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ORIGINAL PAPER

EFFECT OF FLOOD FERTIGATION ON YIELD OF GREENHOUSE CRISPHEAD LETTUCE GROWN IN VARIOUS SUBSTRATES*

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Abstract

Flood fertigation is a hydroponic cultivation method used mainly for the production of vegetable, herb and flower seedlings in greenhouse facilities. In 2012-2014, a study was conducted to identify the influence of flood fertigation with nutrient concentrations of EC: 1.0, 2.0, 3.0, 4.0 mS cm^{-1} on the size and quality of the yield of Elenas crisphead lettuce grown in *different* substrates: coconut coir, peat and rockwool. The experiment was conducted on a heated floor of a flood greenhouse in the spring. The effects of the concentration of the nutrient solution and the substrate used for growing on the quantity and quality of the crops were assessed by measuring the weight and quality of the plants. Cultivation in rockwool with a nutrient concentration of EC 2.0 mS cm^{-1} resulted in the highest total and marketable yields as well as heads of lettuce with the highest commercial weight. Increasing the concentration of the solution resulted in an increase in the nitrate content in the fresh mass of the lettuce heads. The highest amount of nitrates in fresh plant mass, exceeding EU standards, was found in lettuce flooded with the solution concentration of EC 4.0 mS cm^{-1}, grown in peat and coconut coir substrate. The content of N, P and K in lettuce heads increased with the increase of the EC of the solution concentration.

Keywords: EC, lettuce quality, nitrates, macronutrients, growing medium

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INTRODUCTION

Increasingly limited access to water, soil erosion and groundwater contamination are prompting research into cost-effective, efficient, yet environmentally friendly irrigation methods (Durau 2015). Flood-and-drain hydroponics is one of the most technologically advanced methods of irrigation and fertilization of plants in a greenhouse (Komosa 2002). It consists in periodically flooding with nutrient solution the cultivated area on tables or flood floor on which plants are placed. This method is most often used to grow ornamental plants, herbs and to produce vegetable seedlings in a greenhouse. The system is both affordable and environmentally safe due to the efficient and economical use of water and fertilizers. Unlike drip irrigation, in which most irrigation systems discharge drainage water into the environment, in the flood-and-drain system the nutrient solution used for plant nutrition flows in a closed loop and can be used multiple times. This is of great importance for the environment protection, since depending on the plant species cultivated and the cultivation technology, drainage water can comprise 10% to 30% of the total used water (Treder et al. 2019). In line with the rational water management and conservation, water should be circulated in a closed loop (Jeznach, Treder 2006). The flood-and-drain hydroponics system allows not only water efficiency, but also better control of the nutrients supplied to the plants. This is possible with the use of an irrigation automation system, which determines and doses the amount of water and fertilizers for the preparation of the nutrient solution that contains the optimal amounts of nutrients for the proper growth and development of the cultivated plants. Therefore, it is essential to pinpoint and apply an appropriate nutrient composition for various plant species grown with this method.

Dyśko et al. (2011) conducted research on the effect of the nutrient medium concentration used for fertigation in tomato seedling production. The best seedlings were obtained using a nutrient medium with a concentration of nutrients EC 2.5 and EC 3.5 mS cm^{-1}. They had the greatest: height, fresh matter content and number of leaves. Plant height and stem diameter decreased when the EC was raised to 4.5 mS cm^{-1}. Based on their research, Markiewicz and Kleiber (2010) noticed that lettuce has high tolerance to nutrient solution salinity in the range of EC 1.6 to EC 5.1 mS cm^{-1}, while Maas and Hoffman (1977) identified a plant tolerance threshold to the salinity of the medium, above which the plant yield decreases. A decrease in the yield of lettuce after exceeding the threshold value of the concentration of the medium and with a large variation in its EC is also confirmed by the study conducted by Pitura and Michałojć (2012). They also noted a significant reduction in the yield when a high nitrogen dose was applied to the medium. Increasing nitrogen doses also resulted in an increase in the nitrate content in lettuce leaves, as shown in the research conducted by: Kozik (2006), Konstantopoulou et al. (2012), Stefanelli et al. (2012), Di Gioia et al. (2013). A high intake of nitrogen in the form of nitrate (III) may lead to severe health problems in humans, according to research by Gajewska et al. (2009). The capillary irrigation and fertilization method used in flood-and-drain hydroponics allows for the elimination of nitrogen from the nutrient solution before harvesting and for obtaining large heads of lettuce with a low level of nitrates (Stępowska, Kowalczyk 2000).

The content of nitrogen and other mineral components in lettuce heads depends on the substrate used for crops, which was confirmed by research conducted by Sabat (2015, 2019). These studies also showed a significant impact of the substrate used in hydroponic cultivation on the obtained lettuce yield. Cultivation lettuce in rockwool produced the highest marketable yields. Also, in the research conducted by Dyśko (2008), was observed that growing plants in rockwool produced a considerably higher marketable yield of tomato than growing in organic substrates. On the other hand, Stępowska and Nowak (2006) in their study confirmed the possibility of using organic substrates but with adequate air-water properties for the cultivation of lettuce by the capillary method.

Hydroponic plant growing systems are economical and can support the sustainable cultivation of leafy vegetables, according to research by Ferguson et al. (2014). Plants grown by flood-and-drain hydroponics are uniform and healthy. The nutrient solution is supplied to all plants in the right amount and with the optimal composition by the capillary method, thanks to which their leaves remain dry at all times.

A major obstacle to more extensive application of flood-and-drain hydroponics in the production of greenhouse vegetables is the high cost of installing flood-and-drain systems and the automation controlling them. Barbosa et al. (2015), based on their research, indicated places that are scarce in water but plentiful in renewable energy (solar, wind, geothermal) as particularly recommended for the introduction of hydroponic systems. Monsees et al. (2019) investigated the feasibility of producing lettuce in a hydroponic system using aquaculture water for a fish production as a supplement to the nutrient composition of the nutrient medium. To increase the profitability of vegetable production in a greenhouse using the flood-and-drain hydroponics method, it is necessary to develop cultivation methodologies and recommend vegetable species for this mode of cultivation.

The aim of this research was to develop a methodology for growing crisphead lettuce (*Lactuca sativa var. Capitata* L.) in a greenhouse using flood-and-drain fertigation. The study included the evaluation of the impact of the concentration of the nutrient medium used for fertigation and the type of substrate used for cultivation on the height and quality of the lettuce yield.

MATERIAL AND METHODS

The study on effects of flood fertigation on the size and quality of the yield of crisphead lettuce grown on various substrates was conducted in 2012-2014, at the Research Institute of Horticulture in Skierniewice, in a flood-and-drain bay of the greenhouse facility. Crisphead lettuce cv Elenas, which was grown in the spring cycle, was used for this research. The results presented are the average of the three years of research.

A two-factorial experiment was established using the randomized block method. The concentration of the nutrient solution: EC 1.0, 2.0, 3.0, 4.0 (mS cm^{-1}), and the types of the growth substrate were the factors studied. The solution was made using single and two-component fertilizers, and the standard nutrient content (mg dm^{-3}) was: NO_3^- – 170, P – 40, K – 250, Ca – 150, Mg – 40, Fe – 2.0, Mn – 0.55, Zn – 0.33, B – 0.27, Cu – 0.05, Mo – 0.05. The organic substrates tested were: coconut (Promat coconut fiber), peat (Hollas high moor peat, deacidified to pH 5.5-6.5) and rockwool (Grodan rockwool cubes). These organic substrates were characterized by excellent air-water properties, sterility, comparable pH values (5.5-6.5), high water holding capacity and were nearly completely free of mineral components.

Lettuce seeds were sown in the first week of March into rockwool plugs (Grodan AO Plugs). Then, the seedlings were planted into rockwool cubes (10 × 10 × 6.5 cm) and pots designed for hydroponic cultivation (with a volume comparable to that of the cubes) filled with peat and coconut coir. When the plants were at the seedling stage, thirty plants in each substrate were set at a spacing of 0.25 m × 0.25 m on the heated floor of the flood-and-drain bay divided into four equal, independent pools. Throughout the plant growing season, each pool was flooded with a different concentration of a nutrient solution three times a week. The plants in the pots and cubes were immersed in the solution to a height of 3-4 cm and remained in it for 30 minutes. After that time, the solution was returned to four recirculating tanks. The medium, before being reused, was decontaminated with a BenRad device using hydroxyl radicals.

A computerized fertilizer dispenser was used to prepare the fertigation nutrient solution, and to monitor its composition. In order to obtain the right EC for each pool, the nutrient content of the solution was proportionally increased or reduced. During the experiment, the composition of the medium in each pools was monitored (Table 1) by submitting it to chemical analyses using the following methods:

$N-NO_3$, $N-NH_4$, $P-PO_4$ – colorimetrically with a continuous flow autoanalyzer (Sanplus by Skalar);

K, Ca, Na, Mg, Fe, Mn, Zn, Cu, B – with an ICP plasma spectrometer (Atom Scan by Tharmo Jarrel Ash);

Cl – potentiometrically with an ion-selective electrode;

Table 1

Average pH, EC, macro- and micronutrients content in recirculated solution used for lettuce fertigation

EC level	pH	EC (mS cm^{-1})	N-NO_3	N-NH_4	K	Ca	Mg	P	Fe	Mn	Cu	Zn	B	Na	Cl	S-SO_4
			(mg dm^{-3})													
1	6.4	1.2	109.0	0.6	86.3	147.3	39.1	7.0	0.3	0.2	0.1	0.5	0.6	16.1	21.6	80.0
2	6.2	2.3	190.7	3.9	325.3	225.0	81.5	24.9	1.2	0.6	0.2	0.9	1.2	18.0	24.8	223.3
3	5.9	3.2	281.0	8.8	487.0	277.7	115.3	45.6	2.6	1.0	0.4	1.0	1.5	18.4	24.1	315.3
4	6.3	4.0	354.7	12.8	654.7	335.3	151.3	60.5	4.1	1.7	0.5	1.2	1.7	20.3	23.5	428.3

SO_4 – colorimetrically with $BaCl_2$;

EC – conductrometrically in the nutrient solution;

pH – potentiometrically.

Chemical analyzes were performed in the Laboratory of Quality Investigation of Horticulture Products of the Research Institute of Horticulture in Skierniewice.

After five weeks of growing in the greenhouse's flood-and-drain system, the lettuce crop was harvested. Weight, diameter, head compactness were measured and the health and quality of the heads were evaluated (by visually assessing the presence of diseases and physiological disorders). The marketable crop was selected in accordance with the marketing standards defined by the EU Commission Regulation No. 771/2009 of 25 August 2009. Five to six heads from each combination were taken at random for chemical analysis. After fragmentation, the samples were dried at a temp. of 45-50°C and then ground. The samples prepared in this way were used to determine the dry matter (%). The colorimetric method (Scan Plus) was used to determine the $N\text{-}NO_3$ content from dried samples and the level of nitrates was calculated in relation to the fresh plant weight. The results of the measurements and chemical analyses were statistically processed using analysis of variance for multi-year experiments. Student's *t*-test was used to assessed the significance of differences at $LSD_{0.05}$.

RESULTS AND DISCUSSION

The authors have found that the concentration of nutrient solution used for flood fertigation and the type of substrate had a relevant effect on the value of the evaluated parameters: total yield, marketable yield, as well as average weight of marketable head of crisphead lettuce. With an increasing concentration of the nutrient solution from EC 1.0 to 2.0 mS cm^1, all these parameters increased, reaching significantly the highest levels of: total yield – 5,515.3 g m^{-2}, marketable yield – 5,216.7 g m^{-2}, and the average weight of marketable head – 342.9 g (Table 2). The further increase in EC of the nutrient solution caused a noticeable decrease in total yield and average weight of marketable heads at 4.0 mS cm^1, and a reduction in marketable yield at EC 3.0 mS cm^1.

The conducted study confirms the occurrence of a plant tolerance limit to the nutrient solution salinity, which was observed by Mass and Hoffman (1977), as well as Kleiber and Markiewicz (2010). The same correlations were observed by Sabat et al. (2015, 2019) in a research on the effect of flood fertigation on lettuce yield, in which the increase in total and marketable yield of butterhead lettuce occurred up to EC 3.0 mS cm^1, and leaf lettuce up to EC 2.0 mS cm^1.

Table 2

Effect of EC of a nutrient solution and of a substrate type on the average total and marketable yields, and the weight of marketable head of lettuce cv. Elenas

Specification		Total yield ($g \cdot m^{-2}$)	Marketable yield ($g\ m^{-2}$)	Average weight of marketable head (g)
EC ($mS\ cm^{-1}$)	1.0	5179.5 *a**	4406.8 *bc*	323.4 *a*
	2.0	5515.3 *a*	5216.7 *a*	342.9 *a*
	3.0	5423.4 *a*	4794.9 *ab*	337.6 *a*
	4.0	4441.6 *b*	3868.2 *c*	280.0 *b*
Substrate	rockwool	6897.3 *a**	5612.7 *a*	435.4 *a*
	peat	4370.4 *b*	4106.6 *b*	267.7 *b*
	coconut coir	4152.1 *b*	3995.7 *b*	259.8 *b*

* Means followed by the same letter are not significantly different at p=0.05.

Such a relationship was also confirmed by Andriolo et al. (2005) in a study on the effect of increasing nutrient solution salinity on the yield of lettuce grown in hydroponics. Plant fresh weight and LAI increased with an increasing EC of the nutrient solution, but only to a certain level, beyond which examined parameters fall. Fallovo et al. (2009) showed the effect of increasing nutrient concentrations on the increase in the chlorophyll content, plant dry weight, marketable yield and leaf area index.

The type of substrate used for growing lettuce also had a significant impact on the total yield, marketable yield as well as the average weight of marketable head (Table 2). Cultivation in rockwool yielded significantly the highest values for all these parameters: the total yield was 6,897.3 g m^{-2}, marketable yield was 5,612.7 g m^{-2}, and the average weight of head was 435.4 g. The yields of lettuce grown on organic substrates: peat and coconut coir were significantly lower, but did not differ considerably from each other. Based on the research on the effect of various alternative substrates for hydroponic cultivation on the yield of lettuce, Jordan et al. (2018) found that the best substrate is coconut husk, while Rahman et al. (2019) obtained the highest yield and the best-quality lettuce in a substrate composed of: rice husk (60%), coconut (30%) and vermicompost (10%). Studies by Sabat et al. (2015, 2019) in which butterhead and leaf lettuce were grown in the flood-and-drain system, demonstrated that the highest total and marketable yields and the heads with the highest average weight were obtained in the rock-wool.

The nitrate content in lettuce heads was significantly influenced by both of the examined factors: the concentration of nutrients in the solution and the type of substrate, as well as the interaction of these factors (Table 3). The content of nitrates increased with an increasing concentration of the nutrient solution, reaching at EC 4.0 mS cm^{-1} a value of 2,802.2 mg NO_3 kg^{-1}

Table 3

Effect of EC of the nutrient solution and of a substrate type on the nitrate content in heads of lettuce cv. Elenas

N-NO_3 (mg kg $^{-1}$ FW)		
EC (mS cm^{-1})	1.0	1050,95 *d*
	2.0	1663,64 *c*
	3.0	2182,09 *b*
	4.0	2802,21 *a*
Substrate	rockwool	1815,83 *a*
	peat	1893,17 *b*
	coconut coir	2065,17 *b*

*Means followed by the same letter are not significantly different at p=0.05.

fresh weight exceeded the maximum permissible level in the European Union for crisphead lettuce (regulated by the EU Commission Regulation No. 1258/2011). The lowest nitrate content (1,050.9 mg NO_3 kg^{-1} fresh weight) was found at EC 1.0 mS cm $^{-1}$. Similar results were presented in the study conducted by Sabat et al. (2015, 2019), in which, at EC 4.0 mS cm $^{-1}$, the highest nitrate content was found in butterhead and leaf lettuce grown by the flooding method. The study by Fallovo et al. (2009) confirms that the content of nitrate in lettuce increases with an increase of the nutrient solution concentration. The same results appeared in the studies by Konstantopoulou et al. (2012), Di Gioia et al. (2013), Sabat et al. (2015, 2019). According to Kozik (2006), an increase in the amount of potassium available to plants also triggers an increase of the nitrate content in lettuce leaves.

Significantly the highest level of nitrates of 2,065.2 mg NO_3 kg^{-1} FW was found in the lettuce heads grown in coconut coir, although it did not exceed the standards set by the EU (Table 3). On the basis of their research, Stępowska and Kowalczyk (2000) stated it is possible to obtain lettuce of good quality and low nitrate content by growing it in peat using the capillary irrigation. Studying the effect of the type of substrate and the concentration of the nutrient solution on the nitrate content of lettuce heads, significantly the highest values of the examined parameter were recorded in the heads of lettuce grown at EC 4.0 mS cm $^{-1}$ of the medium and in the peat substrate – 3,068.4 mg NO_3 kg^{-1} FW and in coconut – 2,935.6 mg NO_3 kg^{-1} FW, significantly exceeding the permissible standards (Figure 1). Kozik (2006) achieved a significant reduction in nitrates in the lettuce leaves grown in the spring cycle by conducting the harvest in the afternoon and delaying it by 5 days.

The study on the mineral content in heads of lettuce grown at different levels of nutrient solution concentration showed that with increasing EC of the nutrient solution, the content of N, K and P increased significantly, reaching the highest values at EC 4.0 mS cm^{-1}. The content of Mg and Ca at this level of EC was considerably the lowest, while a relevant decrease

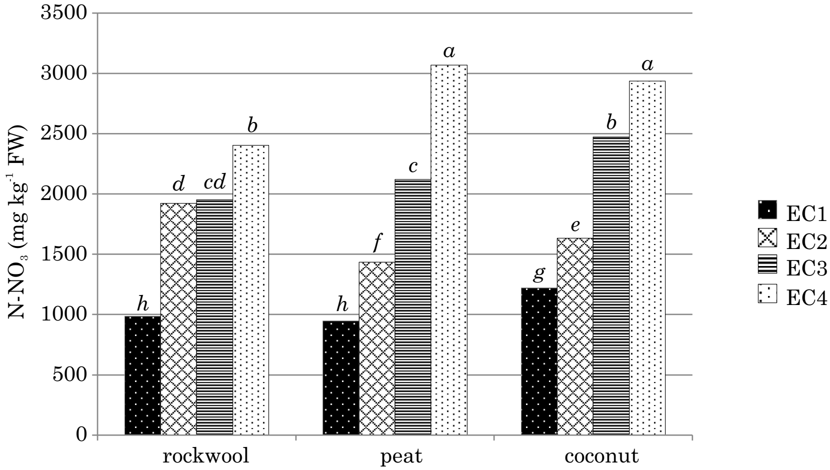

Fig. 1. Combined effect of a substrate type and EC (mS cm^{-1}) of the nutrient solution on the nitrate content in heads of lettuce cv. Elenas. Means followed by the same letter are not significantly different at p=0.05

in Ca content was found already at EC 3.0 mS cm^{-1} (Table 4). A similar relationship was found in the study by Fallovo et al. (2009) in which N, P and K content in lettuce leaves increased in response to increasing nutrient solution concentration. Also in the study of Sabat et al. (2015) an increasing EC level coincided with a relevant increase in the P and K content in butterhead lettuce leaves, while the Ca and Mg content did not differ significantly at various EC levels. Markiewicz and Kleiber (2010) found the effect of nutrient solution salinity on the P, K, Mg content in butterhead lettuce leaves. The content of P and K increased with the increasing salinity of the nutrient solution, while the content of Mg decreased. They found no effect of the nutrient solution salinity on the content of N and Ca in lettuce leaves.

Table 4

Effect of EC of a nutrient solution and of substrate type on N, P, K, Mg, Ca content (g kg^{-1} DW) in lettuce cv. Elenas

Specification		N	P	K	Mg	Ca
		(g kg^{-1} DW)				
EC (mS cm^{-1})	1.0	4.811 *d*	3.574 *d*	45.62 *d*	3.491 *a**	8.438 *a*
	2.0	8.179 *c*	4.493 *c*	57.47 *c*	3.399 *a*	8.034 *a*
	3.0	9.645 *b*	5.408 *b*	66.14 *b*	3.426 *a*	7.461 *b*
	4.0	10.666 *a*	6.032 *a*	77.65 *a*	3.168 *b*	6.406 *c*
Substrate	rockwool	8.709 *a**	4.430 *b*	64.40 *a*	3.281	7.501 *ab*
	peat	7.757 *b*	5.174 *a*	53.97 *b*	3.420	7.965 *a*
	coconut coir	8.511 *a*	5.025 *a*	66.80 *a*	3.413	7.288 *b*

* Means followed by the same letter are not significantly different at p=0.05.

The substrate in which the lettuce was grown also had a significant impact on the N, P, K and Ca content of lettuce heads (Table 4). The highest Ca and P content and significantly lowest N and K content were found in lettuce heads grown in peat. This is consistent with the results of Sabat et al. (2015) where the highest content of P, Ca and Mg and the lowest K content were found in butterhead lettuce leaves grown in peat substrate. There was no significant effect of a substrate alone on the Mg content, but the interaction of the substrate type and nutrient solution showed some effect (Figure 2). The significantly highest content Mg was found in lettuce

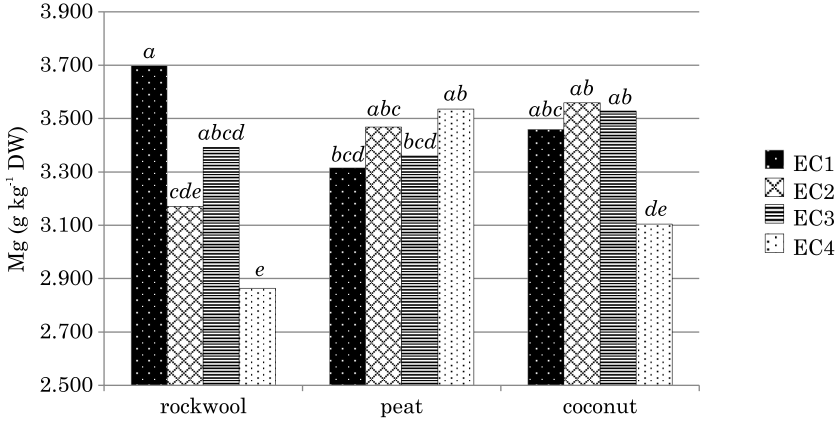

Fig. 2. Combined effect of a substrate type and EC (mS cm^{-1}) of the nutrient solution on Mg content in heads of lettuce cv. Elenas. Means followed by the same letter are not significantly different at *p*=0.05

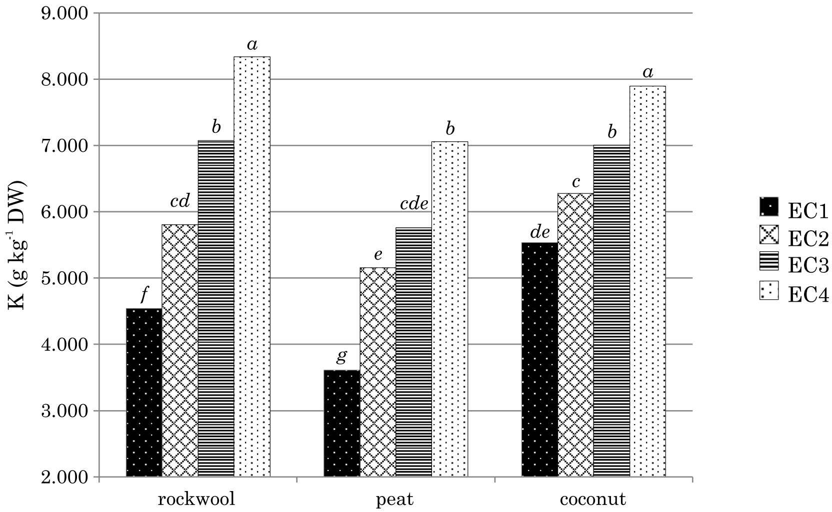

Fig. 3. Combined effect of a substrate type and EC (mS cm^{-1}) of the nutrient solution on K content in heads of lettuce cv. Elenas. Means followed by the same letter are not significantly different at *p*=0.05

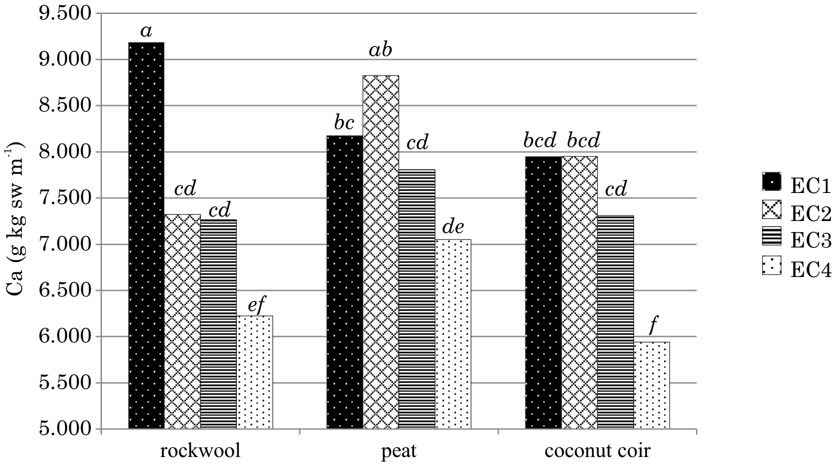

Fig. 4. Combined effect of a substrate type and EC (mS cm^{-1}) of the nutrient solution on Ca content in heads of lettuce cv. Elenas. Means followed by the same letter are not significantly different at p=0.05

flooded with the medium of EC 1.0 mS cm^{-1} and grown in rockwool. The effect of the examined factors on the content of K and Ca was also noted. The notably highest K content was found in the heads of lettuce flooded with an EC of 4.0 mS cm^{-1}, grown in rockwool and coconut substrate (Figure 3). Substantially, the highest Ca levels were detected in lettuce grown in rockwool and flooded with medium with an EC of 1.0 mS cm^{-1} (Figure 4).

CONCLUSIONS

1. Crisphead lettuce could be grown in the spring cycle in the flood-and-drain system in each of the tested substrates, although the cultivation in rockwool produced the highest total and marketable yields, as well as the heaviest heads.

2. The most proper concentration of the nutrient medium for fertigation of crisphead lettuce grown in the flood-and-drain system was EC 2.0 mS cm^{-1}, in which the highest total and marketable yield and the highest mass of heads were obtained.

3. The increase in the nutrient concentration in the medium caused the growth of the content of nitrates in lettuce leaves. At EC of 4.0 mS cm^{-1} of the nutrient solution, the amounts of nitrates in the leaves of crisphead lettuce grown in peat and coconut coir exceeded the maximum allowable limits.

4. With increasing EC of the nutrient solution, the content of N, P and K in the lettuce leaves increased, reaching the maximum amounts at EC

4.0 mS cm^{-1}, while the content of Ca and Mg in the lettuce leaves was the lowest.

5. The substrate in which the lettuce were grown had a substantial influence on the content of minerals in the leaves of crisphead lettuce. The highest amounts of P and Ca and at the same time the lowest amounts of N and K were contained in the leaves of lettuce growing in peat.

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