Effects of Mineral Nutrition on Seed Yield and Quality of Mustard (Brassica Juncea)

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Abstract

Mustard (Brassica juncea) is a significant component of the world production of vegetable oils. Mustard is a thermophilic and very drought-resistant plant well adapted for dry continental climates. Mustard (Brassica juncea) is a drought-resistant crop which can tolerate water stress and can be grown in rotation with other crop species. Mustard is relatively undemanding to soil and it can even grow on saline soils. The nutrients most important for the growth and development of mustard are nitrogen (N) and phosphorus (P). The study was conducted during the 2009, 2010 and 2011 growing seasons on a meadow chestnut soil at the "Agrouniversity" experiment station of the Kazakh National Agrarian University at Almaty, Kazakhstan to evaluate the effect of nitrogen and phosphorus fertilizers on the production of mustard in short crop rotations. Nitrogen rates of 0,40 and 75 kg ha^{-1} gave seed yields of 1.628, 2.095 and 2.191 Mg ha^{-1}, respectively. Protein yields were 0.402, 0.543 and 0.573 Mg $ha^{-1}$and oil yields were 0.352, 0.498 and 0.505 mg $ha^{-1}$for the three respective N rates. Seed, protein and oil yields were 119%, 123% and 127%, respectively, when soil test P was increased to 25 kg ha^{-1} from 15 kg ha^{-1} indicating a need to maintain high soil P in mustard production systems.

Introduction

The key trends of stable agricultural business industry development in Kazakhstan involve working on new high-performance agricultural technologies in terms of cultivation of nonconventional crops ensuring increase in their productivity with simultaneous soil conservation and reproduction. Under these circumstances, the oil crops such as castor-oil plant, brown mustard and flax, which have a high oil content and yielding capacity, along with wheat, sugar beet, corn, soya, safflower, etc. are expected to be very promising for the South-East region of the republic. They are valuable because oil seeds can be used not only for production needs, but also for technical needs [1]. Many researchers have studied various rates of nitrogen and phosphorus fertilizers in order to promote increased seed yield and improved protein and oil yields [2-6]. Various studies have reported differing optimal N rates for high mustard yields. Fertilizers are one of the factors ensuring increase of seed yield and quality improvement with simultaneous soil preservation and fertility enhancement. Irrigation and fertilizer management are important agronomic practices for a higher yield. Irrigation facilitates mustard growth and yield in addition to water need. It also ensures availability of different nutrients in crop plants [7]. The alternative fertilization system increases nitrate-N accretion (by 8.7-15.7%) and labile phosphorus (by 5.6-14.5%) to a less extent than the conventional system, but results in organic matter growth by 0.02-0.05% versus its initial content. The chemical soil load decreases by 30% versus the conventional fertilization system, while its productivity decreases only by 2-10%. The organic fertilization system efficiency is low in the irrigated crop rotation. The yield decreases by 31%, and the entire crop rotation productivity decreases by 21-27% in the compared cases versus the conventional

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fertilization system [8]. Treating with $N_{60}P_{60}K_{60}$ enabled to increase mustard plant conservation by 7.6% and increase the height by 1.2-8.6 cm at all development stages versus the control treatment [9]. R. Patel, Meisheri and J.R. Patel specified that the seeds yield, and straw yield to a greater extent had enhanced in case of increased quantity of organic and nitrogen fertilizers, while the nitrogen content clearly correlated to the seeds yield [10]. Sugave and Sheike established in their studies that the seeds yield for about 2 years had made 12,7; 17,2; 19,4; and 20,1 kg ha^{-1} in case of nitrogen application in the quantity of 0, 40, 80 and 120 kg ha^{-1}[11]. Our research investigated the effects of the nitrogen doses on yield, seed protein content, seed oil content of mustard in a barley-mustard rotation under irrigation in Southeastern Kazakhstan. The objectives of this study were (i) to determine effects of nitrogen (N) fertilizer rates on growth and seed, protein and oil yield of mustard under irrigated conditions, (ii) to determine the effects of soil phosphorus (P) on growth and yield of mustard, and (iii) effects of fertilizer rates on changes in mineral soil N under the mustard crop.

Materials and Methods

Site Characteristics

The study was conducted at the "Agrouniversity" Experimental Station of the Kazakh National Agrarian University, located in the northwestern part of the Enbekshi-Kazakh area of the Almaty region, 37 km from Almaty and 18 km from Issyk, Kazakhstan during the 2009 and 2011 growing seasons. The site lies at longitude 43º28´59.93´´C and latitude 77º19´16.03´´B. The climate of the study area is characterized as strongly continental with an average annual rainfall of 350-420 mm. During the growing season, the precipitation ranges from 120-300 mm. The study area is located in a foothill desert-steppe region with elevations of 550-700 meters above sea level. This region is crossed by a several mountain rivers and streams. Ground water is located at a depth of 1.2-1.6 m. in many parts of this region and currently is an economic source of irrigation water.

The soils at the study site were a meadow chestnut soil with pH=7, organic matter, total phosphorus, and total nitrogen contents of 4.38, 0.211, and 0.258%, respectively. Soil parent materials are loamy loess deposits underlain by gravelly deposits.

The study was conducted on two soil areas with differing plant available soil phosphorus (P) levels at the beginning of the study to evaluate the effects of inherent soil P levels on mustard production. The first area was on soil that had no recent fertilizer P added with soil plant available P levels of 18-20 mg P kg^{-1} soil. The second area had 150 kg P_2O_5 added as single superphosphate (18-19% P_2O_5) prior to the study resulting in initial soluble plant available P levels of 35-38 mg P kg^{-1} soil at the beginning of the study.

Nitrogen fertilizers were applied as ammonium nitrate (NH_4NO_3 – 32-34% N) at rates of 0 (N_0), 40 (N_{40}), and 75 (N_{75}) kg N ha^{-1}. Phosphorus fertilizer was also applied single superphosphate ($Ca(H_2PO_4)$,$CaSO_4$•$2H_2O$) (18-19% P_2O_5).

Soil moisture content was maintained at levels of 60-70 % WHC by 3-4 water applications at a rate of 600-750 m^3 ha^{-1} during the growing season.

Sample collection and preparation

The plots were arranged in a randomized complete block design with three replications. The area of the plot was 54 m^2 (3.6 m x 15 m). Soils and plant materials were sampled during the growing season and at harvest to evaluate their nutrient status. Soil samples were composed individual samples taken from five points in each plot by collecting samples from depths of 0-20 and 20-40 cm. The samples were then composited by soil depth within each treatment plot. Plant samples were collected in each plot at the same points as the soil samples were collected and the materials from the five sampling points were combined for each treatment plot. In 2009, the plots were seeded on May 4 and harvested on July 27. In 2010, the plots were seeded on May 3 and harvested on July 29. In 2011, the plots were seeded on May 4 and harvested on July 29. Spring tillage was accomplished by cultivating the field with heavy harrows for seed bed preparation, previous crop residue incorporation and early weed control by a proceeding cultivation to a depth 6-8 cm. Soil samples were analyzed in a field most condition immediately after collection to determine plant available N. For the remaining analyses, the remainder of the samples were air-dried at room temperature, crushed and then sieved through a 1-mm mesh screen. To evaluate plant uptake of N and P during the growing season, whole plant samples were collected at the 6-leaf growth stage and at harvest to determine nutrient content. In addition to seed yield at harvest, subsamples of the seed were analyzed for protein content and oil content in order to determine protein and oil yields. Seed yield was determined by harvesting grain from 2-m^2 area in each plot. The grain from the harvested area was analyzed for protein and oil content. Crude protein content of the seed was determined by multiplying the total nitrogen content of the seeds by a factor of 5.7.

The soil and plant analytical methods used in this study are shown in Table 1 [12].

Table 1
Analytical methods used for this study

Analysis	Method
NO_3-N	Colorimetric disulfonic acid method of Grandval-Ljazhu
Organic matter	Method of Tyurin
Soluble P	1% ammonium carbonate extract method of Machigin
Soil moisture	Gravimetric
Oil content	By Soxlet apparatus
Total NPK of soil and plant materials	Wet digestion
Total N	Modified Kjeldahl
Total P	Colorimetric

Statistical analysis of the data was performed by using the ANOVA procedure in SAS, version 9.2 (SAS Institute, Inc., Cary, NC).

Results and Discussion

Table 2 presents ANOVA data for soil test N and P at the beginning of the growing season, at the 6-leaf vegetative growth stage and at mustard harvest. There were significant differences in initial soil N between years but not between replications or N fertilizer treatments (this was prior to N application). Significant differences were observed between the low and high soil P plot areas. Initial Soil P levels were significantly different between years but not between replications or N fertilizer treatments. However, as expected, there were significant differences between the low and high soil P plot areas. The initial soil tests indicated that the study was conducted in a field that had relatively uniform soil fertility. At the 6-leaf vegetative stage, there were significant differences in soil N between years, N treatments and soil P levels including the interaction between main effects for both the 0-20 cm and 20-40 cm soil depths and for the total profile soil N (0-40 cm depth). Significant differences were observed for soil test P levels. But, no significant differences were observed for either soil test N or soil test P between replications at this sampling period. At the harvest soil sampling period, significant differences were observed for all main effects except for replications and for interactions for both soil test N and P.

Table 3 shows the ANOVA data for plant N and P concentrations at the 6-leaf growth stage and at harvest; and the protein and oil contents of the seed as well as the seed, protein and oil yields at the $P \leq 0.05$ level. Actual significance levels are noted in the table for those effects that were significant. For the main effects, harvest plant N concentration, seed yield, protein and oil content and protein and oil yield were significantly different between years. The 6-leaf and harvest plant N concentrations and seed yield and quality factors showed significant differences for the N-treatments. The soil P levels significantly influenced the 6-leaf plant N concentrations, seed yield, oil content and protein and oil yield. For interactions between main effects, only the N X P interaction was significant for 6-leaf plant N and the Y X N X P interaction was significant for oil yield. There were no significant effects due to replications.

Table 2
Statistical models and significant effects for soil N and P at the beginning (initial) of the study, and at the 6-leaf vegetative stage and at harvest for mustard at the P≤0.05 level

Model	D.F.	Soil N			Soil P		
		0-20 cm	20-40 cm	Total	0-20 cm	20-40 cm	Average
		----------Pr > F[a]----------					
					Initial Values		
Year (Y)	2	<0.001			<0.001		
Replication	2	0.059			NS		
N Treatments (N)	2	NS			NS		
Soil P Levels (P)	1	<0.001			<0.001		
N X P	2	NS			NS		
Y X N X P	10	<0.001			<0.001		
Error	34						
					6-leaf Vegetative Stage		
Year (Y)	2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Replication	2	NS	NS	NS	NS	NS	NS
N Treatments (N)	2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Soil P Levels (P)	1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
N X P	2	<0.001	<0.001	<0.001	<0.001	<0.001	NS
Y X N X P	10	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Error	34						
					Harvest		
Year (Y)	2	<0.001	<0.001	<0.001	0.009	<0.001	<0.001
Replication	2	NS	NS	NS	NS	NS	NS
N Treatments (N)	2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Soil P Levels (P)	1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
N X P	2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Y X N X P	10	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Error	34						

[a]NS – Not Significant

Table 3
Statistical models and significance of effects for plant N and P concentrations at the 6 leaf and harvest, seed yield, and seed protein and oil contents and yields at the P≤0.05 level

Model	D.F.	6-leaf N	6-leaf P	Harvest N	Harvest P	Seed Yield	Protein	Oil	Protein Yield	Oil Yield
		----------Pr<F[a]----------								
Year (Y)	2	0.057	NS	<0.001	0.080	0.001	<0.001	<0.001	<0.001	<0.001
Replication	2	NS	0.107	NS	NS	NS	NS	NS	NS	NS
N Treatments (N)	2	<0.001	NS	0.050	NS	<0.001	0.051	<0.001	<0.001	<0.001
Soil P Levels (P)	1	0.030	NS	0.060	NS	<0.001	0.060	<0.001	<0.001	<0.001
N X P	2	0.007	NS	NS	NS	NS	NS	NS	NS	NS
Y X N X P	10	NS	NS	NS	NS	NS	NS	NS	0.071	0.018
Error	34									

[a]NS – Not significant

An evaluation of initial soil N and P levels (Table 4) show that significant differences were observed from growing season to season. However, both the soil N and P levels were relatively uniform prior to the application of the N fertilizer treatments to establish the N rate portion of this study. The effectiveness of the pretreatment of the plot area to establish the low P and high P variables are noted by the significant differences in initial soil P levels. The average soil N values for the high P plot area was 2.4 kg N ha^{-1} higher that the low P plot area but was close to the average values for the nitrogen effects component of this study and was not likely to have greatly influenced plant response.

Table 4

Year, N treatment and soil P level effects on initial soil N and P tests

Effect	Initial Soil N[a]	Initial Soil P[a]
	0-20 cm	0-20 cm
	------------Kg ha^{-1}------------	
	Year Effects	
2009	18.7(0.5)a	24.6(4.2)c
2010	23.3(0.8)b	23.7(2.0)b
2011	24.4(3.8)c	18.5(4.4)a
0 kg N ha^{-1}	22.1(3.2)a	22.1(4.5)a
40 kg N ha^{-1}	22.3(3.5)a	22.4(4.7)a
75 kg N ha^{-1}	22.1(3.5)a	22.3(4.7)a
	Soil Phosphorus Effects	
Low P	21.0(2.0)a	18.9(3.4)a
High P	23.4(4.0)b	25.7(2.6)b

[a]Values followed by the same letter within each column under each main effect are not significantly different at P≤0.05. Values within parentheses indicate the standard deviations if the reported means.

Table 5 shows treatment effects on soil N and P tests at the mustard 6-leaf growth stage. Both soil N and P varied from year to year when soil data is averaged across all treatments. Soil N levels were ranked 2009<2010<2011 with the 2011 growing season having the highest N at the 6-leaf stage.

This reflects the effects of both N rate and soil N mineralization from seeding to the 6-leaf stage. Soil P tests were 2009<2011<2009 when averaged across N treatments and initial soil P status. Again, differences at this stage reflect seasonal environmental effects on available soil P.

Table 5

Year, N treatment and soil P effects on soil N and P test levels under a mustard crop at the 6-leaf growth stage

Effect	Soil N Test[a]			Soil P Test[a]		
	0-20 cm	20-40 cm	Total	0-20 cm	20-40 cm	Average
	------------Kg.ha^{-1}------------					
			Year Effects			
2009	30.3(10.5)a	24.8(11.1)a	55.0(20.6)a	23.9(4.4)b	16.2(3.3)c	20.0(7.4)c
2010	42.6(13.9)b	29.6(8.5)b	72.2(21.8)b	22.0(2.5)a	13.5(2.8)a	17.8(4.7)a
2011	43.9(14.8)c	32.4(9.0)c	76.3(23.2)c	22.3(4.8)a	14.6(3.0)b	18.4(7.5)b
			Nitrogen Effects			
0 kg/ha^{-1}	23.1(4.8)a	20.1(4.8)a	43.1(8.2)a	22.0(4.8)a	13.3(2.2)a	17.6(6.6)a
40 kg/ha^{-1}	42.0(9.5)b	28.3(7.3)b	70.3(15.9)b	23.0(3.9)b	15.0(3.4)b	19.0(7.2)b
75 kg/ha^{-1}	51.9(9.2)c	38.4(7.2)c	90.3(14.2)c	23.1(3.4)b	16.0(3.3)c	19.5(6.4)c
			Soil Phosphorus Levels			
Low P	36.0(13.1)a	26.2(9.0)a	62.2(21.7)a	19.5(2.7)a	12.3(1.6)a	15.9(3.8)a
High P	41.9(15.1)b	31.6(10.2)b	73.6(24.0)b	25.9(2.1)b	17.2(2.4)b	21.5(3.9)b

[a]Values followed by the same letter within each column under each main effect are not significantly different at P≤0.05. Values within parentheses indicate the standard deviations if the reported means.

Nitrogen effects across years and soil P levels show the intended effects for H fertilizer rates where the soil test N for the 75 kg ha^{-1} N rate at the 6-leaf stage was significantly higher than either of the other N rates. Significant differences in P soil test levels were also observed between soil N rates but the average levels were relatively small. Although soil pH values were not determined for each of the treatments at this sampling time, it is possible that the addition of N fertilizer may have somewhat changed soil pH which in turn increased the availability of P for the crop. The high soil P plots showed that both soil test N and P levels were significantly higher than for the low soil P plots. This, too, may be due to changes in soil pH due to addition of the N fertilizers.

Soil test N and P levels at mustard harvest are shown in Table 6. Seasonal (year) effects soil nutrient levels are similar to the effects shown in Table 5 but with lower levels indicating the effects of plant nutrient uptake or leaching over the growing season. Soil N was reduced by 32.7%, 22.9% and 27.0% for the 0, 40 and 75 kg N ha-1 treatments, respectively, between the 6-leaf stage and harvest. At the 6-leaf stage, soil test N was higher in the 0-20 cm soil depth than in the 20-40 cm depth. By harvest, the soil test N level differences between the two depths was much smaller. Examining the soil test N between the high and low soil P soils at the 6-leaf stage showed an average of 11.4 kg ha^{-1} difference in N while at harvest, the difference was an average of 15.2 kg ha^{-1} indicating that N under the high soil P conditions was used at a slightly more efficient rate. Soil P levels at harvest were reduced form the 6-leaf growth stage due to uptake by the growing crop.

Table 6

Year, N treatment and soil P effects on soil N and P tests under a mustard crop at harvest

Effect	Soil N Test[a]			Soil P Test[a]		
	0-20 cm	20-40 cm	Total	0-20 cm	20-40 cm	Average
	------------------------	----------------	Kg.ha^{-1}	----------------	------------------------	
			Year Effects			
2009	24.5(10.3)a	17.5(7.8)a	41.9(16.7)a	16.0(5.1)b	14.3(2.9)b	15.2(7.7)b
2010	27.3(9.8)b	24.9(9.3)b	52.2(18.9)b	15.3(2.9)a	12.5(3.1)a	14.1(5.1)a
2011	27.9(10.7)c	27.1(8.5)c	55.0(18.5)c	15.7(3.1)ab	12.5(2.7)a	13.9(4.7)a
			Nitrogen Effects			
0 kg/ha^{-1}	15.1(4.6)a	14.0(4.2)a	29.0(8.2)a	15.1(3.3)a	13.2(3.2)b	14.4(6.0)b
40 kg/ha^{-1}	28.3(14.9)b	26.0(7.7)b	54.2(11.4)b	15.1(3.8)a	11.9(2.4)a	13.5(4.8)a
75 kg/ha^{-1}	36.3(6.0)c	29.6(7.3)c	65.9(11.4)c	16.3(4.3)b	14.3(2.9)c	15.3(6.7)c
			Soil Phosphorus Effects			
Low P	23.0(9.4)a	19.1(6.8)a	42.1(14.9)a	12.3(1.7)a	11.3(1.6)a	11.8(1.5)a
High P	30.1(9.8)b	27.2(10.0)b	57.3(19.1)b	19.0(1.7)b	14.9(2.9)b	17.0(3.9)b

[a]Values followed by the same letter within each column under each main effect are not significantly different at P≤0.05. Values within parentheses indicate the standard deviations if the reported means.

Tables 7 and 8 show the effects of growing seasons , nitrogen rates and soil P levels on plant tissue N and P concentrations at the 6-leaf and harvest stages, respectively. None of the main effects significantly affected plant tissue P concentration with the exception of a seasonal effect in 2011 at harvest (Table 8).

The 40 kg ha-1 N rate gave a significantly greater plant tissue N levels at the 6-leaf growth stage (Table 7) but this difference was not noted at harvest (Table 8) where the plant tissue N levels were essentially the same for both the 40 and 75 kg ha-1 N rates. Significant differences in plant N concentrations were observed at the 6-leaf growth stage but not at harvest although the actual tissue N level at harvest was numerically larger at harvest (Table 8).

Table 7

Year, N treatment and soil P effects on tissue N and P concentrations in a mustard crop at the 6-leaf growth stage

Effect	Plant Tissue N[a]	Plant Tissue P[a]
	----------------------------%--------------------------------	
	Year Effects	
2009	3.92(0.28)a	0.68(0.03)a
2010	4.10(0.30)b	0.70(0.07)a
2011	4.03(0.31)ab	0.71(0.05)a
	Nitrogen Effects	
0 kg N ha^{-1}	3.83(0.29)a	0.68(0.03)a
40 kg N ha^{-1}	4.19(0.24)c	0.70(0.05)a
75 kg N ha^{-1}	4.03(0.26)b	0.70(0.07)a
	Soil Phosphorus Effects	
Low P	3.95(0.31)a	0.69(0.03)a
High P	4.09(0.28)b	0.70(0.07)a

[a]Values followed by the same letter within each column under each main effect are not significantly different at P≤0.05. Values within parentheses indicate the standard deviations if the reported means.

Table 8

Year, N treatment and soil P effects on plant N and P concentration in a mustard crop at harvest

Effect	Plant N[a]	Plant P[a]
	--%--	
	Year Effects	
2009	4.53(0.37)b	0.97(0.14)a
2010	3.37(0.21)a	0.99(0.12)ab
2011	5.67(0.33)c	1.05(0.10)b
	Nitrogen Effects	
0 kg N ha^{-1}	4.37(0.94)a	1.00(0.10)a
40 kg N ha^{-1}	4.59(1.02)b	1.04(0.11)a
75 kg N ha^{-1}	4.60(1.05)b	0.97(0.15)a
	Phosphorus Effects	
Low P	4.44(0.96)a	1.01(0.10)a
High P	4.60(1.03)a	1.00(0.14)a

[a]Values followed by the same letter within each column under each main effect are not significantly different at P≤0.05. Values within parentheses indicate the standard deviations if the reported means.

Table 9 shows year, fertilizer N and soil P level effects on seed protein and oil contents and seed, protein and oil yields. Significant seasonal differences were noted across all N and P variables. The plots that had either 40 or 75 kg N ha^{-1} applied ad fertilizer were consistently significantly higher that the no N control treatment. However there were no significant differences between the 40 and 75 kg N ha^{-1} fertilizer rates for any of the seed and yield component variables. Soil P levels had no influence on seed protein, but the high soil P plots gave higher seed oil contents and seed, protein and oil yields.

Mustard showed the highest seed yield at the 75 kg N ha^{-1} rate which is comparable to eh range of optimum rates. These observations extended to protein and oil yield. However, in all cases, even though seed, protein and oil yields were highest for the 75 kg N ha^{-1} rate, they were not significantly different than the 40 kg N ha^{-1} rate. Appropriate N fertilizer recommendations to mustard farmers in eastern Kazakhstan appear to be in the range of 40 to 75 kg ha^{-1} and should be based on the profitability of production for the farmer.

Table 9
Year, N treatment and soil P level effects on seed protein and oil content and seed, protein and oil yields

Effect	Protein Content[a]	Oil Content[a]	Seed Yield[a]	Protein Yield[a]
	-----------------%----------------		----------------Mg.ha^{-1}--------------	
2009	25.8(2.1)b	21.0(1.4)a	1.938(0.346)b	0.502(0.107)b
2010	19.3(1.2)a	24.4(2.4)c	2.093(0.329)b	0.405(0.077)a
2011	32.3(1.9)c	22.8(2.4)b	1.882(0.367)a	0.611(0.141)c
0 kg ha^{-1}	24.9(5.4)a	21.5(2.6)a	1.628(0.221)a	0.402(0.086)a
40 kg ha^{-1}	26.2(5.8)b	23.8(2.5)b	2.095(0.231)b	0.543(0.108)b
75 kg ha^{-1}	26.2(6.0)b	23.0(1.8)b	2.191(0.308)b	0.573(0.154)b
Low P	25.3(5.5)a	21.9(2.3)a	1.796(0.307)a	0.452(0.115)a
High P	26.2(5.6)a	23.5(2.4)b	2.146(0.311)b	0.560(0.142)b

[a]Values followed by the same letter within each column under each main effect are not significantly different at P≤0.05. Values within parentheses indicate the standard deviations if the reported means.

Conclusions

This study has shown that mineral fertilizers have a definite impact on the nutrient dynamics of mustard on meadow chestnut soils similar to the soil in this study. Although responses can vary from growing season to growing season, this study shows that the apparent optimum rate for N fertilizer application is 75 kg N ha^{-1} to obtain the highest yield of seed, oil and protein. In addition, maintaining soil test P levels at or above 25 kg ha^{-1} will give the highest seed, protein and oil yields in mustard production systems. However, further investigations on N and P fertilization levels are necessary to improve fertilizer recommendations and fertilizer efficiencies in mustard.

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