application of sulphur @ 2% + foliar application of boron @ 0.2% + foliar application of nano phosphorus @ 0.5% at 30 DAS and 45 DAS). Which was being at par with treatment T_4 (RDF+ foliar application of sulphur @ 2% + foliar application of boron @ 0.2% at 30 DAS and 45 DAS) and T_2 (RDF+ foliar application of sulphur @ 2% at 30 DAS and 45 DAS). However, the lowest percentage of sulphur content in grain was recorded (0.48 %) under the treatment T_1 (RDF 120:60:40). These results were similar to those of Parihar *et al.,* (2016)**.**

Boron content in grain (mg kg^{-1}): Table 1. Shows the pooled analysis data for boron content in grains which indicate that irrigation levels I_3 (Two irrigation at pre-flowering and siliqua development) had the highest percent boron content in grains (55.40 mg kg^{-1}), followed by I_2 (One Irrigation at pre-flowering), and lowest boron content in grain was recorded (43.22 mg kg^{-1}) under the treatment I_1 Control (No irrigation).

The pooled analysis of data on boron content in grains were similarly influenced by different nutrient management practices as higher percent of boron content in grains (57.13 mg kg^{-1}) was recorded with the application of treatment T_5 (RDF + foliar application of sulphur @ 2% + foliar application of boron @ 0.2% + foliar application of nano phosphorus @ 0.5% at 30 DAS and 45 DAS). This was followed by T_4 (RDF+ foliar application of sulphur @ 2% + foliar application of boron @ 0.2% at 30 DAS and 45 DAS), T_2 (RDF+ foliar application of sulphur @ 2% at 30 DAS and 45 DAS) and T_3 RDF+ foliar application of boron @ 0.2% at 30 DAS and 45 DAS (54.14, 51.29 and 48.34 mg kg^{-1}) respectively. However, the lowest percentage of boron content in grain was recorded (45.56 mg kg^{-1}) under the treatment T_1 (RDF 120:60:40).

Nitrogen content in grain (%): The percentage nitrogen contents obtained from the studies were presented in Table 2. The pooled analysis data on percentage nitrogen content in grains of indicate that irrigation levels I_3 (Two irrigation at pre-flowering and siliqua development) recorded maximum percent N content in grain (3.92 %), followed by I_2 (One Irrigation at pre-flowering). and lowest percentage of nitrogen content in grain was recorded (3.41 %) under the treatment I_1 Control (No irrigation).

The pooled analysis of data on nitrogen content in grains was similarly influenced by different nutrient management practices (Ghimire and Bana, 2011) as maximum percentage of nitrogen content in grain was recorded (3.99 %) with the application of treatment T_5 (RDF + foliar application of sulphur @ 2% + foliar application of boron @ 0.2% + foliar application of nano phosphorus @ 0.5% at 30 DAS and 45 DAS). Ot was followed by T_4 (RDF+ foliar application of sulphur @ 2% + foliar application of boron @ 0.2% at 30 DAS and 45 DAS), T_2 (RDF+ foliar application of sulphur @ 2% at 30 DAS and 45 DAS) and T_3 RDF+ foliar application of boron @ 0.2% at 30 DAS and 45 DAS (3.86, 3.75 and 3.61 %) respectively. However, the lowest percentage of nitrogen content in grain was recorded (3.49 %) under the treatment T_1 (RDF 120:60:40).

The uptake of nutrients is known to be enhanced by soil moisture content. Adequate soil moisture and foliar application of nutrient create a synergy for nutritional enrichment in the soil solution, essential for nutrient uptake throughout the growth of the plants, thereby encouraging the N content of the grains.

Phosphorus content in grain (%): Data pertaining to phosphorus content in grains Table 2. indicate that irrigation levels I_3 (Two irrigation at pre-flowering and siliqua development) was recorded maximum percent of phosphorus content in grain (0.64%), followed by I_2 (One Irrigation at pre-flowering). and lowest percentage of phosphorus content in grain was recorded (0.56 %) under the treatment I_1 Control (No irrigation).

The pooled analysis of data on phosphorus content in grains show similar influence by different nutrient management practices. Maximum percentage phosphorus content of grains recorded (0.65 %) was with the application of treatment T_5 (RDF + foliar application of sulphur @ 2% + foliar application of boron @ 0.2% + foliar application of nano phosphorus @ 0.5% at 30 DAS and 45 DAS). Which was being at par with T_4 (RDF+ foliar application of sulphur @ 2% + foliar application of boron @ 0.2% at 30 DAS and 45 DAS) followed by T_2 (RDF+ foliar application of sulphur @ 2% at 30 DAS and 45 DAS) and T_3 RDF+ foliar application of boron @

0.2% at 30 DAS and 45 DAS (0.61 and 0.59 %) respectively. However, the lowest percentage of phosphorus content in grain was recorded (0.56 %) under the treatment T_1 (RDF 120:60:40). As earlier reported Ghimire and Bana (2011). The trend may be related to the importance of sulphur, present in the three treatments, five, four and two that received foliar application of sulphur, in the growth and yield of mustard.

Potassium content of grain (%): Table 2. Shows the potassium content of mustard seeds. Pooled analysis data on potassium content in grains indicate that irrigation levels I_3 (Two irrigation at pre-flowering and siliqua development) was recorded maximum percent of potassium content in grain (0.88 %), followed by I_2 (One Irrigation at pre-flowering). and lowest percentage of potassium content in grain was recorded (0.78 %) under the treatment I_1 Control (No irrigation).

The values showed that different nutrient management practices were responsible for maximum percentage of potassium contents recorded (0.89 %) with the application of treatment T_5 (RDF + foliar application of sulphur @ 2% + foliar application of boron @ 0.2% + foliar application of nano phosphorus @ 0.5% at 30 DAS and 45 DAS). Which was being at par with T_4 (RDF+ foliar application of sulphur @ 2% + foliar application of boron @ 0.2% at 30 DAS and 45 DAS), followed by T_2 (RDF+ foliar application of sulphur @ 2% at 30 DAS and 45 DAS) and T_3 RDF+ foliar application of boron @ 0.2% at 30 DAS and 45 DAS (0.84 and 0.82 %) respectively. However, the lowest percentage of potassium content in grain was recorded (0.78 %) under the treatment T_1 (RDF 120:60:40 as obtained from a previous study (Ghimire and Bana 2011). The significance of sulphur in mustard nutrition may be responsible for higher sequestration of P in the grain relative to in plots that did not receive S.

Soil pH: The pH of the soil before and after crop growth in each year were presented in Table 3. The pooled analysis data on soil pH indicate that irrigation levels I_1 Control (No irrigation) had the maximum soil pH (7.59). followed by I_2 (One Irrigation at pre-flowering). And I_3 (Two irrigation at pre-flowering and siliqua development).

The pooled analysis of soil pH data were as usual influenced by different nutrient management practices with maximum soil pH 7.59 recorded with the application of treatment T_1 (RDF 120:60:40). Followed by T_3 (RDF+ foliar application of boron @ 0.2% at 30 DAS and 45 DAS), T_2 (RDF+ foliar application of sulphur @ 2% at 30 DAS and 45 DAS) and T_4 (RDF+ foliar application of sulphur @ 2% + foliar application of boron @ 0.2% at 30 DAS and 45 DAS) (7.56, 7.55 and 7.53) respectively. However, the lowest soil pH was recorded (7.51) under the treatment T_5 (RDF + foliar application of sulphur @ 2% + foliar application of boron @ 0.2% + foliar application of nano phosphorus @ 0.5% at 30 DAS and 45 DAS).

The pH values of the soil after each harvest for the two consecutive years differed. The pH increased in the second year, though the values did not differ significantly from those of the second year.

Electrical conductivity EC (dSm^{-1}): Data presenting EC (dSm^{-1}) values were recorded at both year of investigation. (Table 3.) The pooled analysis data on EC (dSm^{-1}) of indicate that irrigation levels I_3 (Two irrigation at pre-flowering and siliqua development) was recorded maximum EC (dSm^{-1}) (0.40). followed by I_2 (One Irrigation at pre-flowering). and I_1 Control (No irrigation).

The pooled analysis of data on EC (dSm^{-1}) in soil similarly influenced by different nutrient management practices at maximum EC (dSm^{-1}) recorded (0.40) with the application of treatment T_5 (RDF + foliar application of sulphur @ 2% + foliar application of boron @ 0.2% + foliar application of nano phosphorus @ 0.5% at 30 DAS and 45 DAS). Followed by T_4 (RDF+ foliar application of sulphur @ 2% + foliar application of boron @ 0.2% at 30 DAS and 45 DAS), T_2 (RDF+ foliar application of sulphur @ 2% at 30 DAS and 45 DAS) and T_3 RDF+ foliar application of boron @ 0.2% at 30 DAS and 45 DAS). However, the lowest EC (dSm^{-1}) was recorded (0.38) under the treatment T_1 (RDF 120:60:40). The soil maintained its electrical conductivity in both years of the study.

Available Nitrogen in soil (kg ha^{-1}): Data on the enhancement of soil available nitrogen presented in Table 4. The pooled analysis data showed that soil available nitrogen contents increased with irrigation. The highest values were obtained under the irrigation levels I_3 (Two irrigation at pre-flowering and siliqua development) that had maximum soil available nitrogen content of 199.47 kg ha^{-1}, followed by I_2 (One Irrigation at pre-flowering). and the lowest available soil N (184.83 kg ha^{-1}) recorded under treatment I_1 Control (No irrigation).

Table 2. Effects of irrigation scheduling and Treatments on Post Harvest Nutrients Status of grain in 2023-24 and 2024-25

Qualitative studies									
Treatments	**N content in grain (%)**			**P content in grain (%)**			**K content in grain (%)**		
	2023	**2024**	**Pooled**	**2023**	**2024**	**Pooled**	**2023**	**2024-2025**	**Pooled**
Irrigation levels									
I_1: Control (No irrigation)	3.32	3.50	3.41	0.55	0.57	0.56	0.75	0.81	0.78
I_2: One irrigation at pre-flowering	3.74	4.04	3.89	0.61	0.63	0.62	0.81	0.89	0.85
I_3: Two irrigations at pre-flowering and siliqua development	3.80	4.04	3.92	0.63	0.66	0.64	0.83	0.93	0.88
S.E. (m) (±)	0.02	0.02	0.01	0.003	0.004	0.002	0.004	0.005	0.003
CD at 0.05 %	0.06	0.08	0.04	0.01	0.02	0.01	0.01	0.02	0.01
Phosphorus, Sulphur, and Boron levels (T)									
T_1: RDF (120:60:40 NPK)	3.38	3.59	3.49	0.55	0.57	0.56	0.75	0.80	0.78
T_2: RDF+ foliar application of sulphur @ 2% at 30 DAS and 45 DAS	3.62	3.87	3.75	0.60	0.63	0.61	0.80	0.89	0.84
T_3: RDF+ foliar application of boron @ 0.2% at 30 DAS and 45 DAS	3.50	3.73	3.61	0.58	0.60	0.59	0.77	0.86	0.82
T_4: RDF+ foliar application of sulphur @ 2% + foliar application of boron @ 0.2% at 30 DAS and 45 DAS	3.73	3.99	3.86	0.62	0.64	0.63	0.81	0.91	0.86
T_5: RDF + foliar application of sulphur @ 2% + foliar application of boron @ 0.2% + foliar application of nano phosphorus @ 0.5% at 30 DAS and 45 DAS	3.86	4.12	3.99	0.64	0.66	0.65	0.84	0.93	0.89
S.E. (m) (±)	0.05	0.05	0.04	0.01	0.01	0.01	0.01	0.01	0.01
CD at 0.05 %	0.13	0.16	0.12	0.02	0.02	0.02	0.02	0.03	0.02
Interaction Effect (*I* × *T*)									
S.E. (m) (±)	0.08	0.10	0.06	0.01	0.02	0.01	0.01	0.02	0.01
CD at 0.05 %	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 3. Effects of irrigation scheduling and foliar application of phosphorus, sulphur, and boron on post-harvest soil chemical properties of mustard plots in 2023 and 2024

Soil parameter						
Treatments	**pH**			**EC (dSm^{-1})**		
	2023	**2024**	**Pooled**	**2023**	**2024**	**Pooled**
Irrigation levels						
I_1: Control (No irrigation)	7.57	7.61	7.59	0.39	0.39	0.39
I_2: One irrigation at pre-flowering	7.50	7.54	7.52	0.39	0.39	0.39
I_3: Two irrigations at pre-flowering and siliqua development	7.50	7.54	7.52	0.40	0.39	0.40
S.E. (m) (±)	0.05	0.06	0.04	0.004	0.004	0.003
CD at 0.05 %	NS	NS	NS	NS	NS	NS
Phosphorus, Sulphur, and Boron levels (T)						
T_1: RDF (120:60:40 NPK)	7.56	7.60	7.58	0.38	0.37	0.38
T_2: RDF+ foliar application of sulphur @ 2% at 30 DAS and 45 DAS	7.53	7.56	7.55	0.39	0.38	0.39
T_3: RDF+ foliar application of boron @ 0.2% at 30 DAS and 45 DAS	7.53	7.58	7.56	0.40	0.39	0.39
T_4: RDF+ foliar application of sulphur @ 2% + foliar application of boron @ 0.2% at 30 DAS and 45 DAS	7.51	7.55	7.53	0.40	0.39	0.40
T_5: RDF + foliar application of sulphur @ 2% + foliar application of boron @ 0.2% + foliar application of nano phosphorus @ 0.5% at 30 DAS and 45 DAS	7.49	7.53	7.51	0.41	0.40	0.40
S.E. (m) (±)	0.14	0.16	0.11	0.01	0.01	0.01
CD at 0.05 %	NS	NS	NS	NS	NS	NS
Interaction Effect (I × T)						
S.E. (m) (±)	0.24	0.29	0.19	0.02	0.02	0.01
CD at 0.05 %	NS	NS	NS	NS	NS	NS

Table 4. Effect of irrigation scheduling and foliar application of phosphorus, sulphur, and boron on post-harvest soil nutrients content in mustard plots in 2023 and 2024

Soil parameter									
Treatments	**Available N (kg ha^{-1})**			**Available P (kg ha^{-1})**			**Available K (kg ha^{-1})**		
	2023	**2024**	**Pooled**	**2023**	**2024**	**Pooled**	**2023**	**2024**	**Pooled**
Irrigation levels									
I_1: Control (No irrigation)	179.74	189.91	184.83	11.20	11.95	11.57	104.39	110.89	107.64
I_2: One irrigation at pre-flowering	190.77	202.58	196.67	12.32	13.18	12.75	110.12	115.28	112.70
I_3: Two irrigations at pre-flowering and siliqua development	193.88	205.06	199.47	12.48	13.34	12.91	111.87	116.25	114.06
S.E. (m) (±)	1.70	1.14	1.02	0.08	0.09	0.06	1.42	0.77	0.81
CD at 0.05 %	6.67	4.47	3.33	0.30	0.34	0.19	5.58	3.03	2.64
Phosphorus, Sulphur, and Boron levels (T)									
T_1: RDF (120:60:40 NPK)	179.66	192.37	186.02	11.41	12.23	11.82	103.20	110.48	106.84
T_2: RDF+ foliar application of sulphur @ 2% at 30 DAS and 45 DAS	188.25	198.97	193.61	11.98	12.82	12.40	108.97	113.96	111.47
T_3: RDF+ foliar application of boron @ 0.2% at 30 DAS and 45 DAS	184.02	195.90	189.96	11.72	12.54	12.13	105.65	112.27	108.96
T_4: RDF+ foliar application of sulphur @ 2% + foliar application of boron @ 0.2% at 30 DAS and 45 DAS	193.05	202.85	197.95	12.26	13.09	12.68	112.55	116.48	114.51
T_5: RDF + foliar application of sulphur @ 2% + foliar application of boron @ 0.2% + foliar application of nano phosphorus @ 0.5% at 30 DAS and 45 DAS	195.67	205.82	200.74	12.62	13.43	13.03	113.61	117.53	115.57
S.E. (m) (±)	3.78	3.17	2.47	0.26	0.25	0.18	2.14	1.65	1.35
CD at 0.05 %	11.04	9.27	8.05	0.76	0.74	0.59	6.25	4.81	4.40
Interaction Effect (*I* × *T*)									
S.E. (m) (±)	6.55	5.50	4.28	0.45	0.44	0.32	3.71	2.85	2.34
CD at 0.05 %	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 5. Effects of irrigation scheduling and treatments on sulphur, and boron content of soil used to grow mustard 2023 and 2024.

Soil parameter						
Treatments	**Available S (kg ha^{-1})**			**Available B (kg ha^{-1})**		
	2023	**2024**	**Pooled**	**2023**	**2024**	**Pooled**
Irrigation levels						
I_1: Control (No irrigation)	13.99	14.90	14.45	27.39	28.98	28.19
I_2: One irrigation at pre-flowering	15.01	16.20	15.61	33.39	35.40	34.40
I_3: Two irrigations at pre-flowering and siliqua development	15.13	16.33	15.73	34.22	36.28	35.25
S.E. (m) (±)	0.07	0.10	0.06	0.21	0.20	0.14
CD at 0.05 %	0.29	0.38	0.20	0.81	0.78	0.47
Phosphorus, Sulphur, and Boron levels (T)						
T_1: RDF (120:60:40 NPK)	14.20	14.98	14.59	28.86	30.50	29.68
T_2: RDF+ foliar application of sulphur @ 2% at 30 DAS and 45 DAS	14.67	15.87	15.27	30.28	32.10	31.19
T_3: RDF+ foliar application of boron @ 0.2% at 30 DAS and 45 DAS	14.46	15.64	15.05	31.68	33.58	32.63
T_4: RDF+ foliar application of sulphur @ 2% + foliar application of boron @ 0.2% at 30 DAS and 45 DAS	15.00	16.17	15.58	33.08	35.06	34.07
T_5: RDF + foliar application of sulphur @ 2% + foliar application of boron @ 0.2% + foliar application of nano phosphorus @ 0.5% at 30 DAS and 45 DAS	15.22	16.40	15.81	34.46	36.52	35.49
S.E. (m) (±)	0.21	0.28	0.18	0.63	0.61	0.44
CD at 0.05 %	0.61	0.82	0.57	1.85	1.77	1.43
Interaction Effect (I × T)						
S.E. (m) (±)	0.36	0.49	0.30	1.10	1.05	0.76
CD at 0.05 %	NS	NS	NS	NS	NS	NS

The pooled analysis of data on available nitrogen in soil were affected by the different nutrient management practices Maximum available nitrogen in soil (200.74 kg ha^{-1}) was recorded from plots that received treatment T_5 (RDF + foliar application of sulphur @ 2% + foliar application of boron @ 0.2% + foliar application of nano phosphorus @ 0.5% at 30 DAS and 45 DAS). followed by 197.95 kg ha^{-1} for T_4 (RDF+ foliar application of sulphur @ 2% + foliar application of boron @ 0.2% at 30 DAS and 45 DAS), 193.61 kg ha^{-1} T_2 (RDF+ foliar application of sulphur @ 2% at 30 DAS and 45 DAS) and T_3 RDF+ foliar application of boron @ 0.2% at 30 DAS and 45 DAS), 189.96 kg ha^{-1}. However, the lowest soil available nitrogen (186.02 kg ha^{-1}) was recorded treatment T_1 (RDF 120:60:40).

Although the post-harvest N status of the soil did not differ significantly, it can be adduced that the foliar application of Sulphur led to the enhancement of N mineralization in the soil. It may be responsible for the higher soil N content obtained from second irrigation levels relative to the third. Treatment two, four and five received foliar application of Sulphur, while one and three did not. However, the application of boron during the third irrigation practice aided the soil N content relative to the control.

Available Phosphorus in soil (kg ha^{-1}): soilavailable phosphorus data were recorded Table 4. The pooled analysis data on available phosphorus in soil indicate that irrigation levels I_3 (Two irrigation at pre-flowering and siliqua development) was recorded maximum available phosphorus in soil (kg ha^{-1}) (12.91 kg ha^{-1}). followed by I_2 (One Irrigation at pre-flowering). and the lowest available phosphorus in soil (11.57 kg ha^{-1}) recorded under the treatment of I_1 Control (No irrigation).

The pooled analysis of data on available phosphorus in soil influenced by different nutrient management practices with maximum available phosphorus in soil (13.03 kg ha^{-1}) recorded for treatment T_5 (RDF + foliar application of sulphur @ 2% + foliar application of boron @ 0.2% + foliar application of nano phosphorus @ 0.5% at 30 DAS and 45 DAS, followed by T_4 (RDF+ foliar application of sulphur @ 2% + foliar application of boron @ 0.2% at 30 DAS and 45 DAS), T_2 (RDF+ foliar application of sulphur @ 2% at 30 DAS and 45 DAS) and T_3 RDF+ foliar application of boron @ 0.2% at 30 DAS and 45 DAS) (12.68, 12.40 and 12.13 kg ha^{-1}) respectively. However, the lowest available phosphorus in soil (kg ha^{-1}) was recorded (11.82 kg ha^{-1}) under the treatment T_1 (RDF 120:60:40). The trend can again be associated with the application of sulphur.

Available Potassium in soil (kg ha^{-1}): Data on available potassium in the soil were compiled in Table 4. both years of investigation the pooled analysis data on available potassium in soil of indicate that irrigation levels I_3 (Two irrigation at pre-flowering and siliqua development) recorded maximum available potassium in soil (114.06 kg this was followed by I_2 (One Irrigation at pre-flowering). and the lowest available potassium in soil (107.64 kg ha^{-1}) recorded under the treatment of I_1 Control (No irrigation).

The pooled analysis of data on available potassium in soil (kg ha^{-1}) show the influence of different nutrient management practices Hennce, maximum available potassium in soil (kg ha^{-1}) was recorded (115.57 kg ha^{-1}) with the application of treatment T_5 (RDF + foliar application of sulphur @ 2% + foliar application of boron @ 0.2% + foliar application of nano phosphorus @ 0.5% at 30 DAS and 45 DAS). It was followed by the treatments T_4, T_2 and T_3. The control had the least values. The Trend was similar to what had been observed so far, thereby singling out Sulphur as a common factor.

Available Sulphur in soil (kg ha^{-1}): Data pertaining to available Sulphur in soil were presented in Table 5. The pooled analysis data indicate that irrigation levels I_3 (Two irrigation at pre-flowering and siliqua development) improved maximum available Sulphur in soil (15.73 kg ha^{-1}), followed by I_2 (One Irrigation at pre-flowering). and the lowest available Sulphur in soil (14.45 kg ha^{-1}) recorded under the treatment of I_1 Control (No irrigation). Soil moisture enhanced nutrient availability, hence its improved uptake.

The pooled analysis of data on available Sulphur in soil were also influenced by different nutrient management practices. The maximum available Sulphur in soil recorded was 15.81 kg ha^{-1} with the application of treatment Which did not differ significantly fromT_4 and T_2 values. However, the lowest available Sulphur in soil was 14.59 kg ha^{-1}, recorded for treatment T_1 (RDF 120:60:40).

Available Boron in soil (kg ha^{-1}): Table 5 shows available boron content in the soil for both years of study the year during the investigation. The crop growth has been presented in table no. 5. The pooled analysis data on available boron in soil indicate that irrigation levels I_3 (Two irrigation at pre-flowering and siliqua development) recorded maximum available boron in soil (35.25 kg ha^{-1}), followed by I_2 (One Irrigation at pre-flowering). and the lowest available boron in soil (28.19 kg ha^{-1}) recorded under the treatment of I_1 Control (No irrigation).

The pooled analysis of data on available boron in the soil different nutrient management practices at maximising available boron in soil. It was found that the soil boron content was most (35.49 kg ha^{-1}) with the application of treatment T_5 (RDF + foliar application of sulphur @ 2% + foliar application of boron @ 0.2% + foliar application of nano phosphorus @ 0.5% at 30 DAS and 45 DAS). Which was being at par with T_4 (RDF+ foliar application of sulphur @ 2% + foliar application of boron @ 0.2% at 30 DAS and 45 DAS). And treatment T_3 and T_2 is higher over rest of the treatment. However, the lowest available boron in soil was recorded (29.68 kg ha^{-1}) under the treatment T_1 (RDF).

Similar trend were obtained the studies that portrayed the importance of soil moisture in plant nutrition and the obvious impacts of adequate crop nutrition on crop quality.

4. CONCLUSION

During two years of studies conducted on the sandy loam soils of central Uttar Pradesh, it was found that irrigation is indispensable for mustard growth in that region due probably to the low precipitation levels there. The two irrigations applied at the pre-flowering and siliqua formation stages respectively, proved to be most effective, they resulted in the highest recorded values for qualitative traits and soil nutrient availability of Indian mustard. Furthermore, the growth parameters were significantly enhanced when nutrient management was improved by the inclusion of the recommended doses of fertilizers (RDF) along with foliar applications of sulphur at 2%, boron at 0.2%, and nano phosphorus at 0.5% which were applied at both 30 and 45 days after sowing. It is recommended that for profitable mustard farming, these practices should be adopted for marginal soils especially in this era of climate change, which trend to exacerbate water stress in semi-arid environments.

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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Ahmad, A., & Abdin, M. Z. (2000). Effect of sulphur application on lipid, RNA, and fatty acid content in developing seeds of rapeseed (*Brassica campestris* L.). *Plant Science, 150*, 71–76.

Allen, E. J., & Morgan, D. G. (2009). A quantitative analysis of the effects of nitrogen on the growth, development, and yield of oilseed rape. *Journal of Agricultural Science, 78*, 315–324. (Original work published 1972)

Blackshaw, R. E., Brandt, R. N., Janzen, H. H., & Entz, T. (2004). Weed species response to phosphorus fertilization. *Weed Science, 52*, 406–412.

Cheema, M. A., Saleem, M. F., Muhammad, N., Wahid, M. A., & Baber, B. H. (2001). Impact of rate and timing of nitrogen application on yield and quality of canola (*Brassica napus* L.). *Pakistan Journal of Botany, 42*(3), 1723–1731.

Gangwal, T. V., Patel, M. V., & Jadav, N. J. (2011). Effect of phosphorus, sulphur and phosphate solubilizing bacteria on yield, nutrient uptake, and soil fertility after harvest of mustard. *Indian Journal of Fertilizer, 7*, 32–40.

Ghimire, T. B., & Bana, O. P. S. (2011). Effect of fertility levels on mustard (*Brassica juncea*) seed yield, quality, and economics under varying poplar (*Populus deltoides*) tree densities. *Indian Journal of Agronomy, 56*(4).

Hassan, F. U., Manaf, A., Qadir, G., & Basra, S. M. A. (2007). Effects of sulphur on seed yield, oil, protein and glucosinolates of canola cultivars. *International Journal of Agriculture and Biology, 9*, 504–508.

Khourang, M., Brumand, P., & Omidbaigi, R. (2012). Effect of some chemical and biological fertilizers on productivity of a medicinal flax (*Linum usitatissimum*) plant. *International Journal of Agronomy and Plant Production, 3*(3), 78–83.

Meena, B. S., & Sumeriya, H. K. (2003). Influence of nitrogen levels, irrigation and interculture on oil and protein content, soil moisture status, and interaction effects of mustard (*Brassica juncea*). *Crop Research, 26*(3), 409–413.

Mehta, T. K., Shaktawat, M. S., & Singh, S. M. (2005). Influence of sulphur, phosphorus and farmyard manure on yield attributes and yield of maize (*Zea mays*) in southern Rajasthan condition. *Indian Journal of Agronomy, 53*(3), 203–205.

Parihar, S., Kameriya, P. R., & Choudhary, R. (2016). Computation of correlations of fortified vermicompost with sulphur on seed yield and nutrient content of mustard (*Brassica juncea*). *Journal of Applied and Natural Science, 8*(2), 939–944.

Patel, G. M., Patel, B. T., Dodia, I. N., Bhatt, V. K., & Bhatt, R. K. (2011). Effect of sources and levels of sulphur on yield, quality, and nutrient uptake of mustard (*Brassica juncea* L.) varieties in loamy sand soil. *Journal of Soils and Crops, 19*, 30–35.

Phogat, S., Kumar, V. S., & Kaushik, R. D. (2009). Response of Indian mustard (*Brassica juncea*) to irrigation levels and quality of irrigation water. *Environment & Ecology, 27*(1), 53–57.

Singh, A. K., & Singh, R. S. (2012). Effect of phosphorus and bioinoculants on yield, nutrient uptake and economics of long duration pigeonpea. *Indian Journal of Agronomy, 57*(3), 265–269.

Solanki, R. L., Sharma, M., Sharma, S. K., Sharma, F. L., & Jain, H. K. (2016). Effect of phosphorus, sulphur and phosphate solubilizing bacteria on yield and micronutrient cation uptake of mustard (*Brassica juncea* (L.)) on a Haplustept. *Indian Journal of Fertilizers, 12*, 36–41.

Peer-review history:
The peer review history for this paper can be accessed here:
https://pr.sdiarticle5.com/review-history/145970