



**Full Length Article**

## Timing of Phosphorus and Boron Application Affects Seed Yield, Oil Contents and Profitability of Canola under an Arid Climate

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### Abstract

The oil seed production in Pakistan is not sufficient to fulfill the needs of the country. Therefore, it is necessary to optimize the nutrient management practices of oil seed crops to improve their seed yield. This two year field study was conducted at Research Farm of the Islamia University, Bahawalpur, Pakistan during *Rabi* season of 2014–2015 and 2015–2016 to optimize the timing of phosphorous (P) and boron (B) application to improve the productivity and economic returns of canola under an arid climate. The experiment consisted of following treatments viz. 1) no application of P and B, 2) 60 kg P and 3 kg B ha<sup>-1</sup> at sowing, 3) half P at sowing and half at 1<sup>st</sup> irrigation in splits + full B at sowing, 4) P in splits + full B at 1<sup>st</sup> irrigation, 5) Full P at sowing + half B at sowing and half at 1<sup>st</sup> irrigation in splits, and 6) P and B in splits. During both years, the highest crop growth rate, leaf area index, plant height (162 cm), 1000 seed weight (4.4 g), seed yield (1868 kg ha<sup>-1</sup>), oil contents (39.2%), net returns (Rs. 42720 ha<sup>-1</sup>) and benefit cost ratio (2.34) was recorded when full dose of P was applied at sowing combined with B application in splits. Hence, application of 60 kg ha<sup>-1</sup> of P at sowing combined with application of 3 kg B (at sowing and 1<sup>st</sup> irrigation in two splits) proved beneficial for improving the growth, yield, quality and economics of canola under an arid climate. © 2018 Friends Science Publishers

**Keywords:** Canola; Phosphorus; Boron; Arid climate; Growth; Seed yield

### Introduction

Mustard (*Brassica rapa*), rapeseed (*Brassica napus*), sunflower (*Helianthus annuus*) and cotton (*Gossypium hirsutum*) are important oilseed crops of Pakistan. However, the oil produced from these crops is 0.646 million tons which is less against the required oil requirement of 3 million tons. Each year, 2.32 million tons of oil (worth 207 billion rupees) is imported to fulfill the requirements of Pakistani people (Amjad, 2014; GOP, 2016).

There are several reasons for low oil production in Pakistan. For example, the oilseed crops are grown on marginal lands with low soil fertility due to which the oil production from these crops is not sufficient to meet the oil demands of the country (Amjad, 2014). These situation necessities to optimize the oil production in Pakistan through introduction of new oil seed crops and through optimizing the agronomic practices adopted to produce an oilseed crop under field conditions.

Canola (*Brassica napus* L.) is a newly introduced oilseed crop in Pakistan which has the ability to perform well on diverse soil types and it can fulfill the oil requirements of the country. In 2016–2017, 30 thousand acres of cultivated land was brought under canola crop with

seed production of 15 thousand tons and oil production of 6 thousand tons (GOP, 2016). However, the average yield of canola in world is still low due to poor nutrient management (Jones and Olson-Rutz, 2016) including Pakistan.

Among the macro- and micro-nutrients, phosphorous (P) and boron (B) are important crop nutrients useful for improving the seed and oil yield of oil seed crops. In Pakistan, P is typically applied to agricultural land as inorganic fertilizer or as manure (Rehim *et al.*, 2016). Many physiological, biochemical and metabolic processes including photosynthetic activity, maintenance of plant body structure, cell wall thickness and reproductive development of crop plants are triggered by P application in plants (Mohanty *et al.*, 2006; Bastani and Hajiboland, 2017) including the oil seed crops. Mostly, P is applied as basal dose in field crops as its uptake during a crop growth season largely varies from time to time (Tirado and Allsopp, 2012). Thus, it is vital to optimize the timing and rate of P application in canola for improving the seed and oil yield.

In field crops including oilseeds, B is needed for the transport of carbohydrates, cellular differentiation, pollen/anther development, pollen tube viability and pollen tube germination, thus affecting the vegetative and reproductive development of plants (Durbak *et al.*, 2014;

Leonard *et al.*, 2014; Wasaya *et al.*, 2017; Zhang *et al.*, 2017). For example, Ma *et al.* (2015) reported an improvement in the yield parameters and seed yield of canola due to application of B. In India, Sarkar *et al.* (2007) found that split application of B was most useful in wheat, mustard and potato than single application.

In canola, the interactive effect of P with sulphur (S) (Ahmad *et al.*, 2007), nitrogen (N) and P (Cheema *et al.*, 2001), N with S and B (Ma *et al.*, 2015), N with P and K (Tahir *et al.*, 2003), N with S (Asare and Scarisbrick, 1995; Jackson, 2000), and individual application of B (Hussain *et al.*, 2012; Jankowski *et al.*, 2016), S (Beam III, 2015) and N (Ozer, 2003; Rathke *et al.*, 2005; Öztürk, 2010; Ma and Herath, 2016) has been the subject of several studies. Some studies have also reported the positive interaction of P and B in plant biology. For example, the P uptake was low in faba bean roots deficient in B, and was improved by B application (Robertson and Loghman, 1974). In another study, the efflux and uptake of P was enhanced with addition of B in sunflower plant (Goldbach, 1984). The mitigation of B toxicity due to P application has also been reported in tomato plants (Khan and Wajid, 1996). This indicates that combine application of P and B might be beneficial for agronomic crops including the oilseeds.

However, no study has been carried out to evaluate the combined application of P and B on growth, seed and oil yield, and economics of canola production under arid climate. Thus, this study investigated the combined influence of P and B on growth, seed and oil yield and profitability of canola crop. The specific objective of the present was to optimize the timing and rates of P and B application for canola crop under the agro-climatic conditions of study region.

## Materials and Methods

### Experimental Site, Soil and Climate

This two years trial was done at Research Farm, the Islamia University of Bahawalpur, Pakistan during the winter season of 2014–15 and 2015–16. The study site is located at 65° E longitude, and 33° N latitude. Prior to sowing of the crop, the physio-chemical analysis of soil was done to check the nutrient status of the soil (Table 1) after collecting the soil samples from 0.20 m depth using an augur. For the determination of soil texture, Bouyoucos hydrometer method was used. The proportion of each soil particle was determined afterward through international textural triangle (Moodie *et al.*, 1959). The N, P, and K were determined using the standard procedures (Olsen *et al.*, 1954; Richards, 1954; Bremner and Mulvaney, 1982). The soil B status was determined by using the method of John *et al.* (1975) through a spectrophotometer (Perkin Elmer, Richmond, California, USA). The climate of Bahawalpur is arid in nature with <200 mm annual rainfall with average annual temperature of 25.7°C (Fig. 1).

### Experimental Details

The experiment consisted of following treatments viz. i) control (no application of P and B), ii) P (60 kg ha<sup>-1</sup>) + B (3 kg ha<sup>-1</sup>) at sowing, iii) P (30 kg ha<sup>-1</sup> at sowing and 30 kg ha<sup>-1</sup> at 1<sup>st</sup> irrigation) + B (3 kg ha<sup>-1</sup> at sowing), iv) P (30 kg ha<sup>-1</sup> at sowing and 30 kg ha<sup>-1</sup> at 1<sup>st</sup> irrigation) + B (3 kg ha<sup>-1</sup> at 1<sup>st</sup> irrigation), v) P (60 kg ha<sup>-1</sup> at sowing) + B (1.5 kg ha<sup>-1</sup> B at sowing and 1.5 kg ha<sup>-1</sup> B at 1<sup>st</sup> irrigation), vi) P (30 kg ha<sup>-1</sup> at sowing and 30 kg ha<sup>-1</sup> at 1<sup>st</sup> irrigation) + B (1.5 kg ha<sup>-1</sup> B at sowing and 1.5 kg ha<sup>-1</sup> B at 1<sup>st</sup> irrigation). The experiment was laid out in randomized complete block design with 3 replications and the net plot size of 2.25 m × 5 m.

### Crop Husbandry

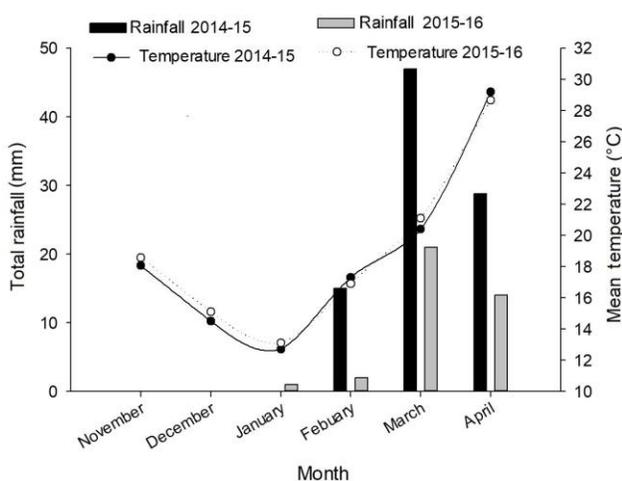
The seed bed was prepared by two cultivations (0.15 m depth) followed by planking with a wooden planker during both years when the soil reached at workable moisture after pre-sowing irrigation. Canola crop was seeded at seed rate of 5 kg ha<sup>-1</sup> on November 15 and 12 during 2014 and 2015, respectively in 45 cm spaced rows. The sowing of the crop was manually done through single row hand drill. After complete emergence, non-healthy plants were removed and the distance of 15 cm was kept uniform between plants. Nitrogen was applied at the rate of 60 kg ha<sup>-1</sup> using urea (46% N) as source. Half of the nitrogen was applied at sowing time and the remaining half at flower initiation. Application of K was done at 60 kg ha<sup>-1</sup> at sowing time using SOP (50% K<sub>2</sub>O) as source. The diammonium phosphate was used as a source of P; boric acid (10.65% boron) as B source. The quantity of P and B was applied as per treatment. The weeds were manually controlled by hand hoeing. In total, 3 irrigations were applied to canola crop during whole crop cycle. First irrigation was applied after one month of sowing, followed by other two irrigations at flower initiation and seed filling. The crop was harvested on March 12 and 16 during 2015 and 2016 respectively and the morphological and yield parameters were recorded as detailed below.

### Data Recording

**Growth parameters:** For the determination of crop growth rate (CGR) and leaf area index (LAI), two plants were harvested at each sampling date from each experimental plot. After 15 days of cultivation, the sampling was initiated and terminated at 135 days after sowing with 20 days interval between two harvests. The leaves of the harvested plants (at each sampling date) were separated and their leaf area was measured manually. For the determination of crop growth rate (g m<sup>-2</sup> day<sup>-1</sup>), the separated leaves and stems of both plants were oven dried at 105°C until a constant dry weight achieved. The leaf area index and crop growth rate was recorded following the Watson (1952), and Hunt (1978), respectively.

**Table 1:** Physio-chemical analysis of the soil prior to sowing

Characteristics	Units	2014	2015
Sand	%	71	71
Silt	%	17	16
Clay	%	12	13
Soil type	Sandy loam		
Electrical conductivity	dS m <sup>-1</sup>	0.54	0.52
Soil pH		8.0	8.1
Soil organic matter	%	0.33	0.34
Total nitrogen	%	0.04	0.04
Available phosphorous	mg kg <sup>-1</sup>	4.02	4.32
Exchangeable potassium	mg kg <sup>-1</sup>	120	122
Boron	mg kg <sup>-1</sup>	0.21	0.22


**Fig. 1:** Weather data of experimental site during crop growth seasons of 2014-2015 and 2015-2016

### Morphological and Quality Parameters

For the measurement of plant height, ten plants from each plot were selected and their height was recorded with the help of a measuring scale and averaged. The primary branches per plant and pods per plant were counted from ten random plants from each plot and averaged. When the canola crop reached at its harvest maturity, the harvesting of the individual plot was done and the crop was sun dried for a week in experimental plots. Then, the biological yield was recorded from each plot and expressed in kg ha<sup>-1</sup>. These sundried bundles were manually threshed to separate the seeds from the chaff. The separated seeds from each plot after threshing were weighed on an electric balance and later on converted into kg ha<sup>-1</sup> to report seed yield. Three sub-samples of 1000 seeds were taken from seed lot of each experimental plot and were weighed on an electric balance to estimate the 1000 seed weight in grams. The protein and oil contents of the seeds were estimated by Near Infrared Reflectance Spectroscopy (NIRS) (Sato, 2002) by using A NIR Systems Model 6500 spectrophotometer (Foss-NIR Systems, Inc., Silver Spring,

MD, USA). The net returns were calculated by subtracting the total cost from gross income. The benefit-cost ratio was calculated by dividing the gross income by total cost. The total cost included all the input costs (cost of land preparation, sowing, fertilizer, irrigation, insect pests and disease management, labor cost). The gross income was calculated by multiplying the total seed yield by unit price of canola seed (CIMMYT, 1998).

### Statistical Analysis

The data recorded on all parameters was statistically analyzed through Fisher Analysis of Variance technique followed by mean separation using least significant difference test at 5% probability level (Steel *et al.*, 1996). The means ( $\pm$ standard error) of allometric traits were presented graphically using Microsoft excel sheet. The year effect was significant, so the means for both years has been presented separately. However, for CGR, LAI, and economic analysis, the data for both years was pooled and the average of both years has been presented.

### Results

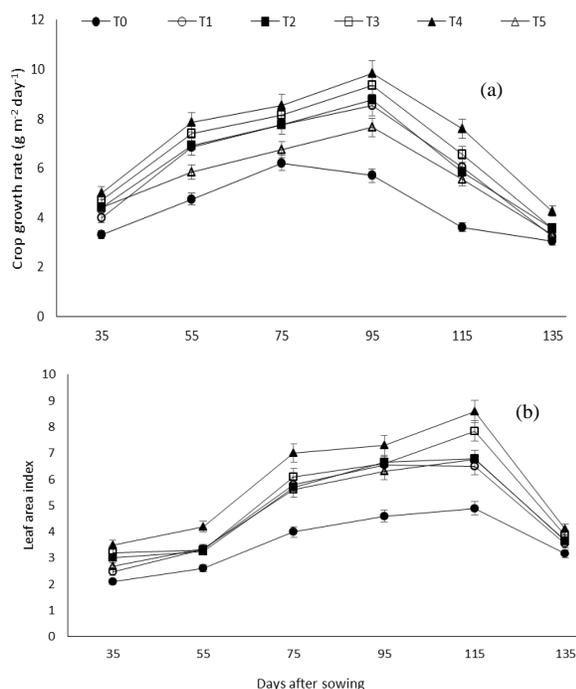
This study indicated that combined application of P and B significantly improved the LAI, plant height, CGR, primary branches per plant, 1000 seed weight, pods per plant, biological/seed yield, and oil contents of seed (Table 1 and Fig. 2). The LAI and CGR increased progressively from 15 days after sowing to 95 days after sowing in all treatments; a decline was observed afterward (Fig. 2). The maximum LAI and CGR was recorded at 95 DAS with treatment [P (60 kg ha<sup>-1</sup> at sowing) + B (1.5 kg ha<sup>-1</sup> at sowing + 1.5 kg ha<sup>-1</sup> at 1<sup>st</sup> irrigation)] followed by treatment [P (30 kg ha<sup>-1</sup> at sowing + 30 kg ha<sup>-1</sup> at 1<sup>st</sup> irrigation) + B (3 kg ha<sup>-1</sup> at 1<sup>st</sup> irrigation)] during both year of experimentation (Fig. 2).

During both years, the taller plants and the highest primary branches per plant were noticed in treatment [P (60 kg ha<sup>-1</sup> P at sowing) + B (1.5 kg ha<sup>-1</sup> B at sowing + 1.5 kg ha<sup>-1</sup> B at 1<sup>st</sup> irrigation)] that was statistically similar with treatment [P (60 kg ha<sup>-1</sup>) + B (3 kg ha<sup>-1</sup>)], at sowing) for both parameters during first year of experimentation (Table 2). Likewise, 1000 seed weight and pods per plant were the maximum in treatment [P (60 kg ha<sup>-1</sup> at sowing) + B (1.5 kg ha<sup>-1</sup> at sowing + 1.5 kg ha<sup>-1</sup> at 1<sup>st</sup> irrigation)] during both years and was statistically similar with treatment [P (30 kg ha<sup>-1</sup> at sowing + 30 kg ha<sup>-1</sup> at 1<sup>st</sup> irrigation) + B (3 kg ha<sup>-1</sup> at 1<sup>st</sup> irrigation)] for numbers of pods per plant during the first year of experimentation (Table 2). The biological yield was significantly higher (30–31% higher than control) in treatment [P (60 kg ha<sup>-1</sup> at sowing) + B (1.5 kg ha<sup>-1</sup> at sowing + 1.5 kg ha<sup>-1</sup> at 1<sup>st</sup> irrigation)] during both years. The seed yield was also 14.8–19.3% higher in treatment [P (60 kg ha<sup>-1</sup> at sowing) + B (1.5 kg ha<sup>-1</sup> at sowing + 1.5 kg ha<sup>-1</sup> at 1<sup>st</sup> irrigation)] during both years than control (Table 2).

**Table 2:** Impact of different application timing of phosphorus and boron on morphological, yield parameters, seed protein contents and seed oil contents of canola

Treatments	Plant height (cm)		Number of primary branches per plant		Number of pods per plant		1000-seed weight (g)	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Control (no P and B)	140 D	137 E	5.6 C	5.8 D	242 D	278 E	3.1 E	2.9 F
FP+FB (sowing)	155 AB	159 B	7.4 A	6.6 CD	295 C	304 D	3.7 C	3.8 C
HP and FB (sowing) + HP (1 <sup>st</sup> irrigation)	148 C	144 D	6.5 B	7.2 B	308 B	328 C	3.4 D	3.2 E
HP (sowing) + HP and FB (1 <sup>st</sup> irrigation)	153 BC	156 BC	5.8 BC	6.0 C	345 A	345 B	3.8 B	4.3 B
FP and HB (sowing) + HB (1 <sup>st</sup> irrigation)	159 A	164 A	7.8 A	8.0 A	338 A	356 A	4.0 A	4.8 A
HP and HB (sowing) + HP and HB (1 <sup>st</sup> irrigation)	151 BC	150 C	6.4 B	6.8 BC	300 BC	340 BC	3.4 D	3.7 CD
LSD ( $p \leq 0.05$ )	5.40	4.02	0.81	0.73	11.02	10.01	0.10	0.11
	Seed yield (kg ha <sup>-1</sup> )		Biological yield (kg ha <sup>-1</sup> )		Seed protein contents (%)		Seed oil contents (%)	
Control (no P and B)	1322 E	1298 F	5427 E	5847 F	24.7 A	25.8 A	37.2 E	37.5 F
FP+FB (sowing)	1552 D	1548 E	6167 D	6761 E	24.5 B	25.2 B	38.3 D	38.0 E
HP and FB (sowing) + HP (1 <sup>st</sup> irrigation)	1591 C	1657 C	6463 C	7064 D	24.4 BC	24.5 CD	38.3 D	38.4 D
HP (sowing) + HP and FB (1 <sup>st</sup> irrigation)	1631 B	1722 B	6575 BC	7365 B	24.3 C	24.6 C	38.4 C	39.2 B
FP and HB (sowing) + HB (1 <sup>st</sup> irrigation)	1895 A	1840 A	7055 A	7632 A	23.4 D	23.7 E	38.8 A	39.6 A
HP and HB (sowing) + HP and HB (1 <sup>st</sup> irrigation)	1544 D	1608 D	6679 B	7125 C	24.3 C	24.0 D	38.5 B	38.8 C
LSD ( $p \leq 0.05$ )	17.53	20	140	125	0.12	0.15	0.04	0.05

Means followed by the same letter are not significantly different at  $p \leq 0.05$ , B = boron; P = phosphorous; FP= 60 kg P ha<sup>-1</sup>; FB = 3 kg B ha<sup>-1</sup>; HP = 30 kg P ha<sup>-1</sup>; HB = 1.5 kg B ha<sup>-1</sup>



**Fig. 2:** Influence of phosphorus and boron application on (a) crop growth rate and (b) leaf area index of canola; T<sub>0</sub> = control (no P and B application), T<sub>1</sub> = 60 kg ha<sup>-1</sup> P and 3 kg ha<sup>-1</sup> B at sowing; T<sub>2</sub> = 30 kg ha<sup>-1</sup> P & 3 kg ha<sup>-1</sup> B at sowing + 30 kg ha<sup>-1</sup> P at 1<sup>st</sup> Irrigation; T<sub>3</sub> = 30 kg ha<sup>-1</sup> P at sowing + 30 kg ha<sup>-1</sup> P and full dose B at 1<sup>st</sup> Irrigation; T<sub>4</sub> = 60 kg ha<sup>-1</sup> P at sowing + 1.5 kg ha<sup>-1</sup> B at sowing + 1.5 kg ha<sup>-1</sup> B at 1<sup>st</sup> Irrigation; T<sub>5</sub> = 30 kg ha<sup>-1</sup> P & 1.5 kg ha<sup>-1</sup> B at sowing + 30 kg ha<sup>-1</sup> P & 1.5 kg ha<sup>-1</sup> B at 1<sup>st</sup> irrigation

Combined application of B and P significantly improved the seed oil contents regardless of dose and timing of application of both nutrients; seed oil contents being

significantly higher in treatment [P (60 kg ha<sup>-1</sup> at sowing) + B (1.5 kg ha<sup>-1</sup> at sowing + 1.5 kg ha<sup>-1</sup> at 1<sup>st</sup> irrigation)] and lowest in control treatment in 2014 and 2015 (Table 2). The protein contents were not affected by combined application of P and B (Table 2). The highest gross income (74720 Rs. ha<sup>-1</sup>), net returns (42720 Rs. ha<sup>-1</sup>) and benefit cost ratio (2.34) was recorded in treatment [P (60 kg ha<sup>-1</sup> at sowing) + B (1.5 kg ha<sup>-1</sup> at sowing + 1.5 kg ha<sup>-1</sup> at 1<sup>st</sup> irrigation)] (Table 3).

## Discussion

The present study showed that combined application of P and B at variable rates improved the growth (CGR, LAI), morphological traits (primary branches per plant, plant height), yield parameters (1000 seed weight, pods per plant), biological/seed yield and quality traits (seed protein and seed oil contents) of canola crop (Table 2 and Fig. 2). Improvement in growth parameters due to P application might be attributed to the role of P in various physiological, biochemical and metabolic process of crop plants including improvement in photosynthesis, maintenance of plant body structure and cell wall thickness (Dar *et al.*, 2015; Fageria, 2016; Bastani and Hajiboland, 2017) and vigorous root system. Indeed, better root system due to P application helps the plants to use the soil water and nutrient resources more efficiently than those plants not supplied with external P. Several other studies have reported that application of P to field crop improved the leaf area, shoot and root dry weight and crop growth rate (Bélanger *et al.*, 2015; Irshad *et al.*, 2016; Said-Al Ahl *et al.*, 2016).

It was observed that LAI and CGR increased upto 95 days followed by a declining trend afterward. Indeed, as the crop progress towards maturity after a specific period of time, the CGR remain stable or declines due to the translocation of assimilates from leaves towards seed which might be the possible reason for decline in CGR and LAI

**Table 3:** Economics of canola production as affected by application timing of phosphorus and boron under an arid climate

Treatments	Seed yield (kg ha <sup>-1</sup> )	Gross income (Rs. ha <sup>-1</sup> )	Total cost (Rs. ha <sup>-1</sup> )	Net Return (Rs. ha <sup>-1</sup> )	Benefit cost ratio
Control (no P and B)	1310	52400	25000	27400	2.10
FP+FB (sowing)	1550	62000	29000	33000	2.14
HP and FB (sowing) + HP (1 <sup>st</sup> irrigation)	1624	64960	30200	34760	2.15
HP (sowing) + HP and FB (1 <sup>st</sup> irrigation)	1677	67080	31580	35500	2.12
FP and HB (sowing) + HB (1 <sup>st</sup> irrigation)	1868	74720	32000	42720	2.34
HP and HB (sowing) + HP and HB (1 <sup>st</sup> irrigation)	1576	63040	28000	35040	2.25

B = boron; P = phosphorous; FP = 60 kg P ha<sup>-1</sup>; FB = 3 kg B ha<sup>-1</sup>; HP = 30 kg P ha<sup>-1</sup>; HB = 1.5 kg B ha<sup>-1</sup>

after 95 days after sowing. Moreover, the leaf senescence due to leaf chlorosis and other cell death processes decreases the growth rate of field crops when it progresses towards maturity (Wu *et al.*, 2012).

Moreover, improvement in growth and yield of canola due to B application was attributed to the role of B in the transport of carbohydrates and cellular differentiation, pollen/anther development, pollen tube viability/growth and pollen tube germination (Blevins and Lukaszewski, 1998; Durbak *et al.*, 2014; Leonard *et al.*, 2014; Zhang *et al.*, 2017) thus improving the seed and oil yield (Ma *et al.*, 2015; Ali *et al.*, 2016; Manaf *et al.*, 2017).

Improvement in CGR and LAI due to P and B application led towards more vigorous plant growth which eventually enhanced the plant height (Table 2). Moreover, the highest biological yield in treatment [P (60 kg ha<sup>-1</sup> at sowing) + B (1.5 kg ha<sup>-1</sup> at sowing + 1.5 kg ha<sup>-1</sup> at 1<sup>st</sup> irrigation)] was the outcome of highest CGR, LAI and taller plants in this treatment (Fig. 2 and Table 2). Seed yield was also highest in the same treatment which was due to increased pods per plant and more 1000 seed weight (Table 2). Seed oil contents were improved due to application of P and B. Increment in seed oil contents may be attributed to improvement in fatty acid profile and biochemical processes due to P application (Said-Al Ahl *et al.*, 2016; Konuskan *et al.*, 2017; Manaf *et al.*, 2017).

In this study, the basal application of full dose of P was most useful than its split application. Indeed, the P is not immediately available to the plants due to various fixation processes with soil particles (Laboski and Lamb, 2003) when compared with N. Thus, P application after sowing was not too much useful as basal dose. Moreover, the split application of B (half as basal and half at 1<sup>st</sup> irrigation) with full dose of P as basal application was the most useful combination compared with all other treatments (Table 2). Indeed, the most critical roles of B has been observed at reproductive stages (Leonard *et al.*, 2014; Zhang *et al.*, 2017) due to which its full basal dose was not as useful as its split dose owing to fixation of B within soil (Padbhushan and Kumar, 2017) when used as basal dose.

The highest gross income, net returns and benefit cost ratio was recorded when the full dose of P at sowing was combined with half dose of B at sowing, and half dose of B at 1<sup>st</sup> irrigation which was attributed to more seed yield in this treatment.

During 2<sup>nd</sup> year of study, the performance of canola crop in terms of yield related traits were a bit better than the 1<sup>st</sup> year. It was due to a storm followed by light hailstorm which destroyed some of the pods of the canola crop leading to reduced seed yield during 1<sup>st</sup> year of study (Fig. 1).

## Conclusion

Application of full dose of P (60 kg ha<sup>-1</sup>) at sowing combined with application of half dose of B (1.5 kg ha<sup>-1</sup>) at sowing and half dose of B (1.5 kg ha<sup>-1</sup>) at 1<sup>st</sup> irrigation was the most useful strategy to improve growth, seed yield and seed protein/oil contents, and profitability of canola crop under arid climate.

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## References

- Ahmad, G., A. Jan, M. Arif, M.T. Jan and R.A. Khattak, 2007. Influence of nitrogen and sulfur fertilization on quality of canola (*Brassica napus* L.) under rainfed conditions. *J. Zhejiang Univ. Sci. B*, 8: 731–737
- Ali, M., W. Muhammad and I. Ali, 2016. Yield of oil seed *Brassica (napus and juncea)* advanced lines as influenced by boron application. *Soil Environ.*, 35: 30–34
- Amjad, M., 2014. *Oilseed Crops of Pakistan*, p. 40. Status Paper, Plant Sciences Division, Pakistan Agricultural Research Council Islamabad
- Asare, E. and D.H. Scarisbrick, 1995. Rate of nitrogen and sulphur fertilizers on yield, yield components and seed quality of oilseed rape (*Brassica napus* L.). *Field Crops Res.*, 44: 41–46
- Bastani, S. and R. Hajiboland, 2017. Uptake and utilization of applied phosphorus in oilseed rape (*Brassica napus* L. cv. Hayola) plants at vegetative and reproductive stages: Comparison of root with foliar phosphorus application. *Soil Sci. Plant Nutr.*, 63: 254–263
- Beam III, W.T., 2015. *The Effects of Sulfur Applications on Canola Crop Yield (Brassica napus)*. Doctoral dissertation, Murray State University, Murray, Kentucky, USA
- Bélanger, G., N. Ziadi, D. Pageau, C. Grant, J. Lafond and J. Nyiraneza, 2015. Shoot growth, phosphorus–nitrogen relationships, and yield of canola in response to mineral phosphorus fertilization. *Agron. J.*, 107: 1458–1464
- Blevins, D.G. and K.M. Lukaszewski, 1998. Boron in plant structure and function. *Annu. Rev. Plant Physiol.*, 49: 481–500
- Bremner, J.M. and C.S. Mulvaney, 1982. Total nitrogen. In: *Methods of Soil Analysis*, pp: 1119–1123. Page, A.L., R.H. Miller and D.R. Keeney (Eds.). American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin, USA

- Cheema, M.A., M.A. Malik, A. Hussain, S.H. Shah and S.M.A. Basra, 2001. Effects of time and rate of nitrogen and phosphorus application on the growth and the seed and oil yields of canola (*Brassica napus* L.). *J. Agron. Crop Sci.*, 186: 103–110
- CIMMYT, 1998. *From Agronomic Data to Farmers Recommendations: An Economics Training Manual*, pp: 31–33 CIMMYT, Mexico
- Dar, T.A., M. Uddin, M.M.A. Khan, A. Ali, N. Hashmi and M. Idrees, 2015. Cumulative effect of gibberellic acid and phosphorus on crop productivity, biochemical activities and trigonelline production in *Trigonella foenum-graecum* L. *Cogent Food Agric.*, 1: 995950
- Durbak, A.R., K.A. Phillips, S. Pike, M.A. O'Neill, J. Mares, A. Gallavotti, S.T. Malcomber, W. Gassmann and P. McSteen, 2014. Transport of boron by the tassel-less1 aquaporin is critical for vegetative and reproductive development in maize. *Plant Cell*, 26: 2978–2995
- Fageria, N.K., 2016. *The Use of Nutrients in Crop Plants*. CRC press, Boca Raton, Florida, USA
- Goldbach, H.E., 1984. Influence of boron nutrition on net uptake and efflux of <sup>32</sup>P and <sup>14</sup>C-glucose in *Helianthus annuus* roots and cell cultures of *Daucus carota*. *J. Plant Physiol.*, 118: 431–438
- GOP (Government of Pakistan), 2016. *Economic survey of Pakistan, 2015-2016*. Finance and Economic Affairs Division, Islamabad, Pakistan
- Hunt, R., 1978. *Plant Growth Analysis*, pp: 26–38. Study in Biology No. 96. Edward Arnold, London
- Hussain, M., M.A. Khan, M.B. Khan, M. Farooq and S. Farooq, 2012. Boron application improves the growth, yield and net economic return of rice. *Rice Sci.*, 19: 259–262
- Irshad, S., H.U. 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
- Jackson, G.D., 2000. Effects of nitrogen and sulfur on canola yield and nutrient uptake. *Agron. J.*, 92: 644–649
- Jankowski, K.J., M. Sokólski, B. Dubis, S. Krzebietke, P. Żarczyński, P. Hulanicki and P.S. Hulanicki, 2016. Yield and quality of winter oilseed rape (*Brassica napus* L.) seeds in response to foliar application of boron. *Agric. Food Sci.*, 25: 164–176
- John, M.K., H.H. Chuah and J.H. Neufeld, 1975. Application of improved azomethine-H method to the determination of boron in soils and plants. *Anal. Lett.*, 8: 559–568
- Jones, C. and K. Olson-Rutz, 2016. *Soil Nutrient Management for Canola*. EB0224. Montana State University Extension, Bozeman, Montana, USA
- Khan, M.R. and M. Wajid, 1996. The effect of fly ash on plant growth and yield of tomato. *Environ. Pollut.*, 92: 105–111
- Konuskan, O., D.B. Konuskan and C.M. Levai, 2017. Effect of foliar boron fertilization on chemical properties and fatty acid compositions of corn (*Zea mays* L.). *Rev. Chim.*, 68: 2073–2075
- Laboski, C.A. and J.A. Lamb, 2003. Changes in soil test phosphorus concentration after application of manure or fertilizer. *Soil Sci. Soc. Amer. J.*, 67: 544–554
- Leonard, A., B. Holloway, M. Guo, M. Rupe, G. Yu, M. Beatty, G. Zastrow-Hayes, R. Meeley, V. Llaca, K. Butler and T. Stefani, 2014. Tassel-less1 encodes a boron channel protein required for inflorescence development in maize. *Plant Cell Physiol.*, 55: 1044–1054
- Ma, B.L. and A.W. Herath, 2016. Timing and rates of nitrogen fertiliser application on seed yield, quality and nitrogen-use efficiency of canola. *Crop Past. Sci.*, 67: 167–180
- Ma, B.L., D.K. Biswas, A.W. Herath, J.K. Whalen, S.Q. Ruan, C. Caldwell, H. Earl, A. Vanasse, P. Scott and D.L. Smith, 2015. Growth, yield, and yield components of canola as affected by nitrogen, sulfur, and boron application. *J. Plant Nutr. Soil Sci.*, 178: 658–670
- Manaf, A., M. Kashif, M.T. Siddque, A. Sattar and A. Sher, 2017. Soil applied boron improved productivity and oil yield of canola cultivars. *Pak. J. Life Soc. Sci.*, 15: 90–95
- Mohanty, S., N.K. Paikaray and Z. Rajan, 2006. Availability and uptake of phosphorus from organic manures in groundnut (*Arachis hypogea* L.) sequence using radio tracer technique. *Geoderma*, 133: 225–230
- Moodie, G.E., W.H. Smith and R.A. McGreery, 1959. *Laboratory Manual for Soil Fertility*, pp: 31–39. Department of Agronomy, Washington State College, USA
- Olsen, S.R., C.V. Cole, F.S. Watanabe and L.A. Dean, 1954. In: *Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate*, pp: 1–18. Banderis, A.D., D.H. Barter and K. Anderson (Eds.). U.S. Department of Agriculture Circular No. 939. Agricultural and Advisor
- 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
- Padbhushan, R. and D. Kumar, 2017. Fractions of soil boron: a review. *J. Agric. Sci.*, 155: 1023–1032
- 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
- Rehim, A., M. Hussain, S. Ahmad, S. Noreen, H. Dogan, M. Zia-UI-Haq and S. Ahmad, 2016. Band application of phosphorus with farm manure improves phosphorus use efficiency, productivity and net returns of wheat on sandy clay loam soil. *Turk. J. Agric. For.*, 40: 319–326
- Richards, L.A., 1954. *Diagnosis and Improvement of Saline Sodic and Alkali Soils*. Handbook 60. USDA Agric., Washington DC, USA
- Robertson, G.A. and B.C. Loughman, 1974. Reversible effects of boron on the absorption and incorporation of phosphate in *Vicia faba* L. *New Phytol.*, 73: 291–298
- Said-Al Ahl, H.A.H., H.M. Mehanna and M.F. Ramadan, 2016. Impact of water regime and phosphorus fertilization and their interaction on the characteristics of rapeseed (*Brassica napus*) and fatty acid profile of extracted oil. *Commun. Biometr. Crop Sci.*, 11: 64–76
- Sarkar, D., B. Mandal and M.C. Kundu, 2007. Increasing use efficiency of boron fertilisers by rescheduling the time and methods of application for crops in India. *Plant Soil*, 301: 77–85
- Sato, T., 2002. New estimation method for fatty acid composition in oil using near infrared spectroscopy. *Biosci. Biotechnol. Biochem.*, 66: 2453–2458
- Steel, R.G.D., J.H. Torrie and D.A. Dickey, 1996. *Principles and Procedures of Statistics: a Biometric Approach*, 3<sup>rd</sup> edition. McGraw Hill Book Co. Inc., New York, USA
- Tahir, M., M.A. Malik, A. Tanveer and R. Ahmad, 2003. Effect of NPK levels on seed yield and oil contents of canola. *Pak. J. Life Soc. Sci.*, 1: 127–132
- Tirado, R. and M. Allsopp, 2012. Phosphorus in agriculture: problems and solutions. Technical report (review) 02-2012, Greenpeace Research Laboratories, Amsterdam, The Netherlands. Available at: <http://www.greenpeace.to/greenpeace/wp-content/uploads/2012/06/Tirado-and-Allsopp-2012-Phosphorus-in-Agriculture-Technical-Report-02-2012.pdf>. Accessed: 23 December 2018
- Wasaya, A., M.S. Shabir, M. Hussain, M. Ansar, A. Aziz, W. Hassan and I. Ahmad, 2017. Foliar application of zinc and boron improved the productivity and net returns of maize grown under rainfed conditions of Pothwar plateau. *J. Soil Sci. Plant Nutr.*, 17:33–45
- Watson, D.J., 1952. The physiological basis of variation in yield. *Adv. Agron.*, 4: 101–145
- Wu, X.Y., B.K. Kuai, J.Z. Jia and H.C. Jing, 2012. Regulation of leaf senescence and crop genetic improvement. *J. Integr. Plant Biol.*, 54: 936–952
- Zhang, Q., H. Chen, M. He, Z. Zhao, H. Cai, G. Ding, L. Shi and F. Xu, 2017. The boron transporter BnaC4. BOR1; 1c is critical for inflorescence development and fertility under boron limitation in *Brassica napus*. *Plant Cell Environ.*, 40: 1819–1833

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