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Effect of the predecessor and the nitrogen rate on productivity and essential oil content of coriander (*Coriandrum sativum* L.) in Southeast Bulgaria

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Abstract. Coriander (*Coriandrum sativum* L.) is one of the most important essential oil crops on a global scale. Coriander productivity is determined by the genotype, the environmental factors, as well the agronomic practices. A field experiment was conducted in Southeast Bulgaria during three vegetation seasons (2015, 2016, and 2017). The present study aimed at analysing the influence of two crop predecessors (winter wheat and sunflower) and four nitrogen (N) levels (0, 40, 80, and 120 kg ha^{-1}). Productivity elements, seed yield, and seed essential oil content of coriander (cv. Mesten drebnoploden) were under evaluation. The results obtained showed that winter wheat was a more suitable predecessor of coriander in comparison to sunflower. The highest results regarding the number of umbels per plant, the umbel's diameter, the number of umbellets per umbel, the number of seeds per umbel, the seed weight per plant, the 1,000 seed mass, as well as the seed yield for the rate of 80 kg ha^{-1} of N were recorded. The highest essential oil content after applying 120 kg ha^{-1} of N was established. Increasing the N level from 0 to 120 kg ha^{-1} led to a positive and significant effect on essential oil yield. No significant differences between the N rates of 80 and 120 kg ha^{-1} were recorded. The received results contributed for the evaluatation of the optimum nitrogen level, as well as for the determination of a more suitable predecessor of coriander in order to obtain the highest yield of better quality in the region of Southeast Bulgaria.

Key words: *Coriandrum sativum*, crop rotation, fertilization, precursor, seed yield.

INTRODUCTION

Coriander (*Coriandrum sativum* L.) is one of the most significant essential oil crops grown in the world. It is an annual herbaceous plant, belonging to the Apiaceae family. Coriander`s habitat is the southern part of Europe and the western Mediterranean region. The coriander plant is used as four main products: fresh green herb, fruit as spice, and herb and fruit essential oils as flavourings (Weiss, 2002). The whole seed is added in pickles, chutneys, and other similar products. It is also used to flavour alcoholic beverages including gin, vermouth and vodka, as well as to be crystallized in sugar as a sweetmeat. The main use of the ground spice worldwide is in flavourings or mixed spices. It is an important ingredient in curry powders - between 25% and 40%. It is extensively added in processed foods, meats, sausages, baked products including special breads, and sauces. The essential oil, obtained from coriander fruits at amounts from 0.5 to 2.5% approximately, is used both in the make of flavours and in the manufacture of perfumes and soaps (Carrubba et al., 2002). The oil is a pale or colourless liquid having a specific odour; the taste is sweet. The flavour is mild, sweet and spicy-aromatic, somewhat warm and slightly burning. Over 200 constituents have been determined, as linalool is the main component. The coriander essential oil is triglyceride oil containing petroselinic acid, which makes it a good source of lipids (Mandal & Mandal, 2015). It is also rich in linalool (60–80%), geraniol (1.2–4.6%), terpinen-4-ol (3%), α-pinene (0.2–8%), myrcene (0.2–2%) and other substances (Nadeem et al., 2013). The productivity of coriander is determined by genotype, environmental factors, and agrotechnical practices (Lenardis et al., 2000; Khalid, 2013).

Fertilization is one of the main agronomic factors for the expression of the variety's biological potential. Nitrogen is a plant nutrient that is effective not only in terms of growth and yield, but also in terms of seed quality (Kizil & Ipek, 2004; Skudra & Ruza, 2019). The latter plays an important role in the synthesis of plant components with enzyme activity (Marschner, 2011; Moosavi et al., 2013; Izgi, 2020). Khalid (2013) stated that after the nitrogen applications the obtained values were significantly higher than those of the control group. They found significant changes in plant growth characteristics. Several studies have shown that nitrogen fertilization increases plant growth, plant height, number of branches, number of umbels per plant, number of umbellets per umbel, seed yield per plant, test weight, and vigor index (Oliveira et al., 2003; Gujar et al., 2005; Kumar et al., 2007; Kumar et al., 2008; Rahimi et al., 2009; Ali et al., 2015). Moosavi et al. (2013) reported that nitrogen level had a significant influence on fruit yield, essential oil percent, and yield. On the contrary, with the increase of N rate from 0 to 80 kg ha^{-1}, plant height and fruit yields increased by 19.8 and 74.1%, respectively. In addition, the percentage of essential oil increased from 0.153 to 0.33%, and the yield of essential oil was 2.68 folds higher. Akbarinia et al. (2007) found that the highest seed and essential oil yield were obtained by using 60 kg ha^{-1} of N, while the highest essential oil content was obtained after the application of 90 kg N ha^{-1}. Erdoğdu & Esendal (2018) established that increasing the nitrogen level led to growth in plant height and seed yield. However, the number of umbels per plant, the number of seeds per umbel, the seed yield per plant, and 1,000 seed weight were not affected by the increase of N level. Lokhande et al. (2015) reported that the 1,000 seed weight and the seed yield differed between the studied N rates. Okut & Yildirim (2005) stated that the seed yield and 1,000 seed weight differed by the increase of N levels, while plant height, number of umbels, and harvest index were not influenced by N levels. Szempliński & Nowak (2015) reported that seed yield, number of umbels per plant, and 1,000 seed weight were not altered by N fertilizer rates.

Rotation of crop is one of the most important agronomic practices that may have a significant effect on crop quality and quantity. It has been reported that proper crop rotation leads to increase in crop yield (Berzsenyi & Gyorffy, 1997; Sieling et al., 2005;

Hilton et al., 2018; Neshev, 2022). It provides more sustainable crop production (Bullock, 1992; Bailey et al., 2001; Mamolos & Kalburtji, 2001). Another benefit of the appropriate crop rotation is the reduction of disease development and prevention of pesticide resistance (Stoddard, 2010). According to Zaitsev & Kovalenko (2020), in the case of winter wheat, the share of influence of predecessors on yield could reach 15–35%. With relation to this, Delibaltova et al. (2012) examined the influence of the predecessor and the sowing rate on seed yield and yield components of coriander.

There is limited information about the interaction between the predecessor and the nitrogen level and its effect on growth and productivity of coriander. Taking into account the above-mentioned facts, the present study aims to enrich the knowledge of coriander cultivation based on different predecessors and different N levels.

MATERIALS AND METHODS

Plant material, experimental design, and soil analyses

The field experiment was carried out in the period 2015–2017 on leached Smolnitsa soil type on the territory of the village of Zhrebino, Southeast Bulgaria. The experiment was conducted with Mesten drebnoploden coriander variety. Two predecessors (Wheat and Sunflower) and four nitrogen levels (0, 40, 80, and 120 kg ha^{-1}) were tested. Fertilization was performed with Portable Chest-mount Spreader (SOLO, model 421-S). The experiment was set by the block (split-plot) method in four replications with experimental plot size of 15 m^2. The soil pH, mobile N, P, and K, as well as the humus content, were analysed in the Accredited Laboratory Complex of the Agricultural University - Plovdiv. The soil pH was measured according to the BDS ISO 10390:2011 standard, the mobile N - according to a modified Kjeldahl method meeting the BDS ISO 11261:2002 standard, the P content was measured via spectrometer - according to BDS ISO 11263:2002 standard, and K was determined according to GOST 26209-91/01.07.93. Humus content was measured according to BDS ISO 14235:2002 standard. The analysis registered the following: pH - 7.77, mobile N - 28.6 mg kg^{-1}, P - 113 mg kg^{-1}, K - 365 mg kg^{-1}, and humus - 1.4%.

Study treatments

During the three experimental years sowing was done in the period 10^{th}–20^{th} February. The spacing between rows was 12–15 cm. The seeding rate was 250 germinating seeds m^{-2}, and the sowing depth was 3–4 cm. Soil cultivation included plowing of the stubble in July and plowing at a depth of 20–22 cm in September, double pre-sowing cultivation with harrowing, the last being at a depth of 5–6 cm. The phosphorus fertilizer was added before plowing at a rate of 80 kg ha^{-1}. The nitrogen fertilizer was added with the last pre-sowing soil cultivation in the form of ammonium nitrate (34.4% N). Weed control was achieved by treatment with the herbicide Linurex 45 SC - 2.00 L ha^{-1}, applied after sowing before crop germination. Harvesting was done at full crop maturity. Seed yield was determined at a standard grain moisture content of 9%.

Meteorological data

The average amount of precipitation and the average monthly air temperatures (from February to July) during the experimental years are presented in Fig. 1. Data showed that air temperatures during the experimental period were close to or slightly higher than temperatures established for a multiple-year period, with no significant deviations from the crop requirements. Differences between the three years of the study were found in the precipitation amount during vegetation. The lowest amount of precipitation was reported in 2017 - 215 mm versus 276 mm for a multiple-year period. The year 2017 was characterized by an uneven distribution of rainfall, which was not enough to meet the water requirements at the critical stages. In April, May, and June at the stages of buttoning, flowering, and fruit setting the amount of rainfall was 107.6 mm versus 156 mm for a multiple-year period, i.e. it was about 31% less. This determined the third experimental year as the less favourable one for the productivity of coriander compared to the other two years.

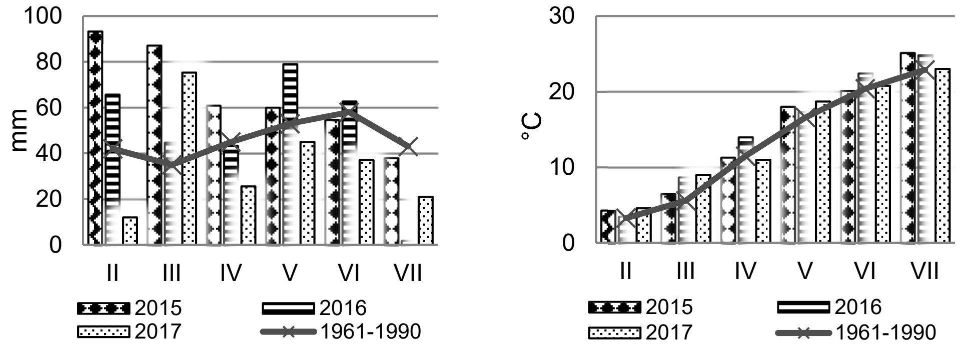

Figure 1. Precipitation, (mm) and average monthly air temperature, (°C) for the years of the experiment and average for the period 1961–1990.

The first year of study (2015) was characterized with the highest amount of precipitation during vegetation (383.9 mm). The registered amount was 107.9 mm above the climatic norm. Precipitation was evenly distributed during vegetation and in combination with the reported temperatures, it was considered to be the most favourable for coriander growth during the three experimental years. In 2016 the total amount of precipitation was 295.7 mm and exceeded the values for the period 1961–1991 by 19.7 mm, however it was not very well distributed. At the beginning of vegetation (February-March), precipitation was 33.5 mm above the norm. During the buttoning and flowering stages, it was 24.5 mm more than the amount reported in the multiple-year period, and during the ripening stage (July) precipitation was very little.

Essential oil extraction

Essential oil content was determined by the steam distillation method in a Clevenger-type apparatus. Samples with a mass of 50 g up to 200 g were set up in 800 mL water and air temperature of 20 °C ± 2. The distillation was carried out at the Institute of Roses, Essential and Medical Cultures - Kazanlak meeting the standard BDS ISO 6571:2010. To speed up the process and reveal the essential oil tanks, the raw material, mature coriander seeds, was crushed before technical processing. The distillation time was 2 hours, calculated from the appearance of the first drop of essential oil.

Yield structural elements were determined on 50 plants per square meter. The following parameters were evaluated: plant height, number of umbels per plant, umbel's diameter, number of umbellets per umbel, number of seeds per umbel, seed weight per plant, 1,000 seed weight, seed yield, essential oil content, and essential oil yield.

Statistical analyses

In order to determine the quantitative relationship between the studied indicators, the experimental data were processed by the Method of analysis of variance (ANOVA), and the differences between the variants were determined using Dunkan's Multiple Range Test.

RESULTS AND DISCUSSION

Yield structural elements averagely for the three years are presented in Table 1. According to the given data, the predecessor, as well as the nitrogen level, had a significant influence on plant height, number of umbels per plant, umbel diameter, number of umbellets per umbel, number of seeds per umbel, seed weight per plant, and 1,000 seed weight of coriander. The highest values of the evaluated parameters for the predecessor winter wheat and the N rate of 80 kg ha^{-1} were reported. The lowest parameters were established for the predecessor sunflower without the use of fertilization.

Table 1. Structural elements of the yield (Average for the period 2015–2017)

		Plants height (cm)	Umbels plant^{-1} (No)	Umbel's diameter (cm)	Umbellets umbel^{-1} (No)	Seeds umbel^{-1} (No)	Weight of seeds umbel^{-1} (g)	1,000 seed weight (g)
Predecessor (A)	Wheat	78.5 ^{a}	13.4 ^{a}	4.31 ^{a}	5.33 ^{a}	31.4 ^{a}	1.24 ^{a}	6.76 ^{a}
	Sunflower	69.0 ^{b}	11.9 ^{b}	4.14 ^{b}	4.92 ^{b}	29.0 ^{b}	1.11 ^{b}	6.43 ^{b}
Nitrogen rate (B)	0	68.8	9.6	3.92	4.58	26.3	1.05	6.49
	40	72.8	11.9	4.18	4.91	30.7	1.20	6.61
	80	75.6	16.5	4.65	6.05	32.7	1.31	6.72
	120	77.8	12.7	4.17	4.96	31.1	1.14	6.58
Wheat	0	74.2 ^{a}	10.5 ^{a}	3.95 ^{a}	4.75 ^{a}	27.7 ^{a}	1.14 ^{a}	6.67 ^{a}
	40	77.5 ^{b}	12.3 ^{b}	4.20 ^{b}	5.08 ^{b}	31.8 ^{b}	1.25 ^{b}	6.79 ^{b}
	80	80.1 ^{c}	17.7 ^{c}	4.85 ^{c}	6.27	33.9 ^{c}	1.39 ^{d}	6.89 ^{c}
	120	82.0 ^{c}	13.2 ^{b}	4.25 ^{b}	5.20 ^{b}	32.0 ^{b}	1.18 ^{c}	6.71 ^{b}
Sunflower	0	63.4 ^{a}	8.6 ^{a}	3.88 ^{a}	4.41 ^{a}	24.8 ^{a}	0.95 ^{a}	6.30 ^{a}
	40	68.0 ^{b}	11.4 ^{b}	4.16 ^{b}	4.74 ^{b}	29.5 ^{b}	1.15 ^{b}	6.43 ^{b}
	80	71.0 ^{c}	15.3 ^{c}	4.44 ^{c}	5.82 ^{c}	31.4 ^{c}	1.22 ^{c}	6.55 ^{c}
	120	73.5 ^{c}	12.2 ^{b}	4.08 ^{b}	4.71 ^{b}	30.2 ^{b}	1.10 ^{b}	6.45 ^{b}
Anova	A	**	*	*	*	*	*	*
	B	*	**	*	*	*	*	*
	AB	n.s	n.s	*	n.s	*	*	n.s

Means within columns followed by different lowercase letters are significantly different ($P < 0.05$) according to the *LSD test* * *F–test* significant at $P < 0.05$; ** *F–test* significant at $P < 0.01$; n.s – non-significant.

Coriander's height, being cultivated after winter wheat as a predecessor was 78.5 cm and 69.0 cm after sunflower predecessor, respectively. The values of plant height rose with the increse of the nitrogen levels from 3.3 to 7.8 cm after the winter wheat predecessor and 4.6 to 10.1 cm after the sunflower, respectively. The differences among the studied variants were statistically significant. These data regarding the influence of nitrogen on the increase of plant height of coriander were consistent with the results reported by other researchers (Khalid, 2013; Lokhande et al., 2015; Erdoğdu & Esendal, 2018). On one hand, according to Erdoğdu & Esendal (2018), plants supplied with 120 kg ha^{-1} of N were the highest compared to those supplied with 60 and 90 kg ha^{-1} of N, respectively. On the other hand, some researchers reported that plant height of coriander was not affected by the fertilization with nitrogen (Okut & Yildirim, 2005; Moosavi et al., 2013).

Analysis results showed the strongest influence of factor A (Predecessor), with a dominant effect on differences in plant height (significant at $P < 0.01$), followed by factor B (Nitrogen rate).

Number of umbels per plant varied from 10.5 to 17.7 for the plants grown after winter wheat, and it varied from 8.6 to 15.3 for the plants grown after sunflower predecessor depending on nitrogen rates. With the increase of nitrogen rate the values of the relevant parameter increased up to 7.2 umbels for the coriander sown after winter wheat, and up to 6.7 - after sunflower. The statistical processing of the obtained data showed significant differences. The effect of nitrogen on the increasing number of umbels per plant in coriander was also found by Erdoğdu & Esendal (2018), Khalid (2013), and Lokhande et al. (2015).

Analysis results related to the influence of the factors (A and B) and their interaction on the number of umbels per plant showed statistically significant variations and the interaction between the two factors was statistically insignificant.

The umbel's diameter varied from 3.88 to 4.85 cm depending on the predecessor and applied nitrogen levels. Coriander's umbel diameter after winter wheat predecessor (4.31 cm) was higher than coriander's umbel diameter grown after sunflower (4.14 cm). The increase of nitrogen levels led to an increase of umbel`s diameter. An increase of 6.3 to 22.8% (after winter wheat predecessor) and of 7.2 to 14.4% (after sunflower predecessor) was reported for the variants applied with N in comparison to the unfertilized control. The obtained results were statistically significant.

The analysis of variance reported for a statistically significant influence of both studied factors A (predecessor) and B (N level). An interaction between the two examined factors (A x B) was also established.

Both, the predecessor and the nitrogen level, influenced the number of umbellets per umbel. The values of the studied parameter varied from 4.75 to 6.27 for the coriander grown after the preceding winter wheat crop, and from 4.41 to 5.82 after the preceding sunflower depending on N rates. The lowest number of umbellets per umbel was reported for the unfertilized control, and the highest – for the plants applied with 80 N kg ha^{-1}.

The predecessor, the nitrogen rate, and their interaction significantly affected the number of seeds per umbel (Table 1). The highest results of this parameter was established after the application of 80 kg ha^{-1} of N, which was 22.3, 6.6, and 5.9% (after wheat predecessor), and 26.6, 6.4, and 3.9% (after sunflower predecessor), which was higher than those treated with 0, 40 and 120 kg ha^{-1} N, respectively.

An important characteristic determining the coriander's seed yield is the seed weight per plant. The different preceding crops, as well as the applied N rate, influenced the formation of seed yields of different weights (Table 1). The lowest values of the indicator for the unfertilized control were reported - 1.14 g after wheat predecessor, and 0.95 g after sunflower predecessor. The highest seed weight per plant was reported after applying 80 kg N ha^{-1}. The received results surpassed those of the unfertilized control with 21.9% and with 28.4% respectively.

Variance analysis related to the effect of the factors and their interaction on seed weight per plant showed a clear statistical significance in the changes of the parameter and the interaction between both factors, which was statistically significant.

With relation to the other structural elements of yield, the 1,000 seed weight also had the highest results for coriander grown after winter wheat having rate of 80 kg N ha^{-1}. Regarding the unfertilized variants, the 1,000 seed weight varied from 6.30 to 6.67 g depending on the predecessor crop. The nitrogen fertilization increased the value index up to 3.3% for the plants grown after winter wheat, and up to 4.0% for the plants grown after sunflower. The received results were statistically significant. Data related to the influence of nitrogen on the increase of 1,000 seed weight of coriander corresponded to the results reported by other authors (Okut & Yildirim, 2005; Patel et al., 2013; Lokhande et al., 2015). On the contrary, some researchers reported that 1,000 seed weight of coriander was not affected by nitrogen fertilization (Szempliński & Nowak, 2015; Erdoğdu & Esendal, 2018).

Seeds yield varied throughout the years being influenced by the predecessor crop and the nitrogen rates (Table 2). Seed yield obtained at different nitrogen rates after wheat predecessor varied from 1,536 to 2,208 kg ha^{-1}, from 1,131 to 1,660 kg ha^{-1}, and from 1,025 to 1,490 kg ha^{-1}, correspondingly for the three experimental years (2015, 2016, and 2017). After sunflower predecessor, seed yield varied from 1,452 to 1,940 kg ha^{-1}, from 990 to 1,375 kg ha^{-1} and from 750 to 880 kg ha^{-1}, respectively. Seed yield increased with statistical significance along with the nitrogen rate increase.

Table 2. Seeds yield (kg ha^{-1}) of coriander, cv. Mesten drebnoploden, depending on the crop predecessor and the N rate

Predecessor	Nitrogen rate	Years of study			Average for the period
		2015	2016	2017	
Wheat	0	1,536 ^{a}	1,131 ^{a}	1,025 ^{a}	1,231
	40	1,910 ^{b}	1,473 ^{b}	1,120 ^{b}	1,501
	80	2,208 ^{d}	1,660 ^{d}	1,490 ^{d}	1,786
	120	2,077 ^{c}	1,518 ^{c}	1,210 ^{c}	1,602
Sunflower	0	1,452 ^{a}	990 ^{a}	750 ^{a}	1,064
	40	1,620 ^{b}	1,110 ^{b}	768 ^{b}	1,166
	80	1,940 ^{c}	1,375 ^{d}	880 ^{c}	1,398
	120	1,755 ^{b}	1,200 ^{c}	770 ^{b}	1,208

Means within columns followed by different lowercase letters are significantly different ($P < 0.05$) according to the *LSD test*.

The yields obtained on average for the experimental period (2015–2017) varied from 1,231 to 1,786 kg ha^{-1} after the predecessor winter wheat and from 1,064 to 1,398 kg ha^{-1} for the sunflower predecessor depending on the applied nitrogen rates.

The highest yields were reported after applying 80 kg ha^{-1} of N. The results surpassed those without fertilization up to 45.1% and up to 31.4% for the predecessor winter wheat and the predecessor sunflower respectively. The effect of nitrogen on increasing seed yield has been also stated by various researchers (Gujar et al., 2005;

Oliveira et al., 2006; Akbarinia, et al., 2007; Carrubba, 2009; Moosavi et al., 2013; Ali et al., 2015; Lokhande et al., 2015; Erdoğdu & Esendal, 2018) while Szempliński & Nowak (2015) reported that seed yield was not affected by the different N rates.

The more favourable combination of the major meteorological conditions during vegetation led to the obtainment of higher yields in the first year of study compared to the second and the third one. The highest seed yield (2,208 kg ha^{-1}) was reported after wheat predecessor having nitrogen rate of 80 kg ha^{-1}, and the lowest (1,452 kg ha^{-1}) - after sunflower predecessor having nitrogen rate of 0 kg ha^{-1}. Differences between the examined variants were statistically significant. In the second experimental year (2016) yields varied from 1,660 to 900 kg ha^{-1}, i.e. they were by 29% lower in average in comparison to the previous year. In the last year of study (2017) yields were within the limits from 1,490 to 750 kg ha^{-1} i.e. they were by 38.7% and 12.5% lower in comparison to 2015 and 2016, respectively. The less amount of precipitation during the critical stages for the crop development led to a decrease in seed yields during the last year of the experiment. This is in line with the results reported by Dyulgerov & Dyulgerova (2016). According to the authors the reduced precipitation in the phases of stem elongation, budding and flowering of coriander leads to a decrease in seed yield.

The dispersion analysis results regarding the effect of the factors and their interaction on seed yield show a clear statistical significance in the changes of the characteristics and the interaction between both factors, which was statistically significant (Table 3).

Table 3. Two-way ANOVA analysis of the seed yield of coriander

Years of study	Source of variation	Sum of square (SS)	df	Mean square (MS)	F	*P*-value	F crit
2015	Predecessor	566,048	1	566,048	107.7981	0.00*	4.2597
	Nitrogen rate	1,394,342	3	464,780.66	88.5128	0.00*	3.0088
	Interactions	116,080	3	38,693.33	7.3688	0.00*	3.0088
2016	Predecessor	612,724.5	1	612,724.5	386.9228	0.00*	4.2597
	Nitrogen rate	864,133.5	3	288,044.5	181.8941	0.00*	3.0088
	Interactions	55,273.5	3	18,424.5	11.6347	0.00*	3.0088
2017	Predecessor	1,360,425	1	1,360,425	1,397.637	0.00*	4.2597
	Nitrogen rate	442,330.4	3	147,443.5	151.4765	0.00*	3.0088
	Interactions	104,445.4	3	34,815.13	35.76743	0.00*	3.0088

* *F-test* significant at $P < 0.05$.

Nitrogen is one of the elements, which are of grate importance for the essential oil synthesis and composition. According to Nurzyńska-Wierdak (2013), nitrogen contributes to the greatest extent to the increase in biosynthesis of essential oil and its composition in numerous aromatic plant species. Plants use nitrogen to synthesize many organic compounds including amino acids, proteins, enzymes, and nucleic acids. Amino acids and enzymes play a key role in the biosynthesis of numerous compounds, which are essential oil constituents (Koeduka et al., 2006). One of the hypotheses about the formation of these compounds links the process of formation of terpenes to the transformation of carbohydrates and makes it dependent on this transformation while the other one links it to the transformation of proteins (Dubey et al., 2003; Lattoo et al., 2006).

According to Aziz & El-Ashry (2009), the type of the N fertilizer plays a significant role in the formation and the essential oil contents in the aromatic plants. Ammonium nitrate gives the highest value of oil yield in coriander while urea is more effective for dill (Olle & Bender, 2010). The application rate also modifies the quantity and composition of oils for several species (Zheljazkov et al., 2010; Hendawy & Khalid, 2011). Some researchers have declared that levels of N from 50 to 200 kg ha^{-1} have no significant effect on yield (Reddy & Rolston, 1999), which is contrary to our results. On the other hand, many researchers are confident that higher nitrogen rates lead to a higher seed yield (Akbarinia et al., 2007). The authors examined three nitrogen doses including 30, 60, and 90 kg ha^{-1} and the highest one proved to be the best for gaining the highest seed yield.

The results of the present study showed that the nitrogen application significantly affected essential oil content but the predecessor and their interaction did not affect this trait (Table 4).

Table 4. Essential oil content (%) of coriander, cv. Mesten drebnoploden, depending on the crop predecessor and the N rate

		Years of study			Average for
		2015	2016	2017	the period
Predecessor (A)	Wheat	1.06 ^{a}	1.14 ^{a}	0.99 ^{a}	1.06
	Sunflower	1.05 ^{a}	1.13 ^{a}	0.96 ^{a}	1.05
Nitrogen rate (B)	0	0.89	0.99	0.86	0.91
	40	1.04	1.10	0.97	1.04
	80	1.11	1.19	1.00	1.10
	120	1.19	1.27	1.09	1.18
Wheat	0	0.90 ^{a}	0.97 ^{a}	0.88 ^{a}	0.92
	40	1.05 ^{b}	1.12 ^{b}	0.99 ^{b}	1.05
	80	1.10 ^{c}	1.20 ^{c}	1.00 ^{b}	1.10
	120	1.20 ^{d}	1.28 ^{d}	1.10 ^{c}	1.19
Sunflower	0	0.88 ^{a}	1.00 ^{a}	0.83 ^{a}	0.90
	40	1.03 ^{b}	1.08 ^{b}	0.95 ^{b}	1.02
	80	1.12 ^{c}	1.18 ^{c}	0.99 ^{bc}	1.10
	120	1.18 ^{d}	1.26 ^{d}	1.07 ^{cd}	1.17
Anova	A	n.s	n.s	n.s	
	B	*	*	*	
	AB	n.s	n.s	n.s	

Means within columns followed by different lowercase letters are significantly different *(P < 0.05)* according to the *LSD test* * *F–test* significant at P < 0.05; ** *F–test* significant at P < 0.01; n.s – non-significant.

The highest seed oil content was reported in 2016. Temperatures during the fruit ripening stage were 2.1 folds higher than those for a multiple-year period. The essential oil content compared with the control was 11.1 to 28.3% higher. In the other years of the experiment the N application increased the essential oil content from 1.04 to 1.19% and from 0.97 to 1.09% in the fertilized variants, and 0.89%–0.86% in the control in 2015 and 2017, respectively. Averagely for the period 2015–2017, the values of that trait in all fertilized variants exceeded the unfertilized control from 14.3 to 29.6%.

The results indicated that the increase in the applied N rate had a positive and significant effect on this trait and the highest essential oil content was obtained at 120 kg ha^{-1} of N. The received results corresponded to those of Akbarinia et al. (2007), Moosavi et al. (2013), and Izgi (2020).

The analysis of variance related to the effect of factors A (predecessor) and B (N rate) on the essential oil yield, as well as their interaction, showed a significant influence of the factors on the changes of the studied indicator and statistically insignificant effect of the interaction between them (Table 5).

Table 5. Essential oil yield (kg ha^{-1}) of coriander, cv. Mesten drebnoploden, depending on the crop predecessor and the N rate

		Years of study			Average for the period
		2015	2016	2017	
Predecessor (A)	Wheat	20.8 ^{b}	16.7 ^{b}	12.1 ^{b}	16.5
	Sunflower	18.0 ^{a}	13.3 ^{a}	7.7 ^{a}	13.0
Nitrogen rate (B)	0	13.3	10.5	7.6	10.5
	40	18.4	14.3	9.4	14.0
	80	23.0	18.1	11.9	17.7
	120	22.8	17.2	10.8	16.9
Wheat	0	13.8 ^{a}	11.0 ^{a}	9.0 ^{a}	11.3
	40	20.1 ^{b}	16.5 ^{b}	11.1 ^{b}	15.9
	80	24.3 ^{c}	19.9 ^{c}	14.9 ^{c}	19.7
	120	24.9 ^{c}	19.4 ^{c}	13.3 ^{c}	19.2
Sunflower	0	12.8 ^{a}	9.9 ^{a}	6.2 ^{a}	9.6
	40	16.7 ^{b}	12.0 ^{b}	7.6 ^{b}	12.1
	80	21.7 ^{c}	16.2 ^{c}	8.8 ^{c}	15.6
	120	20.7 ^{c}	15.0 ^{c}	8.2 ^{c}	14.6
Anova	A	*	*	*	
	B	*	*	*	
	AB	n.s	n.s	n.s	

Means within columns followed by different lowercase letters are significantly different *(P* < 0.05*)* according to the *LSD test* * *F–test* significant at *P* < 0.05; ** *F–test* significant at *P* < 0.01; n.s – non-significant.

The favourable combination of temperature and moisture during the vegetation period of coriander was a precondition for obtaining a higher essential oil yield in 2015 compared to 2016 and 2017.

During the first experimental year, the values of that indicator in the fertilized variants ranged from 20.1 to 24.9 kg ha^{-1} versus 13.8 kg ha^{-1} in the control after winter wheat predecessor, and from 16.7 to 21.7 kg ha^{-1} versus 12.8 kg ha^{-1} in the control after sunflower predecessor. In 2016 the coriander essential oil yield was approximately 24% lower than in the previous year. In the last year of experiment the essential oil yield ranged from 11.1 to 14.9 kg ha^{-1} in the fertilized variants, and in the control, it was 9.0 kg ha^{-1}. After winter wheat predecessor it was from 7.6 to 8.8 kg ha^{-1} versus 6.2 kg ha^{-1} in the control after sunflower predecessor.

Averagely for the study period (2015–2017), the increase in N rates from 0 to 80 kg ha^{-1} of N had a positive and significant effect on essential oil yield. The yield increased by 1.74 folds after winter wheat predecessor and 1.63 folds after sunflower predecessor. There was no significant difference between N rates of 80 and 120 kg ha^{-1}.

CONCLUSIONS

Coriander is an essential oil plant that is gaining more and more interest, as it is widely used both as a spice and as an ingredient in the cosmetic, pharmaceutical and other industries. For this reason, it is essential for farmers to study the most favourable conditions for achieving a large quantity of high quality production.

The present study aimed to investigate the more suitable predecessor and the optimum levels of nitrogen fertilization in order to achieve higher yields and more essential oil.

The examined factors (A predecessor and B nitrogen rate) had a significant influence on the productivity of coriander, grown in the conditions of Southeast Bulgaria.

The highest number of umbels per plant, umbel's diameter, the number of umbellets per umbel, the number of seeds per umbel, seed weight per plant, 1,000 seeds weight, and coriander seeds yield were in favor of the winter wheat predecessor and the N application rate of 80 kg ha^{-1}.

The highest essential oil content after applying 120 kg N ha^{-1} was found. The predecessor did not affect this trait.

The increase of N rate from 0 to 120 kg ha^{-1} had a positive and significant effect on essential oil yield. There was no significant difference between the rates of 80 and 120 kg N ha^{-1}.

REFERENCES

Akbarinia, A., Daneshian, J. & Mohmmadbiegi, F. 2007. Effect of nitrogen fertilizer and plant density on seed yield, essential oil and oil content of *Coriandrum sativum* L. *(Persian) Iranian Journal of Medicinal and Aromatic Plants* **22**(4), 10–19.

Ali, H., Ayub, G., Elahi, E., Shahab, M., Ahmed, S. & Ahmed, N. 2015. Response of coriander (Coriandrum sativum L.) to different nitrogen levels and sowing dates. *Asian Journal of Agriculture and Biology* **3**(4), 155–158.

Aziz, E. & El-Ashry, S. 2009. Efficiency of slow release urea fertilizer on herb yield and essential oil production of lemon balm (*Melissa officinalis* L.) plant. *American-Eurasian Journal of Agricultural and Environmental Science* **5**, 141–147.

Bailey, K., Gossen, B., Lafond, G., Watson, P. & Derksen, D. 2001. Effect of tillage and crop rotation on root and foliar diseases of wheat and pea in Saskatchewan from 1991 to 1998: univariate and multivariate analyses. *Canadian Journal of Plant Science* **81**, 789–803. doi: 10.4141/P00-152

BDS EN ISO 6571. 2010. Spices, condiments and herbs – Determination of volatile oil content (hydrodistillation method) (ISO 6571:2008). European standards, Bulgaria.

BDS ISO 10390:2011. 2011. Soil quality - Determination of pH. International standards, Bulgaria.

BDS ISO 11261:2002. 2002. Soil quality - Determination of total nitrogen - Modified Kjeldahl method. International standards, Bulgaria.

BDS ISO 11263:2002. 2002. Soil quality - Determination of phosphorus - Spectrometric determination of phosphorus soluble in sodium hydrogen carbonate solution. International standards, Bulgaria.

BDS ISO 14235:2002. 2002. `Soil quality – Determination of organic carbon by sulfochromic oxidation`. International standards, Bulgaria.

Berzsenyi, Z. & Gyorffy, B. 1997. Effect of crop–rotation and fertilization on wheat yields and yield stability in long-term experiments. *Novenytermeles* **46**, 145–161.

Bullock, D. 1992. Crop rotation. *Critical Reviews in Plant Sciences* **11**, 309–326. doi: 10.1080/07352689209382349

Carrubba, A. 2009. Nitrogen fertilisation in coriander (*Coriandrum sativum* L.): a review and meta analysis. *Journal of the Science of Food and Agriculture* **89**(6), 921–926. doi: 10.1002/jsfa.3535

Carrubba, A., la Torre, R., Prima, A.D., Saiano, F. & Alonzo, G. 2002. Statistical analyses on the essential oil of Italian coriander (*Coriandrum sativum* L.) fruits of different ages and origins. *Journal of Essential Oil Research* **14**(6), 389–396.

Delibaltova, V., Kirchev, Hr., Zheliazkov, I. & Yanchev, I. 2012. Influence of predecessor and sowing rate on seed yield and yield components of coriander (*Coriandrum sativum* L.) in Southeast Bulgaria. *Bulgarian Journal of Agricultural Science* **18**, 315–319.

Dubey, V., Bhalla, R. & Luthra, R. 2003. Sucrose mobilization in relation to essential oil biogenesis during palmarosa (*Cymbopogon martinii* Roxb. Wats. var. motia) inflorescence development. *Journal of Biosciences* **28**(4), 479–487.

Dyulgerov, N. & Dyulgerova, B. 2016. Effect of some meteorological factors on main breeding traits in coriander. *Bulgarian Journal of Crop Science* **53**(5/6), 6066.

Erdoğdu, Y. & Esendal, E. 2018. The effects of nitrogen doses on the seed yield and some agronomic characteristics of coriander cultivars. *Journal of Tekirdag Agricultural Faculty* **15**(1), 95–101.

GOST 26209-91. 1993. Determination of mobile compounds of phosphorus and potassium by Egner-Riem method (DL-method). Technical standards GOST. (in Russian).

Gujar, S., Warade, A., Mohariya, A. & Paithankar, D. 2005. Effect of dates of sowing and nitrogen levels on growth, seed yield and quality of coriander. Crop Research (Hisar) 29(2), 288–291.

Hendawy, S. & Khalid, K. 2011. Effect of chemical and organic fertilizers on yield and essential oil of chamomile flower heads. *Medicinal and Aromatic Plant Science and Biotechnology* **5**(1), 43–48.

Hilton, S., Bennett, A., Chandler, D., Mills, P. & Bending, G. 2018. Preceding crop and seasonal effects influence fungal, bacterial and nematode diversity in wheat and oilseed rape rhizosphere and soil. *Applied Soil Ecology*, 1–13.

Izgi, M. 2020. Effects of Nitrogen fertilization on coriander (*Coriandrum sativum* L.): Yield and quality characteristics. *Applied Ecology and Environmental Research* **18**(5), 7323–7336. doi:10.15666/aeer/1805_73237336

Khalid, A. 2013. Effect of nitrogen fertilization on morphological and biochemical traits of some Apiaceae crops under arid region conditions in Egypt. *Bioscience* **5**(1), 15–21. doi: 10.13057/nusbiosci/n050103

Kizil, S. & Ipek, A. 2004. The effects of different row spacing and nitrogen on yield, yield components and essential oil content of some coriander (*Coriandrum sativum* L.) lines. *Journal of Agricultural Science* **10**(3), 237–240.

Koeduka, T., Fridman, E., Gang, D., Vassao, D., Jackson, B., Kosh, Ch., Orlova, I., Spassova, S., Lewis, N., Noel, J., Baiga, T., Dudareva, N. & Pichersky, E. 2006. Eugenol and isoeugenol, characteristic aromatic constituents of spices, are biosynthesized via reduction of a coniferyl alcohol ester. *PNAS* **103**(26), 10128–10133.

Kumar, A., Singh, R. & Chhillar, R. 2008. Influence of omitting irrigation and nitrogen levels on growth, yield and water use efficiency of coriander (*Coriandrum sativum* L.). *Acta Agronomica Hungarica* **56**(1), 69–74. doi: 10.1556/AAgr.56.2008.1.7

Kumar, K., Singh, G.P., Singh, N., Bhatla, A. & Nehra, B. 2007. Performance of seed crop of coriander under different levels of row spacing, nitrogen and cycocel. *Haryana Journal of Horticultural Sciences* **36**(1 and 2), 127–128.

Lattoo, S., Dhar, R., Dhar, A., Sharma, P. & Agarwal, S. 2006. Dynamics of essential oil biosynthesis in relation to inflorescence and glandular ontogeny in *Salvia sclarea*. *Flavour and Fragrance Journal* **21**, 817–821.

Lenardis, A., Fuente, E., Gil, A. & Tubra, A. 2000. Response of coriander (*Coriandrum sativum* L.) to nitrogen availability. *Journal of Herbs, Spices and Medicinal Plants* **7**(4) 47–58. doi: 10.1300/J044v07n04_06

Lokhande, S., Jogdande, N. & Thakare, S. 2015. Effect of varying levels of nitrogen and hosphorus on growth and seed yield of coriander (*Coriandrum sativum*). *Plant Archives* **15**(1), 57–59.

Mamolos, A. & Kalburtji, K. 2001. Significance of allelopathy in crop rotation. *Journal of Crop Production* **4**, 197–218. doi: 10.1300/J144v04n02_06

Mandal, S. & Mandal, M., 2015. Coriander (*Coriandrum sativum* L.) essential oil: Chemistry and biological activity. *Asian Pacific Journal of Tropical Biomedicine* **5**(6), 421–428.

Marschner, H. 2011. *Marschner's mineral nutrition of higher plants*. Academic press. London, 651 pp.

Moosavi, G., Seghatoleslami, M., Ebrahimi, A., Fazeli, M. & Jouban, Z. 2013. The effect of nitrogen rate and plant density on morphological traits and essential oil yield of coriander. *Journal of Ornamental and Horticultural Plants* **3**(2), 95–103.

Nadeem, M., Anjum, F., Khan, M., Tehseen, S., El-Ghorab, A. & Sultan, J. 2013. Nutritional and medicinal aspects of coriander (*Coriandrum sativum* L.): A review. *British Food Journal* **115**(5), 743–755. doi: 10.1108/00070701311331526

Neshev, N. 2022. Preceding crop influences on the development and yields of the winter oilseed rape (*Brassica napus* L.). *Agricultural Sciences* **14**(32), 56–62. doi: 10.22620/agrisci.2022.32.009

Nurzyńska-Wierdak, R. 2013. Does mineral fertilization modify essential oil content and chemical composition in medicinal plants? Acta Scientarum Polonorum, Hortorum Cultus 12(5), 3–16.

Okut, N. & Yildirim, B. 2005. Effect of different row spacing and nitrogen doses on certain agronomic characteristics of Coriander (*Coriandrum sativum* L.). *Pakistan Journal of Biological Sciences* **8**(6), 901–904. doi: 10.3923/pjbs.2005.901.904

Oliveira, A., Alves, E., Bruno, R., Sader, R. & Alves, A. 2006. Yield and quality of coriander seeds in function of nitrogen levels. *Revista Brasileira de Sementes* **28**(1), 193–198. doi: 10.1590/s0101-31222006000100027

Oliveira, A., Paiva Sobrinho, S., Barbosa, J., Ramalho, C. & Oliveira, A. 2003. Rendimento de coentro cultivado com doses crescentes de N. *Horticultura Brasileira* **21**(1), 81–83. doi: 10.1590/S0102-05362003000100017

Olle, M. & Bender, I. 2010. The content of oils in umbelliferous crops and its formation. *Agronomy Research* **8**(Special Issue III), 687–696.

Patel, C., Amin, A. & Patel, A. 2013. Effect of varying levels of nitrogen and sulphur on growth and yield of coriander (*Coriandrum sativum* L.). *The Bioscan* **8**(4), 1285–1289.

Rahimi, A., Mashayeki, K., Hemati, K. & Dordipoor, A. 2009. Effect of salicylic acid and mineral nutrition on fruit yield and yield components of coriander (*Coriandrum sativum* L.). *Journal of Plant Production* **16**(4), 149–156.

Reddy, K. & Rolston, M. 1999. Coriander (*Coriandrum sativum* L.) seed production: nitrogen, row spacing, sowing rate and time of sowing. *Journal of Applied Seed Production* **17**, 49–53.

Sieling, K., Stahl, C., Winkelmann, C. & Christen, O. 2005. Growth and yield of winter wheat in the first 3 years of a monoculture under varying N fertilization in NW Germany. *European Journal of Agronomy* **22**, 71–84. doi: 10.1016/j.eja.2003.12.004

Skudra, I. & Ruza, A. 2019. Effect of nitrogen fertilization management on mineral nitrogen content in soil and winter wheat productivity. *Agronomy Research* **17**(3), 822–832.

Stoddard, F. 2010. Improving food and feed security in the Nordic and Baltic region by using appropriate crop rotations. *Agronomy Research* **8**(Special Issue II), 311–316.

Szempliński, W. & Nowak, J. 2015. Nitrogen fertilization versus the yield and quality of coriander fruit (*Coriandrum sativum* L.). *Acta Scientiarum Polonorum Hortorum Cultus* **14**(3).

Weiss, E.A. 2002. Coriander. In Weiss, E.A. (eds). *Spice Crops*, CABI Publishing, Wallingford, 243–261.

Zaitsev, A. & Kovalenko, I. 2020. The influence of crop predecessor and chemicalization levels on grain quality and spring wheat productivity. *IOP Conference Series: Earth and Environmental Science* **548,** 072014. doi: 10.1088/1755-1315/548/7/072014

Zheljazkov, V., Cantrell, C., Astatkie, T. & Ebelhar, M. 2010. Peppermint productivity and oil composition as a function of nitrogen, growth stage, and harvest time. *Agronomy Journal* **102**(1), 124–128.