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ORIGINAL PAPER

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THE EFFECT OF DIFFERENT MICROBIAL FERTILIZER DOSES ON YIELD AND YIELD COMPONENTS IN CORIANDER (*Coriandrum sativum* L.)

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ABSTRACT

Microbial fertilizers containing *Bacillus subtilis* and *Bacillus megaterium* isolates are one of the important organic fertilizers, which strengthen the immune system of plants against harmful effects and promote the plant growth by fixing nitrogen from the atmosphere, to obtain better quality products. This study was conducted to determine the effects of different liquid microbial fertilizer doses (0, 500, 1000, 1500, 2000, and 2500 ml 100 L^{-1}) on the yield and yield components of the coriander (*Coriandrum sativum* L.) grown in Bayburt in 2018 and 2019. The experiment was set up as three replicates in randomized complete block design. The results indicated that there was a considerable variation in the yield and yield components of coriander, and the yield significantly increased as the dose of microbial fertilizer was increased. The maximum essential oil content and seed yield were recorded for the plots grown under the F_1 and F_3 treatment. It was found that the maximum seed yield was obtained in the F_3 treatment (839.0 kg ha^{-1}), and the seed yield decreased in the F_4 (754.1 kg ha^{-1}) and F_5 (759.9 kg ha^{-1}) treatments. Although the increase in the microbial fertilizer dose increases seed yield, using the fertilizer in optimum dose can be more profitable. Therefore, this study suggests that the fertilizer dose "F_3" can improve the productivity of the coriander grown in the areas treated with microbial fertilizer.

Key words: coriander, *Coriandrum sativum* L., microbial fertilizer, seed yield, essential oil content

INTRODUCTION

In recent years, the increasing demand for food due to the population growth has led to a significant increase in the agricultural production [Crist et al. 2017]. Increasing the use of chemical fertilizers and pesticides in agricultural production is not sustainable since it causes ecological imbalances and environmental pollution [Sharma and Singhvi 2017]. So, there is a need for reducing their use. There are many alternatives to the chemical fertilizers and these alternatives can be adopted to achieve a sustainable agriculture and protect the environment. One of these alternatives is the microbial fertilizers with their great potential [Mahanty et al. 2017, Calabi–Flood et al. 2018, Stamenković et al. 2018].

Microbial fertilizers have significant roles in the development of the root system [Contreras-Corneja et al. 2009]. They increase the nutrient intake by reducing the effect of harmful pathogens on the roots and leaves of plants [Siddiqui 2006]. They are also important for reducing the environmental pollution [Berg 2009] and meeting the nitrogen needs of plants by fixing the free nitrogen in the atmosphere through leaves and roots

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[Borkar 2015]. The main mechanism of promoting microorganisms on plant growth is achieved through the nitrogen fixation and the increasing nutrient intake via organic-inorganic phosphate solvent [Çakmakçı et al. 2010]. When the appropriate bacteria such as nitrogen-fixing or phosphate solvent bacteria are used, the microorganisms facilitate the uptake of inorganic fertilizers by plants [Çakmakçı 2005].

In order to increase the soil fertility and prevent the soil degradation, which threatens food safety of future generations; the sustainable agricultural practices should become widespread and the organic material sources that can be used for this should be utilized effectively [Notarnicola et al. 2012]. In this respect, it is also important to fertilize the medicinal and aromatic plants that are used as raw materials in many industries such as cosmetics and pharmaceutical industries as well as the food industry. Fertilization is an indispensable factor for obtaining high yield and high-quality metabolites in the medicinal and aromatic plants [Malik et al. 2011]. Since the inappropriate use of fertilizer can be a risk factor for foodborne diseases, the researchers should determine the type and amount of fertilizer precisely.

Coriander (*Coriandrum sativum* L.) is one of the most important medicinal and aromatic herbs. Its green leaves and fruits are used as both vegetable and spice. The green or dried leaves of the plant are used to flavor salads, soups and to make pickle. It is also used to sweeten the whole or ground seeds (fruit), various cakes, breads and other pastries, alcoholic beverages, frozen milk desserts, confectionery, and various commercial foods [Burdock and Carabin 2009, Laribi et al. 2015].

Coriander is an important agricultural product that does not have soil selectivity, can grow in acidic soils, and responds well to the organic and microbial fertilizers [Filgueira 2008]. On the other hand, a higher biomass efficiency is obtained in the coriander plants, the leaves of which are consumed as vegetables, in mineral and organic fertilizer applications, compared to NPK applications [Santos 2009]. It has been reported that the microbial fertilizers have a positive effect on the yield parameters of coriander (such as plant height, number of branches, number of umbels, 1000-seed weight, seed yield, and essential oil yield) [Abdollahi et al. 2016, Patidar et al. 2016, Yeganehpoor et al. 2019].

The purpose of this study is to examine the effect of the microbial fertilizer applications containining *Bacillus subtilis* and *Bacillus megaterium* isolates on the yield and yield components in coriander.

MATERIALS AND METHODS

Research site and experimental design. The research was carried out in Bayburt University Organic Agriculture Management Experiment Field in 2018 and 2019 at an altitude of approximately 1550 meters above the sea. The small-type "Kudret-K" coriander was used in the experiment. The test site soils, which do not have any drainage problems, are Aridisol according to the US soil classification [Soil Survey Staff 1992]. Some basic soil properties were determined, by using the methods reported by Kacar [2009], in the samples collected as the representation of 30 cm depth before testing. The lime rate of the loamy soil was determined as 8% and 7.85% (moderate lime), the total salt ratio as 0.047% and 0.023% (unsaline), the organic matter ratio as 1.19% and 1.18% (less), the phosphorus amount as 11.87 (high) and 4.31 (less) kg da^{-1}, and the potassium amount as 99 and 129.25 kg da^{-1} (high) in 2018 and 2019, respectively.

Being in a transition climate between the Eastern Black Sea and the Eastern Anatolia, the region is hot and arid in summer, cold and rainy in winter. The average temperatures for the plant development period between May and October for long years, 2018, and 2019 were 15.96, 17.48, and 17.60°C, respectively. The precipitation averages for the last 25 years, 2018, and 2019 were 36.19 mm, 50.54 mm, and 32.48 mm, respectively, in the growing period. According to the long-term average, the monthly average relative humidity in the May–October period was 50.62%; while the humidity averages for the test months was 54.38 and 48.62% in 2018 and 2019, respectively. The climate data (precipitation, temperature, and relative humidity) for long years, 2018, and 2019 are given in the Figure 1.

Study treatments. The experiment was set up with three replications in the Randomized Complete Block Design. Each parcel consisted of 4 rows with a length of 4 m and a width of 1.2 m. The sowing was done on 28 May in the first year and on 5 May in the second year by using 2 kg of seed per decare. The stable

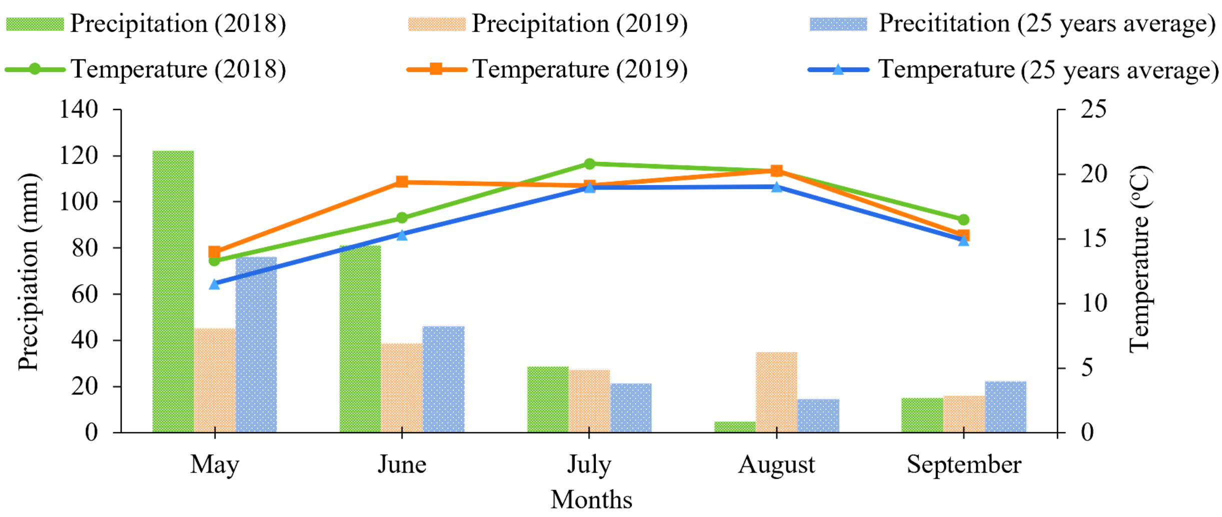

Fig. 1. Average monthly temperature, precipitation values at the experimental site in 2018, 2019 and long term period (1982–2017)

manure (2 tons per decare) was applied as the base fertilizer to the test area before the planting. As for the foliar fertilizers, six different doses [0 (control), 10 (F_1), 20 (F_2), 30 (F_3), 40 (F_4), and 50 (F_5) L ha^{-1}] of *Bacillus subtilis* and *Bacillus megaterium* isolates were applied three times in the vegetation period, once every 20 days. In the growing season, the irrigation was carried out in line with the need of plants and the hoeing was carried out twice for the weed control. The plants were harvested on 10.09.2018 and 15.09.2019.

In this study, the following parameters were examined: plant height, branches per plant, primary branche, number of umbels per plant, number of seeds per umbel, 1000-seed weight, seed yield, and essential oil content.

Statistical analysis. The results of the study were analyzed using SPSS. The differences between the averages were evaluated according to their significance levels using the Duncan multiple comparison test.

RESULTS AND DISCUSSION

The effect of different microbial fertilizer doses on the yield components

The average plant height and variance analysis for the coriander plants grown using different microbial fertilizer doses are given in the Table 1. It was observed that the year, the microbial fertilizer doses for both 2018 and 2019, and the microbial fertilizer doses×year interaction had a significant effect on the plant height; but, the average effect of the microbial fertilizer doses on the plant height for 2018 and 2019 was found to be insignificant. The average plant heights measured under the microbial fertilizer doses for the control, F_1, F_2, F_3, F_4 and F_5 were found to be 57.8, 60.7, 59.8, 60.2, 62.3, and 60.6 cm, respectively. According to these results it can be asserted that as the microbial fertilizer dose increased, the height of the coriander plants also increased (Tab. 1). The difference between the plant lengths in the fertilizer doses×year interaction was found to be statistically significant ($p < 0.01$). Similar findings indicated that the microbial fertilizers containing *Azospirillum* and phosphorous bacteria make the nitrogen and other nutrients beneficial, resulting in increased plant growth. Furthermore, as they provide rapid cell division and proliferation in the meristematic region of coriander, they increase the plant height [Moslemi et al. 2012, Tripathi et al. 2013]. The results of the present study are in close accordance with the findings of the studies carried out by Hnamte et al. [2013], Sahu et al. [2014], and Mounika et al. [2018]. According to the variance analysis in Table 1, the effect of the microbial fertilizer doses applied in 2018, the average effect of the

Table 1. Fertilization levels on the morphological traits and yield components of coriander in 2018 and 2019

Treatment	df	Plant height			Branches per plant			Primary branche height			Number of umbels per plant		
		2018	2019	Mean	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
		cm			no. plant^{-1}			cm			no. plant^{-1}		
Control		55.0c	60.5bc	57.8b	4.5d	4.9	4.7d	5.7e	6.2bc	5.9c	10.0b	4.7b	8.4c
F_1		54.0c	67.3a	60.7ab	4.9c	4.9	4.9cd	6.6de	10.1a	8.4b	9.9b	8.5a	9.2b
F_2		61.0ab	58.7c	59.8ab	5.1c	5.7	5.4ab	6.6d	6.3bc	6.5c	11.4a	8.5a	9.9a
F_3		64.0a	56.4c	60.2ab	6.0a	5.3	5.7a	11.2c	6.6bc	8.9b	10.5ab	7.3ab	8.9bc
F_4		59.7b	64.9ab	62.3a	4.9c	5.1	4.9cd	14.1a	7.4b	10.7a	10.2b	10.3a	10.2a
F_5		62.0ab	59.2c	60.6ab	5.5b	4.9	5.2bc	12.5b	5.6c	9.0b	7.8c	9.4a	8.6bc
Mean		59.3b	61.2a	60.2	5.1	5.2	5.2	9.4a	7.0b	8.2	9.9a	8.5b	9.2
ANOVA		$P > F$											
Year (Y)	1			*			ns			**			*
Fertilizer (F)	5	**	*	ns	**	ns	**	**	**	**	*	**	**
Y × F	5			**			*			**			**

* $P < 0.01$; ** $P < 0.001$; ns: not significant
Means within a column not sharing a lower case letter differ significantly at the $P < 0.01$ levels

microbial fertilizer doses applied in 2018 and 2019, and the microbial fertilizer doses×year intraction were statistically significant (p < 0.01, p < 0.01, and p < 0.05, respectively); however, the effect of the microbial fertilizer doses applied in 2019 was found to be not statistically significant. In the microbial fertilizer doses applied, the highest number of branches per plant was 5.7 (F_3) on average, whereas the lowest number of branches per plant was 4.7 (control parcel) on average. As the microbial fertilizer dose was increased in coriander, a certain increase was observed in the number of branches per plant. Sahu et al. [2014] reported that the biological and organic fertilizers increased the number of branches per plant due to the fact that the protein stimulated protoplasm and vegetative development and more nitrogen was provided. The seed yield per plant can be high in the plants with a high number of branches per plant [Wu et al. 2015]. The findings of the present study were in line with the results of the studies carried out by Malhotra et al. [2006] and Choudhary et al. [2006] in which it was reported that the microbial fertilizer applications had a positive effect on the plants and the number of branches per plant increased.

In the study, the effect of microbial fertilizer doses on the primary branche height in coriander was found to be highly significant (p < 0.01). The highest (10.7 cm) primary branche height was obtained from F_4 and the lowest (5.9 cm) from the control parcel. Increasing the microbial fertilizer dose increased the primary branche height by the desired ratios.

As the primary branche height increases, the seed and oil yields decrease in plants [Çamaş et al. 2007] and the changes in the height of the primary branche may vary depending on the differences in variety, climate, and soil structure of the region.

Since the umbel in coriander consists of many capsules and there are hundreds of seeds in each capsule, the number of umbels per plant can be considered as an important yield parameter [Inan et al. 2014]. It was found that the effect of microbial fertilizer doses on the number of umbels per plant was significant (p < 0.01) (Tab. 1). The highest number of umbels per plant (10.7) was obtained from F_4, whereas the lowest (5.9) was obtained from the control parcel. This result shows that the increase in the microbial fertilizer dose increases the number of umbels. Although the number of umbels per plant and performance vary depending on different factors such as year, environment, and genotype [Kizil 2002], there are some studies in which the organic fertilizer applications were found to cause significant increases [Malhotra et al. 2006, Vasmate et al. 2008, Rahimi et al. 2009].

The number of seeds in the umbel is an important parameter since it is directly related to the seed yield. The results of the variance analysis for the average number of seeds per umbel in the coriander plant grown under different microbial fertilizer dosage conditions are given in the Table 2. It was found that the effects of the year, microbial fertilizer doses, and the year×microbial fertilizer dose interaction on the number of seeds in the umbel were statistically significant ($p < 0.01$ for each). The highest number of seeds in the umbel (54.1) was obtained from F_2, whereas the lowest (46.1) was obtained from F_4. The microbial fertilizer application provided a certain increase (although irregular] in the number of seeds per umbel. The reason for the increase in the number of seeds per umbel obtained in F_2 can be attributed to the growth-promoting feature of the microbial fertilizer application [Tripathi et al. 2013, Pooja et al. 2017, Mounika et al. 2018].

It was found that the effect of the year on 1000-seed weight in coriander was statistically significant ($p < 0.01$); however, the effects of microbial fertilizer doses and year×microbial fertilizer dose interaction were statistically insignificant (Tab. 2). The highest 1000-seed weight was obtained from the control parcel with 6.6 g on average, whereas the lowest was obtained from F_2 and F_4 with 5.9 g on average. We are of the opinion that the difference between the findings of the present study and the findings of the study carried out by Rahimi et al. [2009] may stem from the environmental and climate factors. The reason for the lack of a significant difference between the fertilizer doses in terms of the 1000-seed weight may be the low nutritional requirements of the plants during this period due to the short duration between the flowering time and ripening time [Kazemeini et al. 2010].

The effect of different microbial fertilizer doses on the seed yield and essential oil content

It was found that the seed yield was significantly affected ($p < 0.01$) by the year, 2018 microbial fertilizer doses, and the year×microbial fertilizer dose interaction (Tab. 2).

Table 2. Effect of different fertilization levels on the 1000-seed weight, seed yield and essential oil content of coriander in 2018 and 2019

Treatments	df	Number of seeds per umbel			1000-seed weight			Seed yield			Essential oil content		
		2018	2019	Mean	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
		no. plant^{-1}			g			kg ha^{-1}			%		
Control		54.0b	50.3b	52.2abc	8.0	5.2a	6.6a	686.3e	662.2	674.3c	0.106d	0.167c	0.136e
F_1		51.3b	55.1a	53.2ab	8.1	4.8ab	6.4ab	816.9cd	661.4	739.1b	0.189a	0.206a	0.197a
F_2		57.2a	50.9b	54.1a	7.2	4.7ab	5.9ab	883.9b	656.3	770.1b	0.167b	0192b	0.180b
F_3		58.6a	44.5c	51.5bc	7.5	4.8ab	6.1ab	992.7a	685.3	839.0a	0.168b	0.174c	0.171c
F_4		47.4c	44.8c	46.1d	7.4	4.6ab	5.9b	806.6d	701.6	754.1b	0.151c	0.171c	0.163d
F_5		54.1b	46.1c	50.1c	8.1	4.7b	6.4ab	833.5c	686.3	759.9b	0.148c	0.167c	0.159d
Mean		59.3b	48.6b	51.2	7.7a	4.8ab	6.3	836.6a	675.5b	756.1	0.155b	0.179a	0.167
ANOVA		$P > F$											
Year (Y)	1			**			**			**			**
Fertilizer (F)	5	**	**	**	ns	ns	ns	**	ns	**	**	**	**
Y × F	5			**			ns			**			**

*$P < 0.01$; ** $P < 0.001$; ns: not significant
Means within a column not sharing a lower case letter differ significantly at the $P < 0.01$ levels

According to the microbial fertilizer doses applied, the highest seed yield for 2018 (992 kg ha^{-1}) and the highest seed yield on average for 2018 and 2019 (839.0 kg ha^{-1}) were obtained from F_3. On the other hand, the highest seed yield for 2019 (701.6 kg ha^{-1}) was obtained from F_1. The lowest seed yield for 2018 (686 kg ha^{-1}) and the lowest seed yield on average for 2018 and 2019 (674.3 kg ha^{-1}) were obtained from the control parcel. On the other hand, the lowest seed yield for 2019 (656.3 kg ha^{-1}) was obtained from F_2. It was found that the average seed yield (836.6 kg ha^{-1}) was higher in 2018 compared to 2019 (675.5 kg ha^{-1}) in the coriander plants. This difference in the seed yield may stem from the environmental and climatic factors [Kan 2007]. Improving the physical condition of the soil (ventilation, water holding capacity, biological condition) as well as the plant nutrients is one of the important parameters in obtaining the highest seed yield in coriander [Yousuf et al. 2014]. In the present study, the yield increased with the microbial fertilizer application, and this result was in line with the findings of the studies in literature reporting that the microbial and organic fertilizers increase the physical and biological activity of the soil and increase the seed yield by accelerating the plant growth [Malhotra et al. 2006, Godara et al. 2014, Sahu et al. 2014, Agarwal and Kumar 2016, Mounika et al. 2018]. According to the Table 2, the highest essential oil contents for 2018, 2019, and the two years on average were obtained from F_1 (0.189%, 0.206%, and 0.197%, respectively). On the other hand, the lowest essential oil contents for 2018 and the two years on average were obtained from the control parcel (0.106% and 0.136%, respectively) and the lowest essential oil content for 2019 was obtained from the control parcel and F_2 (0.167%). In the microbial fertilizer applications, the average essential oil content in the first year (0.155%) was lower than that in the second year (0.179%). The essential oil contents of the coriander plants were significantly ($p < 0.01$) affected by the years, microbial fertilizer doses, and the year × microbial fertilizer dose interaction (Tab. 2). Furthermore, the biotic and abiotic environmental factors significantly affect the essential oils and contents of medicinal and aromatic plants [Clark et al. 2008, Aziz et al. 2008]. It has been supported by many research results that the microbial fertilizers, known as living microorganisms, have a positive effect on the plant nutrient uptake, especially when used with other organic fertilizers. [Ordookhani et al. 2011]. There is limited number of studies reporting an increase in the essential oil yield by the microbial fertilizer application in coriander. While the 2% increase found in our study for the essential oil yield was similar to the increase found for the fennel in the studies by Kapoor et al. [2004] and El-Ghadban et al. [2006], it was different from the results of the study carried out by Kapoor et al. [2002] in which the increase was reported to be 43%. This difference may be due to the environmental and climate factors. Besides, many researchers have reported that the biological fertilizers increase the essential oil yield in various medicinal aromatic plants [Leithy 2006, Gharib 2008].

CONCLUSION

Under various microbial fertilizer doses, it was found that the seed yield had the highest value in F_3 (30 L fertilizer per hectare) and the essential oil content had the highest value in F_2 (20 L fertilizer per hectare). When the microbial fertilizer applications were evaluated in terms of seed yield and essential oil content, it was found that they increased the seed yield (up to F_3) and essential oil content (up to F_2) up to the certain doses, and decreased them thereafter.

The microbial fertilizer applications can be an important strategy in increasing the yield, seed ratio, and oil content through making useful the macro and micro nutrients in the soil. In conclusion, although using the microbial fertilizers at high dose increases the yield, the optimum fertilizer doses found in this study can be more effective.

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