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Response of mustard to potassium in combination with other nutrients

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ABSTRACT : Plant height and number of primary and secondary branches at different crop growth stages were not affected significantly due to different nutrient levels, however exhibited some improvement over control. Dry matter accumulation by individual plant increased with advancement in cropage till harvest. The highest dry matter accumulation were recorded at 100% NPK + S @ 40kg/ha treatment. 100% NPK + FYM @ 2.5 t/ha (dry weight) and 100% NPK + $ZnSO_4$ @ 25kg/ha ranked second and third, respectively in dry matter accumulation after 100% NPK + S @ 40kg/ha. Days taken to 50% flowering and 80% maturity remained unaffected by different nutrient application levels.100% NPK + S @ 40kg/ha recorded significantly higher number of total branches at harvest than remaining treatments. 100% NPK + Borax @ 0.2% (foliar) and 100% NPK + FYM @ 2.5t/ha (dry weight) recorded next higher to values 100% NPK + S @ 40kg/ha. Yield attributes *viz.* number of siliquae per plant, length of siliqua, 1000- seed weight and seed weight per plant were affected significantly due to different nutrient levels. 150% NPK recorded higher number of siliquae per plant, higher number of seeds per siliqua, length of siliqua, 1000- seed weight and seed weight per plant. 150% NPK recorded significantly higher values of seed, stover and biological yield per hectare than remaining treatments. This treatment was followed by 100% NPK + FYM @ 2.5t/ha (dry weight). Harvest index did not differ significantly under different nutrient levels. The nutrients (N, P and K) concentration in seed and stover remained unaffected by different nutrient levels.The nutrients (N, P and K) uptake by seed, stover and crop was recorded maximum at 150% NPK. The protein content in seed was found non- significant under different nutrient levels. However, it was recorded maximum at 100% NP treatment. The protein yield was found maximum at 150% NPK. The oil content in seed was found non- significant under different nutrient levels. Oil yield in seed was recorded maximum at 150% NPK. The maximum net returns and gross return were recorded at 150% NPK. Highest return per rupee invested was recorded at 150% NPK which was followed by 50% NPK. However, the lowest return per rupee invested was recorded in control condition.

KEY WORDS : Borax, FYM, NPK, Plant height, DAS

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Rapeseed-Mustard are important oilseed crops which rank third in vegetable oils after soybean and palm while second in oilseed proteins production after soybean in the world (USDA, 2011). The global production of rapeseed mustard is 62.45 mt from an acerage of 33.64 mha with a total productivity of 18.56 q/ha (FAO STAT, 2011). The production of rapeseed-mustard in India is about 8.17 mt covering an area of about 6.51 mha with a total productivity of 12.57 q/ha (GOI, 2011). Brassicas are good source of producing high quality oil for human consumption. The two species, *Brassica napus* L. and *B. rapa* L. (rapeseed) together with *B. juncea* (L.) Czernj. and Cosson (Indian mustard) and *B. carinata* (Ethiopian mustard) are commonly referred to as rapeseed-mustard which constitute an important group of oilseed crops grown under wide range of agroclimatic conditions in India. It is estimated that 58 mt of oilseeds will be required by the year 2020, wherein the share of rapeseed-mustard will be around 24.2 mt (Bartaria *et al.*, 2001). The per hectare production of the crop is quite low in the country (1152kg ha^{-1}) against the world average of 1400 kg ha^{-1} in the world (Pirri and Sharma, 2006). Among the agronomic factors known to augment the crop production, fertilizers stand first and foremost productive input in agriculture. The nutrient requirement of oilseed crops, in general, is very high for almost all the essential mineral nutrients which are to be supplied in adequate quantities. Nutrient use efficiency is barely 30-40 per cent and approximately more than 60 per cent of applied nutrients are lost through various ways. It has been estimated that less than 15 per cent of nutrients absorbed by the oilseeds are contributed by fertilizers while the remaining are obtained from soil resources, organic manures, biological sources and residues as well as wastes (Davari and Mirzakhani, 2009). Adequate nutrient supply increases the seed and oil yields by improving the setting pattern of siliquae on branches, number of siliquae per plant and other yield attributes. Recommended dose of fertilizers (RDF) for different zones vary with climate, soil type and type of cropping systems followed. Balanced fertilization at proper time through proper method of application increases nutrient use efficiency of mustard. Farmers most commonly use DAP that supply only nitrogen and phosphorus. So, for obtaining maximum efficiency of added fertilizer, balanced fertilization to crops including use of potassium, is essential. Potassium plays a major role in the physiological activities of the plant including photosynthesis, assimilates transmission into sink, cell turgor maintenance, and improves drought tolerance, enzyme activities and reducing the additional absorption of sodium and iron ions in saline and torrential soils (Mengel and Kirkby, 2001). It is vital in water regulation of the plant and plays an important balancing role with nitrogen to ensure healthy, vigorous growth and natural resistance to disease, pests and abiotic stress. It regulates the opening and closing of stomata, enhances crop quality, reduces lodging of crops and enhances winter hardiness. It also increases the uptake of other nutrients like nitrogen, phosphorus and sulphur. Among the other major nutrient elements, nitrogen being deficient in most of the Indian soils. Its high requirement by crop is most limiting factor in mustard production. Nitrogen use efficiency is influenced greatly by time, rate, source and method of application. Rate of nitrogen depends on the initial soil status, climate, topography, cropping system in practice and previous crop. Similarly, Phosphorus is also an important factor determining productivity of the crop. Response of rapeseed-mustard to phosphorus is determined by moisture availability, soil P status and yield level. Sulphur plays direct and predominant role in fatty acid synthesis. It is constituent of amino acid, *viz.*, cystine, cyestine and methionine and is essential for chlorophyll synthesis and vitamins, like biotin and thiamine. Thus, oilseeds require more sulphur for higher oil and protein yield. Mustard, in general, is very sensitive to micronutrient deficiency, specially zinc and boron. Zinc plays vital role in carbohydrate and protein metabolism. It controls the plant growth hormone, IAA and is essential component of dehydrogenase, proteinase and peptides enzymes and promotes starch formation, seed maturation and production. Boron plays an important role in cell differentiation and development, translocation of photosynthates and growth regulators from source to sink and growth of pollen grains thereby increases seed yield of crops by increasing fertility index. Bulky organic manures are applied to improve overall soil health and reduce evaporation losses of soil moisture ultimately increasing the seed yield. Nitrogen and potassium complement each other in their mutual beneficial action, each enabling the plant to make use of other. Nitrogen alone has little effect on crop yield but there will be large response to applied nitrogen when potassium is applied together with nitrogen (Gupta, 2005). Thus, there is a direct positive relationship between nitrogen and potassium in plant nutrition. Potassium has antagonistic effect with some of the nutrients like boron and zinc. Thus, increase in availability of potassium, decreases the availability of boron and zinc. Thus, realizing the importance of above mentioned facts, the present investigation entitled “Response of mustard [(*Brassica juncea* L.) Czernj. and Cosson] to potassium in combination with other nutrients” has been undertaken with the following objectives: To study the effect of potassium in combination with nitrogen and phosphorus on growth, yield attributes, yield and quality of mustard, to determine the N, P and K content in mustard and to study the economics of different treatments.

RESEARCH METHODS

The details of the experimental materials used, methods followed and the statistical techniques adopted during the course of the investigation are discussed in this chapter.

Experimental site:

The field experiment was conducted in the Bhagwant University Agriculture Farm Ajmer Rajasthan, India during *Rabi* 2016-17. Ajmer (Rajasthan) falls in the arid zone adjoining the foothills of Shivalik range of the Himalayas and is situated at 26.4°N latitude and 74.32°E longitude having an altitude of 480 meter above the mean sea level (MSL).

Fertilizer application:

A dose of 120kg nitrogen, 60kg P_2O_5 and 40kg K_2O per hectare was applied through urea, single super phosphate and muriate of potash. Half dose of nitrogen was applied as basal in furrows at the time of planting and remaining was top dressed after first irrigation. However, full dose of phosphorus and potassium was applied at the time of planting.

Thinning:

To maintain plant population per unit area through thinning was done at 25DAS. Thinning was done manually keeping a spacing of 15cm between plants to plant.

Harvesting and threshing:

Harvesting of net plot was done manually with the help of sickle at the stage when 75 per cent of the siliqua turned yellowish and seeds obtained their natural colour. Threshing was performed manually after sun drying the plants.

Observations:

Details of the various growth and development studies and post harvest studies are given as under:

Growth studies:

The plant growth studies carried out at 30, 60 and 90 days after sowing and finally at harvest are as below:

Plant height:

Five plants were selected randomly from each plot and tagged. The height was measured in cm with the help of scale from base to the top of the plant. The average of five plants was reported as the plant height in cm.

Number of branches:

Number of primary and secondary branches per plant was counted from the tagged plants. These plants were collected at harvest and their average was used as number of primary and secondary branches on per plant basis.

Dry matter accumulation:

Five plants were uprooted with the help of *Khurpi* and roots were separated. For recording observations, samples were taken from the second row from east in each plot. The different plant parts were separated and subjected to oven dry at 70 ±1°C temperature till the constant weight was obtained. The dry weight of different plant parts has been reported in gram per plant basis.

Days taken for 50 per cent flowering and 80 per cent maturity:

The date on which 50 per cent plants of four central rows had at least one flower, was considered for recording the days taken for 50 per cent flowering. Similarly the day when approximately 80-90 per cent siliqua matured was considered for recording days taken to maturity.

Yield attributes:

The various yield attributing characters *viz.*, total number of branches per plant, number of siliquae per plant, length of siliqua per plant, number of seeds per siliqua, 1000-seed weight and seed weight per plant (g) were recorded as per the details given below:

Number of siliquae per plant:

Total number of siliquae present on main shoot and on respective branches of tagged plants at harvest were separated, counted, averaged and then reported as number of siliqua on per plant basis.

Length of siliqua per plant:

Length of ten randomly selected siliquae from main shoot and respective branches was measured and the average reported as length of siliquae in cm at harvest stage. While reporting the average length of siliquae, the length of siliquae present on different branches has been averaged.

Number of seeds per siliqua:

The seeds obtained from ten randomly selected siliqua present on main shoot, primary and secondary branches were counted and the average number was reported. While reporting average number of seeds per siliqua, the numbers of seeds per siliqua on respective branches were averaged.

1000-seed weight:

1000 seeds were counted randomly and weighted on electronic balance. The weight was reported in gram.

Seed weight per plant:

The seeds obtained after threshing the siliquae of respective branches at harvest from the five tagged plants were separated and reported in gram per main shoot, primary branch and secondary branch. While reporting the total seed weight per plant, the seed weight of all the branches was added together.

Yield: Biological yield:

Total produce of each net plot was allowed to sun drying in the field after harvest and weighed. Biological yield per hectare was computed by multiplying with suitable conversion factor.

Seed yield:

From the individual plot, net plot area was harvested, sun dried and the produce was threshed and cleaned. The final weight was recorded in kg per plot and converted into kg per hectare.

Stover yield:

Stover yield was computed by deducting the seed yield from the total dry matter yield and expressed in kg per hectare.

Chemical studies : Chemical studies of soil sample:

The initial soil samples were collected from the 15cm deep layer of the soil at 10 random points with the help of spade and *Khurpi*, pooled together and processed for the determination of initial physico-chemical properties of soil of the experimental site.

Chemical studies of plant samples:

The uniform and representative plant samples were collected randomly from every plot at harvest. These samples were used for following chemical studies:

Nutrient content and uptake in plant : Nitrogen content and uptake by seed, stover and plant:

Total nitrogen content in seed and stover of each plot at harvest stage was estimated separately by modified micro-Kjeldahl method. The samples were grounded upto 2mm mesh size and 0.2g of this sample were taken and digested. The aliquot was used for analysis of the per cent total N in crop at harvest. The nitrogen uptake was calculated by multiplying the concentration of N in seed and stover with respective dry matter production in one hectare, N uptake by plant was worked out by adding N uptake in seed and stover and expressed as kg ha'.

Phosphorus content and uptake by seed, stover and plant:

Total phosphorus content in seed and stover of each plot at harvest stage was estimated separately by vanado-molybdo-phosphoric acid yellow method. The phosphorus uptake was calculated by multiplying the concentration of P in seed and stover with respective dry matter production in one hectare, P uptake by plant was worked out by adding P uptake in seed and stover and expressed as kg ha^{-1}.

Potassium content and uptake by seed, stover and plant:

Total potassium content in seed and stover of each plot at harvest stage was estimated separately by flame photometry method. The potassium uptake was calculated by multiplying the concentration of K in seed and stover with respective dry matter production in one hectare, K uptake by plant was worked out by adding K uptake in seed and stover and expressed as kg ha^{-1}.

Quality studies : Oil content and oil yield:

The oil content in seed was determined by Soxhlet's extraction method taking petroleum ether as a solvent. The oil content was reported on per cent basis. Oil yield was computed by multiplying the oil content value with seed yield as per treatment and then the oil data were presented in kg ha^{-1}.

Protein content and protein yield:

Protein content in seeds was obtained by multiplying N content with a constant factor of 6.25 and to work out protein yield kg ha^{-1}, protein content in seeds was multiplied by seed yield divided by 100 and multiplied by moisture correction factor.

Economic analysis : Cost of cultivation:

Common cost of cultivation for different treatments was calculated and additional fertilizer management treatments cost was added and cost of cultivation of each treatment was calculated.

RESEARCH FINDINGS AND DISCUSSION

The results of the experiment obtained during the course of investigation are summarized in this chapter with the help of appropriate tables.

Growth and development studies on crop : Plant height:

The data pertaining to plant height at various stages of crop growth are summarized in Table 1. In general, the plant height increased as the crop advanced in age and reached its maximum at maturity. Plant height did not differ significantly at all the stages of crop growth. Maximum height at 30 and 60 DAS were recorded under the application of 150% NPK, but at 90 DAS and harvest stage plant height was recorded maximum under the application of 100% NPK + 40kg S ha^{-1}.

Number of primary branches per plant:

Data on primary branches per plant as influenced by different nutrient application levels are presented in Table 2. In general, the number of primary branches increased with advancement of crop age. At 30DAS significantly higher number of primary branches were recorded with the application of 100% NPK + 40kg S ha^{-1} over all other treatment except 100% NPK + 25kg $ZnSO_4$ ha.

However, the lowest number of primary branches was recorded in control, but at other crop growth stages no significant effect was found under the different nutrient levels. Number of branches increased with nutrient levels and significant response with sulphur application may be ascribed to the functional role of nitrogen and sulphur in the plant body as nitrogen helps in multiplication, cell elongation, and tissue differentiation. Also with adequate supply of nitrogen the plants grew taller and produced more branches.

Number of secondary branches per plant:

Data on secondary branches per plant as influenced by different nutrient application levels are presented in - Table 3. In general, the number of secondary branches increased with advancement of crop age. Higher number of secondary branches was recorded at 60 DAS with the application of 100% NPK + Borax @ 0.2% being at par with all other treatments except 100% NPK, 50% NPK and control which significantly produced more number of secondary branches. However, the lowest number of secondary branches was recorded in control.

Table 1 : Plant height at various stages of crop growth as influenced by different nutrient levels

Treatments	Plant height (cm)			
	30 DAS	60 DAS	90 DAS	At harvest
100% K	19.6	86.2	123.8	212.5
100% N	19.3	84.5	119.8	201.0
100% NK	19.8	87.8	122.9	208.1
100% NP	19.1	84.6	123.1	210.7
50% NPK	19.0	80.8	118.2	198.5
100% NPK (RDF)*	19.2	82.2	124.0	206.6
150% NPK	21.2	89.0	124.8	216.7
100% NPK+ S @ 40kg/ha	20.0	87.8	132.3	220.7
100% NPK+$ZnSO_4$ @25kg/ha	19.4	84.9	126.6	211.4
100% NPK+ Borax @ 0.2% (foliar)	19.7	87.2	124.8	211.8
100% NPK+ FYM** @ 2.5t/ha (Dry weight)	20.2	88.9	126.8	216.7
Control	17.4	71.4	117.4	186.8
S.E.±	0.8	3.7	4.6	10.9
C.D. (P=0.05)	NS	NS	NS	NS

NS= Non-significant

At 90 DAS higher number of secondary branches was recorded with the application of 100% NPK + 40kg S ha^{-1} being at par with all other treatments except 50% NPK, 100% NPK, 100% NK and control which significantly produced more number of secondary branches. However, the lowest number of secondary branches was recorded in control. At 30 DAS and harvest stage the numbers of secondary branches were found to be non- significant. The number of secondary branches increased probably is due to more activities of meristematic tissue of the pant. The increased vigour of the plant during vegetative stage, thus, contributed towards the higher production of branches at different growth stages. Application of sulphur also contributed to increase in number of secondary branches by enhancing cell differentiation and chlorophyll synthesis. Boron also plays an important role in cell differentiation, development and translocation of photosynthates, thus, increasing the number of secondary branches.

Table 2 : Number of primary branches at various stages of crop growth as influenced by different nutrient levels

Treatments	Number of primary branches (Number of $plant^{-1}$)			
	30 DAS	60 DAS	90 DAS	At harvest
100% K	0.5	3.4	4.5	6.1
100% N	0.3	3.0	4.4	4.7
100% NK	0.5	3.5	4.0	5.5
100% NP	0.5	2.7	4.1	6.1
50% NPK	0.3	3.2	3.9	4.7
100% NPK (RDF)*	0.4	3.0	4.3	4.8
150% NPK	0.3	2.4	4.5	6.3
100% NPK+ S @ 40kg/ha	0.8	3.2	4.2	6.1
100% NPK+$ZnSO_4$ @25kg/ha	0.6	3.0	4.0	6.4
100% NPK+ Borax @ 0.2% (foliar)	0.3	2.9	4.3	6.1
100% NPK+ FYM** @ 2.5t/ha (Dry weight)	0.5	3.3	4.1	5.3
Control	0.1	2.4	3.5	4.6
S.E.±	0.1	0.3	0.2	0.5
C.D. (P=0.05)	0.2	NS	NS	NS

NS= Non-significant

Table 3 : Number of secondary branches at various stages of crop growth as influenced by different nutrient levels

Treatments	Number of secondary branches (Number of $plant^{-1}$)			
	30 DAS	60 DAS	90 DAS	At harvest
100% K	0.3	4.5	7.8	9.7
100% N	0.3	4.5	7.9	10.5
100% NK	0.5	4.1	6.7	10.4
100% NP	0.2	3.9	7.1	9.5
50% NPK	0.2	2.5	5.6	8.9
100% NPK (RDF)*	0.3	3.4	6.1	8.7
150% NPK	0.5	4.4	7.7	10.6
100% NPK+ S @ 40kg/ha	0.4	4.9	8.7	11.5
100% NPK+$ZnSO_4$ @25kg/ha	0.3	4.1	7.0	10.4
100% NPK+ Borax @ 0.2% (foliar)	0.3	5.1	8.2	11.0
100% NPK+ FYM** @ 2.5t/ha (Dry weight)	0.3	4.9	8.3	11.3
Control	0.1	2.3	5.1	8.5
S.E.±	0.1	0.4	0.7	0.9
C.D. (P=0.05)	NS	1.2	1.9	NS

NS= Non-significant

Dry matter accumulation per plant:

Data pertaining to dry matter accumulation are summarized in Table 4. The data on dry matter accumulation revealed that in general, dry matter accumulation increased as the crop advanced in age and reached maximum at maturity. The accumulation rate of dry matter in plant was found minimum at 30 DAS whereas a rapid increase was seen upto maturity stage. The data revealed that crop plant accumulate the dry matter very rapidly between 30 and 90 DAS of crop growth. At 30 DAS highest dry matter accumulation was recorded under the treatment of 100% NPK + 40 kg S ha^{-1} being at par with 100% NPK + 25kg $ZnSO_4$ ha^{-1}, 100% NPK + 2.5t FYM ha^{-1} and 100% K which produced the highest dry matter accumulation than remaining other treatments. The lowest dry matter accumulation was recorded in control plot. At 90 DAS highest dry matter accumulation was recorded under the

Table 4 : Dry matter accumulation per plant at various stages of crop growth as influenced by different nutrient levels

Treatments	Dry matter accumulation (g $plant^{-1}$)			
	30 DAS	60 DAS	90 DAS	At harvest
100% K	16.4	53.0	80.5	98.2
100% N	10.5	49.5	71.5	97.0
100% NK	13.5	50.7	79.0	96.0
100% NP	13.4	50.0	73.3	97.2
50% NPK	8.2	42.7	61.4	94.5
100% NPK (RDF)*	10.0	49.9	71.8	97.2
150% NPK	12.1	50.0	72.4	97.4
100% NPK+ S @ 40kg/ha	18.0	56.8	86.5	101.0
100% NPK+$ZnSO_4$ @25kg/ha	17.1	52.7	80.7	102.0
100% NPK+ Borax @ 0.2% (foliar)	15.0	51.0	79.5	97.7
100% NPK+ FYM** @ 2.5t/ha (Dry weight)	17.1	50.2	81.9	99.8
Control	6.5	38.0	55.3	85.6
S.E.±	1.0	3.9	4.7	3.9
C.D. (P=0.05)	2.9	NS	13.8	NS

NS= Non-significant

Table 5 : Number of days taken to 50 per cent flowering and 80 per cent maturity as influenced by different nutrient levels

Treatments	Number of days taken for	
	50% flowering	80% maturity
100% K	54.7	129.3
100% N	55.3	128.3
100% NK	55.0	130.3
100% NP	56.0	127.7
50% NPK	55.0	127.7
100% NPK (RDF)*	54.3	129.0
150% NPK	55.3	129.3
100% NPK+ S @ 40kg/ha	54.7	126.7
100% NPK+$ZnSO_4$ @25kg/ha	55.0	129.0
100% NPK+ Borax @ 0.2% (foliar)	55.0	129.0
100% NPK+ FYM** @ 2.5t/ha (Dry weight)	53.7	129.3
Control	53.3	127.0
S.E.±	0.8	1.4
C.D. (P=0.05)	NS	NS

NS= Non-significant

application of 100% NPK + 40kg S ha^{-1} being at par with all other treatments except 50% NPK, 100% NPK, 150% NPK, 100% N and control which significantly accumulate more dry matter, however, lowest dry matter accumulation was found in control treatment. At 60DAS and harvest stage dry matter accumulation were found to be non- significant. Relatively, under 100% NPK + 40kg S ha^{-1} and 100% NPK + 25kg $ZnSO_4$ ha^{-1} treatment higher dry matter accumulation was recorded. Dry matter accumulation per plant is an ultimate result of all the metabolic processes occurring inside the plant. The higher value of total dry matter per plant might be due to higher values of more number of primary, secondary and total branches and also higher uptake of nutrients by the crop.

Number of days taken to 50 per cent flowering and 80 per cent maturity:

Differences in days taken to 50 per cent flowering and 80 per cent maturity due to different treatments were found to be non- significant. 100% NP and 100% NK treatment took more number of days to 50 per cent flowering and 80 per cent maturity, respectively, than all other remaining treatments. Delay in maturity with potassium application might be due to its role in providing hardiness to the crop.

Yield attributing characters:

Data pertaining to yield contributing characters of the crop are summarized in Table 7.

Total number of branches at harvest :

Number of secondary branches was higher in comparison with primary branches. Different nutrients significantly influenced the number of secondary branches as well as total number of branches but increase in number of primary branches was found non-significant. The higher number of secondary and total branches was found in the treatment of 100% NPK + 40kg S ha^{-1} which was at par with other treatments except 50% NPK, 100% NPK, 100% NP and control, also with 100% NK, which produced higher number of branches. The lowest branches were found in control which was significantly lower than remaining treatments in both the cases. This increase in number of total branches might be due to more dry matter accumulation per plant.

Number of siliquae per plant:

The data on the number of siliquae per plant showed that the 150% NPK recorded higher number of siliquae being significantly superior over all other treatments except control and 50% NPK which did not differ significantly. The lowest number of siliquae was found in control plot which is significantly lower than all the treatments. Increase in number of siliquae per plant is an index of higher seed yield per plant. It is also largely governed by the number of branches per plant. This increase may be attributed to more number of total branches per plant.

Table 6: Total number of branches at harvest as influenced by different nutrient levels

Treatments	Harvest		
	Primary branches	Secondary branches	Total branches
100% K	14.3	22.3	36.5
100% N	12.4	23.3	35.7
100% NK	13.4	21.7	35.1
100% NP	13.1	20.7	33.9
50% NPK	12.1	17.1	29.2
100% NPK (RDF)*	12.5	18.5	31.0
150% NPK	13.3	23.2	36.5
100% NPK+ S @ 40kg/ha	14.1	25.5	39.6
100% NPK+$ZnSO_4$ @25kg/ha	13.9	21.8	35.7
100% NPK+ Borax @ 0.2% (foliar)	13.6	24.6	38.0
100% NPK+ FYM** @ 2.5t/ha (Dry weight)	13.0	24.8	37.8
Control	10.6	16.0	26.6
S.E.±	0.7	1.3	1.4
C.D. (P=0.05)	NS	3.8	4.2

NS= Non-significant

Number of seeds per siliqua:

The number of seeds per siliqua could not be influenced by the application of different nutrients significantly. However, application of 150% NPK and control produced highest and lowest number of seeds per siliqua, respectively. Application of 100% NPK + Borax @ 0.2% and 100% NPK + 2.5t FYM ha^{-1} ranked second and third, respectively, after 150% NPK. This increase in number of seeds per siliqua might be due to the application of recommended nutrients along with the supplemental nutrient which ultimately increase the seed yield.

Length of siliqua :

The siliqua length was recorded higher in 150% NPK. However, the differences among the treatments were not found to be significant except 50% NPK, 100% NPK + 25kg $ZnSO_4$ ha^{-1}, 100% NK and control which remained inferior with the application of 150% NPK in terms of the siliqua length.

1000-seed weight:

The data on1000-seed weight, showed that the application of 150% NPK recorded the highest 1000-seed weight being significantly superior over all other treatments except control, 50% NPK, 100% NPK, 100% NPK + 40kg S ha^{-1} and 100% NP which did not differ significantly. Test weight is an index of boldness of seed resulting from transfer of photosynthates from vegetative phase to reproductive phase.

Seed weight per plant:

Seed weight per plant was found to be significant with the application of different nutrient levels. Higher seed weight per plant was recorded under the treatment of 150% NPK and lower seed weight per plant was recorded under control condition. 150% NPK treatment was at par with all other treatments except control, which do not produce more seed weight per plant. This might be due to more number of branches at harvest, more number of siliquae per plant, more number of seeds per siliqua, more length of siliqua and higher 1000-seed weight. FYM influence the yield attributes by improving the soil physical properties as it decreases the bulk density and increases the porosity.

Yield studies : Seed yield:

The data on seed yield are presented in Table 8, revealed that the 150% NPK recorded highest seed yield per hectare being significantly superior over all the treatments. 100% K being at par with 100% N treatment remained significantly inferior in turn of seed yield per hectare after the control as compared to all other treatments. On an average there was 190.7 per cent increase in the seed yield at 150% NPK as compared to control. The reason for higher yield at 150% NPK was production of effective yield components which contributed towards seed yield. Higher seed yield per

Table 7: Yield attributes as influenced by different nutrient levels

Treatments	No. of siliqua/plant	No. of seeds/ siliqua	Length of siliqua (cm)	1000-seed weight (g)	Seed weight/ plant (g)
100% K	288.9	12.1	3.7	3.5	13.8
100% N	280.6	11.7	3.5	3.4	12.0
100% NK	305.0	11.6	3.1	3.3	13.7
100% NP	278.6	11.7	3.5	3.2	10.9
50% NPK	219.9	11.3	2.9	3.1	10.8
100% NPK (RDF)*	269.1	11.9	3.6	3.2	11.0
150% NPK	324.5	13.5	4.0	3.7	13.9
100% NPK+ S @ 40kg/ha	323.5	12.2	3.7	3.2	12.9
100% NPK+$ZnSO_4$ @25kg/ha	319.7	11.6	3.4	3.5	11.3
100% NPK+ Borax @ 0.2% (foliar)	282.6	12.6	3.6	3.4	13.0
100% NPK+ FYM** @ 2.5t/ha (Dry weight)	310.7	12.4	3.7	3.6	12.2
Control	185.0	10.7	2.7	2.7	7.9
S.E.±	26.4	1.0	0.2	0.1	1.1
C.D. (P=0.05)	77.4	NS	0.5	0.4	3.2

NS= Non-significant

plant is the net result of more number of total branches at harvest more number of siliquae per plant, length of siliqua with more seeds per siliqua and better growth at different stages. Positive response of nitrogen and potassium was obtained in seed yield per hectare as with the application of 100% NK, there was 16.1 per cent and 5.1 per cent increase in seed yield as compared to 100% K and 100% N alone. However, 100% NP recorded lower yield then 100% NK. With the application of nitrogen, phosphorus and potassium together the seed yield per hectare was also increased as compared to 100% K and 100% N alone but all the treatments were at par with each other except control, 100% K and 100% N. This increase in seed yield per hectare with N, P and K together might be due to balanced fertilization which influences the yield attributing characters and ultimately the seed yield per hectare. There was significant difference in the seed yield per hectare. Among different supplementary nutrients, application of FYM with RDF resulted in higher seed yield followed by sulphur and $ZnSO_4$. Antagonistic effect of potassium with borax was obtained in seed yield per hectare as with the application of 100% NPK + Borax @ 0.2% the seed yield per hectare was decreased by 10.2% as compared to the application of 100% NPK + 2.5t FYM ha^{-1}. Increased yield attributes owing FYM incorporation is because it is a slow releasing source of nitrogen, a source of phosphorus, potassium, secondary and micronutrients and available to plants during their growth period, thereby increasing their availability for growth and development. Sulphur increases the nitrogen use efficiency. Zinc closely involves in the nitrogen metabolism of the plant, more leaf area and more photosynthetic area and boron plays active role in carbohydrate biosynthesis and protein metabolism which result in more yield attributes.

Stover yield per hectare:

Data pertaining to stover yield per hectare is summarized in Table 8. The data on stover yield revealed that the application of 150% NPK recorded the higher stover yield per hectare being significantly superior over all the treatments except control, 50% NPK, 100% NK, 100% NP, 100% N and 100% K which did not differ significantly. The lowest stover yield per hectare was found in control. This increase might be due to increased plant growth at different crop growth stages of the crop.

Biological yield per hectare:

The effect of nutrient applied to the crop showed significant influence on biological yield per hectare. 150% NPK being at par with 100% NPK, 100% NPK + 40kg S ha^{-1}, 100% NPK + 25kg $ZnSO_4$ ha^{-1} and 100% NPK + 2.5t FYM ha^{-1} computed significant higher biological yield per hectare than remaining treatments. Control recorded significantly lowest biological yield per hectare. The increase in biological yield per hectare could be due to increased seed and stover yields under these treatments.

Table 8 : Seed yield, Stover yield, biological yield and harvest index as influenced by different nutrient levels

Treatments	Seed yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)
100% K	1104	5388	6493	17.5
100% N	1220	6239	7391	17.6
100% NK	1282	6680	7963	16.1
100% NP	1250	5933	7187	17.7
50% NPK	1391	6554	7922	17.7
100% NPK (RDF)*	1429	7350	8779	16.4
150% NPK	1817	8228	10045	19.0
100% NPK+ S @ 40kg/ha	1567	6885	8453	18.6
100% NPK+$ZnSO_4$ @25kg/ha	1531	7534	9065	16.9
100% NPK+ Borax @ 0.2% (foliar)	1460	6868	8330	17.6
100% NPK+ FYM** @ 2.5t/ha (Dry weight)	1609	7538	9147	17.8
Control	625	2683	3308	19.3
S.E.$\pm$	49	506	549	1.3
C.D. (P=0.05)	144	1485	1611	NS

NS= Non-significant

Harvest-index:

The applied nutrient did not influence the HI significantly. Relatively, more harvest-index was observed in control plot than others. Comparatively, lower harvest-index was observed in 100% NK as compared to the other treatments. It is a real index for determining the economic yield from the total biological yield. The harvest index speaks the conversion efficiency of non-grain portion by turning up nutrient uptake as well as utilization. The lower stover yield in proportion to seed associated under above treatments increased the values of harvest index.

Nutrients (N, P and K) content in crop: Nutrients (N, P and K) content in seed and stover:

None of the nutrient levels was able to bring significant difference in nutrient content *i.e.* nitrogen, phosphorus and potassium in the seed and stover.

Nutrients (N, P and K) uptake by crop : Nitrogen uptake:

The data on nitrogen uptake by seeds, stover and

Table 9: N content in seed and stover at harvest as influenced by different nutrient levels

Treatments	N content (%)	
	Seed	Stover
100% K	2.93	0.43
100% N	2.94	0.45
100% NK	2.96	0.44
100% NP	3.23	0.45
50% NPK	2.98	0.46
100% NPK (RDF)*	3.12	0.46
150% NPK	3.18	0.47
100% NPK+ S @ 40kg/ha	3.00	0.47
100% NPK+$ZnSO_4$ @25kg/ha	3.21	0.44
100% NPK+ Borax @ 0.2% (foliar)	2.97	0.46
100% NPK+ FYM** @ 2.5t/ha (Dry weight)	3.13	0.47
Control	2.87	0.42
S.E.±	0.14	0.02
C.D. (P=0.05)	NS	NS

NS= Non-significant

Table 10 : P content in seed and stover at harvest as influenced by different nutrient levels

Treatments	P content (%)	
	Seed	Stover
100% K	0.70	0.34
100% N	0.65	0.32
100% NK	0.71	0.35
100% NP	0.70	0.34
50% NPK	0.72	0.35
100% NPK (RDF)*	0.73	0.34
150% NPK	0.75	0.36
100% NPK+ S @ 40kg/ha	0.71	0.35
100% NPK+$ZnSO_4$ @25kg/ha	0.69	0.33
100% NPK+ Borax @ 0.2% (foliar)	0.71	0.35
100% NPK+ FYM** @ 2.5t/ha (Dry weight)	0.70	0.36
Control	0.69	0.33
S.E.±	0.03	0.02
C.D. (P=0.05)	NS	NS

NS=Non-significant

crop, presented in Table 12.

Nitrogen uptake by seeds:

Significantly higher nitrogen uptake was made due to the application of 150% NPK as compared to the remaining treatments. 100% K application treatment being at par with 100% N recorded lowest value of N uptake by seeds after the control than remaining treatments.

Nitrogen uptake by stover:

The highest N uptake by stover was computed in 150% NPK being at par with 100% NPK, 100% NPK + 25 kg $ZnSO_4$ ha^{-1} and 100% NPK + 2.5 t FYM ha^{-1} which recorded significant higher N uptake by stover than other treatments. 100% K application treatment being at par with 100% NP recorded lowest value of N uptake by stover after the control than remaining other treatments.

Total nitrogen uptake by crop:

The effect of different nutrient levels in N uptake by the crop was found to be significant. 150% NPK computed significantly higher N uptake by the crop than

Table 11 : K content in seed and stover at harvest as influenced by different nutrient levels

Treatments	K content (%)	
	Seed	Stover
100% K	0.78	1.95
100% N	0.86	2.05
100% NK	0.82	1.97
100% NP	0.81	1.93
50% NPK	0.82	1.94
100% NPK (RDF)*	0.81	1.96
150% NPK	0.85	1.99
100% NPK+ S @ 40kg/ha	0.82	1.98
100% NPK+$ZnSO_4$ @25kg/ha	0.85	2.02
100% NPK+ Borax @ 0.2% (foliar)	0.81	1.95
100% NPK+ FYM** @ 2.5t/ha (Dry weight)	0.84	2.00
Control	0.77	1.92
S.E.±	0.02	0.04
C.D. (P=0.05)	NS	NS

NS= Non-significant

Table 12 : N uptake in seed and stover at harvest as influenced by different nutrient levels

Treatments	N uptake (kg ha^{-1})		
	Seed	Stover	Total
100% K	27.5	19.1	46.6
100% N	30.6	23.6	54.2
100% NK	32.2	24.0	56.2
100% NP	34.4	21.7	56.1
50% NPK	35.3	27.0	62.4
100% NPK (RDF)*	37.9	30.4	68.3
150% NPK	49.0	33.5	82.4
100% NPK+ S @ 40kg/ha	40.0	28.5	68.5
100% NPK+$ZnSO_4$ @25kg/ha	41.9	30.3	72.2
100% NPK+ Borax @ 0.2% (foliar)	36.8	28.9	65.7
100% NPK+ FYM** @ 2.5t/ha (Dry weight)	42.8	30.7	73.4
Control	15.1	9.1	24.2
S.E.±	1.9	1.2	2.4
C.D. (P=0.05)	5.5	3.6	7.1

remaining treatments. The lowest N uptake by the crop was recorded under the application of 100% K being at par with 100% N, after the control plot.

Phosphorus uptake:

The data on phosphorus uptake by seeds, stover and crop, presented in Table 13.

Phosphorus uptake by seeds:

The uptake of P by seeds was made significantly higher due to the application of 150% NPK as compared to the remaining treatments. The lowest P uptake by seeds was recorded in the application of 100% K treatment being at par with 100% N, 100% NK and 100% NP, after the control.

Phosphorus uptake by stover:

The highest P uptake by stover was computed in 150% NPK being at par with 100% NPK and 100% NPK + 2.5t FYM ha T_1 which recorded significantly higher P uptake by stover. The lowest P uptake by stover was recorded under the application of 100% K being at

Table 13 : P uptake in seed and stover at harvest as influenced by different nutrient levels

Treatments	P uptake (kg ha^{-1})		
	Seed	Stover	Total
100% K	6.6	15.5	22.1
100% N	6.8	16.8	23.6
100% NK	7.8	20.0	27.8
100% NP	7.5	17.1	24.6
50% NPK	8.6	19.7	28.3
100% NPK (RDF)*	8.8	21.3	30.1
150% NPK	11.5	25.1	36.6
100% NPK+ S @ 40kg/ha	9.4	20.3	29.7
100% NPK+$ZnSO_4$ @25kg/ha	8.9	20.9	29.8
100% NPK+ Borax @ 0.2% (foliar)	8.9	20.3	29.1
100% NPK+ FYM** @ 2.5t/ha (Dry weight)	9.6	22.8	32.4
Control	3.6	7.5	11.1
S.E.$\pm$	0.5	1.4	1.5
C.D. (P=0.05)	1.3	3.9	4.4

Table 14: K uptake in seed and stover at harvest as influenced by different nutrient levels

Treatments	K uptake (kg ha^{-1})		
	Seed	Stover	Total
100% K	7.3	89.4	96.7
100% N	8.9	109.8	118.7
100% NK	8.9	111.7	120.7
100% NP	8.6	97.3	105.9
50% NPK	9.6	107.7	117.4
100% NPK (RDF)*	9.9	122.6	132.4
150% NPK	13.2	138.8	152.0
100% NPK+ S @ 40kg/ha	10.9	115.7	126.6
100% NPK+$ZnSO_4$ @25kg/ha	11.1	129.4	140.5
100% NPK+ Borax @ 0.2% (foliar)	10.1	113.9	124.0
100% NPK+ FYM** @ 2.5t/ha (Dry weight)	11.4	127.8	139.3
Control	4.1	43.8	47.9
S.E.$\pm$	0.4	9.2	9.4
C.D. (P=0.05)	1.2	27.1	27.5

par with 100% N and 100% NP, after the control.

Total phosphorus uptake by crop:

The effect of different nutrient levels in P uptake by the crop found to be significant. 150% NPK being at par with 100% NPK + 2.5t FYM ha^{-1} computed significantly higher P uptake by the crop than remaining treatments. The lowest P uptake by the crop was recorded under the application of 100% K being at par with 100% N and 100% NP, after the control.

Potassium uptake:

The data on potassium uptake by seeds, stover and crop, presented in Table 14.

Potassium uptake by seeds:

Significantly higher uptake of K by seeds was made due to the application of 150% NPK as compared to the remaining treatments. The lowest K uptake by seeds was recorded in the application of 100% K treatment, after the control.

Potassium uptake by stover:

The highest K uptake by stover was computed in 150% NPK being at par with 100% NK, 100% NPK, 100% NPK + 40kg S ha-1, 100% NPK + 25kg $ZnSO_4$ ha^{-1}, 100% NPK + Borax @ 0.2% and 100% NPK + 2.5 t FYM ha4 which recorded significantly higher K uptake by stover. The lowest K uptake by stover was recorded in control.

Total potassium uptake by crop:

The effect of different nutrient levels in K uptake by the crop was found to be significant. 150% NPK being at par with 100% NPK, 100% NPK + 40kg S ha^{-1}, 100% NPK + 25kg $ZnSO_4$ ha^{-1} and 100% NPK + 2.5t FYM ha^{-1} computed significantly higher K uptake by the crop than remaining treatments. The lowest K uptake by the crop was recorded in control. Nutrient levels differed significantly with the uptake of nutrients by the crop. In 150% NPK plot the uptake of nutrients was 82.4, 36.6 and 152kg of N, P and K ha^{-1} as against 24.2, 11.1 and 47.9kg ha^{-1}, respectively in the control treatment. However, control plot recorded low as compared to other treatments. Since nutrient uptake is a numerical product of nutrient content and dry matter accumulation which was low under control than other treatments. Higher nutrient uptake might be attributed to more proliferation of root system and higher dry matter accumulation by individual plant which in turn yielded higher in comparison to other treatments. Nutrient per cent in various plant parts as well as total nutrient uptake by the crop remained higher under higher rates of nutrient application. The significant improvement in uptake of these nutrients coupled with increased seed and stover yields increased the total uptake of N, P and K substantially.

Protein content in seeds and protein yield: Protein content in seeds:

The data on protein content in seeds are presented

Table 15 : Protein content in seed and protein yield as influenced by different nutrient levels

Treatments	Protein content (%)	Protein yield (kg ha^{-1})
100% K	18.3	171.6
100% N	18.4	191.3
100% NK	18.5	201.2
100% NP	20.2	214.8
50% NPK	18.6	220.8
100% NPK (RDF)*	19.5	236.8
150% NPK	19.9	306.0
100% NPK+ S @ 40kg/ha	18.8	250.3
100% NPK+$ZnSO_4$ @25kg/ha	20.1	261.6
100% NPK+ Borax @ 0.2% (foliar)	18.6	230.2
100% NPK+ FYM** @ 2.5t/ha (Dry weight)	19.6	267.3
Control	17.9	94.3
S.E.±	0.9	11.8
C.D. (P=0.05)	NS	34.5

NS= Non-significant

in Table 15. The effect of different nutrient applied on protein content was found to be non-significant. However, the maximum protein content was found under the application of 100% NP. The minimum protein content was recorded in control plot. Application of 100% NPK + 25 kg $ZnSO_4$ ha^{-1} and 150% NPK ranked second and third, respectively, after 100% NP. The increase might be due to higher nitrogen content in seeds of these treatments as it is a mathematical value calculated from nitrogen content of seeds, as increasing nitrogen levels increases the proteinaceous substance in seeds.

Protein yield:

The effect of different nutrients on protein yield was found to be significant. The protein yield was found significantly superior under the application of 150% NPK than other remaining treatments. The lowest protein yield was recorded in 100% K treatment being at par with 100% N and 100% NK after the control plot. It is a function of protein content in seeds multiplied by seed yield per hectare. Increase in the seed yield, increases the protein yield.

Oil content in seeds and oil yield: Oil content in seeds:

None of the nutrient levels was able to bring significant difference in oil content in the seed. Oil content in seeds was determined by using Soxhlet's extraction method which remained non-significant. Higher concentration of oil in seeds at 100% K followed

Table 16: Oil content in seed and oil yield as influenced by different nutrient levels

Treatments	Oil content (%)	Oil yield (kg ha^{-1})
100% K	41.3	504.5
100% N	40.9	511.1
100% NK	41.1	629.0
100% NP	40.7	566.0
50% NPK	40.6	448.6
100% NPK (RDF)*	40.7	522.1
150% NPK	40.5	736.0
100% NPK+ S @ 40kg/ha	41.0	595.0
100% NPK+$ZnSO_4$ @25kg/ha	40.8	596.4
100% NPK+ Borax @ 0.2% (foliar)	40.8	631.5
100% NPK+ FYM** @ 2.5t/ha (Dry weight)	40.7	655.5
Control	40.3	251.4
S.E.±	0.20	21.0
C.D. (P=0.05)	NS	61.6

NS= Non-significant

Table 17 : Cost of cultivation, gross return, net profit and B: C ratio as influenced by different nutrient levels

Treatments	Cost of cultivation Rs./ha)	Gross return (Rs./ha)	Net return (Rs./ha)	Return per rupee invested
100% K	21223	24216	2993	0.14
100% N	21120	32372	11252	0.53
100% NK	21700	34054	12354	0.56
100% NP	21238	33030	11792	0.56
50% NPK	21355	42191	20866	0.98
100% NPK (RDF)*	21860	37930	16070	0.74
150% NPK	22178	47893	25715	1.11
100% NPK+ S @ 40kg/ha	30015	41241	11226	0.37
100% NPK+$ZnSO_4$ @25kg/ha	21612	40535	18923	0.88
100% NPK+ Borax @ 0.2% (foliar)	23160	38560	15400	0.67
100% NPK+ FYM** @ 2.5t/ha (Dry weight)	34200	37036	2836	0.08
Control	19545	16430	-3115	0.16

by 100% NK and 100% NPK + 40kg S ha^{-1} treatments resulted in higher values of oil content in respective treatments. Increase in oil content on K application is attributed to increase in the activity of enzymes involved in fat synthesis. Positive effect of S along with P and other nutrients on oil content is because of P as it is a constituent of phospholipids and also essential for oil synthesis.

Oil yield:

The effect of different nutrients on oil yield was found to be significant. The oil yield was found significantly superior under the application of 150% NPK than other remaining treatments. The lowest oil yield was recorded with the application of 50% NPK treatment being at par with 100% K, after the control. Oil yield is the function of oil content in seeds multiplied by seed yield per hectare. The higher the seed yield, the higher was the oil yield.

Net return:

The data on economic studies revealed that the maximum net return were made under 150% NPK levels Z 25715.00, whereas, the minimum remained under the 100% NPK + 2.5t FYM ha T_1 treatment Z 2836.00, after the control plot, where no net gain was observed.

Return per rupee invested :

The data pertaining to return per rupee invested has been summarized in Table 17. The maximum return per rupee invested *i.e.* 1.11 was obtained at 150% NPK nutrient level, whereas, the lowest return per rupee invested *i.e.* 0.08 was obtained at 100% NPK + 2.5t FYM ha^{-1} treatment, after the control plot. The results of present investigation indicate appreciable variation in net return due to different nutrient levels. It might be due to fact that 150% NPK got the maximum gross return *i.e.*, Z 47893.00. In general, net return and return per rupee invested is a function of total cost of cultivation and gross returns per hectare. The higher the cost of cultivation, the lower was the net return.

Conclusion :

The soil of the experiment site was silty clay loam in texture having medium organic carbon (0.34%), low in available nitrogen (184kg ha^{-1}), medium in available phosphorus (20.60kg ha^{-1}) and medium in available potassium (184kg ha^{-1}) contents with slightly alkaline in reaction (pH 8). The experiment, comprising of twelve treatments *viz*. T_1 (100% K), T_2 (100% N), T_3 (100% NK), T_4 (100% NP), T_5 (50% NPK), T_6 (100% NPK), T_7 (150% NPK), T_8 (100% NPK + S @ 40 kg/ha), T_9 (100% NPK + $ZnSO_4$@ 25kg/ha), T_{10} (100% NPK + Borax @ 0.2% (foliar), T_{11} [100% NPK + FYM @ 2.5t/ ha (dry weight)] and T_{12} (control) was conducted in Randomized Block Design with three replications. Indian mustard, variety NDRE 4, was sown in rows, 30 cm x 15cm apart on October 16, 2016 and harvested on February 27, 2017. During crop period, a total rainfall of 480mm was received. Based on the findings of the present study, it can be inferred that increasing the nutrient dose to 150% NPK (RDF = 120: 60: 40 kg N, P_2O_5 and 1(20 ha^{-1}) resulted in achieving more seed, protein and oil yield of mustard during *Rabi* season. Since, these findings are based on one season data; investigation needs to be further validated before recommendation to the farming community.

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