

Effect of sowing window, planting geometry and nutrient-management on yield, nutrient uptake and economics of Indian mustard in Vertisols of south-eastern Rajasthan

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Received: May 2020; Revised accepted: February 2022

ABSTRACT

A field experiment was conducted during the winter (*rabi*) seasons of 2017–18, 2018–19 and 2019–20 at Agricultural Research Station, Agriculture University, Kota, India, to find out suitable nutrient-management levels, planting geometry and sowing window for Indian mustard *Brassica juncea* (L.). The treatments comprised sowing window, viz. 10 October, 20 October and 30 October, in main plots; planting geometry, viz. 30 cm × 10 cm and 45 cm × 10 cm and nutrient-management levels, viz. 100% recommended dose of fertilizer (RDF) $N_{80} + P_{40} + K_{30} + S_{40} + Zn_5$ kg/ha, 125% RDF and 150% RDF, in subplots were laid out in split-plot design with 3 replications. Application of 125% RDF $N_{100} + P_{50} + K_{37.5} + S_{50} + Zn_{6.25}$ kg/ha had significance influence on plant height (215.39 cm), dry matter/plant (54.83 g), primary and secondary branches/plant (5.99 and 14.17), siliquae/plant (184.89), seeds/silique (15.59), 1,000-seed weight (5.01 g), seed yield (2.67 t/ha), oil content (38.42%) and oil yield (1011.72 kg/ha), protein content (21.10%), net returns (₹87,570/ha) and benefit : cost ratio (3.06), total nutrient uptake by crop NPKS (108.44, 27.39, 164.22 and 14.77 kg/ha, respectively) and available nutrients in soil NPKS (299.0, 49.8, 467.5 and 10.3 kg/ha, respectively) and zinc (1.36 mg/kg) over 100% RDF and at par with 150% RDF. The crop-sowing period extended from 10 to 30 October were found optimum and had non-significant effect on yield attributes, seed yield and economics, However, significant improvement in dry-matter/plant (58.63 g), primary and secondary branches/plant (6.09 and 14.50), siliquae/plant (202.66), seeds/silique (15.64), 1,000-seed weight (5.18 g), seed yield (2.62 t/ha and benefit : cost ratio (3.05), protein content (21.06 %), available nutrients in soil and total nutrient uptake by crop were observed at planting geometry of 45 cm × 10 cm over 30 cm × 10 cm. Thus, extent of sowing window from 10 to 30 October, planted at 45 cm × 10 cm crop geometry and fertilized with 125% RDF ($N_{100} + P_{50} + K_{37.5} + S_{50} + Zn_{6.25}$ kg/ha) proved beneficial for obtaining high seed yield and net returns of Indian mustard in Vertisols of south-eastern Rajasthan.

Key words: Geometry, Indian mustard, Nutrient management, Nutrient uptake, Returns, Seed yield, Sowing window

Importance of oilseed in agriculture needs further attention, as they are valuable items of human nutrition and soil fertility. In India, rapeseed-mustard is grown over 5.96 million ha area, with a production of 8.32 million tonnes at an average productivity of 1,397 kg/ha (GoI, 2017–18). It is the most important winter (*rabi*) season oilseed crop of Rajasthan which is grown on 2.38 m ha, with annual production of 3.95 million tonnes at an average productivity of 1,656 kg/ha (Commissionerate of Agriculture, 2019–20). The optimum sowing time of Indian mustard [*Brassica*

juncea (L.) Czern & Coss.] in south-eastern Rajasthan is the second fortnight of October for the crop growing on conserve moisture, i.e. fallow-Indian mustard crop sequence, which is already being practiced in the area, but now a majority of Indian mustard growers of the area are showing their interest to change the old-existing cropping system and shifting to diversified double cropping system of urdbean [*Vigna mungo* (L.) hepper]-Indian mustard under changing climatic situation of the area, particularly rainfall pattern and temperature. In addition, availability of early-maturing soybean [*Glycine max* (L.) Merr.]/urdbean varieties, sufficient availability of irrigation water in irrigated area, good rainfall pattern and favourable environmental condition at later crop stage is also catching interest of farmers as well as researchers. Presently in south-

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eastern Rajasthan, Indian mustard is being grown on Vertisols under irrigated conditions after harvesting of urdbean/soybean without considering nutrient management, planting spacing and sowing time which is essential for harvesting good yield.

Imbalanced use of chemical fertilizers especially N, P and K and without application of S and Zn not only lowers productivity but also adversely affects soil health by continuous mining of major nutrients, and of S and Zn which are essential nutrient for oilseed crops. Decline in crop yield due to lack of K supply was reported even in K rich soils like Vertisols (Singh and Wanjari, 2012). Furthermore, the inadequate supply of K also limits the responses to applied N and P fertilizer (Prasad *et al.*, 2004). Nitrogen deficiency may decrease yield, while excess N availability reduces the oil quality. In addition to major nutrients, smaller quantities of secondary and micronutrients such as sulphur and zinc do enhance the yield as well as quality of Indian mustard. Under the present situation, application of nutrient elements especially NPKS and Zn is essential for increasing the yields of Indian mustard and maintaining crop production at higher level in irrigated condition. Further, combined application of major nutrients along with sulphur and zinc results in higher yield and quality of Indian mustard (Meena and Meena, 2015). Sulphur requirement of oilseed crops is generally higher than that of cereal crops (Hegde and Sudhakar Babu, 2009) but its application as a fertilizer is generally overlooked, resulting in widespread deficiency of this element. Sulphur plays vital roles in growth, development and quality of oilseed crops. Several studies have also established the synergistic and interactive response of S nutrition with N and P application on enzymatic activities, protein synthesis and nodulation activities (Sheoran *et al.*, 2013). Proper planting helps maintain optimum moisture level, resulting in better growth and yield. There is meagre scientific information available on nutrient management, planting and sowing time in irrigated Indian mustard-growing regions in the country.

Considering these facts, the present study was undertaken to evaluate the effect of sowing window, planting geometry and nutrient management for Indian mustard grown on Vertisols after harvesting of urdbean in irrigated areas of south-eastern Rajasthan.

MATERIALS AND METHODS

A field experiment was conducted at Agriculture Research Station, Agriculture University, Ummedganj, Kota (26° N, 76°-6' E, 260 m above mean sea-level) during the winter (*rabi*) seasons of 2017–18, 2018–19 and 2019–20 with Indian mustard grown after harvesting of urdbean in Vertisols of south-eastern Rajasthan under irrigated condition. The experimental soil was clay loam in texture, with

a pH of 7.95, medium in organic carbon (0.54%), available nitrogen (280 kg/ha), phosphorus (40.3 kg/ha) and high in potassium (400 kg/ha), zinc (0.92 mg/kg soil) and low in sulphur (8.85 kg/ha) contents. The experiment comprised 18 treatments, having 3 sowing window, viz. S₁, 10 October; S₂, 20 October and S₃, 30 October in main plots; 2 planting geometry; G₁, 30 cm × 10 cm and G₂, 45 cm × 10 cm in subplots and 3 nutrient-management levels, viz. F₁, 100% recommended dose of fertilizer (N₈₀ + P₄₀ + K₃₀ + S₄₀ + Zn₅ kg/ha); F₂, 125% RDF (N₁₀₀ + P₅₀ + K_{37.5} + S₅₀ + Zn_{6.25} kg/ha) and F₃, 150% RDF (N₁₂₀ + P₆₀ + K₄₅ + S₆₀ + Zn_{7.5} kg/ha) were assigned in sub-plots and laid out in a split-plot design with 3 replications. Per cent proportion of recommended dose of potassium was taken up due to high K-fixation capacity of Vertisols which resulted in low availability of K₂O in soil.

The nutrients especially NPKS and Zn were supplied through urea, diammonium phosphate, muriate of potash, bentonite sulphur pellet and zinc sulphate fertilizers respectively. Full dose of P₂O₅, K₂O, sulphur, zinc and half N were applied basal at planting and half dose of N was top-dressed at 40 days after planting of the crop as per treatments. Five kg/ha seed of variety 'DRMRIJ 31' was used, planted as per treatments of sowing window and planting geometry of respective years. The gross plot size for each treatment was 6 m × 3.6 m and net plot size was 5 m × 2.7 m. All the recommended agronomic practices were adopted throughout the crop season. The average annual rainfall received during cropping period of 3 years was 965 mm. The crop was harvested every year manually at physiological maturity stage as per treatments. Initial and post-harvest soil samples during 3 years were collected from 0–15 cm depth, dried processed and analyzed for oxidizable organic carbon, N, P, K, S and Zn using standard procedures. Growth, yield attributes, seed yield, quality parameter and nutrient uptake were worked out as per standard statistical procedure and using standard formulae. Gross and net returns were calculated based on the seed and straw yields and prevailing market prices of Indian mustard in respective seasons. The benefit : cost ratio was calculated by dividing the net returns from the total cost of cultivation. The data were statistically analysed and the results of pooled analysis are presented.

RESULTS AND DISCUSSION

Growth and yield attributes

Application of nutrients and planting geometry had significant influence on growth and yield attributes, while extent in sowing window from 10 October to 30 October were found optimum since it showed non-significant effect on seeds/siliqua and 1,000-seed weight (Table 1). Plant height (220.39 cm) was higher at sowing window of 30

Table 1. Effect of sowing window, planting geometry and nutrient management on growth and yield attributes of Indian mustard (pooled data of 3 years)

Treatment	Plant height (cm) at harvesting	Dry- matter/plant (g) at harvesting	Branches/plant		Siliquae/ plant	Seeds/ siliqua	1,000-seed weight (g)
			Primary	Secondary			
<i>Sowing window</i>							
10 October	208.06	59.39	6.12	14.31	195.82	15.50	5.03
20 October	214.39	53.67	5.91	14.03	186.90	15.35	4.95
30 October	220.39	48.22	5.70	13.05	171.24	15.18	4.90
SEm±	3.75	1.68	0.08	0.30	3.75	0.18	0.07
CD (P=0.05)	11.55	5.17	0.25	0.93	11.55	NS	NS
<i>Planting geometry</i>							
30 cm × 10 cm	218.07	48.89	5.72	13.09	166.97	15.04	4.75
45 cm × 10 cm	210.48	58.63	6.09	14.50	202.66	15.64	5.18
SEm±	4.09	0.65	0.03	0.19	1.62	0.17	0.06
CD (P=0.05)	NS	1.93	0.10	0.55	4.84	0.49	0.18
<i>Nutrient-management</i>							
100% RDF (N ₈₀ + P ₄₀ + K ₃₀ + S ₄₀ + Zn ₅ kg/ha)	207.78	50.67	5.75	12.33	171.73	14.75	4.76
125% RDF (N ₁₀₀ + P ₅₀ + K _{37.5} + S ₅₀ + Zn _{6.25} kg/ha)	215.39	54.83	5.99	14.17	184.89	15.59	5.01
150% RDF (N ₁₂₀ + P ₆₀ + K ₄₅ + S ₆₀ + Zn _{7.5} kg/ha)	219.67	55.78	6.00	14.88	197.33	15.69	5.13
SEm±	1.57	0.49	0.05	0.23	2.42	0.12	0.05
CD (P=0.05)	4.43	1.37	0.15	0.64	6.83	0.34	0.15

RDF, Recommended dose of fertilizer

October than the others, followed by 20 and 10 October; however, the differences between sowing window in this respect were statistically at par with each other. Whereas dry matter/plant (59.39 g), primary branches/plant (6.12), secondary branches/plant (14.31) and silique/plant (195.82) were significantly higher under sowing window 10 October than 30 October sowing period and on par with the crop sown at 20 October, while seeds/silique and 1,000-seed weight did not influence significantly under sowing windows. This might be owing to favourable environment till the physiological maturity and sown crop in all the sowing phase faced the similar climatic conditions. Indian mustard planting 10 days later from normal will offset the climatic effect on these attributes due to favourable climatic conditions at later stage. Although 10 days period might bring extent in Indian mustard sown after harvesting of urdbean in irrigated area of south-eastern Rajasthan and is a better option for farmers to compensate the yield losses in future climates and also helps the farmers for shifting from monoculture to double cropping system. Similar findings were reported by Razzaque *et al.* (2007).

The dry-matter/plant (58.63 g), primary branches/plant (6.09), secondary branches/plant (14.50) and silique/plant (202.66), seeds/silique (15.64) and 1,000-seed weight (5.18) were significantly higher at planting geometry of 45 cm × 10 cm than 30 cm × 10 cm except plant height. Higher yield attributes at wider spacing is attributed owing to improvement in root length and lower plant population/

unit area compared to closer spacing of 30 cm × 10 cm. It was mainly attributed to the lower plant population/unit area at wider spacing which cumulatively increased the growth and yield attributes. The P and Zn interacted negatively with other is also well documented (Meena *et al.*, 2015), and Chaudhary *et al.* (2016) also reported higher yield attributes in Indian mustard.

Application of 125% RDF (N₁₀₀ + P₅₀ + K_{37.5} + S₅₀ + Zn_{6.25} kg/ha) had significance influence on plant height (215.39 cm), dry matter/plant (54.83 g), primary and secondary branches/plant (5.99 and 14.17), silique/plant (184.89), seeds/silique (15.59), 1,000-seed weight (5.01 g) over 100% RDF (N₈₀ + P₄₀ + K₃₀ + S₄₀ + Zn₅ kg/ha) and at par with 150% RDF (N₁₂₀ + P₆₀ + K₄₅ + S₆₀ + Zn_{7.5} kg/ha). However, growth and yield attributes recorded in application of 125% RDF and 150% RDF were statistically at par with each other. Significantly higher yield attributes were observed with the supply of balanced nutrients of N, P, K, S and Zn in appropriate quantity which improved fertility status of soil and created congenial environment in soil which increased the nutrient availability and thereby increased the uptake of nutrients by crop. Our results confirm the findings of Deshbhratar *et al.* (2010) and Sheoran *et al.* (2013), who also reported the highest yield attributes. Positive interaction of nitrogen and phosphorus and nitrogen with potassium is well known. The positive response with NPK on seed yield was also reported by Girase *et al.* (2016)

Yield and quality

The seed yield (2.73 t/ha), oil content (38.57%) and oil yield (1,026.97 kg/ha) were higher by 9.64, 1.90 and 8.72%, respectively, at sowing window of 10 October over 30 October and were non-significant with each other, but all the sowing windows did not influence significantly the seed and stover yields, harvest index, protein content and protein yield (Table 2). However, the differences between sowing window (from 10 to 30 October) in respect of seed yield, oil content and oil yield were observed non-significant. Although extent of planting time up to 30 October can be a better option for harnessing good yield under changing climatic situation. Similar findings were reported by Singh *et al.* (2001) and Razzaque *et al.* (2007).

The seed yield (2.61 t/ha), oil content (38.30%) oil yield (1,012 kg/ha), protein content (21.06%) and protein yield (555.1 kg/ha) significantly higher by 2.35, 0.50, 5.71, 0.86 and 9.34%, respectively at planting geometry of 45 cm × 10 cm than 30 cm × 10 cm except stover yield. Planting geometry of 30 cm × 10 cm resulted in the maximum harvest index (32.32%), which was significantly higher than that of planting geometry of 45 cm × 10 cm. The higher seed yield in 45 cm × 10 cm spacing could be taken as a function of vigorous vegetative growth owing to lower plant population/unit area owing to more number of branches/plant and siliquae/plant compared to closer spacing of 30 cm × 10 cm. Singh *et al.*, (2006), Meena and Meena (2015) and Chaudhary *et al.*, (2016) also reported similar findings.

A linear and significant improvement in yields (seed and stover) and quality parameters, viz. oil, protein content and yield of oil and protein recorded with increase in nutrient management levels up to 125% RDF (Table 2). The maximum seed yield (2.66 and 5.56 t/ha) was obtained under the application of 125% RDF being significantly higher by 10.83 and 11.20%, respectively over 100% RDF and at par with 150% RDF of the nutrient-management treatments. However, the highest harvest index (32.43%) recorded with the application of 100% RDF was significantly higher than that recorded with 150% RDF and at par with 125% RDF. The increase in seed yield might be attributed to higher number of yield attributes, viz. branches/plant, siliquae/plant, seeds/silique and 1,000-seed weight. This is presumably on account of more availability of nutrients, light, higher plant water and lesser competition among sinks (seeds) for source (photosynthates), which result better yield attributes. These findings are in accordance with those of Singh and Meena (2004) and Kumari *et al.*, (2012).

Application of 125% RDF significantly improved the oil content (38.42%), oil yield (1,011.7 kg/ha), protein content (21.1%) and protein yield (548.2 kg/ha) over 100% RDF and at par with 150% RDF. Further increment in nutrient-management from 125% RDF to 150% RDF was reflected oil content in seed. Thus, seed yield and quality parameters were also higher at 125% RDF nutrient-management treatment. The positive effect of balanced nutrients supply of NPK along with S and Zn on seed and

Table 2. Effect of sowing window, planting geometry and nutrient-management on seed yield, harvest index and quality of Indian mustard (pooled data of 3 years)

Treatment	Yield (t/ha)		Harvest index (%)	Oil content (%)	Oil yield (kg/ha)	Protein content (%)	Protein yield (kg/ha)
	Seed	Stover					
<i>Sowing window</i>							
10 October	2.73	5.67	32.50	38.57	1,026.97	21.05	552.53
20 October	2.57	5.39	32.29	38.20	982.84	21.05	531.68
30 October	2.49	5.22	32.30	37.85	944.62	20.81	509.96
SEm±	0.08	0.20	0.09	0.09	24.73	0.11	17.31
CD (P=0.05)	NS	NS	NS	0.26	76.20	NS	NS
<i>Planting geometry</i>							
30 cm × 10 cm	2.50	5.34	32.32	38.11	957.46	20.88	507.68
45 cm × 10 cm	2.62	5.51	32.14	38.30	1,012.16	21.06	555.10
SEm±	0.04	0.18	0.06	0.06	20.79	0.04	12.08
CD (P=0.05)	0.10	NS	0.17	0.17	61.75	0.13	41.79
<i>Nutrient-management</i>							
100% RDF (N ₈₀ + P ₄₀ + K ₃₀ + S ₄₀ + Zn ₅ kg/ha)	2.40	5.00	32.43	38.03	890.49	20.70	473.77
125% RDF (N ₁₀₀ + P ₅₀ + K _{37.5} + S ₅₀ + Zn _{6.25} kg/ha)	2.66	5.56	32.36	38.42	1011.72	21.10	548.25
150% RDF (N ₁₂₀ + P ₆₀ + K ₄₅ + S ₆₀ + Zn _{7.5} kg/ha)	2.72	5.72	32.23	38.17	1052.22	21.11	572.15
SEm±	0.06	0.11	0.06	0.10	26.27	0.07	16.01
CD (P=0.05)	0.17	0.31	0.17	0.28	73.90	0.20	46.73

RDF, Recommended dose of fertilizer

quality yield were also reported by Tatarwal *et al.*, (2013).

The interaction effect of sowing window/ spacing and nutrient-management levels was found significant. Irrespective of fertility levels, the maximum seed yield (3012.96 kg/ha) was recorded under nutrient-management level of 150% RDF with planting geometry at 45 cm × 10 cm and sowing window of 10 October, which was significantly superior to 20, 30 and 10 October sowing periods with 100% RDF and observed at par among each other. However, irrespective of sowing window from 10 to 30 October with planting geometry at 30 cm × 10 cm and 45 cm × 10 cm with varying nutrient-management levels failed to produce significant effect on seed yield compared with other treatment combinations (Table 5). This was mainly attributed to higher values of yield parameters owing to supply of nutrients in balanced amount through fertilizers.

Economics

The economic analysis of the crop revealed that net returns and benefit : cost ratio were influenced significantly by the nutrient-management treatments, but it was statistically at par in sowing window and planting geometry treatments. There were differences in cost of cultivation and net returns due to different treatment cost. Though the highest net returns (₹ 89,690/ha) and B : C ratio (3.13) were recorded in sowing window of 10 October, all the sowing windows did not influence significantly net returns and B : C ratio (Table 3). The highest net returns (₹ 86,170/ha) and B : C ratio (3.3.05) recorded under planting geometry of 45 cm × 10 cm which was significantly superior to

30 cm × 10 cm, however the net returns were statistically on par with each other. The wider spacing of 45 cm × 10 cm realized higher net returns and B : C ratio than 30 cm × 10 cm owing to the maximum seed yield. The incremental increase in yield attributes and yield ultimately resulted in higher net returns and benefit : cost ratio.

Application of 125% RDF ($N_{100} + P_{50} + K_{37.5} + S_{50} + Zn_{6.25}$ kg/ha) fetched significantly higher net returns of ₹ 87,570/ha and benefit: cost ratio of 3.06 than 100% RDF ($N_{80} + P_{40} + K_{30} + S_{40} + Zn_5$ kg/ha) and at a par with 150% RDF ($N_{120} + P_{60} + K_{45} + S_{60} + Zn_{7.5}$ kg/ha). It showed increase of 12.86% in net returns and 6.25% in B : C ratio over 100% RDF, indicating the positive response to NPK along with S and Zn up to 125% RDF. However, the rate of increase in net return was very less with 150% RDF, indicating the non-responsiveness and the non suitability of this treatment for increasing production of India mustard. Maximum production cost (₹ 30,310/ha) recorded in 150% RDF due to higher cost of fertilizer and lower added of nutrients, whereas the minimum production cost and net returns were recorded in 100% RDF. The combined effect of plant nutrients played a very significant role owing to their synergistic effect which enhanced the partitioning of photosynthates in vegetative and reproductive parts goes simultaneously in the later growth phases. The results confirm the findings of Meena *et al.*, (2018) and Singh *et al.*, (2020).

Nutrient uptake

Different sowing window, planting geometry and nutrient-management levels had significant influence on uptake

Table 3. Effect of sowing window, planting geometry and nutrient-management on economics and nutrient uptake by Indian mustard (pooled data of 3 years)

Treatment	Cost of cultivation (×10 ³ ₹/ha)	Net returns (×10 ³ ₹/ha)	Benefit: cost ratio	Total nutrient uptake by crop (kg/ha)			
				N	P	K	S
<i>Sowing window</i>							
10 October	28.63	89.69	3.13	109.67	27.11	164.11	14.66
20 October	28.63	84.06	2.94	106.22	26.06	162.11	14.93
30 October	28.63	80.06	2.80	101.22	25.78	158.72	14.14
SEm±	—	3.45	0.12	1.33	0.24	1.00	0.17
CD (P=0.05)	—	NS	NS	4.09	0.75	3.04	0.54
<i>Planting geometry</i>							
30 cm × 10 cm	28.63	83.04	2.90	102.56	25.07	159.48	14.24
45 cm × 10 cm	28.63	86.17	3.05	108.85	27.56	163.81	14.91
SEm±	—	2.34	0.05	1.06	0.15	0.97	0.19
CD (P=0.05)	—	NS	NS	3.12	0.43	2.88	0.58
<i>Nutrient-management</i>							
100% RDF (N ₈₀ + P ₄₀ + K ₃₀ + S ₄₀ + Zn ₅ kg/ha)	26.95	77.59	2.88	98.39	23.78	155.50	13.81
125% RDF (N ₁₀₀ + P ₅₀ + K _{37.5} + S ₅₀ + Zn _{6.25} kg/ha)	28.62	87.57	3.06	108.44	27.39	164.22	14.77
150% RDF (N ₁₂₀ + P ₆₀ + K ₄₅ + S ₆₀ + Zn _{7.5} kg/ha)	30.31	88.65	2.93	110.28	27.78	165.22	15.16
SEm±	-	2.53	0.06	0.81	0.21	0.89	0.30
CD (P=0.05)	-	7.32	0.14	2.32	0.60	2.50	0.83

of total nutrients by the crop (Table 3). Sowing on 10 October exhibited significantly maximum total uptake of N (109.67 kg/ha), P (27.11 kg/ha), K (164.11 kg/ha) and S (14.66 kg/ha) by the crop over 30 October, and on a par with that of 20 October; timely sowing helped in maintaining congenial environment conditions in soil system throughout the crop-growth period, increased the availability of nutrients and also total dry matter production/ha, resulting in increase the uptake of nutrients by the crop when sown on 10 October. The maximum uptake of N (108.85 kg/ha), P (27.56 kg/ha), K (163.81 kg/ha) and S (14.91 kg/ha) by the crop was recorded under planting geometry of 45 cm × 10 cm, being significantly superior to 30 cm × 10 cm spacing. The wider spacing of 45 cm × 10 cm realized higher dry-matter production and seed yield/ha owing to vigorous plant growth; increased availability of nutrients resulted in increased content and uptake of nutrients by crop under planting geometry of 45 cm × 10 cm; Meena *et al.*, (2015) also reported similar findings.

Significant improvement in total uptake of N, P, K and S by the crop recorded with the increase in nutrient management levels up to 125% RDF ($N_{100} + P_{50} + K_{37.5} + S_{50} + Zn_{6.25}$ kg/ha), indicated availability of these nutrients in labile pool to support the crop growth and yield (Table 3). The maximum total uptake of N (108.4 kg/ha), P (27.39 kg/ha), K (164.2 kg/ha) and S (14.77 kg/ha) was observed in the application of 125% RDF, being significantly higher than 100% RDF ($N_{80} + P_{40} + K_{30} + S_{40} + Zn_5$ kg/ha) and at par with 150% RDF ($N_{120} + P_{60} + K_{45} + S_{60} + Zn_{7.5}$ kg/ha), indicating that balanced amount of nutrients is essential for soil

health sustainability. The increase in uptake of nutrients may be attributed to higher N, P, K, S content, higher dry-matter production and seed yield/ha which was owing to continuous supply of essential plant nutrients to plants throughout crop growth period by providing balanced nutritional environment inside the plant and higher photosynthetic efficiency, that favoured higher dry-matter accumulation resulting in more uptake of N, P, K and S at higher fertilizer levels. These results are in accordance with those of Singh *et al.*, (2006) and Chaudhary *et al.*, (2016)

Available soil nutrients

The available N, P, K, S and Zn content in soil at the end of crop cycle was higher in all the sowing windows (Table 4) compared to initial nutrient status. The available N, P, K and S recorded in all 3 sowing dates did not vary significantly among them. However, available Zn was recorded highest in sowing window of 20 October (1.42 mg/kg), which was significantly higher to that of sowing window of 30 October and at a par with 10 October. Non-significant variation observed in residual soil-nutrient status might be owing to the fact that the entire sowing window received same amount of nutrients. The P (52.30 kg/ha) and Zn (1.43 mg/kg) content in soil after harvesting of Indian mustard were significant higher under planting geometry of 45 cm × 10 cm than 30 × 10 cm. This might be owing to the higher initial nutrient content in soil and low uptake by the crop. The available N, K and S in soil were not influenced significantly by the planting geometry, however the highest available of nitrogen (300 kg/ha), potassium

Table 4. Effect of sowing window, planting geometry and nutrient-management on available soil nutrients after harvesting of Indian mustard (pooled data of 3 years)

Treatment	Available soil nutrients (kg/ha)				
	N	P	K	S	Zn (mg/kg)
Sowing window					
10 October	293.64	48.86	462.39	9.90	1.35
20 October	298.50	51.06	468.42	10.60	1.42
30 October	300.92	50.39	464.92	9.80	1.21
SEm±	4.12	0.75	2.63	0.26	0.04
CD (P=0.05)	NS	NS	NS	NS	0.12
Planting geometry					
30 × 10 cm	295.21	47.91	462.80	9.90	1.22
45 × 10 cm	300.17	52.30	467.69	10.33	1.43
SEm±	2.32	0.85	2.85	0.15	0.02
CD (P=0.05)	NS	2.54	NS	NS	0.06
Nutrient-management					
100% RDF($N_{80} + P_{40} + K_{30} + S_{40} + Zn_5$ kg/ha)	289.09	41.58	455.78	9.20	1.25
125% RDF ($N_{100} + P_{50} + K_{37.5} + S_{50} + Zn_{6.25}$ kg/ha)	299.03	49.84	467.50	10.27	1.36
150% RDF ($N_{120} + P_{60} + K_{45} + S_{60} + Zn_{7.5}$ kg/ha)	304.95	58.89	472.45	10.86	1.37
SEm±	1.80	1.57	1.61	0.13	0.03
CD (P=0.05)	5.04	4.43	4.53	0.43	0.08

RDF, Recommended dose of fertilizer

(467.69 kg/ha) and sulphur (10.33 kg/ha) in the soil were recorded under the planting geometry of 45 cm × 10 cm. Wider planting geometry helped in maintaining soil fertility with continuous sharing of nutrient supply, which increased the availability of nutrients in the soil. Our results confirm the findings of Kumar (2003) and Razzaque *et al.*, (2007).

The available NPKS and Zn content in soil increased significantly with the increase in nutrient management level from 100% RDF to 150% RDF. Application of 150% RDF ($N_{120} + P_{60} + K_{45} + S_{60} + Zn_{7.5}$ kg/ha) significantly improved the available nitrogen (304.95 kg/ha), phosphorus (58.89 kg/ha), potassium (472.45 kg/ha), sulphur (10.86 kg/ha) and Zn (1.37 mg/kg) in the soil over application of 100% RDF ($N_{80} + P_{40} + K_{30} + S_{40} + Zn_5$ kg/ha) and 125% RDF ($N_{100} + P_{50} + K_{37.5} + S_{50} + Zn_{6.25}$ kg/ha) except zinc in 125% RDF. The post-harvest available nutrient content of the soil indicated a significant and progressive increase with corresponding nutrients application. The highest improvement in soil-fertility status owing to application of NPK along with S and Zn may be attributed to positive interaction of applied nutrients in balanced amount which solubilize the soil nutrient reserve and make it available to crop, as reported by Meena and Meena (2015).

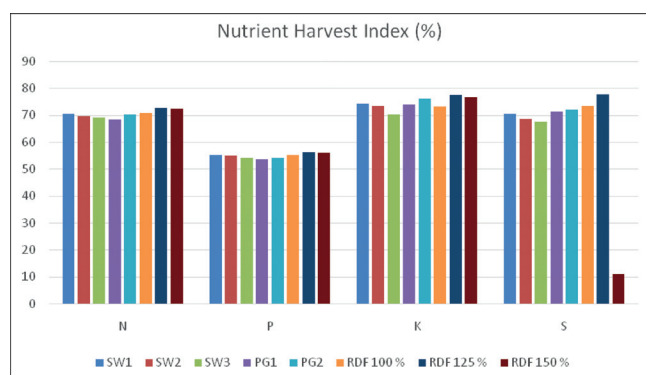


Fig. 1. Effect of sowing window, planting geometry and nutrient-management on nutrient harvest index after harvest of Indian mustard (pooled data of 3 years)

Harvest index of N (70.42 %), P (55.20 %), K (74.10 %), and S (70.50 %) were highest in sowing window of 10 October, followed by 20 October and 30 October (Table 4 and Fig. 4). The harvest index of N (70.30 %), P (54.00 %), K (76.10 %), and S (72.10 %) under planting geometry of 45 cm × 10 cm than 30 cm × 10 cm. Among nutrient-management treatments, application of 125% RDF ($N_{100} + P_{50} + K_{37.5} + S_{50} + Zn_{6.25}$ kg/ha) resulted in maximum harvest index of N (72.60%), P (56.30%), and K (77.40%), except S harvest index, being maximum (77.90%) with 150% RDF ($N_{120} + P_{60} + K_{45} + S_{60} + Zn_{7.5}$ kg/ha). Such differences in nutrient use efficiency of N, P, K and S were due to application and availability of these nutrients from the respective sources, as also reported by Meena *et al.*, (2018).

It can be concluded that Indian mustard sown from 10 to 30 October after harvesting of urdbean, planted at 45 cm × 10 cm crop geometry and fertilized with 125% RDF ($N_{100} + P_{50} + K_{37.5} + S_{50} + Zn_{6.25}$ kg/ha) was found beneficial for obtaining higher seed yield, net returns and soil available nutrients under irrigated condition of Vertisols of south-eastern Rajasthan.

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Table 5. Interaction effect of sowing window, planting geometry and nutrient-management on seed yield of Indian mustard (kg/ha)

Treatment	Sowing window/ Planting spacing					
	30 cm × 10 cm			45 cm × 10 cm		
	10 October	20 October	30 October	10 October	20 October	30 October
<i>Nutrient-management</i>						
100% RDF ($N_{80} + P_{40} + K_{30} + S_{40} + Zn_5$ kg/ha)	2,291	1,836	2,283	2,569	2,556	2,207
125% RDF ($N_{100} + P_{50} + K_{37.5} + S_{50} + Zn_{6.25}$ kg/ha)	2,561	2,596	2,401	2,761	2,606	2,644
150% RDF ($N_{120} + P_{60} + K_{45} + S_{60} + Zn_{7.5}$ kg/ha)	2,546	2,892	2,445	3,012	2,648	2,701
<i>Sowing window × geometry × nutrient-management interaction</i>						
SEm±	181.98					
CD (P=0.05)	711.28					

RDF, Recommended dose of fertilizer

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