INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
16–285/2016/18–6–1137–1142
DOI: 10.17957/IJAB/15.0217
http://www.fspublishers.org

Full Length Article

Response of Nitrogen, Phosphorus and Potassium Fertilization on Productivity and Quality of Winter Rapeseed in Central China

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Abstract

Winter rapeseed (*Brassica napus* L.) is a dominant oilseed crop and has become an alternate crop both for edible oil production and energy agriculture. This study was conducted to find out the response of nitrogen (N), phosphorus (P) and potassium (K) fertilizer combinations on yield, oil and protein contents in oilseed rape crop. Four fertilizer treatments of N, P and K fertilizers (NPK, NP, NK, and PK) were applied according to the local recommendations at three different sites in Hubei province, during the year 2012-2013. Rapeseed yield was significantly increased by 61-72% under NPK fertilization as compared to PK across study sites. Yield responses to fertilization were ranked as NPK>NP>NK>PK, illustrating that N was the most limiting nutrient in rapeseed productivity following P and K. Oil and protein yields were significantly affected to applied N, P, and K fertilizers. Among all combinations, NPK combination performed best. Oil and protein contents along with other fatty acids (palmitic acid, stearic acid, oleic acid, linoleic acid and linolenic acid) were not influenced significantly by the application of P and K fertilizer. By increasing the amounts of N fertilizer application, oil contents of rapeseed reduced and protein contents increased consistently. These results suggest that NPK combination is more productive as compared to the other combinations.

Keywords: Winter rapeseed; NPK; Yield; Protein yield; Oil content

Introduction

Oilseed rape (*Brassica napus* L.) is an essential agricultural crop generally grown for oil and biofuel generation. Rapeseed oil is ordinarily utilized in human diets on account of its great nutritional quality with a high proportion of unsaturated fatty acids and fair-minded fatty-acid composition (Rehman *et al.*, 2013; Wang *et al.*, 2014). After extraction, remaining rapeseed meal can be used as an organic fertilizer to the cropland or as a source of animal feed (Gao *et al.*, 2010). The nutritional nature of these products is of prime significance, because of their immediate and circuitous effects on human health. Additionally, rapeseed oil is developing consideration as an imperative option for bioenergy asset, because of the deficiency and unpredictability of the worldwide petroleum supply (Högy *et al.*, 2010). The rapeseed is broadly planted on 34.3 million ha around the globe, with almost 22% of the planting ranges situated in China (FAO, 2013).

Among numerous other parameters, the nutritional values of the crop are thought to be most imperative element. N, P, and K are considered to be critical being the crucial part of harvest yield and nutritious values of the oilseed rape yield. Nitrogen is the most important macro-element required for seed oil (Colnenne *et al.*, 1998) and it is suggested that oilseed rape has a higher basic N demand for biomass development than wheat. The suitable quantity of N fertilizer is requisite for optimal economic yield and oil generation (Mason and Brennan, 1998). Smith *et al.* (1988) reported that high amount of N fertilizer reduced the oil contents but enhanced the protein contents in canola and found a negative co-relation between oil concentration and protein contents.

Phosphorus (P) is an imperative nutrition for plant development as concerned with photosynthesis, cellular energy transfer, and respiration. Regardless of the way that canola demands more phosphorus than grain crops for perfect yields, it might need minor levels of P fertilizers, as it is extraordinarily suitable for utilizing both applied and soil P

To cite this paper: Yousaf, M., X. Li, T. Ren, R, Cong, S.T. Ata-Ul Karim, A.N. Shah, M.J. Khan, Z. Zhang, S. Fahad and J. Lu, 2016. Response of nitrogen, phosphorus and potassium fertilization on productivity and quality of winter rapeseed in central China. *Int. J. Agric. Biol.*, 16: 1137–1142

(Bailey and Grant, 1990; Irshad *et al.*, 2016). Higher P applications presume a significant role in achieving the yield and quality contents of the crop. P fertilizations additionally improved the seed and oil yield when applied up to 60 kg P ha^{-1} (Reddy *et al.*, 1997; Tamak *et al.*, 1997). Besides N and P, potassium fertilization has been accounted for to impact the efficiency of seed yield and its oil concentrations (Ghosh *et al.*, 1995). K is obligatory in enough amounts for common plant development and advancement. Kandil (1984) documented that use of K alongside N and P fertilizers enhanced the seed yield of rapeseed. The study objectives were to (i) evaluate the effectiveness of N, P, and K fertilization on yield, oil andprotein contents of winter rapeseed and (ii) explore the responses of rapeseed quality to N, P, and K application on five major fatty acids.

Fig. 1: Map of three experimental sites in central China

Materials and Methods

Description of Experimental Sites

Field experiments were conducted during the year of 2012–2013 on winter rapeseed (*Brassica napus* L.) at three study sites, Honghu (HH), Shayang (SY) and Jingzhou (JZ) of the Hubei province of China (Fig. 1). The climate is of subtropical type in the study region, with a mean temperature ranging from 4.7 to 23.6°C at HH, 3.9 to 23.4°C at SY and 4.1 to 23.2°C at JZ site while rainfall varies from 19.2 to 217.8 mm at HH, 17.0 to 240.2 mm at SY and 8.7 to 244.6 mm at JZ site (Fig. 2). During the cropping season, the temperature was mostly low (4°C or lower) with little precipitation (<120 mm) from January to February. Location of experimental sites and soil properties of the plow layer (0–20 cm) before the start of the on-farm experiments are given in Table 1.

Experimental Design and Operation

The experiment was laid out in a randomized complete block design with four treatments and three replicates consisting of; PK=chemical phosphorus and potassium fertilization with no nitrogen; (2) NK= chemical N and K fertilization with no phosphorus; (3) NP = chemical N and P fertilization with no potassium; (4) NPK= chemical N, P and K fertilization. The plot size for each replicate was 20 m^2 (3 m × 6.7 m). This bigger plot size allowed the convenient drainage during the oilseed rape growing season. All fertilization treatments received N 180 kg ha^{-1} as urea (N 46.4%) and applied in three splits i.e., 60% was applied just before seeding, 20% in over-wintering stage and 20% at the initiation of stem elongation. The whole P fertilizer at the rate of 60 kg ha^{-1} as calcium superphosphate (P 5.2%) was applied at sowing. The K fertilizer was applied at 90 kg ha^{-1} as potassium chloride (K 52.3%), 70% of which was applied before sowing of oilseed rape and 30% at the top dressing stage. Borax fertilizer (15 kg ha^{-1}) was added 100% as a basal application in all plots to meet the nutrients requirement for normal growth of oilseed rape.

The experimental fields at the three sites were well prepared, plowed and leveled by the rotary plow and basal fertilizers were incorporated during final plowing. The straw residues were removed before the construction of experimental plots and local cultivar, Hua youza 9 was used for investigation, because it is widely cultivated in the experimental regions with a high yield performance and extensive adaptability. The nursery was raised near the experimental sites on fertile seed bed and transplanted to the fields after 30 days. Previous crops were different at each site following rapeseed.

All other field operations such as planting density, herbicide appliance, irrigation, and disease and pest control were managed by following a local methodology. No major attack of weeds, disease, and pest or the weather was recorded during the growth season of nursery and fields. Planting densities were kept uniform as 112, 500 plants ha^{-1} for oilseed rape at each site. The previous crop was rice before growing of oilseed rape. The seeding, transplanting and harvesting time of oilseed rape cultivars at each site are shown in Table 2.

Sampling and Measurement

Soil and plants sampling and measurement were performed using the similar protocols at each study site. When each experimental site was established, soil samples were taken at depths 0–20 cm from 20 random points. A subsample of fresh soil was used for the measurement of inorganic N according to Rowell, 1994. The residual soil was air-dried and put through a 2 mm sieve for the measurements of pH (1:2.5 soil/water ratio), organic C (dichromate oxidation method), total N (Kjeldahl acid-digestion method), Olsen-P by spectrophotometer, NH_4OAc-K by flame photometer, and soil type was determined by hydrometer method. Before harvesting, 10 oilseed rape plants were collected from each plot and separated into two parts: seed and straw (including stem and pod wall). A subsample of seed was used to measure quality traits by using a Near-Infrared Seed Analysis System (NYDL-3000; Oil Crops Research

Table 1: Locations and soil properties (0–20 cm) of three experimental sites in central China

Site	Coordinate	Soil texture	pH	Organic C (g kg^{-1})	Total N	Olsen-P (mg kg^{-1})	NH_4OA_C-K
Honghu	30°01′N, 113°32′E	Silty clay loam	7.47	24.2	1.93	6.9	96.1
Shayang	31°00′N, 112°24′E	Silt loam	5.88	21.1	1.59	18.9	86.5
Jingzhou	30°20′N, 112°13′E	Silt loam	6.31	26.6	1.97	7.9	98.0

Table 2: Timing of each operation for oilseed rape at three study sites in central China

Operation	Experimental sites		
	Honghu	Shayang	Jingzhou
Seeding	20 Sept. 2012	20 Aug. 2012	10 Sept. 2012
Transplanting	21 Oct. 2012	21 Sept. 2012	9 Oct. 2012
Harvesting	13 May 2013	11 May 2013	5 May 2013

Table 3: Effects of N, P and K fertilization on oil, protein and fatty acid (FA) concentrations (%) of oilseed rape in 2012-2013

Site	Treatment	Oil	Protein	Oleic acid	Linoleic acid	Linolenic acid	Stearic acid	Palmitic acid
Honghu	PK	48.88a	17.71b	63.90a	16.97a	9.48a	1.68a	3.89a
	NK	42.10c	24.07a	79.07a	10.66b	6.89a	2.16a	4.02a
	NP	45.22b	22.55a	59.96a	17.06a	9.16a	2.00a	3.76a
	NPK	44.37bc	22.23a	71.34a	16.63a	8.03a	2.13a	4.12a
	Analysis of variance	**	*	ns	ns	Ns	ns	ns
Shayang	PK	48.01a	17.84b	69.38a	17.10a	8.70a	2.13a	3.92a
	NK	43.70b	23.93a	71.74a	18.18a	10.54a	1.67a	3.39a
	NP	47.55a	23.10a	78.31a	15.59a	7.77a	2.49a	4.25a
	NPK	42.83b	22.12a	69.76a	16.85a	10.60a	2.38a	4.12a
	Analysis of variance	*	*	ns	ns	Ns	ns	ns
Jingzhou	PK	48.66a	18.56b	65.66a	15.98a	8.49a	1.75a	4.18a
	NK	43.81c	24.36a	70.81a	16.86a	8.29a	2.05a	4.13a
	NP	45.22bc	22.64a	67.53a	15.94a	8.35a	1.73a	4.11a
	NPK	45.96b	22.12a	74.30a	16.75a	7.51a	2.04a	4.15a
	Analysis of variance	**	**	ns	ns	Ns	ns	ns

Mean values within a column for each season followed by different letters are significantly different at $P < 0.05$ according to LSD
*Indicates significance at P<0.05; ** Indicates significance at P<0.01

Institute, Chinese Academy of Agricultural Sciences, Wuhan, China), including oil, protein, and other fatty acids (palmitic acid, stearic acid, oleic acid, linoleic acid and linolenic acid). At maturity stage, rapeseed was harvested from each plot to measure its yield.

Calculations and Data Analysis

Oil and protein yields were measured by multiplying seed yields with oil and protein contents respectively. Analysis of variance (ANOVA) was conducted on data to evaluate treatment means. The differences among the treatments were calculated according to least significance difference test (LSD) at 0.05 probability level by using the SPSS 17.0 version. Figures were prepared using the MS Excel 2007 and Origin Pro 8.5 software program.

Results

Yield of Rapeseed in Response to NPK Fertilization

A significant effect of different fertilization treatments on rapeseed yield was observed at each study site (Fig. 3). Depending on different fertilization treatments, the rapeseed yield varied from 793 to 2060 kg ha^{-1}, 639 to 2268 kg ha^{-1} and 727 to 2600 kg ha^{-1} at HH, SY and JZ sites respectively. Among sites, the highest rapeseed yield was observed at JZ site followed by SY and HH. Compared to PK fertilization, NPK and NP treatments significantly increased the rapeseed yield at each site, while NK fertilization found significant only at SY site. The highest rapeseed yield was observed under NPK application followed by NP and NK, while the lowest yield was observed under PK fertilization at each site. The results indicated that fertilization under NPK for rapeseed productivity was found to be statistically better compared to the other fertilizer treatments and increased the total yield across all study sites by 61–72% compared to PK treatment where no N was applied.

Oil and Protein Yield Responses to NPK Fertilization

The oil yields showed a significant response to different fertilizer treatments at all three sites (Fig. 4). Among sites, the highest oil yield was observed at JZ followed by SY and HH. Oil yield ranged between 354 to 1195 kg ha^{-1} at JZ site, 307 to 972 kg ha^{-1} at SY and 388 to 914 kg ha^{-1} at HH. Significantly, maximum oil yield was observed under NPK treatment followed by NP and NK, while minimum oil yield was observed in PK treatment having similar trend at all three sites. NPK and NP treatments were statistically at par with each other at HH and JZ site while at SY site; NPK was significantly higher than NP. Consequently, the response of protein yield to applications of N, P, and K indicated comparative patterns as oil yield response to applied N, P, and K (Fig. 5). Across all the sites, an increase in protein yield was ranged from 114 to 574 kg ha^{-1} depending on different fertilization treatments. The significantly maximum protein yield was obtained by the application of NPK followed by NP and NK, while lowest was observed when PK was applied.

Rapeseed Quality Responses to NPK Fertilization

Seed quality parameters like palmitic acid, stearic acid, oleic acid, linoleic acid and linolenic acid were not significantly affected by different fertilization treatments across all experimental sites (Table 3). Application of P and K fertilizer showed no significant effect on protein contents of rapeseed at each site but regarding oil concentrations, P and K applications found significant only at JZ and SY sites respectively (Table 3). In contrast, regardless of the P and K applied, application of fertilizer N consistently reduced oil contents (Fig. 6) and enhanced protein contents in rapeseed (Fig. 7) at each site. Consequently, N fertilizer always found significant to concentrations of oil and protein in rapeseed.

Discussion

Seed and Nutritional Yields

We found that application of different fertilization treatments significantly affected the rapeseed yield. Compared with PK fertilization, the yield of rapeseed was increased at each site by NPK, NP, and NK, NK, indicating the importance of N to improve crop productivity (Fig. 3). At each site, the results of this study showed that oil and protein yields of rapeseed were significantly affected by fertilization treatments. As the oil and protein yields were closely associated with seed yield so the yield was higher in plots receiving N compared to the no-N plots (Fig. 4; 5). Ozer (2003), Barłóg and Grzebisz (2004a, b), Rathke *et al.* (2005) and Juan *et al.* (2009) documented that N fertilization improved seed yield, dry matter production, N uptake and demonstrated the importance of N fertilizer in oilseed rape production and in other crops (Sheoran *et al.*, 2016). Furthermore, the highest yields were obtained in plots receiving P. According to Malhi *et al.* (2007), there ought to be an adequate provision of nutrients at early development stages since canola plant uptakes a large portion of its phosphorus during the early

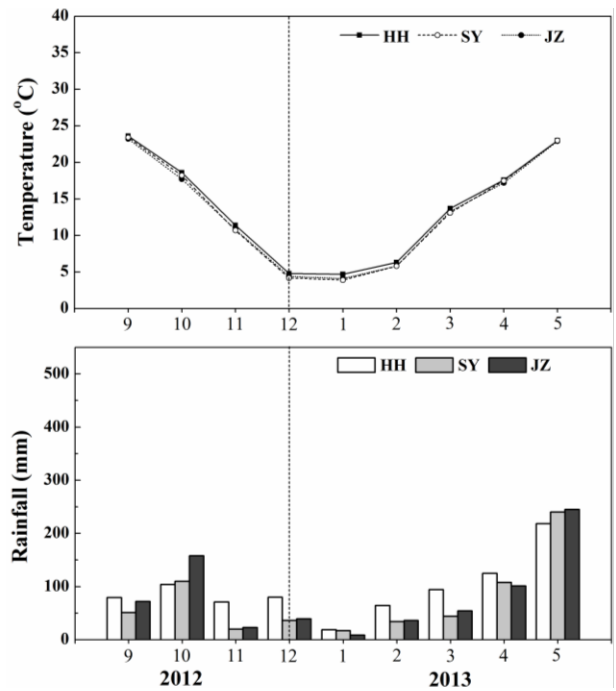

Fig. 2: Weather records during the oilseed rape growing season (2012-2013) at three experimental sites in Hubei province, China

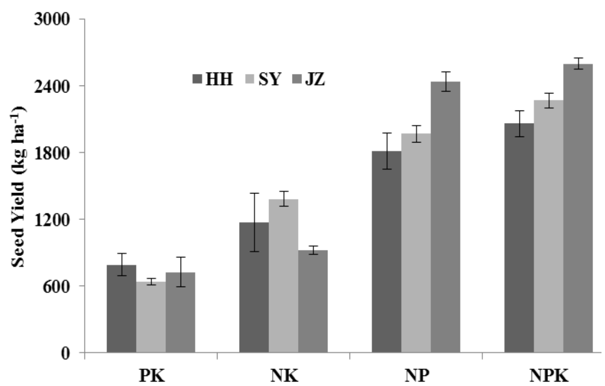

Fig. 3: Effects of N, P and K fertilization on seed yield (kg ha^{-1}) of rapeseed in 2012-2013. HH, SY and JZ represent Honghu, Shayang and Jingzhou sites, respectively

development phase, both from soil and applied fertilizer for receiving higher yields. Elevated levels of P significantly increased the P concentration in plants (Idris *et al.*, 1989) and increased canola productivity (Ibrahim, 1989; Kar *et al.*, 1989). K also plays a significant role for oil and protein yield of rapeseed. The K and N interaction were observed significant for seed productivity and oil yield (Brennan and Bolland, 2007). Among treatments, NPK fertilization was best in producing the highest seed yield and oil and protein yield of rapeseed compared with all other treatments. This was due to the balanced supply of all important nutrients to

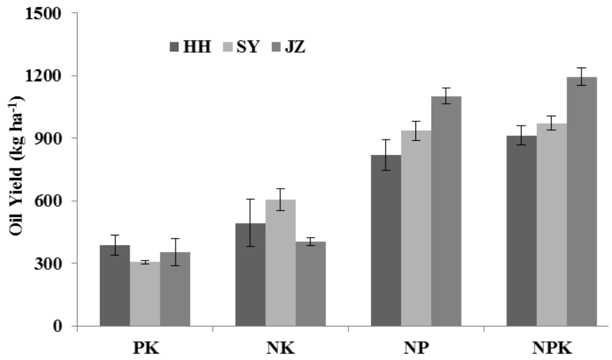

Fig. 4: Effects of N, P and K fertilization on oil yield (kg ha^{-1}) of rapeseed in 2012-2013. HH, SY and JZ represent Honghu, Shayang and Jingzhou sites respectively

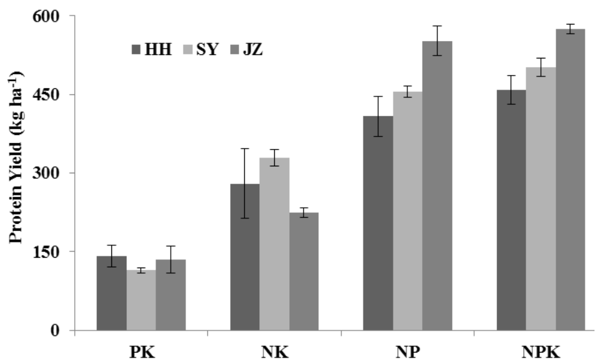

Fig. 5: Effects of N, P and K fertilization on protein yield (kg ha^{-1}) of rapeseed in 2012-2013. HH, SY and JZ represent Honghu, Shayang and Jingzhou sites, respectively

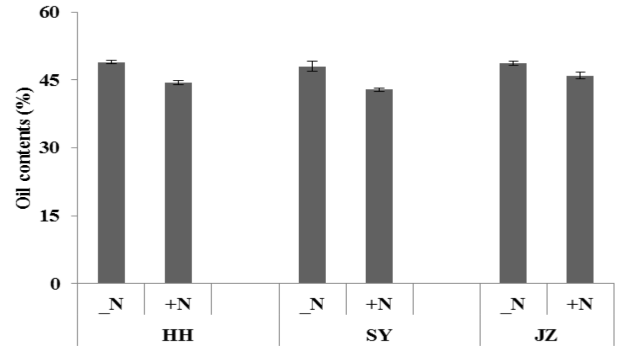

Fig. 6: Effects of N fertilization on oil contents (%) of oilseed rape in 2012-2013. HH, SY and JZ represent Honghu, Shayang and Jingzhou sites respectively

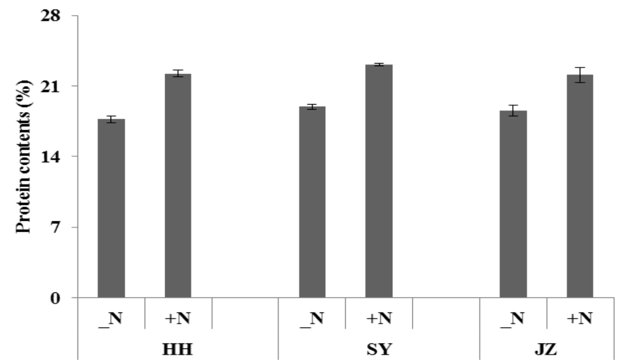

Fig. 7: Effects of N fertilization on protein contents (%) of oilseed rape in 2012-2013. HH, SY and JZ represent Honghu, Shayang and Jingzhou sites, respectively

plants. Other treatments such as NP, NK, and PK were lacking a supply of at least one major nutrient i.e., either N, P or K thus may induce that specific nutrient deficiency stress and retard overall growth of rapeseed with a concomitant reduction in yields. The variation in the seed and nutritional yields at different sites was might be due to the different weather conditions and the differences in indigenous nutrients supply capacity of soil. These differences were also observed in the yield of rice cultivars grown in seven different rice regions of China (Chen *et al.,* 2011; Wang *et al.,* 2012). Further, this discrepancy could also be partly explained by the different previous crops at each site affecting the indigenous nutrients supply capacity of soil (Ren Tao *et al.,* 2015). However, the contributions of mineral fertilizer to seed and nutritional yields were different but yields of the 0–N treatment were significantly lower than of the 0–P and 0–K treatments, revealing that N was the most restrictive element following P and K.

Rapeseed Quality

In our study, non-significant improvements were observed in palmitic acid, stearic acid, oleic acid, linoleic acid and linolenic acid under applied N, P and K fertilizers (Table 3). Oil and protein contents were not responded to applied K fertilizer, supporting the results of previous studies (Brennan and Bolland, 2007) except that at SY site, the oil concentrations decreased by K fertilizer application in rapeseed might be due to different soil fertility status and weather conditions (Chen *et al.,* 2011; Wang *et al.,* 2012). P application did not alter the oil and protein concentrations of rapeseed except at JZ, but a seed oil concentration was decreased. This might be due to the different previous crops affecting the indigenous nutrients supply capacity of soil at study sites (Chen *et al.,* 2011; Ren Tao *et al.,* 2015). Oil contents remain unchanged under applied P fertilizer (Lickfett *et al.,* 1999) and seed protein contents increased at high P supply at 80 kg ha^{-1} (Tomar *et al.,* 1996). Delivering higher amounts of N consistently decreased the oil contents (Fig. 6) and increased the protein contents (Fig. 7). The results are in agreement with Brennan and Bolland (2007) and Rathke *et al.* (2005). The conceivable purpose behind the diminishment in seed oil content with expanding N may be because of the way that N is the significant constituent of protein so it advances the seed protein contents, thus, there may be lessening in the level of oil contents since it has an inverse relationship with protein (Öztürk, 2010).

Conclusion

This multi locational study showed that seed and nutritional yields responded significantly to applied N, P, and K fertilizers. Other fatty acids of rapeseed palmitic acid, stearic acid, oleic acid, linoleic acid and linolenic acid) were not affected by N, P and K applications. Oil and protein contents did not respond significantly to P and K fertilizer application, but N fertilizer applications consistently decreased the contents of oil and increased the protein contents. This shows that N is the major constituent of protein so it promotes the seed protein contents, thus, there might be a reduction in the percentage of oil content due to the inverse relationship of oil content with protein. Combined application of NPK increased seed, oil and protein yields. So we recommend combined application of NPK for better rapeseed quality and productivity. These results could be valuable to the researchers seeking to increase the rapeseed quality and also for farmers for oilseed rape productivity in China and throughout the world.

Acknowledgements

This research was supported by National Natural Science Foundation of China (41401324), Special Fund for Agro-scientific Research in the Public Interest (201303103), and the Fundamental Research Funds for the Central Universities (2662015PY135).

References

Bailey, L.D. and C.A. Grant, 1990. Fertilizer placement studies on calcareous and non-calcareous chernozemic soils: growth, P uptake, oil content and yield of Canadian rape. *Commun. Soil Sci. Plant Anal.,* 21: 2089–2104

Barłóg, P. and W. Grzebisz, 2004a. Effect of timing and nitrogen fertilizer application on winter oilseed rape (*Brassica napus* L.). I. Growth dynamics and seed yield. *J. Agron. Crop Sci*., 190: 305–313

Barłóg, P. and W. Grzebisz, 2004b. Effect of timing and nitrogen fertilizer application on winter oilseed rape (*Brassica napus* L.). II. Nitrogen uptake dynamics and fertilizer efficiency. *J. Agron. Crop Sci*., 190: 314–323

Chen, J., Y. Huang and Y. Tang, 2011. Quantifying economically and ecologically optimum nitrogen rates for rice production in south-eastern China. *Agric. Ecosyst. Environ*., 142: 195–204

Colnenne, C., J.M. Meynard, R. Reau, E. Justes and A. Merrien, 1998. Determination of a critical nitrogen dilution curve for winter oilseed rape. *Ann. Bot.,* 81: 311–317

FAO, 2013. *FAOSTAT Database*. *In:* F.A.A.C., (Ed.) Production. Food and Agriculture Organization of the United Nations, Rome. http://faostat.fao.org/ (accessed 10 Jan. 2014)

Gao, J., K.D. Thelen, D.H. Min, S. Smith, X. Hao and R. Gehl, 2010. Effects of manure and fertilizer applications on canola oil content and fatty acid composition. *Agron. J*., 102: 790–797

Ghosh, D.C., P.K. Panda and P.M. Sahoo, 1995. Response of rainfed rapeseed (*Brassica campestris* L.) to NPK. *Ind. J. Agric. Res*., 29: 5–9

Högy, P., J. Franzaring, K. Schwadorf, J. Breuer, W. Schütze and A. Fangmeier, 2010. Effects of free-air CO_2 enrichment on energy traits and seed quality of oilseed rape. *Agric. Ecosyst. Environ*., 139: 239–244

Ibrahim, S.A., 1989. Growth, yield and nutrients uptake responses of pea plants to phosphorus and micronutrients. *Egypt. J. Soil Sci.,* 29: 251–259

Idris, M., T. Mahmood and K.A. Malik, 1989. Response of field-grown chickpea (*Cicer arietinum* L.) to phosphorus fertilization for yield and nitrogen fixation. *Plant Soil*, 114: 135–138

Irshad, S., H. Rehman, M.A. Wahid, M.F. Saleem, S.M.A. Basra and M.T. Saeed, 2016. Influence of phosphorus application on growth, yield and oil quality of linola. *J. Plant Nutr.,* 39: 856–865

Juan, Z., L. JianWei, C. Fang and L. YinShui, 2009. Effect of nitrogen, phosphorus, potassium, and boron fertilizers on yield and profit of rapeseed (*Brassica napus* L.) in the Yangtze River Basin. *Acta Agron. Sin.,* 35: 87–92

Kandil, A., 1984. A preliminary study on the effect of NPK fertilization on the oilseed rape (*Brassica napus*). In Egypt in 6th International Repeseed Conference, Paris, France. *Field Absts*., 37: 296

Kar, P.C., G.K. Patro and K. Mohanty, 1989. Effect of fertilizer levels on the growth and yield of Bengal gram. Current Research. *Univ. Agric. Sci. Dharwad*., 18: 80–81

Lickfett, T., B. Matthäus, L. Velasco and C. Möllers, 1999. Seed yield, oil and phytate concentration in the seeds of two oilseed rape cultivars as affected by different phosphorus supply. *Eur. J. Agron*., 11: 293–299

Malhi, S.S., A.M. Johnston, J.J. Schoenau, Z.H. Wang and C.L. Vera, 2007. Seasonal biomass accumulation and nutrient uptake of canola, mustard, and flax on a Black Chernozem soil in Saskatchewan. *J. Plant Nutr*., 30: 641–658

Mason, M.G. and R.F. Brennan, 1998. Comparison of growth response and nitrogen uptake by canola and wheat following application of nitrogen fertilizer. *J. Plant Nutr*., 21: 1483–1499

Ozer, H., 2003. Sowing date and nitrogen rate effects on growth, yield and yield components of two summer rapeseed cultivars. *Eur. J. Agron*., 19: 453–463

Öztürk, Ö., 2010. Effects of source and rate of nitrogen fertilizer on yield, yield components and quality of winter rapeseed (*Brassica napus* L). *Chil. J. Agric. Res.,* 70: 132–141

Rathke, G.W., O. Christen and W. Diepenbrock, 2005. Effects of nitrogen source and rate on productivity and quality of winter oilseed rape (*Brassica napus* L.) grown in different crop rotations. *Field Crops Res*., 94: 103–113

Ren, T., H. Li, J. Lu, R. Bu, X. Li, R. Cong and M. Lu, 2015. Crop rotation-dependent yield responses to fertilization in winter oilseed rape (*Brassica napus* L.). *Crop J*., 3: 396–404

Rehman, H., Q. Iqbal, M. Farooq, A. Wahid, I. Afzal and S.M.A. Basra, 2013. Sulphur application improves the growth, seed yield and oil quality of canola. *Acta Physiol. Plant.,* 35: 2999–3006

Rowell, D.L., 1994. *Soil Science: Methods and Applications.* Department of Soil Science, University of Reading

Sheoran, P., V. Sardana, S. Singh, A. Kumar, A. Mann and P. Sharma, 2016. Agronomic and physiological assessment of nitrogen use, uptake and acquisition in sunflower. *Int. J. Plant Prod*., 10: 2

Smith, C.J., G.C. Wright and M.R. Woodroofe, 1988. The effect of irrigation and nitrogen fertilizer on rapeseed (*Brassica napus*) production in South-Eastern Australia. *Irrig. Sci*., 9: 15–25

Tamak, J.C., H.C. Sharma and K.P. Singh, 1997. Effect of phosphorus, sulphur and boron on seed yield and quality of sunflower (*Helianthus annuus*). *Ind. J. Agron*., 42: 173–176

Tomar, H.P.S., K.S. Dadhwal and H.P. Singh, 1996. Oil content, oil and cake yield and protein content of sunflower (*Helianthus annuus* L.) as influenced by irrigation, nitrogen and phosphorus levels. *Ind. J. Soil Consev*., 24: 215–220

Reddy, V.P., A. Sreenivasa Raju, A. Prasad Rao and F. Sultana, 1997. Response and utilization of phosphorus by sunflower: *J. Nucl. Agric. Biol*., 26: 181–184

Wang, W., J. Lu, T. Ren, X. Li, W. Su and M. Lu, 2012. Evaluating regional mean optimal nitrogen rates in combination with indigenous nitrogen supply for rice production. *Field Crops Res*., 137: 37–48

Wang, Y., J. Li, X. Gao, X. Li, T. Ren, R. Cong and J. Lu, 2014. Winter oilseed rape productivity and nutritional quality responses to zinc fertilization. *Agron. J*., 106: 1349–1357

(Received 10 June 2016; Accepted 30 July 2016)