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ORIGINAL PAPER

FLOOD FERTIGATION OF LEAF LETTUCE GROWN IN VARIOUS SUBSTRATES*

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Abstract

The hydroponic system is very often used for greenhouse plant production. Flood irrigation on benches or on flood floors is applied in the production of vegetable transplants and ornamental plants. Since fertigation is used in a closed system using the recirculation of a nutrient solution, this system is environmentally friendly. The aim of the research conducted in 2012-2014 was to determine the effect of flood fertigation with nutrient concentrations of EC 1.0, 2.0, 3.0 and 4.0 mS cm^{-1} on the quantity and quality of leaf lettuce cv. Locarno grown in different substrates: coconut coir, peat and rockwool. The experiment was conducted on the flood floor of a greenhouse in the spring. The effects of the tested concentrations of the nutrient solution and the growth substrate on crop yield and quality were assessed by measuring the weight of lettuce heads and the nitrate content in them. The highest total and marketable yields and the heaviest heads were obtained from cultivation in rockwool. Also recommendable was the coconut coir substrate, in which, at the solution concentration of EC 2.0 mS cm^{-1}, the lettuce plants produced a high marketable yield of good quality heads with a low nitrate content. An increase in the concentration of the solution caused the nitrate content in lettuce heads to increase, and at EC 3.0 mS cm^{-1} the nitrate levels exceeded the permissible limit. The highest nitrate content was found in the crop grown in rockwool, and the lowest in coconut coir.

Keywords: lettuce, flood fertigation, nutrient concentration, substrates.

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INTRODUCTION

One of the methods for the irrigation and fertilization of plants in a greenhouse is a closed system of nutrient medium circulation which includes flood-and-drain hydroponics (Komosa 2002). This method is often used in the greenhouse production of ornamental plants and vegetable seedlings on ebb-and-flow benches and flood floors. The system is environmentally friendly and very economical because the medium used for plant nutrition circulates in a closed circuit and can be used repeatedly. Fertilizers and water are used very efficiently because the nutrient solution contains optimal amounts of fertilizers for the proper growth and development of crop plants. In order to obtain good quality crops and high yields, appropriate composition of fertigation media for different plant species grown by this method must be determined. Dyśko et al. (2011) studied the effect of the concentration of a medium used for fertigation in the production of tomato seedlings. They obtained the best seedlings at nutrient concentrations of EC 3.5 and EC 2.5 mS cm^{-1}. Sabat et al. (2015) harvested the highest yields of butterhead lettuce in a medium with EC 3.0 mS cm^{-1}. Markiewicz and Kleiber (2010) found that lettuce plants had a high tolerance to nutrient solution salinity in the range EC 1.6 to EC 5.1 mS cm^{-1}, but exceeding the threshold of tolerance and fluctuations in the EC of the medium can cause a decrease in yield, which has also been confirmed by Pitura and Michałojć (2012). Capillary irrigation and fertilization allow the gardener to maintain good air-water relations in the profile of a pot and to eliminate nitrogen from the solution before harvest (Stępowska, Kowalczyk, 2000). Based on their own research, Ferguson et al. (2014) found that hydroponic systems were cost effective and can complement sustainable cultivation of vegetables. Plants produced by this method are uniform and healthy because all of them always receive the same optimum amount of nutrient medium which they take up by the capillary action, while their leaves remain dry at all times. The disadvantage of this cultivation method are high installation costs of flood-and-drain systems in greenhouse facilities and a long period of their depreciation. These costs can be reduced if one makes the best use of the space in a greenhouse throughout the year. It is advisable to introduce into cultivation vegetables with a short vegetative growth period, constant high demand on the market, and reliable yielding. These conditions are met by leafy vegetables, which include leaf lettuce (*Lactuca sativa* L. *var. foliosa*). This vegetable enjoys great popularity among consumers because of its taste and nutritional and decorative qualities. It can be grown in several cycles, as well as before or after other crops. The aim of this study was to develop a method of growing leaf lettuce in a flood-and-drain system. The study determined the effects of concentrations of the nutrient solution used for fertigation and the type of substrate used for cultivation on crop yield and quality.

MATERIAL AND METHODS

The study was conducted in 2012-2014 at the Research Institute of Horticulture in Skierniewice. The objects studied were plants of leaf lettuce cv. Locarno, which were grown in springtime. A two-factor experiment was established in a randomized block design in a flood-and-drain bay of a greenhouse. The experimental factors were: concentrations of the nutrient solution – EC 1.0, 2.0, 3.0 and 4.0 mS cm^{-1}, and types of the growth substrate. Organic substrates were used: coconut coir, peat (high moor peat, de-acidified to pH 5.5-6.5), and rockwool. These biodegradable organic substrates were characterized by sterility, excellent air-water properties, similar pH (5.5-6.5), high water capacity, and were almost completely devoid of minerals. Lettuce seeds were sown into rockwool plugs, next the seedlings were planted into rockwool cubes (10 × 10 × 6.5 cm) and pots designed for hydroponic cultures (with a volume similar to the volume of the cubes), which were filled with peat and coconut coir. The seedlings, 30 plants in each substrate, were spaced (0.25 m × 0.25 m) on the floor of the flood-and-drain bay divided into four equal, independent pools. Each pool was filled with a nutrient solution of a different concentration, three times a week throughout the plant growing period. 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. Before being re-used, the solution was subjected to disinfection with a BenRad device, which uses hydroxyl radicals. The nutrient solution for fertigation was prepared, and its composition was controlled before each use, with a computerized fertilizer dispenser. The solution was prepared from single and two-component fertilizers, and the standard nutrient content was: (mg dm^{-3}) 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 nutrient content of the solution was modified (reduced, increased) so as to obtain the appropriate EC for a given pool. During the experiment, the composition of the nutrient solution was monitored in the individual pools (Table 1) by subjecting it to chemical analyses using the following methods:

- $N\text{-}NO_3$, $N\text{-}NH_4$, $P\text{-}PO_4$ – colorimetrically with a continuous flow autoanalyzer (Skalar Sanplus);
- K, Ca, Na, Mg, Fe, Mn, Zn, Cu, B – ICP plasma spectrometer (Thermo Jarrell Ash Atom Scan);
- Cl – potentiometrically with an ion-selective electrode (Dyśko, Kowalczyk, 2005);
- SO_4 – colorimetrically with $BaCl_2$;
- EC – conductrometrically in the nutrient solution;
- pH – potentiometrically.

The crop of lettuce was harvested after 4-5 weeks of cultivation in the able 1

Average pH, EC, macro- and micronutrient content in the 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

flood-and-drain system in the greenhouse. At the time of harvest, biometric measurements of plants (weight, diameter, head compactness) and assessments of the health and quality of the heads were made, and on that basis marketable crop was selected using the marketing standards defined by the EU Commission Regulation No. 771/2009 of 25 August 2009. For chemical analysis, 5-6 heads were randomly taken from each combination. After breaking apart, the samples were dried at a temperature of 45-50°C, and then ground. The samples thus prepared were used to determine the dry matter content in %, and the $N\text{-}NO_3$ content in mg kg^{-1} DW by the colorimetric method (Scan Plus), and the results were used to calculate the level of nitrates in relation to the fresh weight of plants. The results of the measurements and chemical analyses were statistically analyzed using analysis of variance for multi-year experiments, and the significance of differences at $LSD_{0.05}$ was assessed with Student's *t*-test.

RESULTS AND DISCUSSION

The study showed a significant effect of the concentration of nutrients in the solution used for flood fertigation on the value of the assessed parameters: total yield, marketable yield, and the average weight of marketable head (Table 2).

With the increase in the nutrient concentration from EC 1.0 to 2.0 mS cm^{-1}, the total yield, marketable yield and the average weight of marketable head increased significantly. The total yield increased from 3,110.4 to 3,637.2 g m^{-2}, marketable yield from 2,628.3 to 3,124.9 g m^{-2}, and the average weight of marketable head from 187.6 to 220.5, respectively. The increase in the EC of the nutrient solution to 3.0 mS cm^{-1} no longer caused any increase in yield, whereas a further increase in EC to 4.0 mS cm^{-1} caused a significant

Table 2

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

EC (mS cm^{-1})	Total yield (g m^{-2})	Marketable yield (g m^{-2})	weight of marketable head (g)
1.0	3,110.4*b*	2,628.3*b*	187.6*b*
2.0	3,637.2*a*	3,124.9*a*	220.5*a*
3.0	3,617.9*a*	3,171.7*a*	217.1*a*
4.0	3,185.4*b*	2,775.8*b*	195.8*b*
$LSD_{0.05}$	348.16	333.49	15.96

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

decrease in yield. Similar correlations were found by SABAT et al. (2015) in a study on the effect of flood fertigation on the yield of butterhead lettuce grown in a spring cycle. The results are also confirmed by the research conducted by MAAS and HOFFMAN (1977), who distinguished a threshold of plant tolerance to the salinity of nutrient solution, beyond which crop yields fall. FALLOVO et al. (2009) demonstrated the influence of an increasing nutrient concentration on the increase in marketable yield, plant dry weight, leaf area index, chlorophyll content and levels of macroelements and nitrates in lettuce grown in the flood-and-drain system. In a study by KLEIBER and MARKIEWICZ (2010), in turn, lettuce plants showed no injuries resulting from excessive salinity despite the use of fertigation solutions with salt levels considerably above the optimal level.

The type of substrate used for growing lettuce also had a significant effect on the total yield, marketable yield and the average weight of marketable head (Table 3).

Table 3

Effect of a substrate type on the average total and marketable yields, and the weight of marketable head of lettuce cv. Locarno

Substrate	Total yield ($g\ m^{-2}$)	Marketable yield ($g\ m^{-2}$)	Avg. weight of marketable head (g)
Rockwool	4,659.7*a*	3,691.0*a*	283.4*a*
Peat	2,700.2*b*	2,493.7*b*	164.2*b*
Coconut coir	2,803.2*b*	2,590.9*b*	168.1*b*
$LSD_{0.05}$	220.70	226.26	14.32

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

The highest values of all these traits were found in the cultivation in rockwool. The total yield was 4,659.7 g m^{-2}, marketable yield 3,691.0 g m^{-2}, and the average weight of marketable head was 283.4 g. A significant effect of the interaction between the two experimental factors on these parameters was observed in the study. In the cultivation in rockwool, the yield of lettuce increased up to the EC level of 3.0 mS cm^{-1}, with a significant increase in yield observed between EC 1.0 and 2.0 mS cm^{-1} (Figure 1). In the cultivation in peat, there were no differences in the total yield between the tested levels of EC, whereas the marketable yield increased up to the level of EC 2.0 mS cm^{-1}, and at EC 3.0 and 4.0 mS cm^{-1} a decrease in yield was observed. In the coconut coir substrate, EC 4.0 mS cm^{-1} caused a significant decrease in the total and marketable yields. The concentration of the nutrient solution had a positive effect on the average weight of marketable head of lettuce grown in rockwool, but it had no effect in the cultivation in peat, whereas in the cultivation in coconut coir EC 4.0 mS cm^{-1} caused a decrease in the average weight of a marketable lettuce head.

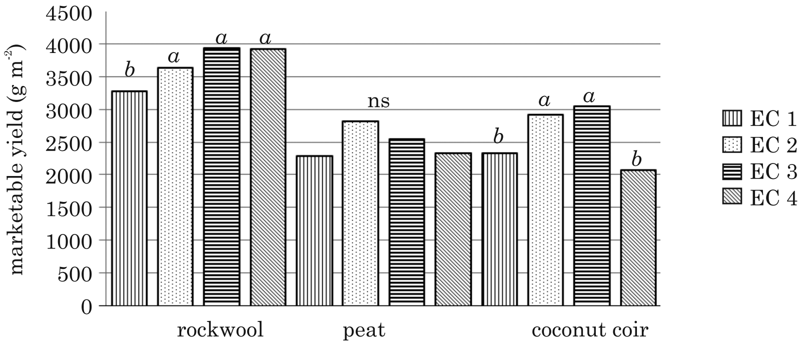

Fig. 1. Effect of nutrient solution concentrations on marketable yield of lettuce grown in substrates of rockwool, peat and coconut coir. Means followed by the same letter are not significantly different at $p = 0.05$

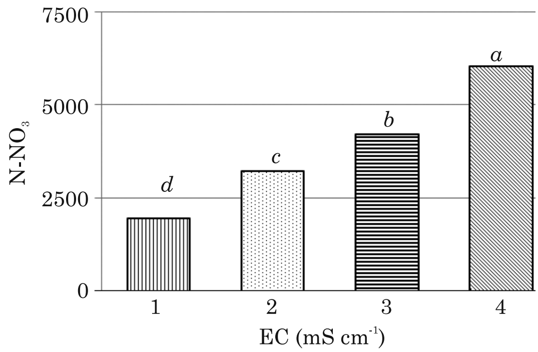

Fig. 2. Effect of EC of the nutrient solution on the nitrate content (mg kg^{-1} FW) in heads of lettuce cv. Locarno. Means followed by the same letter are not significantly different at $p = 0.05$

The study showed a significant effect of the concentration of nutrients in the solution used for flood fertigation on the nitrate content in lettuce heads (Figure 2). This content increased with an increasing concentration of the solution, and already at EC 3.0 mS cm^{-1} exceeded the permissible limit applicable in the European Union (4000 mg NO_3 kg^{-1} fresh weight), regulated by the EU Commission Regulation No. 1258/2011 of 2 December 2011. The highest significant level of nitrate content, i.e. 6,027.1 mg NO_3 kg^{-1} FW, was found in lettuce grown in the medium with EC 4.0 mS cm^{-1}. The lowest significant nitrate content, i.e. 1,946.1 mg NO_3 kg^{-1} FW, was found in the heads of lettuce grown in the solution with EC 1.0 mS cm^{-1}. Studies by Wojciechowska (2005), Kozik (2006) and Stefanelli et al. (2012) demonstrated that with increasing doses of nitrogen, the nitrate content in lettuce also increased. Soundy et al. (2005) showed that both plant dry weight and the nitrogen content in the leaves of lettuce grown in flood-and-drain hydroponic systems increased with an increasing nitrogen concentration in the nutrient

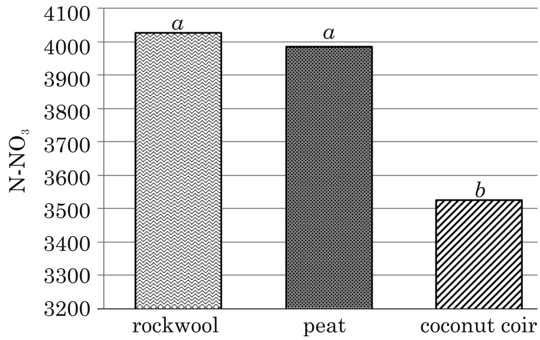

Fig. 3. Effect of a substrate type on the nitrate content (mg kg^{-1} FW) in heads of lettuce cv. Locarno. Means followed by the same letter are not significantly different at $p = 0.05$

solution. PAVLOU et al. (2007) found that the nitrate content in lettuce was affected by the type and dose of the fertilizer used.

In this study, the nitrate content in lettuce heads was also significantly affected by the type of substrate in which the plants were grown (Figure 3). The lettuce plants grown in rockwool and peat were found to have the highest nitrate levels, exceeding the permissible limit (4025 and 3984 mg NO_3 kg^{-1} FW, respectively, on average for the tested substrates). The least nitrates accumulated in the lettuce plants grown in coconut coir (an average of 3,525 mg NO_3 kg^{-1} FW). In an earlier study with butterhead lettuce (SABAT et al. 2015), the lowest amounts of nitrates had been found in lettuce plants cultivated in peat, and the highest in those grown in coconut coir. STĘPOWSKA and NOWAK (2006) are of the opinion that the decrease in nitrate transformations in lettuce is attributed to the reduced amount of oxygen available to plants in the growing substrate. Organic substrates, with better physical properties, ensure that proper air-water conditions are maintained in the root zone. This study indicates that there are species differences in the accumulation of nitrates. Leaf lettuce, compared to butterhead lettuce, accumu-

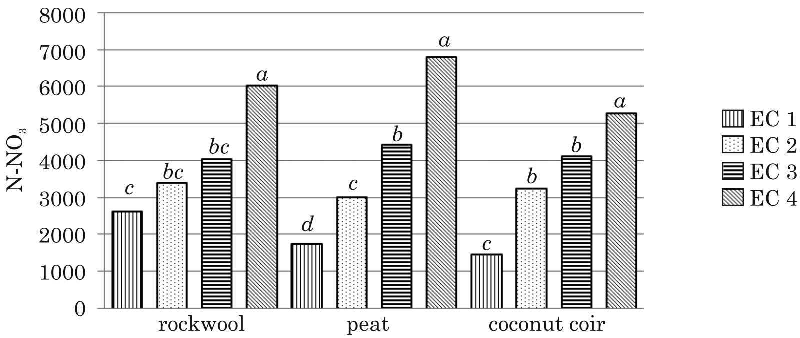

Fig. 4. Combined effect of a substrate type and EC of the nutrient solution on the nitrate content (mg kg^{-1} FW) in heads of lettuce cv. Locarno. Means followed by the same letter are not significantly different at $p = 0.05$

lated higher amounts of nitrates, in excess of the permissible limit, at EC 3.0 and 4.0 mS cm^{-1}, whereas the amounts of nitrates at the same EC levels in a study with butterhead lettuce did not exceed the permissible limit (Sabat et al. 2015). The nitrate content in lettuce was significantly influenced by the interaction of the two experimental factors. Lettuce plants grown in all the tested substrates and at nutrient concentrations of EC 1.0 and EC 2.0 mS cm^{-1} contained nitrates in amounts within the permissible limits. At the higher concentrations of EC 3.0 and EC 4.0 mS cm^{-1}, the levels of nitrates were found to exceed the limit considerably in each growing substrate. The highest increase in nitrate content resulting from the increase in EC was observed in the plants cultivated in peat and rockwool, and the lowest in those cultivated in coconut coir (Figure 4). For each of the growing substrates, the nitrate content in lettuce was significantly the lowest after fertigation with the solution at EC 1.0 mS cm^{-1}, and significantly the highest at EC 4.0 mS cm^{-1} (Figure 4).

CONCLUSIONS

1. Leaf lettuce can be grown in the flood-and-drain system in each of the substrates tested, but the highest total and marketable yields, and the heaviest marketable heads were obtained from the cultivation in rockwool.

2. Coconut coir is worth recommending for this type of cultivation of leaf lettuce because, when grown in a nutrient solution with EC 2.0 mS cm^{-1}, it produced marketable heads of good quality, with a large mass and a low nitrate content.

3. An increase in nutrient concentration increased the nitrate content in lettuce heads, and at EC 3.0 mS cm^{-1} the nitrate levels exceeded the permissible limit.

4. The levels of nitrates in lettuce heads depended on the growth substrate. The highest nitrate content was found in the cultivation in rockwool, and the lowest in coconut coir.

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