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Effect of geotextile and agrotextile covering on productivity and nutritional values in lettuce

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ABSTRACT

In order to optimize the lettuce (*Lactuca sativa* L.) production in greenhouses and to evaluate how a usage of mulching and covering plants with woven agrotextile affects its yields, N content, nitrate, Zn and vitamin C in lettuce leaves, a 2-yr experiment was established. In the experiments, black and white plastic foils were used for mulching before planting, and woven agrotextile for plant covering after planting. The effect of each, as well as combination of them, on lettuce growth and productivity was evaluated. The experiment involved six treatments: control (without mulch), polyethylene black plastic mulch, polyethylene white plastic mulch, polyethylene black plastic mulch and woven agrotextile, polyethylene white plastic mulch and woven agrotextile, and woven agrotextile. In the first growing season the yield was 23% higher when polyethylene black plastic mulch was used compared to the control. In the second growing season the yield was 29% higher when polyethylene black plastic mulch was used compared to the control. Nitrogen content decreased 9% when the woven agrotextile was used compared to the control. Polyethylene black plastic mulch and polyethylene black plastic mulch with agrotextile reduced Zn content compared to the control. Vitamin C content increased 21% when woven agrotextile was used compared to the control. The overall effect of mulching and covering plants with woven agrotextile showed positive effect on lettuce production. The results obtained could assist lettuce growers in selecting most effective production technologies in order to achieve highest yield and nutritional value in this crop.

Key words: Lettuce, nitrate, nitrogen, plastic mulch, vitamin C, zinc, woven agrotextile.

INTRODUCTION

In South Eastern Europe countries, such as Bosnia and Herzegovina, open field production of lettuce (*Lactuca sativa* L.) was dominant until several years ago, when an increasing trend of growing lettuce in greenhouses started to substitute traditional growing. Greenhouse production is very intensive, which gives producers the advantage to rotate crops throughout the year (Niari et al., 2012; Tringovska et al., 2015). Due to the greenhouse production and availability of numerous high yielding cultivars that could be well grown from early spring until late summer, lettuce is available on markets almost throughout the year (Theurl et al., 2017).

The different plastic mulch colours and woven agrotextile for plant covering are used for improvement of vegetable production. Plastic mulch application is effective in increasing soil temperature, conserving soil moisture and yield increase (Kumar and Lal, 2012; Tosic et al., 2014). Woven agrotextile is made of natural fibres and is used as a protection of young seedling from cold and to increase yield (Manna et al., 2018). It is a challenge to find the most optimum mulching and woven agrotextile combination. Selection of the appropriate colour mulch in the lettuce production is important for achieving higher yields and better quality. In order to achieve high yield and better quality of vegetables, apart

from adequate adjustment of various production technologies, it is necessary to select proper cultivars, since besides the variation in yield, there is significant genotypic difference in nutritional quality and antioxidant traits in lettuce (Rouphael et al., 2017).

Nitrogen is an important element for successful plant development. It is of primary importance because it has several important roles in metabolic and regulatory processes in plants. However, the rational use of N fertilizers is extremely important because the accumulation of nitrates in lettuce leaves depends on the applied amount of N fertilizer. Lettuce may contain considerable amounts of nitrate (Zhou et al., 2013; Iammarino et al., 2014). Since lettuce is used fresh for human consumption, exceeded nitrate concentrations in lettuce may cause health problems (Keszei et al., 2013). High concentrations of nitrate in vegetables have led the European Union to introduce the limits of nitrate concentration in lettuce in order to reduce the consumption of nitrate by consumers (Commission regulation Nr 1258/2011; European Union, 2011). Accumulation of nitrate in lettuce plants is complex, because it is affected by both genetic and environmental factors. Nitrate content in leaf lettuce depends on various production technologies (Aires et al., 2013), as well as genotype. In conventional production, there is a greater content of vitamins and antioxidants and a lower content of nitrates than in organic-grown vegetables (Sobieralski et al., 2013). Vitamin C has an important role in the human body by increasing the resistance of organism to viral and bacterial infections. It is considered an important indicator of lettuce quality (Cometti et al., 2011).

Lettuce is rich in minerals and vitamins and is therefore essential in human nutrition (White and Brown, 2010). Spinach and lettuce can accumulate heavy metals (Zn, Mn, Fe and Cu) in their tissues (Uwah et al., 2012). Zinc is an element essential for maintaining good health throughout life (Radwan and Salama, 2006). Lettuce is one of the plant species that easily absorbs metals. Because of the high amounts of metals in soil, product quality can be reduced due to accumulation of metals in plants (Polat et al., 2008). The main objective of this experiment was to examine the impact of mulching and covering plants with woven agrotextile on the content of N, nitrate, Zn and vitamin C in lettuce leaves, as well as to evaluate their impact on the yield of different lettuce cultivars.

MATERIALS AND METHODS

Experimental data

The experiment was conducted in a greenhouse at the experimental field of the National Agricultural Institute of Republika Srpska in Banja Luka on the location Lazarevo (44°46' N, 17°11' E) in a 2-yr period (2012 and 2013). The soil of the experimental field is classified as Fluvisol (IUSS Working Group WRB, 2015). Factorial experiment was set as randomized block design. Factor 1 was cultivar, with two levels ('Nizzi' and 'Devonia'), and factor 2 was the cover system, with six levels. The area of one plot was 5 m^2 (1 m × 5 m). In each plot lettuce was planted in 4 rows, 16 plants per row. Lettuce seeds were sown in Styrofoam containers on the Tref substrate (Jiffy, Singapore) in the second half of January and seedlings were transplanted 40 d later, with a row spacing of 25 cm and the distance between plants of 30 cm. In total, 3072 plants were used, of that 1536 'Nizzi' plants and another 1536 'Devonia' plants were organized in parallel distribution. Lettuce cropping cycle from planting to picking lasted 60 d. In the experimental field, for mulching before planting the following were used: black plastic foil (thickness 22 μm with 64 holes on 5 m^2) and white plastic foil (thickness 30 μm with 64 holes on 5 m^2), and woven agrotextile (made of natural fibres, 25 g m^{-2}) for plant covering after planting. The experiment involved six treatments: control (CO), polyethylene black plastic mulch (BPF), polyethylene white plastic mulch (WPF), a combination of polyethylene black plastic mulch and woven agrotextile (BPFWA), a combination of polyethylene white plastic mulch and woven agrotextile (WPFWA) and woven agrotextile (WA). Before the planting of lettuce, NPK fertilizer (7:20:30, Petrokemija, Kutina, Croatia) was applied to soil in the amount of 640 and 300 kg ha^{-1} with calcium ammonium nitrate fertilizer (KAN 27% N, Petrokemija, Kutina, Croatia). During the lettuce growth, the fertilization was performed twice, in the phase of intense rosette growing and before wrapping of lettuce head with Ferticare fertilizer (Yara Suomi Oy, Helsinki, Finland) with microelements (10:5:26) in the amount of 1 g per plant. Soil moisture was maintained at an optimum level by the system of drop by drop (four times during lettuce vegetation with 15 L water m^{-2}). Soil moisture was maintained at an optimum level by the drip irrigation system where drop emitters brought water on demand during 5 h at rate of 3 L m^{-2} h^{-1} at a pressure of around 1 bar. In total four irrigations were applied, first immediately after transplanting seedlings and the next three every 15 d.

Harvest was carried out when lettuce plants reached the stage of technological maturity in the first week of May. Maturity is based on the number of leaves and head development. The mature lettuce heads had 36 leaves.

Soil properties

The standard properties of the soil in the greenhouse (pH in H_2O, pH in KCl, organic matter, $CaCO_3$, $N\text{-}NO_3^-$ and $N\text{-}NH_4^+$) were analysed prior to the direct establishing of the experiment (Table 1). The soil in greenhouse in which the experiment was conducted had a high content of organic matter (6.0%), and medium content of $CaCO_3$ (5.2%). Soil reaction was determined in a suspension with H_2O and KCl (ratio of 1:2.5), using a pH-meter (PHM240 pH/ion meter; Radiometer Analytical SAS, Lyon, France). The humus content in soil was determined by the colorimetric method, in the wet burned sample with $K_2Cr_2O_7$ and concentrated H_2SO_4. $CaCO_3$ content was determined using Scheibler's calcimeter. The method Scheibler involves a determination of the carbonate content in the soil based on a volumetric method. The carbonates present in the sample were converted into CO_2 by adding hydrochloric acid to the sample. The carbonate content is expressed as an equivalent calcium carbonate content. Nitrates and ammonia N ($N\text{-}NO_3^-$ and $N\text{-}NH_4^+$) were determined by Bremner method (Bremner and Mulvaney, 1982). Extraction of mineral forms of N (NH_4^+, NO_2^-, NO_3^-) with KCl in ratio 1:10, followed by double distillation.

Greenhouse and soil temperature

The mean, minimum and maximum air temperatures were measured by using digital thermometer (M288CTH, Mumbai, India) from March 2012 until May 2013 (Table 2).

Soil temperature was measured at 10 cm below the plastic mulch. The measurement of soil temperature was done using a digital soil thermometer (Rapitest; Luster Leaf Products, Woodstock, Illinois, USA).

Chemical analysis of plant biomass

The lettuce plants were harvested at technological maturity. During the harvest, 30 plants from each plot were weighed to determine the lettuce yield and from each plot four whole plants were randomly sampled for the chemical plant analysis.

The N content in leaves (N%) was determined by Kjeldahl method (Horneck and Miller, 1998). The wet burning of plant material by concentrated H_2SO_4+H_2O_2+450 °C-Kjeltec analyzer (Foss Tecator 8400, Hilleroed, Denmark) and then distillation. The nitrate content in leaves was determined by the xylenol method. The extraction of nitrates by hot water, then distillation, and then colouring and reading of optical density on a UV/VIS spectrophotometer (6405; Jenway, Dunmow, Essex, England). The Zn content in leaves was determined by the preparation of plant material by wet burning with the mix of acids (HNO_3 + $HClO_4$ + H_2SO_4), and then the Zn is converted to soluble salts and in the ionic form introduced as an aerosol into the atomic absorption spectrophotometer SP9 (Pye Unicam Ltd., Cambridge, England). The vitamin C content in leaves was determined by Tillman's titration method (Pijanowski et al., 1973). The leaf material was homogenized with 30 cm^3 2% oxalic acid and filtrated. The filtrate was charged with 1% oxalic acid (v/v) to a volume of 100 cm^3. Then 10 cm^3 of the extract were transferred to the Erlenmeyer bottle and then 40 cm^3 1% oxalic acid were added. The solution was titrated with 2,6-dichlorophenolindophenol.

Table 1. Soil characteristics of the experimental site.

Depth	pH in H_2O	pH in KCl	Organic matter	$CaCO_3$	$N\text{-}NO_3^-$	$N\text{-}NH_4^+$
cm			%		kg ha^{-1}	
0-30	7.3	7.0	6.0	5.2	497.6	98.2

Table 2. Mean monthly temperature.

	Mean air temperature		Mean maximum temperature		Mean minimum temperature	
Month	2012	2013	2012	2013	2012	2013
			°C			
March	12.2	14.7	17.4	20.5	5.3	7.3
April	15.7	19.4	23.7	26.9	0.5	10.1
May	20.4	22.6	26.2	29.1	4.2	10.8

Statistical analysis

The obtained data were processed by InfoStat software (Grupo InfoStat, FCA, Universidad Nacional de Córdoba, Córdoba, Argentina). Two-factorial ANOVA was run for each year and the means were compared using Tukey's test.

RESULTS AND DISCUSSION

Effect of mulching and agrotextile on the lettuce yield

Mean lettuce yield in 2012 and 2013 was 68.1 and 73.0 t ha^{-1}, respectively. Significant differences between studied cultivars were observed in both growing seasons, where 'Devonia' tended to have significantly higher yield in both seasons. Based on the results of the analysis, soil was fertile and could provide optimal soil conditions for lettuce production (Boskovic-Rakocevic and Pavlovic, 2007). Growing conditions in 2013 were more favourable for lettuce production, with desirable temperature conditions (Table 2) resulting in higher yield in both cultivars. Results of yield in lettuce cultivars are shown in Table 3. Moreover, mulching treatment had significant effect on yield in both growing seasons. The lowest yield in both seasons of experiment was recorded in control treatments. The results obtained are consistent with previous studies, showing that soil mulching has a positive effect on plant growth and that it increases the vegetative mass and yield (Tosta et al., 2010). According to Franquera (2015) the use of different coloured mulches could enhance plant productivity and the quality of the products obtained from them. In both growing seasons, black plastic mulch produced the highest yield. In the second year of research, the cultivars were manifesting significant differences in the lettuce yield. The highest soil temperature was recorded below the black plastic mulch, and the lowest in WA treatment. This study showed that the colour of the plastic mulch positively influenced the yield of lettuce. Treatment with a black plastic mulch had a higher soil temperature than a white plastic mulch, as confirmed by the studies of Rangarajan and Ingall (2001). Ponjican and Bajkin (2008) state that the temperature difference due to the use of various materials for mulching and plant covering ranges in the interval of 6.22 to 12.71 °C. In 'Devonia', in 2012 and 2013, higher soil temperatures were registered in all treatments compared to 'Nizzi'. As a result of soil covering with black and white plastic mulch, a higher soil temperature was measured within the range of 4.2 to 6.82 °C. The minimum daily average temperature in 2012 was measured in control treatment at 1.94 °C, while in 2013 it was 3.48 °C. In 2013, the maximum average daily soil temperature (35.9 °C) was recorded in black plastic mulch treatment with 'Devonia', when the highest lettuce yield was achieved.

Effect of mulching and agrotextile on N content

Mean N content varied between two growing seasons, and both cultivars had a lower N content in the first year of the experiment compared to the second year (Table 4).

There was nonsignificant difference between N content in the first growing season, while in the second growing season significant differences were noticed. The difference in the N content between studied cultivars in the second growing season indicated the presence of significant variation in N uptake potential of cultivars. Mean N content in 'Nizzi' was 38.9 (2012) and 40.3 g kg^{-1} (2013) and 39.5 (2012) and 45.5 g kg^{-1} (2013) in 'Devonia'. Therefore, it could be concluded

Table 3. Effect of mulching/woven agrotextile and cultivars on the lettuce yield during two growing seasons.

	2012			2013		
Treatments	Nizzi	Devonia	Mean	Nizzi	Devonia	Mean
	t ha^{-1}					
CO	57.9h	67.7ef	62.8E	59.9i	70.2f	65.0D
BPF	73.8c	81.4a	77.6A	79.7c	88.7a	84.2A
WPF	66.6f	76.0b	71.3B	76.0d	82.6b	79.3B
BPFWA	62.4g	71.8d	67.1C	64.1h	76.1d	70.1C
WPFWA	61.2g	68.1ef	64.6D	65.2gh	74.0e	69.6C
WA	61.3g	69.1e	65.2D	66.7g	73.0e	69.8C

Different letters represent significant differences according to LSD test ($P < 0.05$). Uppercase letters represent significant difference between treatments; lowercase letters represent significant difference between cultivars.
CO: Control; BPF: polyethylene black plastic mulch; WPF: polyethylene white plastic mulch; BPFWA: polyethylene black plastic mulch and woven agrotextile; WPFWA: polyethylene white plastic mulch and woven agrotextile; WA: woven agrotextile.

that 'Devonia' more efficiently accumulates N in the leaves than 'Nizzi'. Different authors have already reported existence of considerable variation in N content among different lettuce cultivars (Liu et al., 2014). In addition, N content varied in relation to treatments. In both growing seasons, in treatment BPF and treatment BPF in combination with WA, the highest level of N in leaves was registered, compared to the control treatment. Treatment BPF provides the highest productivity, but also the maximum values for N as well as its content in leaves.

Effect of mulching and agrotextile on the nitrate content

The results showed that nitrate content in plants varied between the growing seasons. On average in the second growing season, which was more suitable for lettuce cropping cycle, the plants had a higher nitrate content in their leaves. Furthermore, there were significant differences between examined cultivars in the nitrate content.

'Devonia' tends to have higher nitrate content than 'Nizzi' in both growing seasons. In the first growing season average nitrate content in leaf was the highest in treatment BPF, followed by combination of BPF and WA (Table 5). In the following season, application of black plastic mulch led to the highest nitrate content accumulation in leaf compared to the other treatments. On the other hand, the lowest nitrate content in both seasons was registered in treatment WA. Lower nitrate content was registered in spring in comparison to winter (Kosma et al., 2013). The treatments with plastic mulch and combined plastic mulch with woven agrotextile had higher nitrate contents in the second year, which was due to higher temperatures in that year (Table 2). The maximum values of nitrate content in our study are below the acceptable norms (4000 mg kg^{-1} for lettuce grown in protected area) that are provided by the European Commission (Commission regulation Nr 1258/2011; European Union, 2011).

Effect of mulching and agrotextile on the Zn content

As result of different agroecological conditions, Zn content varied between the growing seasons (Table 6). Furthermore, total Zn content was significantly higher in 'Devonia' than in 'Nizzi' in each growing season.

Table 4. Effect of mulching/woven agrotextile and cultivars on the N content in lettuce during two growing seasons.

	2012			2013		
Treatments	Nizzi	Devonia	Mean	Nizzi	Devonia	Mean
	g kg^{-1}					
CO	36.9b	37.8ab	37.3C	37.0f	40.3def	38.7D
BPF	41.1ab	42.0a	41.5A	45.0bc	50.2a	47.6A
WPF	39.6ab	38.6ab	39.1ABC	39.6def	42.3cde	41.0CD
BPFWA	40.0ab	40.3ab	40.2AB	38.9ef	50.3a	44.6B
WPFWA	36.9b	38.4ab	37.7BC	39.3def	46.9ab	43.2BC
WA	38.6ab	39.7ab	39.2ABC	41.7cde	43.0Bcd	42.3BC

Different letters represent significant differences according to LSD test ($P < 0.05$). Uppercase letters represent significant difference between treatments; lowercase letters represent significant difference between cultivars.
CO: Control; BPF: polyethylene black plastic mulch; WPF: polyethylene white plastic mulch; BPFWA: polyethylene black plastic mulch and woven agrotextile; WPFWA: polyethylene white plastic mulch and woven agrotextile; WA: woven agrotextile.

Table 5. Effect of mulching/woven agrotextile and cultivars on the nitrate content in lettuce during two growing seasons.

	2012			2013		
Treatments	Nizzi	Devonia	Mean	Nizzi	Devonia	Mean
	mg kg^{-1}					
CO	2136.0g	2298.0f	2217.0E	2267.0Gh	2664.0e	2466.0E
BPF	3183.0a	3035.0b	3109.0A	3444.0a	3299.0b	3372.0A
WPF	2495.0e	2716.0c	2606.0C	2610.0e	2898.0c	2754.0C
BPFWA	2596.0d	2970.0b	2783.0B	2696.0de	3299.0b	2998.0B
WPFWA	2300.0f	2592.0d	2446.0D	2390.0f	2806.0cd	2598.0D
WA	1978.0h	2084.0g	2031.0F	2175.0h	2308.0fg	2242.0F

Different letters represent significant differences according to LSD test ($P < 0.05$). Uppercase letters represent significant difference between treatments; lowercase letters represent significant difference between cultivars.
CO: Control; BPF: polyethylene black plastic mulch; WPF: polyethylene white plastic mulch; BPFWA: polyethylene black plastic mulch and woven agrotextile; WPFWA: polyethylene white plastic mulch and woven agrotextile; WA: woven agrotextile.

The total Zn content in lettuce leaves was significantly influenced by the soil mulching in 2012 and 2013 growing seasons. Across genotype, Zn content in lettuce leaves varied between 56.0 and 65.0 mg kg^{-1} in 2012 and between 49.0 and 68.0 mg kg^{-1} in 2013. According to Adu et al. (2012) the Zn content in leaves was 0.062 ± 0.047 mg kg^{-1}. Treatment BPFWA and the combination of BPFWA and WA enabled higher accumulation of Zn in lettuce leaves in both growing seasons. Treatment BPF and combination of BPF and WA in 2012 and treatment BPFWA in 2013 resulted in the lowest Zn content in lettuce leaves. Zinc content in all treatments is lower than the safety limit prescribed by FAO/WHO (2001) of 99.40 mg kg^{-1}. Also, Tosic et al. (2012) pointed out that the soil mulching with black plastic mulch significantly reduced the Zn content in lettuce leaves. The Zn content in lettuce ranged from 42.0 to 91.0 mg kg^{-1} fresh weight (Meagy et al., 2016). The Zn content in treatments with woven agrotextile in combination with plastic mulch was significantly higher than in mulching treatments. The occurrence of Zn toxicity in humans is unlikely even when taking a rather high amount of Zn in lettuce leaves.

Effect of mulching and agrotextile on the vitamin C content

The average vitamin C content in lettuce leaves was 11.7 mg 100 g^{-1} in 2012 and 15.2 mg 100 g^{-1} in 2013. Mainly, 'Devonia' had higher content of vitamin C than 'Nizzi' (Table 7). Moreover, mulching with plastic foil had significant influence on vitamin C content in lettuce leaves.

Average vitamin C content varied from 10.1 to 15.3 mg 100 g^{-1} in 2012 and from 13.5 to 16.4 mg 100 g^{-1} in 2013. The black plastic mulch absorbs sunlight, which increases soil temperature and reduces the content of vitamin C. Vitamin C is a significant factor in the human diet and the strongest antioxidant among vitamins. Vitamin C has distinct antioxidant characteristics and is a major antioxidant agent involved in removal of free radicals, together with mineral Zn. The level of vitamin C was found to depend on the soil mulching, plant coverage and cultivar. All treatments had lower vitamin C content in the first year of the study than in the second year. Lettuce is not rich in vitamin C, but the advantage of this vegetable is that it is consumed fresh, so the vitamin C is fully exploited.

Table 6. Effect of mulching/woven agrotextile and cultivars on the Zn content in lettuce during two growing seasons.

	2012			2013		
Treatments	Nizzi	Devonia	Mean	Nizzi	Devonia	Mean
	mg kg^{-1}					
CO	58.0cde	60.0bcde	59.0B	47.0g	59.0cd	53.0C
BPF	57.0de	59.0cde	58.0B	50.0fg	60.0c	49.0D
WPF	64.0abc	67.0a	65.0A	51.0efg	62.0bc	62.0B
BPFWA	59.0cde	57.0de	58.0B	54.0ef	63.0bc	55.0C
WPFWA	63.0abcd	66.0ab	64.0A	55.0de	65.0b	68.0A
WA	55.0e	58.0cde	56.0B	55.0de	70.0a	61.0B

Different letters represent significant differences according to LSD test ($P < 0.05$). Uppercase letters represent significant difference between treatments; lowercase letters represent significant difference between cultivars.
CO: Control; BPF: polyethylene black plastic mulch; WPF: polyethylene white plastic mulch; BPFWA: polyethylene black plastic mulch and woven agrotextile; WPFWA: polyethylene white plastic mulch and woven agrotextile; WA: woven agrotextile.

Table 7. Effect of mulching/woven agrotextile and cultivars on the vitamin C content in lettuce during two growing seasons.

	2012			2013		
Treatments	Nizzi	Devonia	Mean	Nizzi	Devonia	Mean
	mg 100 g^{-1}					
CO	9.9f	10.3ef	10.1C	13.3f	13.7ef	13.5D
BPF	10.2ef	11.2de	10.7C	14.1de	15.0c	14.6C
WPF	10.4ef	10.6ef	10.5C	15.3c	14.6cd	14.9C
BPFWA	10.7ef	12.2c	11.5B	16.9b	15.1c	16.0AB
WPFWA	12.0cd	12.2cd	12.1B	14.1de	17.7a	15.9B
WA	14.2b	16.4a	15.3A	14.8cd	18.1a	16.4A

Different letters represent significant differences according to LSD test ($P < 0.05$). Uppercase letters represent significant difference between treatments; lowercase letters represent significant difference between cultivars.
CO: Control; BPF: polyethylene black plastic mulch; WPF: polyethylene white plastic mulch; BPFWA: polyethylene black plastic mulch and woven agrotextile; WPFWA: polyethylene white plastic mulch and woven agrotextile; WA: woven agrotextile.

CONCLUSIONS

Based on the results of the study, it is evident that geotextile and agrotextile had a major impact on the most frequently examined parameters of lettuce. The results obtained emphasize importance of appropriate cultivars selection and application of adequate mulching for achievement of high yield and quality in lettuce. In treatment with polyethylene black plastic mulch the highest level of N in lettuce leaves was registered. The woven agrotextile treatment led to significant reduction of nitrate level in lettuce. The Zn content in treatments with woven agrotextile in combination with plastic mulches was significantly higher than in plastic mulches treatments. The polyethylene black plastic mulch produced the highest yield, but also a higher nitrate content. The treatment with woven agrotextile had a positive effect on the vitamin C content in lettuce.

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