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ORIGINAL PAPER

RESPONSE OF CORIANDER TO FERTILIZATION WITH NITROGEN AND BORON*

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Abstract

The agrotechnical recommendations for the cultivation of coriander draw attention to the need for fertilization with boron, an element which is deficient in Polish soils but which, like nitrogen, is necessary for the proper growth and development of the plants. A study based on a two-factor field experiment was carried out in 2012-2014, and the aim was to assess the effect of nitrogen and boron fertilization on the yield and selected quality features of the fruit of coriander. The first factor was soil fertilization with nitrogen (n = 4): N_0 – no nitrogen fertilization, N_1 – 30 kg ha^{-1}, N_2 – 50 kg ha^{-1} and N_3 – 70 kg ha^{-1}. The second factor was pre-sowing fertilization with boron (n = 2): B_0 – no boron fertilization, B – 0.5 kg ha^{-1}. The following were determined: fruit yield, total nitrogen content (based on a modified Berthelot reaction), and essential oil content (by distillation). The yield of oil and protein was calculated. The highest average yield of coriander fruit and essential oil was obtained after the application of 30 and 50 kg N ha^{-1}. The use of 50 and 70 kg N ha^{-1} reduced the amount of oil in the fruit in comparison with the control and with the plants fertilized with 30 kg N ha^{-1}. Irrespective of nitrogen application, boron fertilization resulted in an increase in fruit yield and in the content and yield of protein, but reduced the amount and yield of essential oil in the fruit. We found a significant interaction of nitrogen, particularly at 30 kg N ha^{-1}, with boron in determining the yield of coriander fruit and its quality features. Supplementation of nitrogen fertilization with boron on light soil helps to obtain a high yield of coriander fruit with good chemical quality characteristics.

Keywords: *Coriandri fructus,* chemical composition, essential oil, medicinal plants.

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INTRODUCTION

Coriander is an annual herbal, spice and melliferous plant from the family *Apiaceae*. It grows to a height of 60-120 cm. All parts of this plant are edible and have dietary value, but the herbal material is the fruit (*Fructus Coriandri*), mainly used to obtain oil (*Oleum Coriandri*), which contains coumarin compounds, triterpenes, flavonoids, phytosterols and protein compounds (Nurzyńska-Wierdak et al. 2012, Mandal, Mandal 2015). The main goal of research on coriander is to obtain a sufficiently high fruit yield with good oil yield and high-quality parameters. Cultivation methods, irrigation, harvest time, and especially fertilization can modify the fruit yield as well as its chemical composition (Nurzyńska-Wierdak 2013). To obtain a high-quality crop of herbal plants, care should be taken to meet their requirements for nutrients, particularly those whose content in the soil is insufficient. Availability of these nutrients throughout a growing season is not only conducive to the proper development of plants, but it also reduces their deficiencies in the soil (Radulov et al. 2009).

Nitrogen is one of the main nutrients increasing yield (Janušauskaitė 2013), improving the yield of coriander fruit and modifying its quality (Szempliński, Nowak 2015). To obtain a yield of fruit weighing one tonne, plants must take up nearly 33 kg of this nutrient from the soil.

Poland's soils are low in available forms of boron. In addition to a number of physiological functions that it performs in plants, this microelement reduces their susceptibility to stress factors (Imtiaz et al. 2010, Nowak, Szempliński 2011). An inadequate flower formation is a very serious consequence of boron deficiency, leading to a decrease in the seed yield. The agrotechnical recommendations for coriander cultivation highlight the need for boron fertilization.

In view of the above, a study was undertaken to determine the effect of different nitrogen application doses as well as application of boron on the yield and chemical composition of the fruit of coriander grown in the climate and habitat conditions typical of northern Poland.

MATERIAL AND METHODS

The research involved the coriander (*Coriandrum sativum* L.) cultivar Jantar grown in 2012-2014. The soil was Haplic Luvisol (IUSS Working Group WRB 2015), with the textural composition of loamy sand (light soil in the agronomic soil categories). The soil represented very good rye complex, soil valuation class IIIb, with an average content of available forms of magnesium (48 mg kg^{-1}), phosphorus (53 mg kg^{-1}) and potassium (91 mg kg^{-1}). The soil reaction ranged from slightly acidic to neutral (pH_{KCl} 6.5-6.6) and had an average content of available forms of copper, zinc and manganese, while its content of available forms of boron was low.

The experiment was set up at the Research Station of the Faculty of Agriculture and Biotechnology of the University of Technology and Life Sciences in Bydgoszcz, located in the village of Wierzchucinek (53°26′ N, 17°79′ E). It was designed as a two-factor, randomized split-plot trial with four replications.

The first factor (A) was nitrogen fertilization applied to the soil (n = 4): N_0 – no nitrogen application (control); N_1 – 30 kg N ha^{-1} (15 kg N ha^{-1} before sowing and 15 kg N ha^{-1} top dressing); N_2 – 50 kg N ha^{-1} (25 kg N ha^{-1} before sowing and 25 kg N ha^{-1} top dressing); and N_3 – 70 kg N ha^{-1} (35 kg N ha^{-1} before sowing and 35 kg N ha^{-1} top dressing). Nitrogen was applied in the form of ammonium nitrate. The second factor (B) was boron fertilization (n = 2): B_0 – no boron application (control); B – 0.5 kg B ha^{-1}. Boron was applied before sowing in the form of sodium tetraborate decahydrate ($Na_2B_4O_7$ 10 H_2O). The doses of fertilizers were established in accordance with the agrotechnical recommendations for the cultivated species.

In all fertilizer treatments, the same amounts of phosphorus and potassium were applied before sowing (17 kg P ha^{-1} and 66 kg K ha^{-1}), in the form of enriched superphosphate (17,5% P) and 60% potassium chloride, respectively. The crop preceeding coriander was root parsley. The area of each plot in the experiment was 3 m^2. In every growing seasons, coriander was sown in the first 10 days of April, in rows spaced at 40 cm. Cultivation treatments such as scarification of the interrows and weeding were performed manually.

The average air temperature (Table 1) in the coriander growing season (April-August) in each year of the study was higher than the long-term average, by 0.5, 2.0 and 1.2°C, respectively. Moisture conditions were particularly unfavourable for growing coriander in 2012 and 2013. The lack of moisture

Table 1

Chosen meteorological data in the experimental years (2012-2014) and long-term means (1949-2012) according to the research station in Wierzchucinek

Years	April	May	June	July	Aug	Mean or total
Temperature (°C)						
2012	8.4	14.5	15.2	18.8	17.6	14.9
2013	13.6	14.2	17.4	18.9	18.1	16.4
2014	9.9	13.3	16.0	21.5	17.2	15.6
1949-2012	7.4	12.9	16.2	18.0	17.5	14.4
Precipitation (mm)						
2012	15.4	25.4	133.8	115.6	51.8	342.0
2013	7.0	91.7	49.3	79.0	56.6	283.6
2014	40.7	65.7	44.9	55.4	57.3	264.0
1949-2012	27.2	43.9	54.4	72.9	55.8	254.2

in April impeded plant emergence, while excessive rainfall in June and July 2012 and May 2013 did not favour the development of the plants. In June and July 2014, the total rainfall was by 9.5 and 17.5 mm lower than the long-term average, as a result of which the average fruit yield of coriander was the lowest in that year. In subsequent months, precipitations were favourable to the growth of this species.

Fruit yield was determined immediately after harvest. Afterwards, fruit samples were wet mineralized in concentrated sulfuric acid, and the content of total nitrogen was determined based on a modified Berthelot reaction. In brief, after dialysis against a buffer solution of pH 5.2, ammonia in the sample is chlorinated to monochloramine, which reacts with salicylate to form 5-aminosalicylate. Following oxidation and oxidative coupling, a green complex is formed. The absorption of the complex is measured at 660 nm (Skalar SANplus flow analyser), and total phosphorus is determined with the method employing ammonium molybdate (Skalar SANplus flow analyser). The content of potassium and calcium was determined by flame photometry, and that of magnesium was assayed with the Atomic Absorption Spectrometry (AAS) method.

The content of essential oil in the coriander fruit was determined by 3-hour hydrodistillation of the raw material in a glass Deryng apparatus. Based on the oil and total nitrogen content in the fruit, oil and protein yields were calculated for all samples.

The results were statistically analysed using a two-way randomized split-plot analysis of variance. To assess the differences between treatments, the Tukey test at a probability of error of $P = 0.05$ was applied.

RESULTS AND DISCUSSION

The average coriander fruit yield was 139.4 g m^{-2} (Table 2). Of all nitrogen application doses, 30 kg ha^{-1} had the greatest effect on yield, ensuring the highest fruit yields. Namely, the average yield obtained from the three-year study was 157.5 g m^{-2}, which was by 18.2% higher than the yield from the control treatment. The 50 kg N ha^{-1} application dose also had a beneficial effect on yield, causing a significant increase in comparison to the control (8.8% on average). Increasing the nitrogen dose to 70 kg ha^{-1} (N_3) significantly reduced fruit yield as compared to the control and the lower levels of nitrogen. Although they originate from wild species, herbs are plants which in field cultivation respond to mineral fertilization by increasing yield. This is especially true of nitrogen, which is the most important agrotechnical yield-stimulating factor (Kozera et al. 2013). This element is the main component of protoplasm, and plays an important role in the synthesis of proteins and enzymes that affect the growth and development of plants (Khalid 2013). Although nitrogen is a highly productive nutrient, its effectiveness

Table 2

Yielding, protein and essential oil content in coriander fruits (means for 2010-2012)

	Dose of boron fertilization (kg ha^{-1})	Nitrogen fertilization (kg ha^{-1})				Mean	LSD
		0	30	50	70		
Fruit yield (g m^{-2})	0	129.6	152.8	139.5	110.5	133.1	A=4.00 B=1.93 Interaction: B/A=3.86 A/B=4.78
	0.5	136.8	162.3	150.5	133.0	145.6	
	mean	133.2	157.5	145.0	121.7	139.4	
Protein content (g kg^{-1})	0	155.9	163.2	167.0	165.0	162.8	A=4.83 B=2.36 Interaction: B/A=4.72 A/B=5.80
	0.5	158.9	168.8	180.3	173.1	170.3	
	mean	157.4	166.0	173.6	169.1	166.5	
Yield of protein (g m^{-2})	0	20.3	24.9	23.2	18.1	21.6	A=1.11 B=0.53 Interaction: B/A=1.05 A/B=1.31
	0.5	21.9	27.7	27.1	23.0	24.9	
	mean	21.1	26.3	25.1	20.5	23.3	
Oil content (cm^3 kg^{-1})	0	9.5	8.6	8.6	7.9	8.7	A=0.20 B=0.11 B/A=0.23 A/B=0.25
	0.5	7.1	8.0	7.6	7.5	7.6	
	mean	8.3	8.3	8.1	7.7	8.1	
Yield of oil (cm^3 m^{-2})	0	1.24	1.28	1.22	0.83	1.14	A=0.046 B=0.024 Interaction: B/A=0.049 A/B=0.065
	0.5	0.96	1.33	1.11	1.03	1.11	
	mean	1.10	1.30	1.17	0.93	1.13	

A – fertilization with nitrogen, B – fertilization with boron, n.s. – non-significant differences

largely depends on habitat conditions, as evidenced by the research results of other authors. Patel et al. (2013) obtained the highest coriander fruit yield after applying 20 kg ha^{-1}, and Bhunia et al. (2009) collected most coriander fruit from plots treated with a dose of 60 kg N ha^{-1}. Oliveira et al. (2006), who cultivated coriander in Brazil, harvested the highest fruit yield having applied 80 kg N ha^{-1}, while the highest fruit yield in a study conducted by Khalid (2013) in Egypt followed the application of 200 kg N ha^{-1}.

Based on regression equations, the dose of nitrogen leading to the highest coriander fruit yield for the entire experiment was 29.39 kg N ha^{-1} (Figure 1*a*). The highest dose (70 kg N ha^{-1}) was ineffective because in combination with the high soil moisture it resulted mainly in the growth of vegetative parts of plants, to the disadvantage of the fruit yield. Irrespective of the levels of nitrogen applied, boron fertilization caused a significant increase in the yield of coriander fruit, amounting to 9.4% on average.

Different results were obtained by Nowak and Szempliński (2011), who

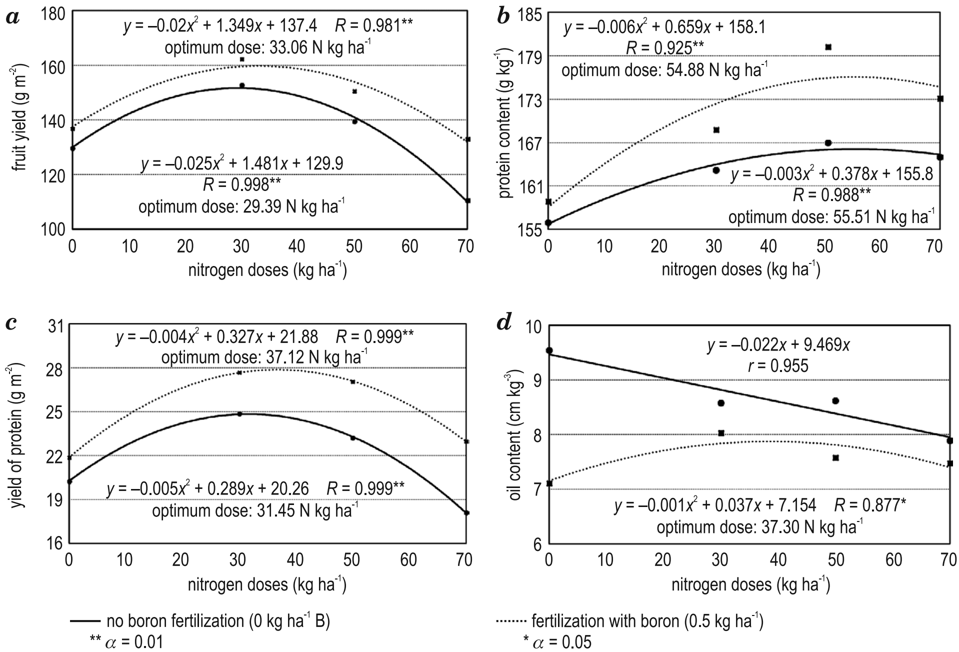

Fig. 1 Dependence of the fruit yield (*a*), protein content (*b*), yield of protein (*c*) and oil content (*d*) on the nitrogen dose

did not find significant differences in the yield of coriander depending on boron fertilization. In our study, boron fertilization failed to influence the fruit yield only in the first year (2012), which may have been due to the weather conditions in that growing season. The abundant but unevenly distributed rainfall in spring (April-June), when the total precipitation was 16.4 mm higher than the long-term average, ensured adequate availability of boron for plants from natural soil resources, so that fertilization did not affect the fruit yield.

A significant interaction of the experimental factors influencing the coriander fruit yield was confirmed. Boron applied together with nitrogen enhanced the effect of this nutrient on yield. Regression analysis shows that 33.1 kg N ha^{-1} was the optimum application dose of nitrogen used together with boron for coriander yield (Figure 1*a*).

Boron is one of the most important micronutrients for plants (Zahoor et al. 2011, Giansoldati et al. 2012). This is due to the effect of this element on a number of physiological processes occurring not only in plants, but also in humans and animals (Imtiaz et al. 2010). The content of this nutrient depends on a species, variety, stage of development, or organ of the plant (Giansoldati et al. 2012), and boron deficiency, according to Szulc and Rutkowska (2013), may lead to a reduction in plant yields.

The chemical composition of crops, including herbs, has a significant impact on food quality. Protein is a natural bioactive component of food (Darewicz et al. 2013), and its optimal content in products has a beneficial effect on metabolism, ensuring the proper functioning of a human body.

The average protein content in the coriander fruit for the entire study period was 166.5 g kg^{-1} (Table 2) and depended significantly on the fertilizer used. As the amount of nitrogen applied increased, the protein content in the coriander fruits increased significantly in comparison with the control fruits. Most protein in the fruit was obtained after the application of 50 kg N ha^{-1} (173.6 g kg^{-1}); the increase in comparison to the treatment with no nitrogen fertilization was 10.3%.

Irrespective of nitrogen fertilization, the content of protein in the coriander seeds following boron application increased on average by 4.6% in comparison to the treatments without boron fertilization. On average for the three years, there was a significant interaction of the experimental factors influencing the protein content in coriander fruit.

The study showed that the protein yield in the coriander fruits, same as in the fruit yield, was influenced by the experimental factors (Table 2). The average protein yield ranged from 21.1 g m^{-2} in the control to 26.3 g m^{-2} after the dose of 30 kg N ha^{-1}. Higher levels of nitrogen (50 and 70 kg ha^{-1}) were found to cause a significant decrease in protein yield as compared to the lowest dose, i.e. 30 kg ha^{-1}. This was a consequence of their effect on the fruit yield as well as the protein content. According to the quadratic regression model, the maximum protein content in the coriander fruit was obtained following the application of 55.51 kg N ha^{-1} (Figure 1*b*), while the protein yield was the highest after the application of 31.45 kg N ha^{-1} (Figure 1*c*).

The average protein yield of the coriander fruit from the plants fertilized with boron increased by 15.3% in comparison with the fruit from the treatments without boron fertilization. The interaction of the experimental factors had a significant effect on the protein yield of the fruit. The regression analysis (Figure 1*c*) showed that the highest protein yield in the treatments with boron supplementation was obtained for the nitrogen application at 37.1 kg N ha^{-1}.

Coriander fruit contains on average 1.5-22 cm^3 kg^{-1} of essential oil (Telci, Hisil 2008, Zheljazkov et al. 2008*a*), while its content in the present study ranged from 7.1 to 9.5 cm^3 kg. Increasing levels of nitrogen, with the exception of 30 kg ha^{-1}, reduced the amount of oil in the coriander fruit, as evidenced by the negative correlation coefficient (Figure 1*d*). The schizocarps from plants fertilized with 50 and 70 kg N ha^{-1} contained less oil than the controls, by 2.4% and 7.2%, respectively, which was statistically confirmed.

The content and chemical composition of essential oil testify to the value of the coriander fruit for processing (Burdock and Carabin 2009). Optimizing the fertilization of herb plants, especially with nitrogen, in order to obtain a suitable amount of oil is a complex issue, because it is associated with the effect of various factors during the growing period, such as environmental (Sriti et al. 2011), genetic (Ebrahimi et al. 2010), ontogenetic (Mohammadi, Saharkhiz 2011) or agronomic (Aćimović et al. 2015) conditions. This leads to discrepancies in the research results on this subject. In a study by Szempliński and Nowak (2015), increasing nitrogen application doses did not differentiate the amount of essential oil in coriander fruit in relation to the control; its average content was higher than in our research, ranging from 12.5 to 13.1 cm^3 kg^1. A lack of variation in the amount of oil in coriander fruit was also reported by Gil et al. (2002) for a range 0-135 kg N ha^{-1}, and by Khalid (2013) for a range of 0-200 kg N ha^{-1}. The results obtained by El-Din et al. (2010) from the cultivation of caraway seeds, and by Moosavi et al. (2013) in a study on coriander indicate an increase in the amount of oil in the fruit resulting from application of various amounts of nitrogen. In a study by Kozera et al. (2013), the highest NPK application doses resulted in a decrease in the amount of oil in caraway fruit compared to the control and to a treatment with the lowest application of NPK. Similar results were obtained by Bielski et al. (2011) from a sage cultivation experiment. Aćimović et al. (2015) found no influence of NPK fertilizer on the content of oil in caraway and coriander fruits, but *did* observe an increase in its quantity in anise fruits.

The average content of oil in fruits where boron had been applied together with nitrogen was 7.6 cm^3 kg^{-1} (Table 2). Application of this nutrient significantly reduced the amount of oil in the fruit, by 12.6% as compared to the fruit of plants grown without boron. A significant interaction of the experimental factors influenced the amount of oil in the fruit, which is confirmed by the regression equations, according to which the application of boron together with 37.3 kg N ha^{-1} had the most favourable effect on this parameter (Figure 1*d*).

The oil yield, which is the product of the fruit yield and oil content in the fruit, ranged from 0.83 to 1.33 cm^3 m^{-2} (Table 2). The highest oil yield compared to the control, which was confirmed statistically, was recorded after application of 30 and 50 kg N ha^{-1}. A further increase in the level of nitrogen caused a decrease in oil yield with respect to the control and the other nitrogen application doses. Zheljazkov et al. (2008b) obtained the highest yield of essential oil in basil after applying 50-60 kg N ha^1. In a study by Kozera et al. (2013) on caraway, which like coriander belongs to the *Apiaceae* family, increased nitrogen application together with varied phosphate and potassium fertilization resulted in a significant increase in oil yield as compared to the non-fertilized control.

Irrespective of increasing nitrogen doses, boron application significantly reduced the yield of oil in the coriander fruits, on average by 2.63% compared to the fruit of plants that were not fertilized with boron.

The varied nitrogen fertilization and its interaction with boron essentially influenced the content of total phosphorus in coriander seeds (Table 3).

Table 3

Content of macronutrients in coriander fruits, means for 2010-2012 (g kg^{-1})

Macro-nutrients	Dose of boron fertilization (kg ha^{-1})	Nitrogen fertilization (kg ha^{-1})				Mean	LSD
		0	30	50	70		
Phosphorus	0	7.11	6.74	6.80	6.77	6.85	A=0.192 B=n.s. Interaction: B/A=0.205 A/B=0.271
	0.5	6.81	7.35	6.76	6.82	6.94	
	mean	6.96	7.05	6.78	6.80	6.90	
Potassium	0	14.49	14.57	14.14	14.11	14.33	A=0.339 B=0.181 Interaction: B/A=0.362 A/B=0.479
	0.5	14.72	14.91	14.64	13.89	14.54	
	mean	14.61	14.74	14.39	14.00	14.43	
Calcium	0	5.19	4.94	5.02	4.94	5.02	A=0.157 B=0.084 Interaction: B/A=0.168 A/B=0.222
	0.5	4.81	4.95	4.84	4.19	4.70	
	mean	5.00	4.94	4.93	4.56	4.86	
Magnesium	0	6.52	6.72	7.10	6.60	6.74	A=0.212 B=0.113 Interaction: B/A=0.227 A/B=0.300
	0.5	6.57	6.71	6.71	6.31	6.58	
	mean	6.55	6.72	6.91	6.45	6.66	

A – fertilization with nitrogen, B – fertilization with boron, n.s. – non-significant differences

The highest average concentration of this element was found after the application of 30 kg N ha^{-1} (7.05 g kg^{-1}). A further increase of nitrogen doses up to 50 kg ha^{-1} and 70 kg ha^{-1} led to a statistically proven decrease in this macroelement's quantity in the coriander fruit compared to its quantity after of 30 kg N ha^{-1} dose. These differences were 3.83% and 3.55%, respectively. The results confirm the significant effect of nitrogen fertilization on the content of total phosphorus in herbal plants, a finding supported by BIESIADA and KUŚ (2010). However, the results of NURZYŃSKA-WIERDAK et al. (2012) do not confirm the significant effect of nitrogen doses on modifying the amount of phosphorus in the coriander fruit. An essential influence of the interaction of the analysed factors on the content of total phosphorus in coriander fruits has also been proved. The highest content was observed after the application of a total dose of 30 kg N ha^{1} and boron in an amount of 0.5 kg ha^{-1} (Table 3).

The content of potassium in the studied plant material was significantly determined by diversified nitrogen and boron fertilization and by the interaction of these factors (Table 3).

An increase in the nitrogen dose in coriander cultivation from 30 to 70 kg ha^{-1} led to a significant decrease in this element's content in fruit from

14.74 g kg^{-1} to 14.00 g kg^{-1} (by 5.0%). Intensive nitrogen fertilization reduced the concentration of this macroelement in herbal plants (Dzida, Jarosz 2006). The average content of potassium in the coriander fruit increased after the use of boron by 0.21 g K kg^{-1} compared to the control.

A decrease in the calcium content in seeds under the influence of increasing nitrogen doses in relation to the control object was observed (Table 3). However, the lowest amount of this element was found only after the application of 70 kg N ha^{-1} (4.56 g Ca kg^{-1}), independently of the boron application.

A similar tendency for the potassium content in herbs after nitrogen fertilization was confirmed by Nurzyńska-Wierdak et al. (2012). Boron fertilization leads to a statistically confirmed decrease in the average content of calcium (0.32 g K kg^{-1}) in the coriander fruit in comparison to unfertilized objects.

An increase in nitrogen doses up to 50 kg ha^{-1} caused an increase in the average magnesium content in the coriander fruit in comparison to the object not fertilized with this element (Table 3). However, a significant difference (5.5%) was found only for the dose of 50 kg ha^{-1}. The collected seeds from the plots fertilised with the dose of 70 kg N ha^{-1} contained, on average, significantly less magnesium in relation to fruit from plots fertilized with doses of 30 and 50 kg N ha^{-1}. These differences were 0.27 and 0.46 g Mg kg^{-1}, respectively. Boron application in the amount of 0.5 kg ha^{-1} caused a proven reduction by 2.37% in the average magnesium concentration in coriander fruit yield in comparison to the control. Nurzyńska-Wierdak et al. (2012) and Dzida and Jarosz (2006) showed that nitrogen fertilization did not modify the amount of magnesium in the yield of herbal plants.

CONCLUSIONS

1. The highest average yield of fruit and essential oil in the coriander fruit, in comparison to the control, was obtained after the application of 30 and 50 kg N ha^{-1}.

2. The coriander fruits harvested from plants grown on plots fertilized with 50 kg N ha^{-1} accumulated the most total protein, while the highest yield of protein was obtained owing to the dose of 30 kg N ha^{-1}.

3. The use of 50 and 70 kg N ha^{-1} reduced the amount of oil in the fruit as compared to the plants not fertilized with nitrogen and those fertilized with 30 kg N ha^{-1}.

4. Irrespective of nitrogen application, boron fertilization caused an increase in fruit yield and in protein content and yield, while reducing the amount of essential oil and its yield in the fruit.

5. A significant interaction of nitrogen fertilization, especially at 30 kg ha^{-1},

with boron influenced the yield of coriander fruit and the quality features investigated.

6. The research suggests that supplementation of nitrogen fertilization with boron under light soil conditions is of great importance for obtaining a high yield of coriander fruit and influencing its chemical quality criteria.

7. It was found that nitrogen fertilization with the dose of 50 kg ha^{-1} caused an increase in the magnesium content in the coriander fruit, but the application of 70 kg N ha^{-1} caused a decrease in the potassium, calcium and magnesium concentrations.

8. After the application of boron at the level of 0.5 kg ha^{-1}, independently of nitrogen fertilization, an increase in the potassium content and a decrease in the calcium and magnesium accumulation were observed.

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