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The Effect of Nitrogen Fertilizer on the Growth and the Yield Characteristics of Spinach

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Summary: This study analyzes the impact of different nitrogen fertilization levels, in the form of UREA, on the growth and yield of spinach (*Spinacia oleracea* L.) under greenhouse conditions in Raška during the 2022 and 2023 growing seasons. The experiment was set up using a Randomized Complete Block Design with three replications, on a 12 m² plot. UREA (46% N) was applied in various rates (0, 40, 80, 120, and 140 kg ha^{-1}) to evaluate its effect on spinach growth and productivity. Key parameters such as plant height, days taken to first cutting, number of leaves per plant, leaf length, fresh weight of leaves, and yield per pot and hectare were measured. The results showed significant differences in most of the analyzed parameters. As the N rate increased, plant height, number of leaves per plant, leaf length, and yield increased, with the highest values recorded at 140 kg ha^{-1}. However, excessive doses showed diminishing returns, particularly between 120 kg ha^{-1} and 140 kg ha^{-1}. The control group exhibited the lowest values for all parameters. Additionally, earlier flowering and potentially reduced quality with higher nitrogen doses were observed. The study concludes that optimal nitrogen levels are crucial for spinach yield and quality, and a balanced approach to fertilization is necessary to achieve sustainable production while minimizing environmental risks.
Keywords: fertilizer, plant growth, productivity, spinach, UREA, yield

Introduction

Spinach (*Spinacia oleracea* L., Chenopodiaceae family) is a leafy vegetable crop originating from Western Asia (South Turkestan, the Caucasus, and Nepal), Iran, and China. Spinach is a good source of minerals (Fe, Cu, P, Zn, Se), B-complex vitamins (B3 and B9), ascorbic acid, carotenoids (β-carotene, lutein, zeaxanthin), phenols (flavonoids, *p*-coumaric acid), apocynin, and omega-3 fatty acids (Roughani & Miri, 2019). In 100 grams of fresh spinach, there are about 2.9 grams of protein, which accounts for approximately 30% of its total calories. The proteins in spinach contain all essential amino acids, although in different proportions. Its productivity depends on proper nutrition, with nitrogen playing a key role in regulating growth, leaf formation, and overall yield (Tei et al., 2000). Nitrogen (N) is an essential macronutrient necessary for plant growth and development, as it participates in key physiological and biochemical processes, including the synthesis of proteins, amino acids, nucleic acids, and chlorophyll (Marschner, 2012).

Spinach can be grown year-round but thrives best in spring and autumn, as it prefers moderate temperatures between 15 and 20°C. At temperatures above 25°C, early flowering and reduced leaf quality occur, while temperatures below 5°C can slow down germination and growth (Santamaria, 2006; Chitwood et al., 2016). Soil suitable for spinach cultivation should be rich in organic matter, well-drained, and slightly acidic to neutral, with a pH value ranging from 6.0 to 7.5 (Grubinger, 2017). Optimal soil moisture is crucial for plant development, as spinach requires regular irrigation to prevent wilting and yield reduction (Simić et al., 2023a; 2023b; Stupar et al., 2024). A lack of moisture can lead to a decrease in leaf mass and an increase in nitrate concentration in the leaves (Hochmuth et al., 2012). Spinach is most commonly grown through direct seeding in open fields or greenhouses, depending on climatic conditions and the season. Sowing is carried out at a depth of 1 to 2 cm, with a row spacing of 20 to 30 cm to provide optimal growing space. Depending on the variety and growing conditions, harvesting can begin as early as 30 to 45 days after sowing. Adequate N levels enhance spinach yield by increasing both the number and size of leaves (Sajirani et al., 2012). However, excessive N application can lead to nitrate accumulation in the leaves, posing a potential health risk to consumers (Santamaria, 2006). The optimal N dosage depends on soil type, climatic conditions, and spinach variety, with fractional application proving more effective compared to a single fertilization (Rakašćan et al., 2021; Gülüt & Şentürk, 2024). N can be supplied in the form of ammonium nitrate (AN), urea, or organic fertilizers (e.g. compost and manure). Organic nitrogen sources are becoming increasingly important in sustainable spinach production. A combination of mineral and organic nitrogen sources yields the best results while ensuring nitrate levels in the leaves remain controlled (Mahmoud et al., 2019).

UREA, as the most concentrated N fertilizer containing 46% N, is widely used in agriculture. It can be applied during soil preparation, before sowing, or as top dressing during the growing season. Foliar application of urea in autumn can increase N reserves in plants, positively affecting leaf size and yield in the following season. Proper nitrogen dosing in spinach cultivation is a challenge, as nitrogen deficiency can lead to reduced growth, pale leaf color, and loss of nutritional value, whereas excessive use can result in nitrate accumulation in the leaves and negative environmental consequences, such as groundwater contamination and greenhouse gas emissions (Guo et al., 2017). Therefore, it is necessary to identify optimal nitrogen levels that ensure high spinach yield and quality while maintaining soil sustainability and environmental protection (Li et al., 2018). The aim of this study is to analyze the impact of different nitrogen fertilization levels in the form of urea on the growth and yield of spinach in greenhouse production under the agroecological conditions of Raška.

Material and Methods

This study was conducted in a greenhouse under the agroecological conditions of Raška, with the aim to evaluate the influence of nitrogen in the form of urea on the growth and productivity of spinach during 2022 and 2023 (September-October). The trial was arranged in a Randomized Complete Block Design with three replications. The total plot area was 3×4 meters (12 m²). The land was well prepared before sowing. Two plowings were applied to the experimental area. After plowing, the soil was well tilled by hand hoeing and thoroughly prepared for sowing.

After soil preparation for planting, fertilization with UREA was carried out in different doses (40, 80, 120, and 140 kg ha^{-1} or 18.4, 36.8, 55.2, 64.4 kg N ha^{-1}). The sowing of Matador variety spinach seeds (Institute of Vegetable, Smederevska Palanka) was carried out in beds during September. A distance of about 30 cm and 7 cm was maintained between rows and plants, respectively. Eighteen days after sowing, thinning of the plants was performed. No pesticides were applied for the protection against pathogens and weeds. Irrigation by drip watering was performed daily, lower water rate, watering to 10 mm. 10 plants were sampled per experimental area. Forty days after planting, the spinach was harvested manually, and data were collected on plant characteristics, including plant height (cm), days taken for first cutting, number of leaves per plant, leaf length (cm), fresh weight of leaves per plant (g), yield per pot, and yield per hectare.

The greenhouse intended for growing spinach has an area of 10 ares, dimensions 100 x 10 meters. The sides of the greenhouse can be raised vertically, which enables more efficient ventilation and regulation of humidity and temperature. The height of the structure along the side walls is 1.8 meters, while the maximum height in the ridge reaches 4.5 meters, which ensures good air circulation and a stable microclimate inside. The entire structure is covered with a 250 micron thick greenhouse film (nylon), which ensures high resistance, good light diffusion and stability over several seasons. Thanks to the quality of the foil and the volume of air in the building, night temperatures between 10 pm and 7 am vary by a maximum of 2 °C. These conditions enable spinach to have a relatively stable night regime, which is important for uniform growth and leaf mass formation. During the day, the temperature in the greenhouse can rise significantly. In September, the average daytime temperature ranged from 23 to 26 °C, the average night temperature was from 9 to 12 °C. The average daytime temperature in October was from 15 to 17 °C, and the night temperature from 6 to 9 °C. The five levels of UREA including a control were evaluated: 0 (control), 40, 80, 120 and 140 kg ha^{-1}.

According to the data presented in Table 1, the soil on which spinach was grown for the purposes of this experiment has a pH value of 7.64 in water extract and 7.00 in potassium chloride extract. Based on the classification by Thun, this soil is neutral to slightly alkaline (Manojlović & Čabilovski, 2020). As stated by Marković et al. (2007), the optimal uptake of essential nutrients occurs in soils with a pH value ranging between 6 and 8. The presence or absence of calcium carbonate ($CaCO_3$) directly affects the soil reaction. Soil is optimally supplied with calcium carbonate if it contains 2.5% $CaCO_3$, which classifies it as a medium-carbonate soil. It is important to emphasize that this compound plays a significant role in the application of both organic and mineral fertilizers, and special attention should be paid when determining available phosphorus and micronutrients. According to Predić (2011), soils with higher total nitrogen content also have a higher amount of mineral forms of nitrogen due to intensified mineralization of organic compounds in the rhizosphere layer. The soil used for the experiments contained 0.557% total nitrogen, which can be defined as very rich in nitrogen. The quality of humus, apart from individual fractions and the degree of saturation with humic acids and bases, is determined by the C:N ratio, which varies between 10 and 20. When this ratio is 10:1, the soil can be considered rich in humus. The results of the agrochemical analysis of the experimental field soil showed that the soil was well supplied with humus (C:N ratio was 11.4:1).

Table 1. Agrochemical properties of the examined soil (Raška)

pH		$CaCO_3$	Organic C	Total N	C/N
H_2O	KCl	%			
7.64	7.00	2.5	6.35	0.557	11.4:1

The obtained values for available phosphorus petnaoxide (P_2O_5) and potassium oxide (K_2O) were 26.8 mg P_2O_5/100g and 54.8 mg K_2O/100g of soil, respectively (Table 2). Based on the content of available phosphorus and potassium, the soil is classified as rich in phosphorus and very well supplied with potassium (Manojlović et al., 1995).

Optimal P_2O_5 availability plays an important role in the plant life cycle. Primarily, it is a biogenic element that is part of various organic compounds. P_2O_5 deficiency is reflected in visible changes in above-ground plant organs, such as leaf curling and the drying of leaf tips. On the other hand, in cases of more severe deficiency, root growth slows down and root rot may occur. Stević et al. (2010) emphasize that under optimal phosphorus supply, plants show increased tolerance to disease-causing agents. It should be noted that although K_2O does not become part of organic compounds, it plays a crucial role in regulating plant tolerance to abiotic stress factors such as low temperatures and frost, as well as during drought periods. This is because it positively affects water uptake and transport to above-ground plant organs.

Table 2. Available microelement content in the examined soil sample

NH_4-N	NO_3-N	(NH_4 + NO_3)-N	P_2O_5	K_2O
mg/kg			mg/100g	
8.4	9.1	17.5	26.8	54.8

Statistical analysis. The obtained experimental data were processed using appropriate mathematical-statistical methods with the statistical package IBM SPSS Statistics 21. In order to make objective conclusions about the influence of the observed factors on the examined properties of spinach, and the possibility of applying parametric tests, the homogeneity of variances was tested with the Levenes test for a significance level of 0.01, which showed that the homogeneity of variances was not violated, and that the mentioned parametric tests can be used in the further testing procedure.

The statistical significance of differences between the UREA fertilization levels, for all analyzed characteristics of the spinach plant, was measured using parametric tests: ANOVA and Duncan's test at a 5% risk level. The relative dependence of the analyzed plant traits was defined by Pearson's correlation coefficient.

Levene 's test for homogeneity of variance (df_1=9 i df_2=20))

Variable	F	Sig
Plant height (cm)	3,5257	0,0459
Days taken to first cutting	0,9609	0,4985
Number of leaves per plant	1,4652	0,0995
Length of leaves per plant (cm)	2,6398	0,0399
Fresh weight of leaves plant^{-1}(g)	1,8391	0,1229
Yield pot^{-1} (kg)	3,5078	0,0439
Yield ha^{-1} (kg)	1,7200	0,1496

Results and Discussion

Table 3 presents the average values of the examined characteristics: the effect of N fertilizer on plant height and the effect of applied N fertilizers on the yield characteristics of spinach, their variability across different urea doses over the analyzed years, as well as the statistical significance of the observed differences between treatments using Duncan's multiple range test.

For plant height, Duncan's test indicates a significant difference between all treatments on an annual level. The control (0 kg ha^{-1}) has a significantly lower plant height compared to all treated variants. As the N rate increases, plant height continuously increases, with the difference between

120 kg ha^{-1} and 140 kg ha^{-1} being significant but smaller compared to previous differences. The optimal dose for a significant height increase is between 80 and 120 kg ha^{-1}, while an additional increase to 140 kg ha^{-1} has a smaller incremental effect. However, differences in Plant height between years indicate that the differences between the control groups (0 kg ha^{-1}) and between the 40 kg ha^{-1} treatments are not statistically significant.

Table 3. Effect of fertilizers on plant heigh (cm), days taken to first cutting, number of leaves per plant and length of leaves per plant (cm)

Year	UREA treatment (kg ha^{-1})	Plant height (cm)	Days taken to first cutting	Number of leaves per plant	Length of leaves per plant (cm)
2022	0 – control	$8.66^{a}\pm0.15$	$31.3^{a}\pm0.3$	$5.33^{a}\pm0.58$	$7.77^{a}\pm0.12$
	40	$15.66^{b}\pm0.32$	$28.2^{b}\pm0.15$	$10.33^{b}\pm0.58$	$13.30^{b}\pm0.1$
	80	$22.23^{c}\pm0.83$	$26.1^{c}\pm0.2$	$14.33^{c}\pm0.58$	$18.10^{c}\pm0.1$
	120	$24.13^{d}\pm0.15$	$23.4^{d}\pm0.2$	$16.66^{d}\pm0.58$	$22.60^{d}\pm0.1$
	140	$27.30^{e}\pm0.26$	$20.9^{e}\pm0.1$	$17.33^{d}\pm0.58$	$23.33^{e}\pm0.32$
2023	0 – control	$8.97^{a}\pm0.12$	$32.1^{f}\pm0.1$	$6.33^{c}\pm0.58$	$7.87^{a}\pm0.06$
	40	$15.93^{b}\pm0.06$	$28.9^{g}\pm0.06$	$10.67^{b}\pm0.58$	$14.07^{f}\pm0.06$
	80	$23.03^{f}\pm0.12$	$27.5^{h}\pm0.1$	$14.67^{c}\pm0.58$	$19.20^{g}\pm0.2$
	120	$25.03^{g}\pm0.15$	$24.1^{i}\pm0.1$	$16.67^{d}\pm0.58$	$23.07^{h}\pm0.06$
	140	$28.10^{h}\pm0.10$	$20.1^{j}\pm0.1$	$18.67^{d}\pm0.58$	$24.20^{j}\pm0.1$

*Means followed by different letters within the same columns are statistically different according to Duncan's multiple range test. *: Significant at $P < 0.05$

For days taken to first cutting, the test shows significant differences between all treatments, with the number of days decreasing as the N rate increases. The control group exhibits the longest time to the first cutting, while the shortest time is recorded at the highest dose (140 kg ha^{-1}). Adding urea accelerates plant growth, but it raises the question of whether excessive reduction in time to the first cutting could negatively affect the overall plant quality.

For number of leaves per plant, the test shows a statistical difference between most treatments. The control group produced the lowest number of leaves in both analyzed years, with a statistically significant difference. The number of leaves increases with the rise in fertilizer dose. The highest number of leaves was recorded at a N rate of 140 kg ha^{-1}. However, the difference compared to 120 kg ha^{-1} is small, which may indicate reduced efficiency at higher doses. This observation is confirmed by Duncan's test, which shows that the number of leaves at 120 kg ha^{-1} and 140 kg ha^{-1} is not statistically significantly different in 2022, nor is there a significant difference compared to 2023 ($p>0.05$).

For length of leaves per plant, as with the other parameters, according to Duncan's test significant differences between the examined treatments ($p<0.05$). The control group has the shortest leaves, while the longest leaves are found in the 140 kg ha^{-1} treatment. Leaf length increases proportionally with the N rate, but it should be considered whether longer leaves are also nutritionally superior. The difference in leaf length between the control groups across different years is not statistically significant ($p>0.05$).

For fresh weight of leaves per plant, according to Duncan's test significant differences between most treatments ($p<0.05$). The control group has the lowest leaf mass, while the 140 kg ha^{-1} treatment yields the highest leaf mass. UREA significantly contributes to an increase in leaf mass. However, the difference in fresh leaf mass of spinach between the control groups was not statistically significant, nor was the difference between the highest N rate (140 kg ha^{-1}) in 2022 and 2023, Table 4.

According to Duncan's test statistically significant differences between treatments for yield pot^{-1} on an annual basis. Yield significantly increases with the N rate, with 140 kg ha^{-1} producing the highest yield. Analyzing the differences across years, no statistically significant differences in yield pot^{-1} (kg) were observed between the control groups or between the 140 kg ha^{-1} dose in 2022 and the 120 kg ha^{-1} dose in 2023.

Table 4. Effect of applied fertilizers on the fresh weight of leaves plant^{-1} and yield characteristics of Spinach

Year	UREA treatment (kg ha^{-1})	Fresh weight of leaves plant^{-1}(g)	Yield pot^{-1} (kg)	Yield ha^{-1} (kg)
2022	0 control	12.23^{a}±0.21	13.28^{a}±0.19	2407.76^{a}±0,05
	40	17.20^{b}±0.1	7.38^{b}±0.14	6025.77^{b}±0,48
	80	22.30^{c}±0.26	10.98^{c}±0.22	8441.66^{c}±0,44
	120	24.13^{d}±0.06	13.60^{d}±0.36	11040.6^{d}±0,53
	140	25.53^{e}±0.12	14.22^{e}±0.10	11750.79^{e}±0,65
2023	0 control	12.46^{a}±0.21	13.19^{a}±0.04	2625.50^{f}±0,69
	40	17.87^{f}±0.25	7.87^{f}±0.02	6541.24^{g}±0,23
	80	22.83^{g}±0.06	11.09^{g}±0.12	9208.80^{h}±0,46
	120	24.90^{h}±0.1	13.98^{e}±0.12	11583.97i±0,58
	140	25.77^{e}±0.15	15.16^{h}±0.08	12592.33^{j}±0,59

*Means followed by different letters within the same columns are statistically different according to Duncan's multiple range test. *: Significant at $P < 0.05$

As with other parameters, Duncan's test shows significant differences between all treatments for yield ha^{-1}. The control group has the lowest yield, while the 140 kg ha^{-1} treatment results in the highest yield per hectare. There is a clear relationship between increasing the N rate and yield, but the long-term sustainability of this fertilization model should be analyzed.

In the study of effects of nitrogen fertilization on yield and quality of spinach conducted by Abdelraouf (2016), using four N rate (56, 112, 168 and 224 kg N ha^{-1} as UREA), the results indicated that increasing N rates up to 224 kg N ha^{-1} increased plant growth (fresh and dry plant weight, leaf area and leaf area index).

Nitrogen promotes the development of green mass, because it is the main ingredient of chlorophyll and protein. Adequate nitrogen levels increase photosynthetic activity and accelerate leaf growth (Tei et al., 2000). Nitrogen deficiency leads to chlorosis (yellowing of leaves), weaker growth and reduced yield, while excessive application can result in excessive vegetative growth and lower nutritional value (Elia et al., 1998).

Wang and Li (2004) found that the application of different nitrogen sources (ammonium chloride, ammonium nitrate, sodium nitrate and UREA) positively affects the yield of spinach and Chinese cabbage. However, increasing the amount of nitrogen fertilizer does not lead to a continuous increase in yield, but excessive use can negatively affect plant growth and reduce yield, especially in early harvests. On the other hand, Zhang et al. (2014) found that the highest spinach yield was achieved when the soil had 16.5% moisture in combination with the application of 170 kg ha^{-1} nitrogen. Based on the results obtained, Abdelraouf (2016) states that increasing N rate up to 224 kg N ha^{-1} increased yield (fresh and dry weight as ton ha^{-1}). Also, increasing N rate significantly decreased spinach quality parameters (moisture and dry matter contents and nitrate content).

The ANOVA test for two factors (year and UREA treatment) showed that the statistical significance of differences was observed for all individual factors across all examined characteristics (p<0.01). However, the interaction of factors was not significant for plant height and number of leaves per plant (p>0.05), as shown in Table 5.

Additionally, the variance analysis test indicates that the effects of year and urea treatment, as well as their interaction, contribute highly significantly (Table 5) to the variation in the examined yield characteristics of spinach.

Table 5. ANOVA test at tested parameters, year and treatment of UREA

F-test				
Effect of fertilizers on plant heigh				
Effect	Plant height (cm)	Days taken to first cutting	Number of leaves per plant	Length of leaves per plant (cm)
Year	25.2**	103.4**	8.10**	158.1**
UREA treatment	3496.9**	5165.1**	442.15**	12865.6**
Year x UREA treatment	2.0^{NS}	45.6**	1.35^{NS}	10.9**
Effect of applied fertilizers on the yield characteristics of Spinach				
	Fresh weight of leaves plant^{-1}(g)	Yield pot^{-1} (kg)	Yield ha^{-1} (kg)	
Year	62.7**	70.3**	100673**	
UREA treatment	6466.**7	4659.6**	363924**	
Year x UREA treatment	3.2*	9.0**	351977**	

p<0.05 and p<0.01

This statement is confirmed by the following graphs, which illustrate the trend of changes in the examined characteristics depending on the addition of mineral fertilizer in both analyzed years. With a higher fertilizer application, the properties of spinach-plant height, number of leaves per plant, and length of leaves per plant-increase, while days taken to first cutting decreases (Figure 1).

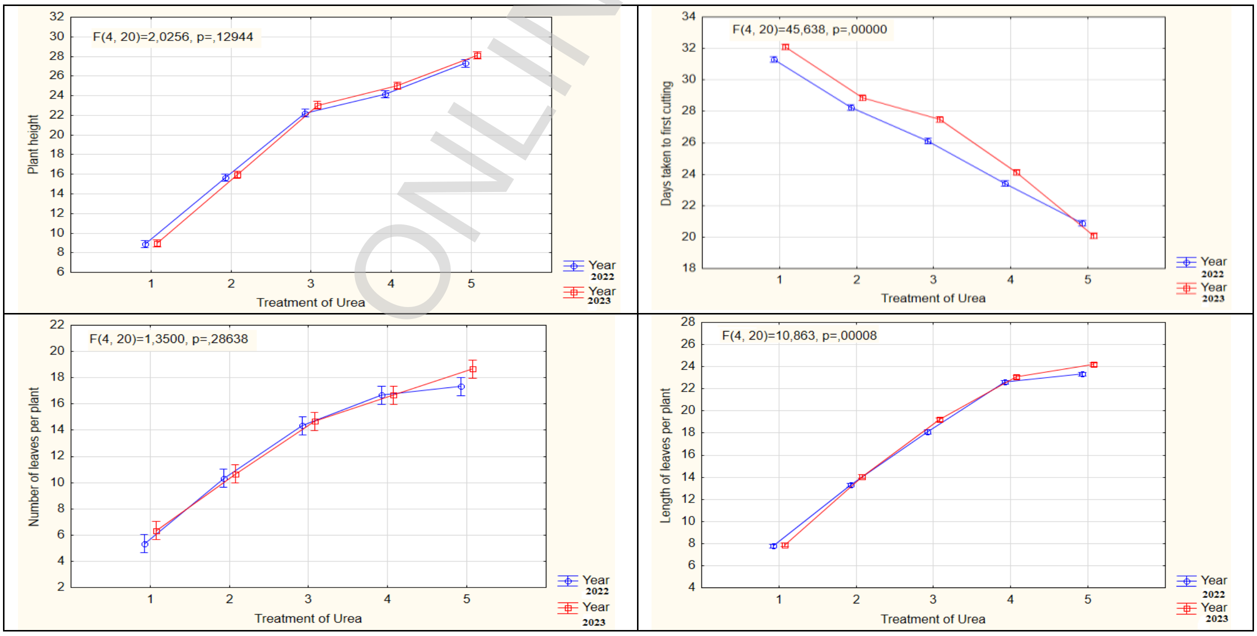

Figure 1. Effect of fertilizers on plant heigh

Figure 2 confirms that the lowest value of the examined spinach properties is in the control variant of fertilizer application, and that with its increase, the value of the examined spinach characteristics significantly rises in both analyzed years. This increase shows a sharp rise up to a fertilizer application of 120 kg ha⁻¹ of UREA, after which the growth becomes more moderate. The correlation between all examined spinach properties indicates a very strong and statistically significant dependence (Table 6, $p<0.05$). The characteristic "days taken to first cutting" has a negative correlation with plant height (cm) and number of leaves per plant, while the other coefficients are positive. The significance of the examined yield characteristics of spinach shows that the relationship between them is positive, very strong, and statistically significant.

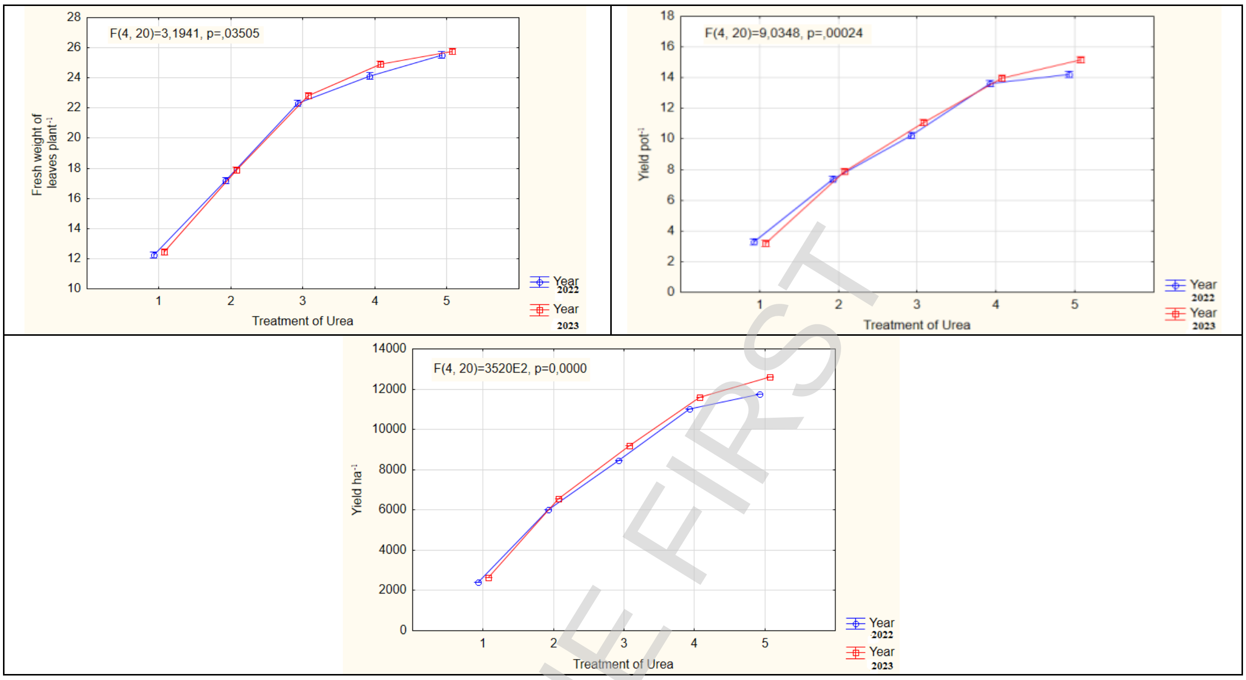

Figure 2. Effect of applied fertilizers on the yield characteristics of Spinach

Table 6. Correlation matrix of the analyzed parameters

Variable	Plant height (cm)	Days taken to first cutting	Number of leaves per plant	Length of leaves per plant (cm)	Fresh weight of leaves plant⁻¹(g)	Yield pot⁻¹ (kg)	Yield ha⁻¹ (kg)
Plant height (cm)	-	-0.942**	0.990**	0.989**	0.996**	0.988	0.989**
Days taken to first cutting		-	-0.938**	-0.946**	-0.927**	-0.953**	-0.951**
Number of leaves per plant			-	0.989**	0.989**	0.989**	0.989**
Length of leaves per plant (cm)				-	0.993**	0.998**	0.998**
Fresh weight of leaves plant⁻¹(g)					-	0.989**	0.991**
Yield pot⁻¹ (kg)						-	0.999**

** Significant at $p<0.05$

Conclusions

The results of this study show a significant impact of different nitrogen fertilization levels in the form of urea on the growth and yield of spinach under greenhouse conditions. Increasing the urea dose led to an increase in plant height, number of leaves, leaf length, and overall yield, while the control group had the lowest values for all parameters. However, at higher urea doses, particularly between 120 and 140 kg ha^{-1}, the increases were smaller, indicating reduced efficiency at higher doses. Additionally, higher nitrogen levels could reduce the time to the first cutting, which may negatively affect plant quality. This study confirms the importance of optimizing nitrogen fertilizer application to achieve high spinach yields, while maintaining quality and minimizing negative ecological consequences. Optimal nitrogen doses are crucial for sustainable production, and the implementation of a balanced approach to plant nutrition is recommended. In future research, the impact of increasing doses of nitrogen on the content of nitrates and nitrites in spinach leaves should be examined in order to ensure the health safety of spinach in addition to the yield.

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Uticaj azotnih đubriva na rast i karakteristike prinosa spanaća

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Sažetak: Ova studija analizira uticaj različitih nivoa đubrenja azotom, u obliku UREA-e, na rast i prinos spanaća (*Spinacia oleracea* L.) u uslovima plasteničke proizvodnje u Raški tokom vegetacionih sezona 2022. i 2023. godine. Eksperiment je postavljen po potpunom slučajnom blok sistemu sa tri ponavljanja, na parceli površine 12 m². UREA je primenjena u različitim dozama (0, 40, 80, 120 i 140 kg ha^{-1}) kako bi se procenio njen uticaj na rast i produktivnost spanaća. Praćeni su ključni parametri kao što su visina biljke, broj dana do prve berbe, broj listova po biljci, dužina lista, sveža masa listova i prinos. Rezultati su pokazali značajne razlike kod većine analiziranih parametara. Sa povećanjem doze UREA, povećavala se visina biljke, broj listova po biljci, dužina lista i prinos, pri čemu su najveće vrednosti zabeležene pri dozi od 140 kg ha^{-1}. Međutim, prekomerne doze pokazale su smanjeni efekat, naročito između 120 kg ha^{-1} i 140 kg ha^{-1}. Kontrolna grupa (bez primene UREA) imala je najniže vrednosti svih parametara. Takođe je primećeno ranije cvetanje i potencijalno smanjenje kvaliteta kod viših doza azota. Studija zaključuje da su optimalni nivoi azota ključni za prinos i kvalitet spanaća, te da je uravnotežen pristup đubrenju neophodan za postizanje održive proizvodnje uz minimizaciju rizika po životnu sredinu.

Ključne reči: spanać, UREA, đubrivo, prinos, rast biljke, produktivnost