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Biopriming and mineral fertilizers effects on agronomical performance of rapeseed (*Brassica napus* L.)

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Increasing and extending the role of biofertilizers can reduce the need for chemical fertilizers and decrease adverse environmental effects. They can play a significant role in fixing atmospheric nitrogen and production of plant growth promoting substances. Therefore, in the development and implementation of sustainable agriculture techniques, biofertilization has great importance in alleviating environmental pollution and deterioration of nature. In order to study the effects of mineral nitrogen fertilization and biofertilizer inoculation on grain yield and its components of rapeseed (*Brassica napus* L.) under different levels of sulfur fertilizer, a field experiment in Factorial scheme based on Randomized Complete Block design was conducted in three replications. Experimental factors were as follows: (i) Four levels of chemical nitrogen fertilizer (0, 100, 150 and 200 kg N ha^{-1}), (ii) Two levels of biofertilizer (with and without inoculation) containing *Azotobacter* sp. and *Azospirillum* sp. and (iii) Two levels of sulfur application (0 and 50 kg S ha^{-1}). Rapeseed yield and yield components had a strong association with the N fertilization, biofertilizer inoculation and S application. Higher rates of N fertilization, biofertilizer inoculation and S application increased plant height, pods number $plant^{-1}$, grains number pod^{-1}, 1000-grains weight, grain yield and biological yield. It seems that moderate N rate (about 150 kg N ha^{-1}) and S application (about 50 kg S ha^{-1}) can be beneficial to improve growth, development and total yield of inoculated rapeseed plants. So, it is suggested to use a combination of organic and inorganic fertilizer to achieve the highest yield without a negative effect on grain quality that will lead to sustainable environment.

Key words: biofertilizer, *Brassica napus* L., grain yield, nitrogen, sulfur, yield components

INTRODUCTION

Rapeseed (*Brassica napus* L.) is one of the important oil seed crops throughout the world which ranks third among the oil seed crops after soybean and palm in production of vegetable oils, while fifth in the production of oil seed proteins. Rapeseed oil is used widely as cooking and salad oil, and in making margarine. It has the lowest saturated fat content of all edible vegetative oils available to day. It is also used in lubricants and hydraulic fluids, especially when there is a significant risk of oil leaking to waterways or into ground water (Malhi, Gill, 2007; Negawer, Mahfouz, 2010; Naderifar, Daneshian, 2012; Seyed Sharifi, 2012).

Nitrogen (N) is the most important nutrient supplied to most non-legume crops, including rapeseed. The most important role of N in the plant is its presence in the structure of protein and nucleic acids, which are the most important building and information substances of every cell. In addition, N is also found in chlorophyll that enables

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the plant to transfer energy from sunlight by photosynthesis. Thus, N supply to the plant will influence the amount of protein, amino acids, protoplasm and chlorophyll formed. Moreover, it influences cell size, leaf area and photosynthetic activity (Dordas, Sioulas, 2008; Grant et al., 2011; Namvar, Khandan, 2013; Piccinin et al., 2013; Diacono et al., 2013). Therefore, an adequate supply of N is necessary to achieve high yield potential in crops. N fertilizer is known to affect the plant height, number of pods per plant, number of grains per pod, 1000-grains weight, grain yield and biological yield of rapeseed (Negawer, Mahfouz, 2010; El-Habbasha, Taha, 2011; Azimzadeh, Azimzadeh, 2013; Rehman et al., 2013). Grant et al. (2011) investigated rapeseed response to different levels of nitrogen fertilizer and stated that oil yield increased with low to moderate N rates, but stabilized or fell with high N rates while, chlorophyll content increased with increasing N rates.

Increasing and extending the role of biofertilizers can reduce the need for chemical fertilizers and decrease adverse environmental effects. They can play a significant role in fixing atmospheric N and production of plant growth promoting substances. Therefore, in the development and implementation of sustainable agriculture techniques, biofertilization has great importance in alleviating environmental pollution and deterioration of nature (Namvar et al., 2013). *Azotobacter* sp. and *Azospirillum* sp. are used as biofertilizers in the cultivation of many agricultural crops. The estimated contribution of these free-living N fixing prokaryotes to the N input of soil ranges from 0–60 kg ha^{-1} per year (Vessey, 2003). Existence of microbial communities like *Azotobacter* sp. and *Azospirillum* sp. in the rhizosphere promotes the growth of the plant through the cycling and availability of nutrients, increasing the health of the roots during the growth stage by competing with root pathogens and increasing the absorption of nutrients and water (Vessey, 2003; Salvagiotti et al., 2008; Zorita, Canigia, 2009; Hasanalideh, Hojati, 2010; Namvar et al., 2011). El-Habbasha and Taha (2011) studied the effects of inoculation with different biofertilizers on rapeseed and observed that inoculated rapeseed plants gave higher plant height, pods per plant, grains per pod, grain weight, biological yield, grain yield and oil yield compared to non-inoculated plants. Similar results were reported by Azimzadeh and Azimzadeh (2013). Some of the investigations have suggested that integrated nutrient management strategies involving inoculation of seeds with *Azotobacter* sp. and *Azospirillum* sp. in combination with chemical fertilizers result in improving both growth and yield of crops, i. e. rapeseed (El-Habbasha, Taha, 2011; Piccinin et al., 2013).

Sulfur (S) is the fourth major plant nutrient after nitrogen (N), phosphorus (P) and potassium (K). It is essential for the synthesis of amino acids like *cystine*, *cysteine* and *methionine*, a component of vitamin A and activates certain enzyme systems in plants. Under S deficient conditions, the efficiency of applied NPK fertilizers may be seriously affected and crop yield levels may not be sustainable (Ahmad et al., 2007; Jamal et al., 2010; Grant et al., 2012). This fertilizer also helps in accelerating the photosynthesis activity (Jackson, 2000; Salvagiotti, Miralles, 2008). Recently, the observed lower sulfur emission to the atmosphere decreased the amount of sulfur in soil and caused worse sulfur nutrition of crop plants. So sulfur is one of the most limiting nutrients for agricultural production in many countries (Jackson, 2000; Rehman et al., 2013). For many years, little attention was paid to sulfur as a plant nutrient mainly because it has been applied to soil in incidental inputs; in rainfall and volcanic emissions, and as a component of N, P and K fertilizers (Grant et al., 2012). The awareness of sulfur deficiency is increasing, as is the development of S deficiency in previously S sufficient areas in many parts of the world (Ahmad et al., 2007; Mansoori, 2012). The symptoms of sulfur shortage appeared especially in *Brassicaceae* crops, e. g. rapeseed, which has high sulfur demands. High content of glucosinolates and sulfur amino acids is characteristic of rapeseed and other plants from the same family and consequently their sulfur demand is higher (Malhi, Gill, 2007; Ahmad et al., 2007; Sattar et al., 2011). Therefore, sulfur nutrition must be seriously considered in the rapeseed fertility programs. Seyed Sharifi (2012) studied the effects of four levels (0, 25, 50 and 75 kg S ha^{-1}) of sulfur fertilizer on rapeseed and reported that sulfur fertilizer affected grain yield, plant height, harvest index, grain per pod and pod per plant significantly, the maximum values of these characteristics were obtained by the plots that received 75 kg sulfur ha^{-1}. Sulfur (S) and nitrogen (N) are closely related, synergistic and of vital importance for plants. A strong interaction between S and N for seed and oil production in oilseed crops has been reported by Malhi and Gill (2007); Sattar et al. (2011) and Mansoori (2012).

It is important to develop integrated fertilization strategies for various crops that enhance the competitive ability of the crop, maximize crop production, and reduce the risk of nonpoint source pollution from fertilizers. Moreover, it seems that there are no investigations about the combined effects of organic and inorganic nitrogen fertilization under different rates of sulfur application on rapeseed crop. Considering the above facts, the present study was undertaken to elucidate the effects of various rates of mineral nitrogen fertilization and biofertilizer (*Azotobacter* sp. and *Azospirillum* sp.) inoculation on yield and its attributes of rapeseed under different levels of sulfur application.

MATERIALS AND METHODS

In order to study the effects of chemical nitrogen fertilization and biofertilizer inoculation on grain yield, yield components and some physiological traits of rapeseed (*Brassica napus* L.) under different levels of sulfur application, a field experiment in Factorial scheme based on Randomized Complete Block design was conducted in three replications. Experimental factors were as follows: (i) Four levels of chemical N fertilizer (0, 100, 150 and 200 kg N ha^{-1}); (ii) Two levels of biofertilizer (with and without inoculation) containing *Azotobacter* sp. and *Azospirillum* sp. and (iii) Two levels of S application (0 and 50 kg S ha^{-1}). Chemical N fertilizer (used in urea form) in each level, divided into two equal parts; the first part of N was spread by hand and incorporated immediately in planting time, the second part was used in flowering stage. Nitroxin was used as a biological fertilizer (containing *Azotobacter* sp. and *Azospirillum* sp., 10^8 cfu mL^{-1}) in the amount of one litre per 30 kg of seed. Total of sulfur fertilizer was given at the time of sowing.

The area is located at latitude 38°05' N and longitude 46°17' E at an altitude of 1 360 m above the mean sea level. Climatically, the area belongs to the semi arid temperate zone with cold winter and hot summer. Annual average rainfall was about 300 mm, and that was rainfall mostly concentrated between winter and spring. Mean annual air temperature was 10.1 °C with maximum and minimum daily air temperature of 17.3 °C and 2.9 °C, respectively. The soil was sandy loam, with electrical conductivity about 1.7 ds m^{-1}, pH about 7.1, organic matter about 0.78%, exchangeable K about 231 mg kg^{-1} and extractable P about 13.5 mg kg^{-1}. The field was well prepared before sowing by plowing twice with tractor followed planking to make a fine seed bed. Seeds of rapeseed (*Brassica napus* L.) were planted at 8 kg ha^{-1} rate in 6 rows plots, 5 m long with spacing of 0.25 m between rows. Plots were separated by 1.5 m and blocks by 2.5 m unplanted spaces. The field was immediately irrigated after planting to ensure uniform germination. All other agronomic operations except those under study were kept normal and uniform for all treatments.

The plants were harvested at maturity and traits such as plant height, number of pods per plant, number of grains per pod and 1000-grains weight were recorded on 10 randomly selected plants in each plot. Grain yield and biological yield were obtained by harvesting an area of 2 m^2 from the middle of each plot, to avoid marginal effects. Analysis of variance was carried out using SAS computer software packages. The comparison of means was investigated using Duncan's Multiple Range Test (DMRT) at 0.05% probability.

RESULTS AND DISCUSSION

The effects of N fertilization, biofertilizer inoculation and S application on grain yield and yield components of rapeseed were presented in Table. The results obtained from the variance analysis of data indicated that N fertilization and S application had significant effects on all of studied traits except S application on plant height. Moreover, inoculation with biofertilizer significantly affected the studied traits except 1000-grains weight. Furthermore, interactions between N fertilization × S application were found significant in number of pods per plant and number of grains per pod. Interactions between N fertilization × biofertilizer inoculation showed significant effects on grain yield and biological yield of rapeseed.

Plant height (P H)

The plant height was significantly affected by N application and biofertilizer inoculation but S application showed no significant effects on this trait (Table). The highest plant height was observed in the maximum rate of N application (200 kg N ha^{-1}) that not differed significantly with 150 kg N ha^{-1}. The minimum plant height was recorded in control. Application of 200 kg N ha^{-1} increased plant height by 30.92%, compared to control (Table). Moreover, inoculated plants had more height than non-inoculated plants. Inoculation with biofertilizer increased plant height about 8.11% compared with non-inoculated plants. These results are in line with the findings of other researchers (Negawer, Mahfouz, 2010; Naderifar, Daneshian, 2012; Azimzadeh, Azimzadeh, 2013; Namvar, Khandan, 2013). Although variance analysis of data indicated that S application had no significant effects on plant height but comparisons of means showed that plants in the presence of S fertilizer had more height than non-fertilized plants (Table).

Number of pods per plant (N P)

Number of pods $plant^{-1}$ increased with increasing of N application rate. Increasing of N fertilizer from 0 to 200 kg N ha^{-1} increased this trait by 23.48%. The lowest and the highest values of pods number were recorded in 0 and 200 kg N ha^{-1}, respectively (Table). Negawer and Mahfouz (2010), El-Habbasha and Taha (2011) and Azimzadeh and Azimzadeh (2013) reported similar results in rapeseed. Plants that were treated with biofertilizer showed more values (about 11.36%) of this trait than non-inoculated plants (Table). Moreover, the maximum values of pods number were recorded

Table. **Effects of mineral nitrogen fertilizer, biofertilizer inoculation and sulfur application on yield and its components in rapeseed (*Brassica napus* L.)**

Treatment	P H (cm)	N P (per plant)	N G (per pod)	1000-G W (g)	G Y (kg ha^{-1})	B Y (kg ha^{-1})
Nitrogen rates (kg ha^{-1})						
N_0	92.78 **c**	88.49 **c**	12.79 **d**	2.97 **b**	803.05 **c**	2771.27 **c**
N_{100}	109.85 **b**	100.60 **b**	19.17 **c**	3.14 **a**	1362.04 **b**	4526.39 **b**
N_{150}	118.94 **a**	107.92 **a**	24.24 **b**	3.21 **a**	1746.38 **a**	5235.36 **a**
N_{200}	121.47 **a**	109.27 **a**	26.53 **a**	3.16 **a**	1805.82 **a**	5313.46 **a**
Biofertilizer						
B_{non}	106.44 **b**	96.11 **b**	18.92 **b**	3.09 **a**	1297.05 **b**	4207.86 **b**
B_{with}	115.08 **a**	107.03 **a**	22.43 **a**	3.15 **a**	1561.62 **a**	4715.38 **a**
Sulfur fertilizer (kg ha^{-1})						
S_0	109.85 **a**	98.51 **b**	19.74 **b**	3.04 **b**	1349.87 **b**	4312.37 **b**
S_{50}	111.67 **a**	104.63 **a**	21.61 **a**	3.20 **a**	1508.79 **a**	4610.87 **a**
Mean	110.76	101.57	20.68	3.12	1429.33	4461.62
Nitrogen (N)	**	**	**	*	**	**
Biofertilizer (B)	**	**	**	ns	**	**
Sulfur (S)	ns	**	*	*	**	**
N × B	ns	ns	ns	ns	**	**
N × S	ns	**	**	ns	ns	ns
B × S	ns	ns	ns	ns	ns	ns
CV (%)	8.79	7.34	9.63	6.88	11.91	10.41

P H: Plant Height, **N P**: Number of Pods, **N G**: Number of Grains, **1000-G W**: 1000 Grains Weight, **G Y**: Grain Yield, **B Y**: Biological Yield. Mean values followed by the same letters in each column and treatment showed no significant difference by DMRT (P = 0.05). *, ** and ns showed significant differences at 0.05, 0.01 probability levels and not significant, respectively in the presence of S fertilizer. Sulfur application increased number of pods plant^{-1} about 6.21% compared with the plants that did not receive this fertilizer (Table). These results demonstrated that biofertilizer inoculation and S fertilization resulted in greater pod number, probably caused by effective presence of these factors on rapeseed growth and development as has been observed previously (Seyed Sharifi, 2012; Mansoori, 2012). Pods number plant^{-1} of rapeseed was significantly affected with the interaction effects of N fertilization and S application (Table). Generally, pods number of S application treatments in each level of N application was greater than non-usage of this fertilizer at the same level of N application (Fig. 1). The highest value of pods number was recorded in the plants treated with 150 kg N ha^{-1} and 50 kg S ha^{-1}. The lowest pods number plant^{-1} was observed in the application of 0 kg N ha^{-1} and 0 kg S ha^{-1} (Fig. 1).

Number of grains per pod (N G)

Variance analysis of data indicated that N fertilization, biofertilizer inoculation and S application had statistically significant effects on number of grains pod^{-1} (Table). The highest number of grains pod^{-1} was recorded in 200 kg N ha^{-1} application and the least number of this trait was obtained from control. Application of 200 kg N ha^{-1} increased the number of grains pod^{-1} about 107.42% compared with control in each plant (Table). Similar trends were reported by Sattar et al. (2011), Mansoori (2012) and Naseri et al. (2013). Inoculated rapeseed plants had statistically greater number of grains per pod than non-inoculated plants. Inoculation with biofertilizer increased this trait by 18.55% compared with plants that were not treated with inoculum (Table). Vessey (2003) reported that *Azotobacter* sp. and *Azospirillum* sp. increased the available N in the soil which could enhance the grain number. Furthermore, the highest number of grains per pod were observed in the presence of 50 kg S ha^{-1} treatment. Application of S fertilizer resulted in 9.47% greater number of grains per pod than non- usage of S (Table). These results are in the line with the findings of Seyed Sharifi (2012) and Rehman et al. (2013). Interaction effects of N fertilizer × S application were found significant in number of grains pod^{-1} (Table). The highest number of grains pod^{-1} in rapeseed was recorded in 50 kg S ha^{-1} treatment that was treated with 200 kg N ha^{-1}. The least value of this trait was obtained from non-fertilized plants (Fig. 1). Application of 200 kg N ha^{-1} in presence of S fertilizer increased the number of grains pod^{-1} by 114.96% compared with control (Fig. 1).

1000-grains weight (1000-G W)

1000-grains weight was significantly affected by N fertilization and S application but biofertilizer inoculation showed no significant effects on this trait (Table). Increasing of N application rate significantly increased the weight of 1000-grains in rapeseed. The highest 1000-grains weight was

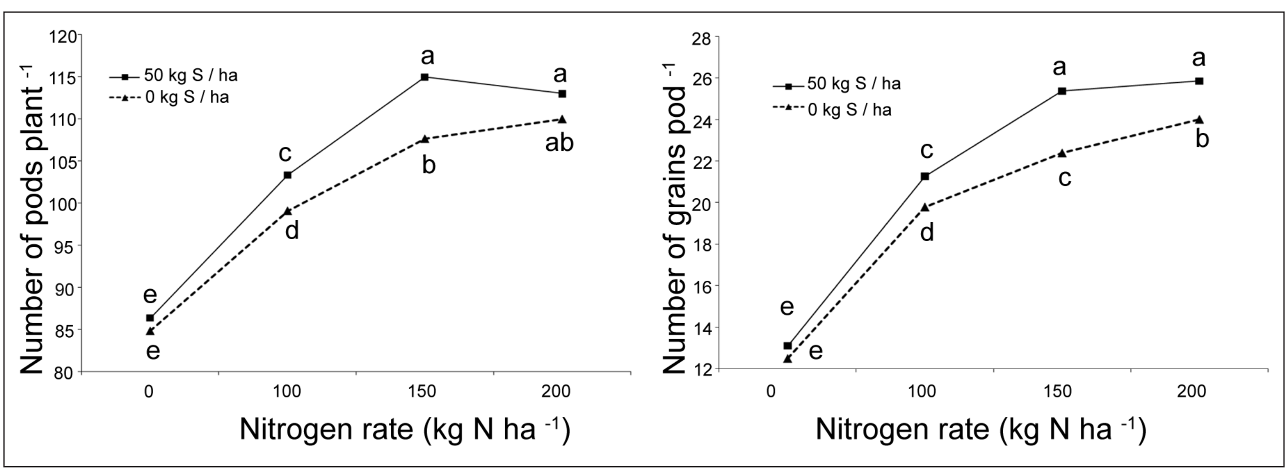

Fig. 1. Effects of different levels of nitrogen application and sulfur fertilization on number of pods plant^{-1} and number of grains pod^{-1} in rapeseed (*Brassica napus* L.). Values with the same letters in each trait are not significantly different (DMRT at 5% level)

recorded in the application of 150 kg N ha^{-1} while the lowest values of this trait were obtained from non-fertilized plants. Application of 150 kg N ha^{-1} increased the 1000-grains weight by 8.08% compared with control (Table). Inoculated plants showed about 1.94% greater 1000-grains weight than non-inoculated plants but this increase was insignificant. Previous studies justified the positive effects of N application (Mansoori, 2012; Namvar et al., 2013) and biofertilizer inoculation (Namvar, Khandan, 2013) on 1000-grains weight. Moreover, the maximum 1000-grains weight was recorded in the application of 50 kg S ha^{-1} that showed about 5.26% increase compared to the application of 0 kg S ha^{-1} (Table). Increasing 1000-grains weight was attributed to larger grains as a result of more nutrition availability at the presence of N and S fertilizer. These results are in accordance with the works of Sattar et al. (2011) and Naderifar and Daneshian (2012).

Grain yield (G Y)

The data presented in Table showed that all studied experimental factors (N fertilization, biofertilizer inoculation and S application) had significant effects on grain yield of rapeseed. Grain yield continuously increased with increasing of N application, however, this trait of rapeseed increased until 150 kg N ha^{-1} and further increase in N rate resulted in no significant grain yield increase. The highest rate of N fertilizer (200 kg N ha^{-1}) showed the greatest grain yield, however, this rate of N fertilizer was statistically in par with 150 kg N ha^{-1} (Table). Application of 200 kg N ha^{-1} increased grain yield per unit of area by 124.87%, compared with the least application of N fertilizer (control). Malhi and Gill (2007) investigated N requirements of rapeseed and found that N fertilization positively influenced the grain yield. Moreover, inoculated plants showed greater grain yield rather than non-inoculated plants. Biofertilizer inoculation increased grain yield about 20.39% compared with control (Table). Similar results were reported about the effects of N fertilizer (Dordas, Sioulas, 2008; Salvagiotti, Miralles, 2008; Zorita, Canigia, 2009; Azimzadeh, Azimzadeh, 2013) and biofertilizer (Yasari et al., 2008; El-Habbasha, Taha, 2011; Namvar, Khandan, 2013; Piccinin et al., 2013) on grain yield of different crop plants. The increase in the yield components, grain yield and oil content in the inoculated plants could be attributable to the exudation of plant growth regulators (PGRs), such as auxins and gibberellin and cytokinin by *Azotobacter* sp. and *Azospirillum* sp. beside the increasing of the nutrient availability (Vessey, 2003). Piccinin et al. (2013) showed that the grain yield of wheat improved when wheat plants were grown with a combination of chemical N and biofertilizer inoculation.

Interaction effects of N fertilization and biofertilizer inoculation were found significant for grain yield of rapeseed (Table). Grain yield of inoculated plants at all rates of N application was higher than the non-inoculated plants at the same rate of N application (Fig. 2). The highest grain yield was recorded in inoculated plants with 150 kg N ha^{-1} application. The lowest rate of N application showed the lowest grain yield in non-inoculated plants (Fig. 2). The study on the interactions between N application and inoculation showed that inoculation with *Azotobacter* sp. and *Azospirillum* sp. bacteria had more effects on grain yield in 150 kg N ha^{-1} than other levels of fertilizer application (Fig. 2). Furthermore, application of 50 kg S ha^{-1} treatment showed the maximum grain yield. This rate of S fertilizer increased grain yield by 11.77% compared with the application of 0 kg S ha^{-1} (Table). Previous studies justified these results in various crops (Jackson, 2000; Salvagiotti, Miralles, 2008; Seyed Sharifi, 2012).

Biological yield (B Y)

Biological yield of rapeseed also showed the same trend as grain yield. As shown in Table, the highest biomass was obtained from the application of 200 kg N ha^{-1}, however there was no significant difference between the application of 150 and 200 kg N ha^{-1} in biological yield. Usage of 200 kg N ha^{-1} increased the biological yield by 91.73%, compared with control. These results concur with observations made by Salvagiotti and Miralles (2008), Sattar et al. (2011), El-Habbasha and Taha (2011), Namvar et al. (2011) and Azimzadeh and Azimzadeh (2013). Namvar and Khandan (2013) noted that a decrease in biomass production with decreasing N supply was associated with decreases in both radiation interception and radiation use efficiency (RUE).

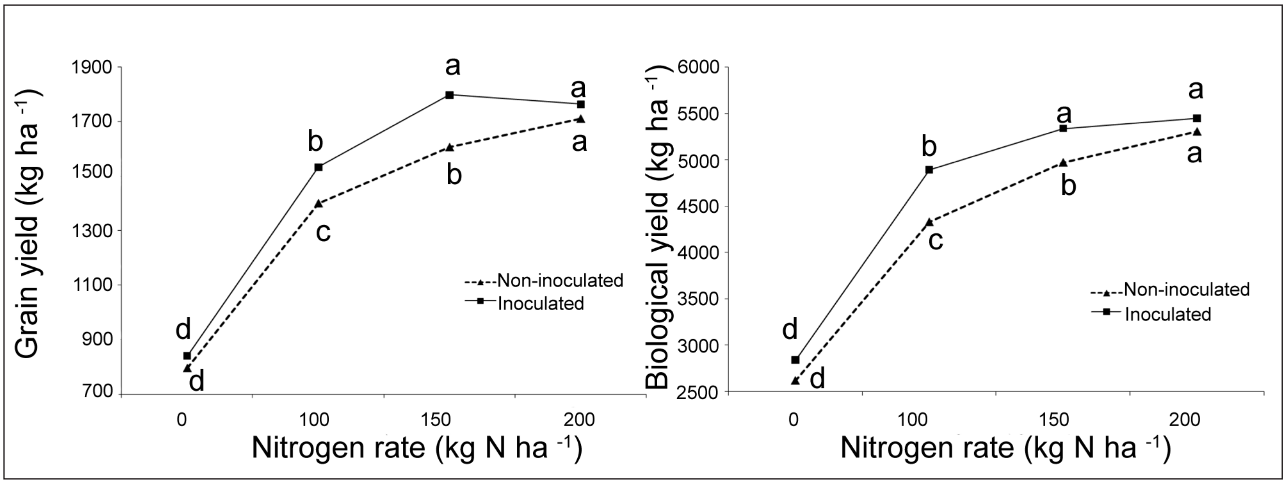

Fig. 2. Effects of different levels of nitrogen application under *Azotobacter* sp. and *Azospirillum* sp. inoculation and non-inoculation on grain yield and biological yield in rapeseed (*Brassica napus* L.). Values with the same letters in each trait are not significantly different (DMRT at 5% level)

Nitrogen is known to be an essential nutrient for plant growth and development involved in vital plant function such as photosynthesis, DNA synthesis, protein formation and respiration (Diacono et al., 2013; Piccinin et al., 2013). The growth parameters such as LAI, biomass, and leaf photosynthesis significantly decreased due to unsatisfactory N availability (Salvagiotti et al., 2008; Diacono et al., 2013). The results obtained from this study indicated that usage of N fertilization had positive effects on rapeseed yield and its attributes. Adding N increases the production of total dry matter in plants which can increase the potential of plant to produce more plant height, pods number, grains number and weight that ultimately resulted in high grain and biological yield. N fertilization increases the total dry matter for a number of reasons: (i) N can increase the LAI in plants (Salvagiotti et al., 2008). More LAI increases the interception of solar radiation by plants that resulted in higher accumulation in plants. (ii) N can increase photosynthesis rate in plants. Increasing photosynthetic rate with N fertilization can be attributed to increasing amount of chlorophyll pigments, since N is one of the main components of chlorophyll (Salvagiotti et al., 2008; Dordas, Sioulas, 2008; Namvar, Khandan, 2013). In contrast, supplementation of adequate N for crops can increase their growth and development. In this condition, plants are able to produce more yield components that result in higher grain yield.

Moreover, rapeseed plants treated with biofertilizer had greater biomass than plants that were not treated with this inoculum. Inoculation with biofertilizer increased the biological yield about 12.06% compared to control (Table). The observed benefits on rapeseed by biofertilizer inoculation seem to be due to the supply of N to the crop (El-Habbasha, Taha, 2011; Naseri et al., 2013). Moreover, growth promoting substances (phytohormones) were produced by these organisms. Phytohormones as secondary metabolites are known to play a key role in plant growth regulation. They promote seed germination, root elongation and stimulation of leaf expansion. In addition, great root development and proliferation of plants in response to biofertilizer activities, i. e. *Azotobacter* sp. and *Azospirillum* sp., enhance water and nutrient uptake (Vessey, 2003; Salvagiotti et al., 2008; Hasanalideh, Hojati, 2010). Zorita and Canigia (2009) noted that greater response to inoculation was observed in the absence of major crop growth limitations, i. e. essential nutrients, suggesting the complementary contribution of the biofertilizers treatment to more efficiently developing higher yielding crops. Interactions between different levels of N application and biofertilizer inoculation were found significant in biological yield (Table). Generally, inoculation with *Azotobacter* sp. and *Azospirillum* sp. in all levels of N application increased the biomass production rather than non-inoculated plants (Fig. 2). The highest biological yield was recorded at the plots of 200 kg N ha^{-1} and biofertilizer inoculation. Control plots (non-fertilized and non-inoculated) had the lowest values of this trait (Fig. 2).

Furthermore, application of 50 kg S ha^{-1} had the maximum magnitude of biological yield. Usage of S fertilizer increased biological yield about 6.92% compared with plants that were not treated with this fertilizer (Table). These results are in accordance with the works of Jackson (2000), Salvagiotti and Miralles (2008) and Seyed Sharifi (2012). S is best known for its role in the formation of amino acids, synthesis of proteins and chlorophyll, oil content of the seeds and nutritive quality of forages (Jackson, 2000; Jamal et al., 2010; Grant et al., 2012) hence S is one of the essential elements required for the normal growth of plants. Deficiency of this nutrient will cause basic metabolic impairment which will not only reduce crop yield but also the quality of produce. As noted by Ahmad et al. (2007), application of S fertilizer increases leaf area index, photosynthesis rate, and assimilates accumulation. Consequently, the crop supplied with adequate doses of S during the growth period produced the optimum number of pods per plant and also optimized the grain number of pods due to the availability of higher amounts of photoassimilates. Also, the increased supply of photosynthates to pods would likely provide an opportunity for grains to grow to their full size, with an obvious increase in 1000-grains weight, as found in these experiments. Thus, management of S fertilizer sources should consider both the short- and long-term impacts on crop yield, grain quality and economics of production. Salvagiotti and Miralles (2008) stated that plants under low S levels produced 10.8 kg of grain per unit of N fertilizer, however, S addition increased this efficiency by 51%. Therefore, the positive interaction between N and S was reflected in higher N use efficiency when the crop had no S deficiency.

CONCLUSIONS

In summary, the results obtained from this study clearly indicated that:

1. Rapeseed (*Brassica napus* L.) yield and yield components had a strong association with the nitrogen fertilization, biofertilizer inoculation and sulphur application.

2. Higher rates of nitrogen fertilization, biofertilizer (*Azotobacter* sp. and *Azospirillum* sp.) inoculation and sulphur application increased plant height, pods number $plant^{-1}$, grains number pod^{-1}, 1000-grains weight, grain yield and biological yield.

3. It seems that moderate nitrogen rate (about 150 kg N ha^{-1}) and sulphur application (about 50 kg S ha^{-1}) can be beneficial to improve growth, development and total yield of inoculated rapeseed plants. So, it is suggested to use a combination of organic and inorganic fertilizer to achieve the highest yield without negative effect on grain quality that will lead to sustainable environment.

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SĖKLŲ INOKULIAVIMO SU MINERALINIU TRĘŠIMU POVEIKIS RAPSŲ (*BRASSICA NAPUS* L.) DERLINGUMUI

Santrauka

Platesnis biotrąšų naudojimas gali sumažinti sintetinių mineralinių trąšų poreikį ir kartu neigiamą poveikį aplinkai. Atlikti lauko bandymai, kurių tikslas – nustatyti mineralinių ir biologinių trąšų – inokuliavimo – poveikį rapsams (*Brassica napus* L.). Tirta: 1) tręšimo azotu skirtingos normos (0, 100, 150 ir 200 kg N ha^{-1}); 2) dvi skirtingos biotrąšų (*Azotobacter* sp. Ir *Azospirillum* sp.) normos; 3) dvi sieros turinčių trąšų normos (0 ir 50 kg S ha^{-1}). Didesnės azoto, bioinokuliantų ir sieros normos didino augalų aukštį, ankščių kiekį, tenkančių vienam augalui, sėklų kiekį vienoje ankštyje, sėklų svorį, bendrą sėklų ir biomasės derlių. Gauti duomenys rodo, jog vidutinis azoto (apie 150 kg N ha^{-1}) ir sieros junginių (apie 50 kg S ha^{-1}) kiekis gali padidinti rapso augalų augimą, vystymąsi ir derlingumą, kai taikomas inokuliavimas. Siūloma taikyti kombinuotą tręšimą – inokuliavimą kartu su neorganinėmis trąšomis tam, kad būtų gaunamas maksimalus derlius be neigiamų pasekmių aplinkai.

Raktažodžiai: biotrąšos, *Brassica napus* L., grūdų derlius, azotas, siera, sulfatai, derliaus komponentai