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EFFECT OF GROUND COVER MANAGEMENT ON NITRATE CONTENT AND LETTUCE (*Lactuca sativa* L.) YIELD

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ABSTRACT

Ground cover management and woven agrotextile have an important role in lettuce production. However, there is limited information available on their combined effects. This research aimed to assess the influence of black and white geotextile mulching and woven agrotextiles used as plant cover on lettuce yield, soil nitrate content ($N\text{-}NO_{3^-}$) (kg ha^{-1}) and nitrate content in lettuce leaves (mg kg^{-1}). The experiment was set up as a randomized block design with six treatments, in four repetitions and three seasons, in the greenhouse and the open field in Banja Luka, Bosnia and Herzegovina. The applied soil mulching and plant covering treatments significantly increased lettuce yield in both greenhouse and open field. The highest lettuce yields were determined in the black geotextile treatment in both production systems. The $N\text{-}NO_3^-$ content at a depth of 20-40 cm was on average four times higher in the greenhouse than in the open field. The nitrate content in lettuce leaves was on average 95.2% higher in the greenhouse production compared to the lettuce in the open field. The lowest $N\text{-}NO_3^-$ content was recorded in the white geotextile treatment in the open field, while the use of black and white geotextile in the greenhouse led to the highest $N\text{-}NO_3^-$ content in lettuce leaves.

Key words: *geotextile; greenhouse;* ***$N\text{-}NO_3^-$*** *open field; woven agrotextile*

Abbreviations: C – control (uncovered soil); BG – black geotextile; WG – white geotextile; BGWA – black geotextile and covering the plants with woven agrotextiles; WGWA – white geotextile and covering plants with woven agrotextiles; WA – covering plants with woven agrotextiles

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INTRODUCTION

Lettuce (*Lactuca sativa* L.) is a leafy plant belonging to the Asteraceae family and it is one of the most important vegetable crops in the human diet. In Bosnia and Herzegovina, lettuce cultivation covers 915 ha, with an average yield of 7,4 t ha^{-1} (Agency for Statistics of Bosnia and Herzegovina, 2022). In recent years, regulations on nitrate concentrations in vegetables have caused great concern (Dezhangah et al., 2022). To ensure food safety, nitrate levels must remain below the limits prescribed by law: 4000 mg kg^{-1} for lettuce grown in protected area and 2500 mg kg^{-1} in open-field production (EU, 2011).

The use of geotextiles is of great importance in lettuce production, not only for increasing yield but also for promoting environmental protection. Geotextile is a woven or non-woven structure made from natural or synthetic textile fibres used for soil conservation. Soil mulching improves crop growth, increases yield and optimizes water use (Kader et al., 2019). Numerous studies have shown that geotextiles can accelerate plant growth and improve productivity (Bajgai et al., 2014; Tošić et al., 2014; Tosic et al., 2019b). In addition, selecting the appropriate colour of geotextiles is very important in vegetable production (Mutetwa and Mtaita, 2014; Tošić et al., 2012), especially to improve lettuce quality.

Nitrate content in lettuce leaves is significantly influenced by temperature (Liu et al., 2016), nitrogen application (N) fertilizer application (Liu et al., 2014) and the place of production (Anjana and Iqbal, 2007). Accordingly, this research investigates the relationship between N content in the soil (nitrate N) and N and nitrate content in lettuce leaves.

The aim of the research is to assess the influence of geotextile and plant covering with woven agrotextiles on lettuce yield, the content of soil nitrate nitrogen ($N\text{-}NO_3^-$) and the $N\text{-}NO_3^-$ content in lettuce leaves grown in the greenhouse and the open field.

MATERIAL AND METHODS

Experimental conditions

The experiment was set up in a greenhouse and in open-field conditions at the Agricultural Institute of the Republic of Srpska, Banja Luka, Budžak (44°46' N and 17°11' E) during the period from 2011 to 2013. Lettuce was sown in styrofoam containers intended for seedling production in the second half of January 2011, 2012 and 2013. Lettuce seedlings aged 40 days were planted in March 2011, 2012 and 2013 in the greenhouse and the open field, with a row spacing of 25 cm and intra-row spacing of 30 cm. The experiments in the greenhouse and the open field were set up following a randomized block system with six treatments and four repetitions. The area of each basic plot was 5 m^2 (1 m × 5 m). The research included the following treatments: **C –** control (uncovered soil); BG – black geotextile; WG – white geotextile; BGWA – black geotextile and plant covering with woven agrotextiles; WGWA – white geotextile and plant covering with woven agrotextiles; WA – plant covering with woven agrotextiles.

Based on an agrochemical analysis of the soil, NPK fertilizer (formulation 7:20:30) at a rate of 640 kg ha^{-1} and calcium ammonium nitrate fertilizer (KAN 27%) at 300 kg ha^{-1} were applied in the soil before planting lettuce. Fertilization was performed twice during the growing season using a water-soluble NPK fertilizer produced by Yara (formulation 10-5-26) applied at a rate of 1 g per plant. Black and white geotextiles (each measuring 1.2 m in width and 5.5 m in length) were used to cover the soil, while agrotextiles were used to directly cover the plants. Basic and surface tillage was performed with a machine at a depth of 15 to 20 cm. Black and white geotextile soil covering and agrotextiles plant covering were applied in the first decade of March in 2011, 2012 and 2013. During the lettuce growing season, irrigation was applied four times. Standard soil properties were analyzed before setting up the experiment in both greenhouse and the open field. Optimal soil moisture was ensured using a drip irrigation system. Four irrigations were applied, every 15 days in the open field and the greenhouse.

Soil reaction

The humus content in the soil was determined using a colorimetric method (Resulović et al., 1982) (SRPS ISO 14235: 2005). pH value was measured potentiometrically using "METREL" MA 3657 pH meter, in soil suspension with water and soil suspension with 1 M KCl (ratio 1:2.5) (SRPS ISO 10390: 2007). Nitrate N ($N\text{-}NO_3^-$) was determined using the Bremner method, which involves the extraction of mineral nitrogen forms (NO_2^-, NO_3^-) with 2 N KCl at a 1:10 ratio, followed by double distillation. Soil samples were collected from two depths (0–20 cm and 20–40 cm) immediately before lettuce harvest (Bremner and Mulvaney, 1982). The nitrate content in the leaves was determined using the Xylenol method (Hartley and Asai, 1960).

Soil conditions

The research was conducted on an alluvial soil, fluvisol (FAO, 2015). Before setting up the experiment, the standard properties of the soil were analyzed for both greenhouse and open-field conditions (Table 1). The chemical analysis showed that the soil in the greenhouse had a favourable pH value for lettuce cultivation. In addition, the soil in the greenhouse had high humus content (6.0% and 5.5%), while the humus content in the open field was moderate (3.1% and 3.2%) (Ubavić and Bogdanović, 2001). Data on N content indicated a good supply of nitrogen in the greenhouse, and low nitrogen content in the open field (Škorić, 1991).

Table 1. Agrochemical analysis of soil in the open field and the greenhouse before the first year of the research

Location	Depth (cm)	pH in H_2O	pH in KCl	Humus (%)	$N\text{-}NO_3^-$ (kg ha^{-1})
Greenhouse	0-20	7.6	7.3	6.0	401.4
	20-40	7.1	6.8	5.5	614.4
Open field	0-20	8.3	7.5	3.1	86.7
	20-40	8.5	7.5	3.2	68.7

Air temperature and precipitation

During the lettuce transplanting period in the first half of March, temperatures reached 25.2°C (Figure 1), which affected the lettuce seedling. Since the greenhouse was not heated, the temperatures in the greenhouse directly depended on the temperatures in the open field. Figure 2 shows the average monthly precipitation (mm) recorded in the area of Banja Luka during the experiment period.

Figure 1. Minimum, maximum and average daily air temperature (°C) recorded during the experiment period

Figure 2. The average monthly precipitation (mm) for the area of Banja Luka

Statistical Analysis

Data analysis was conducted using InfoStat software (Infostat, Argentina). Analysis of variance was performed for each year. Tukey's test was used to compare means. The dependences between individual studied properties were examined applying logistic linear regression.

RESULTS AND DISCUSSION

The $N\text{-}NO_3^-$ content in the soil in both the open field and greenhouse before planting was higher compared to the $N\text{-}NO_3^-$ content measured immediately before harvest. Most nitrogen is introduced into the soil through N fertilizers and residual N (Bošković-Rakočević et al., 2023; Güereña et al., 2015). In the open field, the $N\text{-}NO_3^-$ content was influenced by plant uptake of $N\text{-}NO_3^-$, soil cover, plant cover and precipitation, while the $N\text{-}NO_3^-$ content in the greenhouse was affected by the same factors, except for precipitation. The seasonal $N\text{-}NO_3^-$ leaching can be significant, as shown by a substantial decrease in its concentration in the soil layer from 0 to 20 cm, depending on soil texture, climatic conditions, irrigation and tillage (Zhao et al., 2016). Similar findings were reported by Jungić et al. (2017) and West et al. (2014), who stated that mulching reduces the leaching of N-NO_3^- into deeper layers, contributing to better utilization of N fertilizers and reducing the risk watercourse pollution with N. The N-NO_3^- content was three times higher in the greenhouse compared to the open-field production (Table 2), which is a consequence of the N-NO_3^- leaching in the open field after precipitation. The N-NO_3^- content ranged from 57.78 kg ha^{-1} in the open field under woven agrotextile treatment to 295.05 kg ha^{-1} in the greenhouse control. In all treatments with mulching and plant covering with agrotextiles, the N-NO_3^- content before harvesting lettuce was lower than its content measured before setting up the experiment. This reduction is a consequence of the N-NO_3^- adoption by plants and partly leaching caused by irrigation. Previous studies have shown that fully irrigated lettuce provides significantly higher yields (Villa e Vila et al., 2024; Farooq et al., 2019).

Table 2. Content of N-NO_3^- (kg ha^{-1}) in the soil at a depth of 0-20 cm depending on the system (mulching and covering) and place of production (open field and greenhouse) for lettuce cultivation

Treatments	2011			2012			2013		
	Open field	**Green house**	**Average**	**Open field**	**Green house**	**Average**	**Open field**	**Green house**	**Average**
C	95.24g	295.05a	195.15A	75.97g	217.28d	146.62B	45.63g	203.83b	124.73BC
BG	52.95jk	280.00b	166.48B	42.07jk	249.35c	145.71B	52.16efg	260.85a	156.51A
WG	60.75hi	148.80e	104.78E	52.14hi	159.45f	105.80C	62.14ef	174.18c	118.16CD
BGWA	47.18k	259.15c	153.17C	37.35k	259.15b	148.25B	48.55fg	176.93c	112.74D
WGWA	65.60h	198.00d	131.80D	55.44h	296.68a	176.06A	67.94e	195.43b	131.68B
WA	57.78ij	140.85f	99.31F	46.76ij	169.78e	108.27C	58.04efg	138.53d	98.28E
Average	63.25B	220.31A	141.78	51.62B	225.28A	138.45	55.74B	191.62A	123.68

Legend: Different letters indicate a significant difference ($p<0.05$). Lowercase letters indicate the interaction between the treatments and the place of production (open field and greenhouse) within one research year. Capital letters indicate the difference between the system average and the place of production during the spring season over a three-year period.

In the greenhouse production, the highest N-NO_3^- content in the 0-20 cm layer was measured in the treatments using white geotextile and woven agrotextile. In contrast, in the open field, the highest content was recorded in the control treatment (75.97 kg ha^{-1}). The N-NO_3^- content was significantly higher in the greenhouse compared to the open field (Table 3). The impact of geotextile application on soil temperature and moisture usually decreases with soil depth (Díaz-Hernández and Salmerón, 2012; Heißner et al., 2005). The increase in the nitrate N content in the soil at the 0-20 cm depth resulted in increased N-NO_3^- content in lettuce leaves. Similar findings were reported by Vargas et al. (2017). Hoque et al. (2010) found that higher N levels in soil led to increased nitrate accumulation in lettuce. At all depths, an increase in N-NO_3^- content in the soil resulted in higher NO_3^- content in lettuce leaves. The maximum nitrate values recorded in the study remained below the limits set by the European Commission (4000 mg kg^{-1} for lettuce grown in protected area and 2500 mg kg^{-1} for lettuce cultivated in open fields) (EU, 2011).

Table 3. N-NO_3^- content (kg ha^{-1}) in the soil at 20-40 cm depth depending on the system (mulching and covering) and place of production (open field and greenhouse) for lettuce cultivation

Treatments	2011			2012			2013		
	Open field	**Green house**	**Average**	**Open field**	**Green house**	**Average**	**Open field**	**Green house**	**Average**
C	151.43f	649.35a	400.39A	111.10f	540.53a	325.81A	131.24f	650.85a	391.04A
BG	107.60g	508.30b	307.95B	77.12i	404.55d	240.84D	87.39i	505.55b	296.47B
WG	104.08g	501.15bc	302.61B	101.89g	402.15d	252.02C	106.14g	406.65c	256.40C
BGWA	87.65h	495.65c	291.65C	87.28h	412.90c	250.09C	95.55hi	498.90b	297.23B
WGWA	101.68g	309.78e	205.73E	99.89g	429.60b	264.74B	99.62gh	298.50d	199.06D
WA	86.78h	346.4d	216.59D	86.75h	202.90e	144.82E	100.91gh	263.65e	182.28E
Average	106.53B	468.44A	287.48	94.00B	398.77A	246.38	103.47B	437.35A	270.41

Legend: Different letters indicate a significant difference ($p<0.05$). Lowercase letters indicate the interaction between the system (mulching and covering) and the place of production (open field and greenhouse) in the spring of season in a three-year period. Capital letters indicate the difference between the system average and the place of production in the spring season.

The use of geotextiles and woven agrotextiles, both in the greenhouse and open field, significantly reduces the N-NO_3^- content in the soil. Mulching with geotextile enhances the water regime of the soil, while simultaneously improving the accessibility of N (Kim et al., 2015). The average N-NO_3^- content in the greenhouse (191.62 kg ha^{-1}) was significantly higher compared to the open field (55.74 kg ha^{-1}). The highest average N-NO_3^- content was recorded in the treatment with black geotextile, while the lowest content was found in the treatment with woven agrotextile (WA). Season N-NO_3^- leaching can be substantial, as indicated by a large decrease in the N-NO_3^- concentration in the 0-20 cm soil layer, depending on soil texture, climatic conditions, irrigation and tillage (Fan et al., 2020). On average, mulching led to a decrease in the average nitrate content compared to the control. Our results can be attributed to a combination of microclimatic conditions and indirect effects of mulching. Nitrate content increases with rising temperatures and high light intensity, especially when nitrogen supply is high.

Table 4. Content of N-NO_3^- (mg/kg) in lettuce leaves depending on the system (mulching and covering) and year of production

Treatments	**2011**	**2012**	**2013**	**Average**
C	2284.5a	1959.5f	2121.0d	2121.67A
BG	2224.5b	1875.5h	2222.0b	2107.33B
WG	1530.0k	1573.5j	2159.5c	1754.33E
BGWA	1465.5l	2105.5d	1998.0e	1856.33D
WGWA	1458.5l	1740.5i	1960.5f	1719.83F
WA	1906.0g	1900.5g	1962.5f	1923.00C
Average	1811.5C	1859.17B	2070.58A	1913.75

Legend: Different letters indicate a significant difference ($p<0.05$). Lowercase letters indicate the interaction between the system (mulching and covering) and the year of production. Capital letters indicate the difference between the system average and the year of production.

Table 5. N-NO3- content (mg/kg) in lettuce leaves depending on the place (open field and greenhouse) and year of production

Year	**Open field**	**Greenhouse**	**Average**
2011	1264.83e	2358.17c	1811.50C
2012	1270.33e	2448.00b	1859.17B
2013	1354.17d	2787.00a	2070.58A
Average	1296.44B	2531.06A	1913.75

Legend: Different letters indicate a significant difference ($p<0.05$). Lowercase letters indicate the interaction between the system (mulching and covering) and year of production. Capital letters indicate the difference between the system average and year of production.

The lowest average N-NO_3^- content in lettuce leaves was observed in the treatment using white geotextile and agrotextile, while the highest average N-NO_3^- content was recorded in the control treatment (Table 4). The N-NO_3^- levels in lettuce leaves were significantly higher in the greenhouse compared to the open field (Table 5). Light exposure affects vegetative growth and the concentration of nitrates accumulated by plants. The lettuce grown in the open field receives higher sunlight intensity compared to the plants cultivated in the greenhouse. As a result, nitrate content in lettuce produced in the greenhouse is significantly higher than in the open-field lettuce.

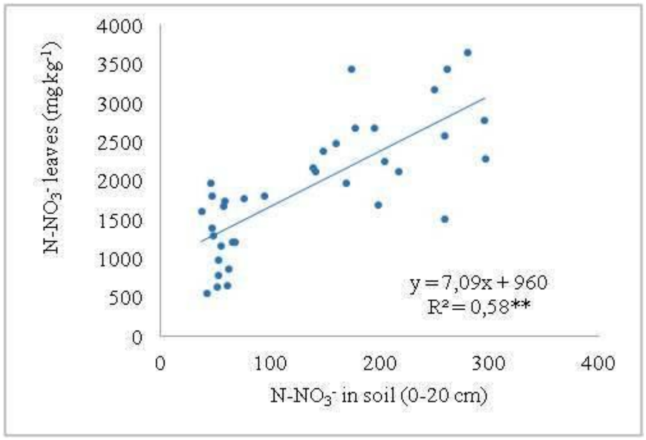

Figure 3. Relationship between N-NO_3^- content in soil and N-NO_3^- content in lettuce leaves (depth 0-20 cm) in the greenhouse and the open field

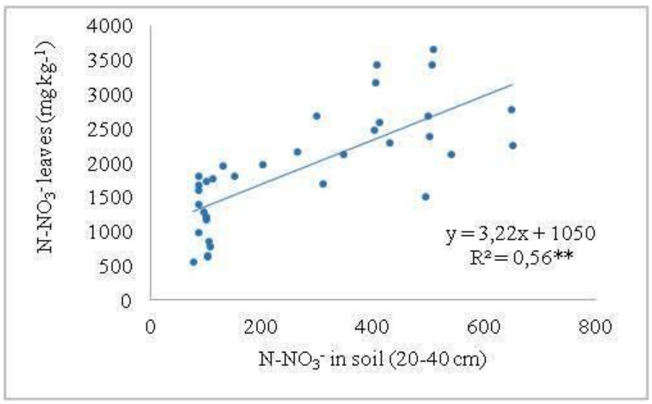

Figure 4. Relationship between N-NO_3^- content in soil and N-NO_3^- content in lettuce leaves (depth 20-40 cm) in the greenhouse and open field

The average lettuce yield in all years of the research was 40.83 t/ha, with significant variations observed depending on the system and the production year. The highest yield was achieved when the soil was covered with black geotextile (Table 6). Growing lettuce on non-mulched soil proved to be an inadequate option for achieving the maximum total yield. The results obtained in this experiment align with previous research indicating that the lettuce yield is affected by production conditions, nutrition and harvesting (Sinkovič et al., 2023; Lee et al., 2022; Tošić et al., 2019a). The influence of mulching and plant cover on the reduction of N-NO_3^- content at the examined depths can be associated to their positive effects on increasing the lettuce yield (Tesfa et al., 2018). Mulching has been shown to increase the total yield and the yield of lettuce heads (Chen et al., 2019), changing the efficiency of N utilization, which result in reduced N-NO_3^- content in the soil. The effects of geotextiles on soil temperature and moisture typically decrease with soil depth, becoming mostly negligible below 40 cm (Díaz-Hernández and Salmerón, 2012). An increase of nitrate N content in the soil at the 0-20 cm and 20-40 cm depths leads to higher N-NO_3^- content in lettuce leaves, clearly indicating the connection between soil properties and lettuce quality. Increased N levels in the soil promote nitrate accumulation in lettuce leaves (M'hamdi et al., 2014). The lowest N-NO_3^- content in lettuce leaves was recorded in lettuce production in the open field in the treatment with white geotexitle. In all treatments, the nitrate concentration in lettuce was below the limit prescribed by the European Commission (EU, 2011). On the other hand, the highest N-NO_3^- content in lettuce leaves was observed in the treatment using white and black geotextile in the greenhouse. These results align with the findings of Tošić et al. (2014), who reported that increased nitrate levels are associated with higher temperatures, i.e. more intense aeration during that period. Covering the soil with white geotextile reduces the nitrate content in lettuce leaves, as also observed by Guiller et al. (2023) in their research. The connection between the N-NO_3^- content in the soil and in lettuce leaves is essential for production of high-quality lettuce in both greenhouse and open-field systems. Figure 3 shows a positive regression between the N-NO_3^- content in the soil and the N-NO_3- content in lettuce leaves both in the greenhouse and open field. Also, an increase in nitrate content in the leaves was associated with higher nitrate N concentrations at greater depths (20-40 cm) (Figure 4), clearly indicating the connection between soil properties and lettuce quality.

Table 6. Yield of lettuce (t/ha) depending on the system (mulching and covering) and year of production

Treatments	2011	2012	2013	Average
C	37.63k	34.14n	37.82k	36.53F
BG	50.93a	44.10d	48.92b	47.98A
WG	46.10c	40.03g	43.82d	43.32B
BGWA	40.95f	37.72k	41.32ef	39.99C
WGWA	39.39h	37.00l	38.86i	38.42E
WA	41.45e	36.45m	38.37j	38.75D
Average	42.74A	38.24C	41.52B	40.83

Legend: Different letters indicate a significant difference ($p<0.05$). Lowercase letters indicate the interaction between the system (mulching and covering) and the year of production. Capital letters indicate the difference between the system average and the year of production.

The increase in lettuce yield resulted in the decrease of N in the soil. According to Franquera and Mabes (2015), the use of geotextils enhances both the yield and quality of vegetables. The results of this research clearly demonstrate that the application of soil cover and plant cover reduces the $N\text{-}NO_3^-$ content in the soil, both in the open field and the greenhouse.

CONCLUSION

Mulching and plant covering reduced the $N\text{-}NO_3^-$ content in the soil both in the open field and the greenhouse. The increase of the nitrate content in the soil at the 0-20 cm depth resulted in higher $N\text{-}NO_3^-$ content in lettuce leaves. Also, higher nitrate concentration at the 20-40 cm depth led to increased nitrate content in lettuce leaves, clearly indicating the relationship between soil properties and lettuce quality. The applied soil mulching and plant covering treatments significantly increased lettuce yield both in the greenhouse and the open field. The highest yields were observed in both production systems in the black geotextile treatments. These findings could help producers choose the most efficient technologies to achieve the highest yield and nutritional value of lettuce.

Authors' Contribution: Conceptualization – I.T.; Data curation – I.T.; Formal analysis – I.T..; Funding acquisition – I.T.; Investigation – I.T. and J.Č.; Methodology – I.T.; Project administration – I.T.; Resources – I.T., J.Č. and A.L.G.; Software – I.T.; Supervision - I.T., J.Č. and A.L.G; Validation - I.T. and J.Č.; Visualization – I.T.; Writing – original draft – I.T.; Writing – review & editing - I.T., J.Č. and A.L.G. All authors have read and agreed to the published version of the manuscript.

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REFERENCES

Agency for statistics of Bosnia and Herzegovina. 2022. Harvested area, production and yield by crop. [Cited 18 May 2024]. https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://bhas.gov.ba/%3Flang%3Den&ved=2ahUKEwiV9eDJhK-NAxX2m_0HHc-aAv8QFnoECBwQAQ&usg=AOvVaw02zMAP5SpAEqcFvpdUmCSl

Anjana, S.U. & Iqbal, M. 2007. Nitrate accumulation in plants, factors affecting the process, and human health implications. A review. *Agronomy for Sustainable Development*, 27: 45-57. https://doi.org/10.1051/agro:2006021

Bajgai, Y., Kristiansen, P., Hulugalle, N. & Mchenry, M. 2014. Effect of residue management and conventional and organic soil management systems on crop yields and weed biomass. *Acta Horticulturae*, 1018: 227–234. https://doi.org/10.17660/ActaHortic.2014.1018.23

Bošković-Rakočević, Lj., Pavlović, N., Mladenović, J., Zdravković, J., Tošić, I. & Marjanović, M. 2023. Yield and quality of lettuce (*Lactuca sativa* L.) depending on variety and type of nitrogen fertilizer. *Emirates Journal of Food and Agriculture*, 35(8): 715-721. https://doi.org/10.9755/ejfa.2023.3128

Bremner, J.M. & Mulvaney, C.S. 1982. Salicylic acid-thiosulfate modification of Kjeldahl method to include nitrate and nitrite. In: A.L. Page, eds. *Methods of soil analysis*. *Part 2. Chemical and microbiological properties*. Second edition, pp. 621-622. Agronomy. Madison, Wisconsin, USA.

Chen, Z., Han, Y., Ning, K., Luo, C., Sheng, W., Wang, S., Fan, S., Wang, Y. & Wang, Q. 2019. Assessing the performance of different irrigation systems on lettuce (*Lactuca sativa* L.) in the greenhouse. *PLoS ONE* 14(2): e0209329. https://doi.org/10.1371/journal.pone.0209329

Dezhangah, S., Nazari, F., Kamali, K., Hosseini, M.J. & Mehrasbi, M.R. 2022. A survey on nitrate level in vegetables to assess the potential health risks in Iran. *International Journal Food Properties*, 25(1): 1958-1973. https://doi.org/10.1080/10942912.2022.2117377

Díaz-Hernández, J.L. & Salmerón, T. 2012. Effects of a plastic cover on soil moisture change in a Mediterranean climatic regime. *Soil Use and Management*, 28(4): 596–605. https://doi.org/10.1111/sum.12000

EU (European Union). 2011. [Cited 16 May 2024]. https://www.legislation.gov.uk/eur/2011/1258

Fan, Y., Hao, X., Ding, R. & Kang, S. 2020. Soil water and nitrogen dynamics from interaction of irrigation and fertilization management practices in a greenhouse vegetable rotation. *Soil Science Society of America Journal*, 84(3): 901-913. https://doi.org/10.1002/saj2.20048

FAO. 2015. World Reference Base for Soil Resources 2014, Update 2015 - International soil classification system for naming soils and creating legends for soil maps. World soil resources reports 106, Rome. https://openknowledge.fao.org/server/api/core/bitstreams/bcdecec7-f45f-4dc5-beb1-97022d29fab4/content

Farooq, M., Hussain, M., Ul-Allah, S. & Siddique, K.H.M. 2019. Physiological and agronomic approaches for improving water-use efficiency in crop plants. *Agricultural Water Manag*ement, 219: 95–108. https://doi.org/10.1016/j.agwat.2019.04.010

Franquera, E.N. & Mabesa, R.C. 2015. Effect of plastic mulch color on leaf anatomy of lettuce (*Lactuca sativa* L.). *Current Agriculture Research Journal*, 3(2): 105-108. http://dx.doi.org/10.12944/CARJ.3.2.03

Güereña, D.T., Lehmann, J., Thies, J.E., Enders, A., Karanja, N. & Neufeldt, H. 2015. Partitioning the contributions of biochar properties to enhanced biological nitrogen fixation in common bean (*Phaseolus vulgaris*). *Biology and Fertility of Soils*, 4: 479-491. https://doi.org/10.1007/s00374-014-0990-z

Guiller, A.E., Cherry, M.A., Romil, L.A., Richard, L.M.N. & Alejandro, A.J. 2023. The influence of different mulching on the productivity of lettuce (*Lactuca sativa* L.). *International Journal of Multidisciplinary Research and Publications (IJMRAP)*, 5(11): 144-150.

Hartley, A.M. & Asai, R.I. 1960. Suggested method for nitrate determination with 2,6-xylenol reagent. *Journal American Water Works Association*, 52(2): 255-258. https://www.jstor.org/stable/41256202

Heißner, A, Schmidt, S., & Von Elsner, B. 2005. Comparison of plastic films with different optical properties for soil covering in horticulture: test under simulated environmental conditions. *Journal of the Science of Food and Agriculture*, 85: 539 – 548. https://doi.org/10.1002/jsfa.1862

Hoque, M.M., Ajwa, H. & Othman, M. 2010. Yield and postharvest quality of lettuce in response to nitrogen, phosphorus and potassium fertilizers. *HortScience*, 45(10): 1539–1544. https://doi.org/10.21273/HORTSCI.45.10.1539

Jungić, D., Gunjača, J., Herak-Ćustić, M., Šimunić, I., Ban, D. & Sraka, M. 2017. Content of mineral N in soil and tomato yields considering fertigation and mulch. *Agriculturae Conspectus Scientificus*, 82(4): 361-365.

Kader, M.A., Singha, A., Begum, M.A., Begum, M.A., Jewel, A., Khan, F.H. & Khan, N.I. 2019. Mulching as water-saving technique in dryland agriculture: review article. *Bulletin of the National Research Centre*, 43: 147. https://doi.org/10.1186/s42269-019-0186-7

Kim, Y., Seo, Y., Kraus, D., Klatt, S., Haas, E., Tenhunen, J. & Kiese, R. 2015. Estimation and mitigation of N_2O emission and nitrate leaching from intensive crop cultivation in the Haean catchment, South Korea. *Science of the Total Environment*, 529: 40–53. https://doi.org/10.1016/j.scitotenv.2015.04.098

Lee, J.S., Chandra, D. & Son, J. 2022. Growth, physicochemical, nutritional, and postharvest qualities of leaf lettuce (*Lactuca sativa* L.) as affected by cultivar and amount of applied nutrient solution. *Horticulturae*, 8(5): 436. https://doi.org/10.3390/horticulturae8050436

Liu, C.W., Sung, Y., Chen, B.C. & Lai, H.Y. 2014. Effects of nitrogen fertilizers on the growth and nitrate content of lettuce (*Lactuca sativa* L.). *International Journal of Environmental Research and Public Health*, 11(4): 4427-4440. https://doi.org/10.3390/ijerph110404427

Liu, H., Fu, Y.M., Yu, J. & Liu, H. 2016. Accumulation and primary metabolism of nitrate in lettuce (*Lactuca sativa* L.) grown under three different light sources. *Communications in Soil Science and Plant Analysis*, 47(17): 1994-2002. https://doi.org/10.1080/00103624.2016.1225076

M'Hamdi, M., Boughattas, I., Chikh-Rouhou, H., Souhli, E. & Bettaieb, T. 2014. Effect of different levels of nitrogen fertilizer on morphological and physiological parameters and nitrates accumulation of lettuce cultivars (*Lactuca sativa* L.). *Research in Plant Biology*, 4(4): 27-38.

Mutetwa, M. & Mtaita, T. 2014. Effects of mulching and fertilizer sources on growth and yield of onion. *Journal of Global Innovations in Agricultural and Social Sciences*, 2(3): 102-106. https://doi.org/10.17957/JGIASS/2.3.561

Resulović, H., Jovandić, P. & Bisić-Hajro, Dž. 1982. *Mali pedološki priručnik* [*A small pedological manual*]. Poljoprivredni fakultet, Univerzitet u Sarajevu [Faculty of Agriculture, University of Sarajevo].

Sinkovič, L., Kokalj Sinkovič, D. & Ugrinović, K. 2023. Yield and nutritional quality of soil-cultivated crisphead lettuce (*Lactuca sativa* L. var. *capitata*) and corn salad (*Valerianella* spp.) harvested at different growing periods. *Food Science & Nutrition*, 11(4): 1755-1769. https://doi.org/10.1002/fsn3.3205

Škorić, A. 1991. *Sastav i svojstva tla, pedološki i biljni ekološki značaj* [*Soil composition and properties, pedological and plant ecological significance*]. Agronomski fakultet [Faculty of Agriculture], Zagreb, Croatia.
Tesfa, T., Asres, D. & Woreta, H. 2018. Lettuce (*Lactuca sativa* L.) yield and yield components as affected by mulching at Teda, Centeral Gondar, Ethiopia. *International Journal of Scientific Research and Management*, 6(9): 190-194. https://doi.org/10.18535/ijsrm/v6i9.ah01
Tošić, I., Ilin, Ž., Maksimović, I., Bogdanović, D. & Dardić, M. 2012. Utjecaj malčiranja i izravnog prekrivanja na sadržaj nekih hranjivih elemenata u salati [The effect of mulching and direct covering on content of some nutrient elements in lettuce]. *47th Croatian and 7th International Symposium on Agriculture, 13-17 February 2012.* Opatija, Croatia, 429-431.
Tošić, I., Ilin, Ž., Maksimović, I. & Pavlović, S. 2014. The effect of plant mulching and covering on the lettuce yield and nitrate content (*Lactuca sativa* L.). *African Journal of Agricultural Research*, 9(23): 1774-7177. https://doi.org/10.5897/AJAR2012.856
Tošić, I., Mirosavljević, M., Pržulj, N. & Stošić, M. 2019a. Yield and content of nutrient elements in various cultivars of lettuce depending from production method. *Genetika*, 51: 757-768. https://doi.org/10.2298/GENSR1902757T
Tosic, I., Mirosavljevic, M., Przulj, N., Trkulja, V., Pesevic, D. & Barbir, J. 2019b. Effect of geotextile and agrotextile covering on productivity and nutritional values in lettuce. *Chilean Journal of Agricultural Research*, 79 (4): 523-530. http://dx.doi.org/10.4067/S0718-58392019000400523
Ubavić, M. & Bogdanović, D. 2001. *Agrohemija* [*Agrochemistry*]. Institut za ratarstvo i povrtarstvo [Institute of Field and Vegetable Crops], Novi Sad, Serbia.
Vargas, P.F., Zecchini, A.C., Soares, R.S., Duarte, L.S. & Silva, E.H.C. 2017. Performance of crispy lettuce cultivars in different soil covers. *Comunicata Scientiae*, 8(4): 514-520. https://doi.org/10.14295/cs.v8i4.1942
Villa e Vila, V., Marques, P.A.A., Gomes, T.M., Nunes, A.F., Montenegro, V.G., Wenneck, G.S. & Franco, L.B. 2024. Deficit irrigation with silicon application as strategy to increase yield, photosynthesis and water productivity in lettuce crops. *Plants*, 13(7): 1029. https://doi.org/10.3390/plants13071029
West, P.C., Gerber, J.S., Engstrom, P.M., Mueller, N.D., Brauman, K.A., Carlson, K.M., Cassidy, E.S., Johnston, M., Macdonald, G.K., Ray, D.K. & Siebert, S. 2014. Leverage points for improving global food security and the environment. *Science*, 345(6194): 325–328. https://doi.org/10.1126/science.1246067
Zhao, X., Christianson, L.E., Harmel, D., Pittelkow, C.M. 2016. Assessment of drainage nitrogen losses on a yield-scaled basis. *Field Crops Research*, 199: 156–166. https://doi.org/10.1016/j.fcr.2016.07.015