Journal of Elementology ISSN 1644-2296

Sabat T., Kaniszewski S., Dyśko J. 2015. *Effect of flood fertigation on yield of greenhouse lettuce grown in different substrates*. J. Elem., 20(2): 407-416. DOI: 10.5601/jelem.2014.19.1.626

EFFECT OF FLOOD FERTIGATION ON YIELD OF GREENHOUSE LETTUCE GROWN IN DIFFERENT SUBSTRATES

Teresa Sabat, Stanisław Kaniszewski, Jacek Dyśko

Research Institute of Horticulture in Skierniewice

Abstract

The hydroponic system is very often used for greenhouse vegetable production. The flood irrigation on a bench or on the flood floors is applied in the production of ornamental plants and vegetable transplants. This system is environmentally friendly, since fertigation is used in a closed system using the recirculation of nutrient solution. The aim of this study, conducted in 2010-2012, was to determine the effect of flood fertigation with different concentrations of nutrient solution (EC: 1.0; 2.0; 3.0; 4.0 mS cm^{-1}) on the yield and quality of the butterhead lettuce cultivar Natalia grown in different substrates (coconut coir, peat and rockwool). The experiment was conducted in the spring and autumn cycle. The highest marketable yield at each concentration of the nutrient solution was achieved in the cultivation in rockwool, both within the spring and autumn. The highest nitrate content in lettuce in terms of both cultivation cycles was found in the lettuce grown in the nutrient solution concentration of EC 4 mS cm^{-1}, and the lowest one was achieved in the nutrient solution concentration of EC 1.0 mS cm^{-1}. Significantly less of nitrates was in lettuce grown in spring than in autumn. Higher levels of EC significantly increased the content of P and K in lettuce leaves during in both growing cycles, while the content of Ca and Mg was not significantly different. The applied substrates had a significant impact on the content of K, P, Ca and Mg in leaves of lettuce. The best concentration of the nutrient solution used for flood fertigation of greenhouse lettuce was EC 3.0 mS cm^{-1} for the spring cultivation and EC 4.0 mS cm^{-1} for the fall crop.

Key words: EC, nitrates, macronutrients, coconut coir, peat, rockwool.

mgr inż. Teresa Sabat, Research Institute of Horticulture in Skierniewice, Konstytucji 3 Maja 1/3, 96-100 Skierniewice, Poland, e-mail: teresa.sabat@inhort.pl

INTRODUCTION

Many forms of hydroponics is used for vegetable greenhouse production, and lettuce (*Lactuca sativa*) is one of the most commonly grown hydroponic vegetables. The hydroponic system is used widely for the production of seedlings on flood benches and a flood heated floor. The benches or the floor are periodically flooded to supply water and nutrients for the plants. This system is environmentally friendly, since fertigation is used in a closed system using the recirculation nutrient solution. A hydroponic system with the recirculation of nutrient solution allows for better nutrient supply control and may save up 40% of water and nutrients. When using flood irrigation, the nutrient concentration in the medium fed to plants is very important, because excessive concentrations can have serious consequences for plants. Dyśko et al. (2011) demonstrated that tomato transplants fertigated with nutrient solution of EC 2.5 and 3.5 mS cm^{-1} had best parameters such as the height, fresh matter content and the number of leaves. Higher EC (4.5 mS cm^{-1}) decreased the plant height and stem diameter of transplants. Markiewicz, Kleiber (2010) showed a relatively high tolerance lettuce to salinity in the range of 1.6 to 5.1 mS cm^{-1}, while Maas, Hoffman (1977) distinguish the threshold salinity tolerance of the plant, above which the plant yield falls. According to Pitura, Michałojć (2012), significantly lower crop yield was recorded when a high nitrogen dose was applied and when there was high variation in EC between particular types of nutrient solution. A high concentration of nutrients in the nutrient solution, especially nitrogen, may cause an increase in the nitrate content in lettuce leaves and brand tipburn. Stefanelli et al. (2012) and Kozik (2006) found experimentally that increasing doses of nitrogen results in an increased nitrate content in lettuce. Excessive nitrogen application may cause serious health problems in humans due to a high intake of nitrogen in its nitrate form. The uptake of nitrogen as well as other nutrients can be modified by substrates used for lettuce cultivation. According to Dyśko at al. (2008), a significantly higher marketable yield of tomato was obtained from plants cultivated in rockwool than in organic media.

The aim of the present study was to determine the effects of flood fertigation with different concentrations of nutrient solution on yield and quality of greenhouse lettuce grown in different substrates.

MATERIAL AND METHODS

The study on effects of flood fertigation on yield and quality of lettuce *cv*. Natalia grown in different substrates in a flood heated floor greenhouse was conducted in 2010 - 2012. Four concentrations of the nutrient solution, such as EC 1.0; 2.0; 3.0 and 4.0 mS cm^{-1}, were applied to lettuce grown in pots or cubes filled with three different substrates: coconut coir, sphagnum peat and rockwool. The experiment was conducted in the spring and autumn cycle. Lettuce seeds were sown in plugs of rockwool. Seedlings were planted in rockwool cubes (10x10x6.5) and "10" pots used for hydroponics (with the capacity close to the volume of rockwool cubes) filled with peat or grounded coconut coir. Lettuce seedlings were set at a spacing of 0.25 x 0.25 m on the greenhouse floor divided into four independent parts. There were thirty plants in every combination. The nutrient solution in a different concentration was supplied to each part three times a week throughout the growing season. Rockwool cubes and pots with substrates were flooded by recirculating nutrient solutions to the level of 3-4 cm, and remained in it for about 30 minutes. The nutrient solutions were prepared for fertigation from single fertilizer in a one- or two-component dispenser supplied by AMI Completa and coupled with four recirculating tanks.

The standard content of nutrients in the solution used for lettuce fertigation was (mg dm^{-3}): N-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. In the standard solution, the proportion of nutrients was changed (increased or reduced) to obtain proper EC for a given object. During the lettuce culture, the composition of the nutrient solution collected from flooded plots was analyzed. Mineral components were measured with the following methods:

- N-NO_3, P-PO_4 – colorimetrically with a flow-autoanalyzer Sanplus (Skalar);
- K, Ca, Na, Mg, Mn, Zn, Cu, B – with a plasma spectrometer ICP, Atom Scan (Tharmo Jarrel Ash);
- Cl^- – potentiometrically with an ion-selective electrode;
- SO_4 – colorimetrically with $BaCl_2$;
- EC – conductometrically, directly in the naturient solution;
- pH – potentiometrically.

The average pH, EC and content of macro- and micronutrients at the applied EC levels are shown in Table 1.

Lettuce was harvested after 4-5 weeks of greenhouse cultivation. At harvest, lettuce samples were collected for analysis. Sample were dried at 45-50°C and then grounded. In the samples collected from fully developed lettuce heads and rpepared as above, dry matter and the content of N-NO_3, P, K, Ca, Mg were determined. The nitrogen concentration was determined with the colorimetric method using a Scan-Plus flow analyzer, and the other elements were measured with a plasma spectrometer (ICP) Perkin-Elmer OPTIMA 2000 DV.

The results were statistically analyzed by analysis of variance based on t-Student test at a significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

The concentration of the nutrient solution had a significant effect on the total and marketable yield of lettuce (Table 2). In the spring cultivation, an increase of EC from 1.0 to 3.0 mS cm^{-1} caused an increase in the total yield from 4041 g m^{-2} to 5197 g m^{-2}, and marketable yield from 3526 g m^{-2} to 4712 g m^{-2}. However, the further increase in the nutrient solution concentration to EC 4.0 mS cm^{-1}, caused an insignificant decrease in yield. Markiewicz, Kleiber (2010) showed a relatively high tolerance of lettuce to salinity ranging from 1.6 up to 5.1 mS cm^{-1}, which is also confirmed herein. In contrast, Maas, Hoffman (1977) distinguished the salinity tolerance threshold of plants above which plant yields fall. In the autumn, the highest total yield of 2997 g m^{-2} was harvested from the lettuce flooded with the solution of EC 4.0 mS cm^{-1}, and the lowest one equalled 1652 g m^{-2} was produced by lettuce supplied the nutrient solution of EC 1.0 mS cm^{-1}.

The substrate used for the cultivation also had a significant effect on the yield of lettuce (Table 3). In the spring growing cycle, the highest total (5641 g m^{-2}) and marketable yield (5019 g m^{-2}) were obtained in the rockwool lettuce cultivation. Lettuce grown in peat and coconut coir substrate produced significantly lower yields in both spring and autumn cycles as compared to that grown in rockwool. Also, the average weight of lettuce heads was the highest in rockwool cultivation and the lowest in coconut coir culture.

The total and marketable yields of lettuce grown in the spring cycle almost doubled those obtained in the autumn. According to Stępowska, Kowalczyk (2000), lower yields of lettuce in the autumn are due to inferior light conditions. During the spring cultivation of lettuce, a high concentration of the nutrient solution (EC 4.0 mS cm^{-1}) caused tipburn, thus reducing the marketable yield. These symptoms are the result of disturbances in the uptake of nutrients, mainly Ca, due to large fluctuations in temperature and humidity or salinity of the substrate. In the autumn, no symptoms of "brand tipburn" appeared, owing to more stable thermal and humidity conditions during that season. The highest marketable yield and the highest average weight of the marketable lettuce head in these conditions were obtained at EC 4.0 mS cm^{-1}. This is also confirmed by Kleiber, Markiewicz (2010), who found no damage to lettuce plants caused by excessive salinity or symptoms of "brand tipburn" despite using fertigation lettuce media of concentrations exceeding the optimum level (EC 1.7-2.3 mS cm^{-1}) for lettuce cultivation.

There was a significant effect of the nutrient concentration on the nitrate content in lettuce heads cultivated both in the spring and autumn (Figure 1). The highest content of nitrates in both cultivation cycles was found in lettuce grown in treatments fertigated with the solution concentration of EC 4 mS cm^{-1}, while the lowest one was determined in lettuce flooed with the solution of EC 1.0 mS cm^{-1}. In the spring lettuce cultivation, the nitrate content in lettuce leaves supplied the EC 4.0 mS cm^{-1} solution exceeded the EU

Table 1

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

Cycle	EC level	pH	EC ($mS\ cm^{-1}$)	$N\text{-}NO_3$	$N\text{-}NH_4$	K	Ca	Mg	P	Fe	Mn	Cu	Zn	B	Na	Cl	$S\text{-}SO_4$
				($mg\ dm^{-3}$)													
Spring	1.0	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
	2.0	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
	3.0	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
	4.0	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
Autumn	1.0	6.1	1.4	120.7	0.9	129.3	165.0	57.0	12.8	1.1	0.4	0.2	0.8	0.6	16.6	20.7	142.0
	2.0	6.0	2.1	168.3	2.9	247.0	207.0	95.0	23.2	2.1	0.8	0.3	1.0	0.7	18.1	20.8	240.0
	3.0	5.9	2.9	251.3	7.0	431.7	265.0	112.0	42.8	3.8	1.4	0.4	1.3	1.0	18.2	18.1	247.0
	4.0	5.8	3.8	346.0	9.4	614.7	325.0	150.0	58.9	5.2	1.9	0.5	1.5	1.3	19.8	18.5	354.0

Table 2

Effect of EC level on total and marketable yield as well as average head weight of lettuce cv. Natalia in spring and autumn cultivation cycles (means from 2010-2012)

EC level (mS cm^{-1})	Spring			Autumn		
	total yield (g m^{-2})	marketable yield (g m^{-2})	average weight of head (g)	total yield (g m^{-2})	marketable yield (g m^{-2})	average weight of head (g)
1.0	4041*c*	3526*c*	222.4*c*	1652*c*	1107*c*	79.92*b*
2.0	4573*b*	3896*bc*	234.6*bc*	2014*bc*	1583*c*	91.56*b*
3.0	5197*a*	4712*a*	293.4*a*	2404*ab*	2303*b*	151.7*a*
4.0	5086*ab*	4214*ab*	280.2*ab*	2997*a*	2911*a*	183.8*a*

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

Table 3

Effect of the substrate on total and marketable yield as well as average head weight of lettuce cv. Natalia in spring and autumn cultivation cycles (means from 2010-2012)

Type of substrate	Spring			Autumn		
	total yield (g m^{-2})	marketable yield (g m^{-2})	average weight of head (g)	total yield (g m^{-2})	marketable yield (g m^{-2})	average weight of head (g)
Rockwool	5641*a*	5019*a*	313.5*a*	2716*a*	2616*a*	165.2*a*
Peat	4564*b*	3957*b*	242.9*b*	2278*b*	1993*b*	144.0*b*
Coconut coir	3969*c*	3285*c*	216.4*c*	1806*c*	1318*c*	71.02*c*

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

acceptable standard, i.e. 4000 mg kg^{-1} of fresh weight. In the autumn, however, there were no significant differences in the levels of nitrates in lettuce grown at EC 3.0 and EC 4.0 mS cm^{-1}, and the content of nitrates, despite being high, was within the permissible norm of 5000 mgNO_3 kg^{-1} of fresh weight. STEFANELLI et al. (2012), KOZIK (2006) found that increasing doses of nitrogen increase the nitrate content in lettuce. Also in our study, there was an increase of nitrates in lettuce leaves with higher nitrogen concentrations in the nutrient solution, and the increase was greater in the autumn than in the spring crop cycle except for the highest EC (Figure 1). This is consistent with the results obtained by KOZIK (2006), which found that significantly less of nitrates accumulated in lettuce grown in the spring than in the autumn because the the higher light intensity in the spring stimulates photosynthesis and the activity of nitrate reductase, thus reducing the level of nitrates in the plant. Similarly, STĘPOWSKA, NOWAK (2006) found that the deterioration of light conditions in the autumn resulted in an increased accumulation of nitrates in plants. However, according to PAVLOU et al. (2007), the concentra-

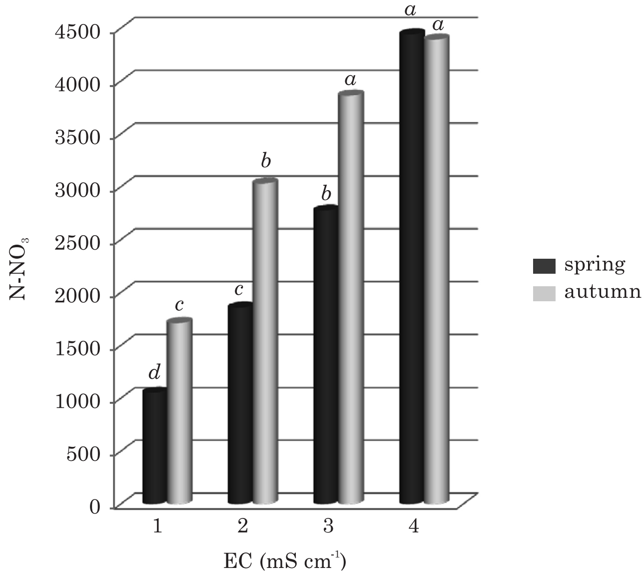

Fig. 1. Effect of nutrient solution concentration on the N-NO$_3$ (mg kg^{-1} FW) content in lettuce (means followed by the same letter are not significantly different at P = 0.005)

tion of nitrates in Romaine lettuce leaves depended on the fertilizer type and dose rather than on the crop season.

A significant impact on the content of nitrates in lettuce heads in both cycles of cultivation was produced by the growing substrates (Figure 2). The highest content of nitrates was found in lettuce grown in the coconut subs-

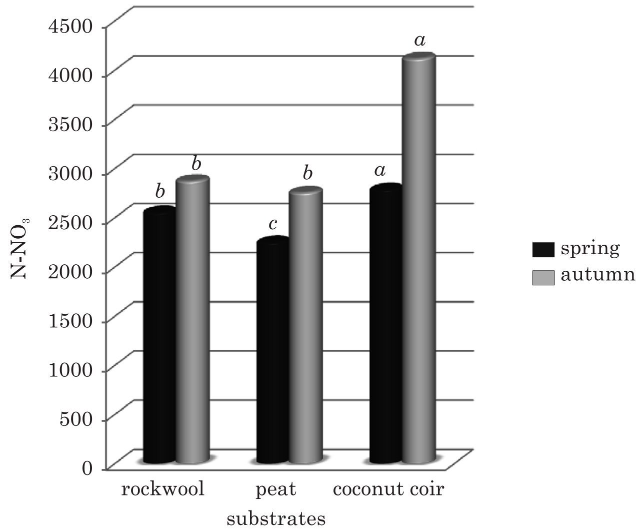

Fig. 2. Effect of substrates used for lettuce cultivation on the content of N-NO$_3$ (mg kg^{-1} FW) in lettuce (means followed by the same letter are not significantly different at P = 0.005)

Table 4

Effect of EC level of nutrient solution on P, K, Ca and Mg content (g kg^{-1} DW) in lettuce cv. Natalia grown in spring and autumn cycles

EC level (mS cm^{-1})	Spring				Autumn			
	P	K	Ca	Mg	P	K	Ca	Mg
1.0	3.257*c*	56.46*b*	9.161	3.570	3.190*c*	70.79*c*	10.53	3.961
2.0	4.325*b*	63.66*b*	8.582	3.825	5.017*b*	90.26*b*	10.40	4.309
3.0	5.300*a*	89.68*a*	7.712	3.580	6.591*a*	104.5*ab*	9.014	4.043
4.0	5.687*a*	10.47*a*	8.283	4.055	7.155*a*	111.2*a*	19.95	3.992

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

trate during both cultivation cycles, and the lowest one appeared in lettuce grown in peat.

The increase in the level of EC was followed by a significant increase in the content of P and K in lettuce leaves in both autumn and spring growing cycles, although the differences at 3.0 and 4.0 EC were not statistically significant. (Table 4). The content of Ca and Mg in lettuce leaves was not significantly different depending on the EC levels in both cycles of cultivation, although the content of these compounds in the autumn cycle was higher than in the spring. This is consistent with the results obtained by Markiewicz, Kleiber (2010).

The growing substrates also had significant influence on the content of P, K, Ca and Mg in lettuce leaves (Table 5). The highest potassium content was found in lettuce grown in rockwool and coconut coir in the spring, and in coconut coir in the autumn, while the lowest potassium concentration was in lettuce grown in peat. The phosphorus content was the highest in lettuce grown in peat and coconut coir, while magnesium and calcium were the highest in lettuce grown in peat.

Table 5

Effect of type of substrate on P, K, Ca and Mg content (g kg^{-1} DW) in lettuce cv. Natalia grown in spring and autumn cycles

Type of substrate	Spring				Autumn			
	P	K	Ca	Mg	P	K	Ca	Mg
Rockwool	4.215*b*	85.67*a*	8.593*ab*	3.579*b*	4.796*b*	97.55*b*	9.882	4.213*b*
Peat	4.797*a*	67.64*b*	9.155*a*	4.212*a*	5.799*a*	75.55*c*	19.24	4.438*a*
Coconut coir	4.916*a*	82.57*a*	7.555*b*	3.481*b*	5.869*a*	109.4*a*	8.300	3.577*c*

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

CONCLUSIONS

1. In the hydroponic cultivation of lettuce on a flood heated floor, the highest marketable yield and highest weight of heads were obtained from cultivation in rockwool, both in the spring and autumn cycles of cultivation.

2. The best concentration of a nutrient solution used for greenhouse lettuce flood fertigation was 3.0 mS cm^{-1} for the spring growing cycle and 4.0 mS cm^{-1} for the autumn crop. At these nutrient solution concentrations, the highest marketable yield and the heaviest heads were grown.

3. The type of substrate used for growing lettuce influenced the content of nitrates in lettuce heads. The highest content was found in lettuce grown in coconut coir, and the lowest – in peat substrate.

4. With an increase in EC, the content of P and K in the leaves of lettuce in both growing cycles increased significantly, while the content of Ca and Mg was not significantly different.

5. The substrates had a significant impact on the content of K, P, Ca and Mg in leaves of lettuce.

REFERENCES

Dyśko J., Kaniszewski S., Kowalczyk W. 2008. *The effect of nutrient solution pH on phosphorus availability in soilless culture of tomato*. J. Elementol., 13(2): 189-198

Dyśko J., Kaniszewski S., Kowalczyk W. 2011. *The influence of flood fertigation on the growth of greenhouse tomato transplants grown in organic substrates*. Infrastructure andecology of rural areas. Polish Academy of Sciences. Cracow Branch. Commission of Technical Rural Infrastructure., 5: 157-165. (in Polish)

Kleiber T., Markiewicz B. 2010. *Lettuce (Lactuca sativa* L.*) tolerance to salinity*. Part 3. *Metallic microelements and sodium content in plants*. Nauka Przyr. Technol., 4(4): #48. (in Polish)

Kozik E. 2006. *Effect of harvest term and nitrogen and potassium fertilization on the conten tof nitrates in greenhouse lettuce*. Acta Agroph., 7(3): 633-642. (in Polish)

Maas E.V., Hoffman G.J. 1977. *Crop salt tolerance – a current assessment*. Irrigat. Drain. Div. Am. Soc. Civ. Eng., 103: 115-134

Markiewicz B., Kleiber T. 2010. *Lettuce (Lactuca sativa* L.*) tolerance to salinity*. Part 2. *Growth, development, yielding and nutrient content in aboveground parts of plants*.Nauka Przyroda Technologie., 4(4): #47. (in Polish)

Pavlou G.C., Ehaliotis C.D., Kavvadias V.A. 2007. *Effect of organic and inorganic fertilizers applied during successive crop seasons on growth and nitrate accumulation in lettuce*. Sci. Hort., 111: 319-325.

Pitura K., Michałojć Z. 2012. *Influence of nitrogen doses on salt concentration, field, biological value and chemical composition of some vegetable plant species*. Part 1. *Yield and biological value*. Acta Sci. Pol. Hort. Cult., 11(6): 145-153.

Commission regulation (EU) No 1258/2011 of 2 December 2011 amending *Regulation (EC) No 1881/2006 as regards maximum levels for nitrates in foodstuffs*. Official Journal of the European Union, L 320: 15-17.

Commission regulation (EU) No 771/2009 of 25 August 2009 amending *Regulation (EC) No 1580/2007 as regards certain marketing standards in the fruit and vegetable sector*. Official Journal of the European Union, L 223: 3-19.

STEFANELLI D.B., RADY S., WINKLER S., JONES R.B., TOMKINS B.T. 2012. *Lettuce (Lactuca sativa* L.*) Growth and quality response to applied nitrogen under hydroponic conditions*. Acta Hort., 927: 353-359.

STĘPOWSKA A., KOWALCZYK W. 2000. *The influence of cultivation method on yield andnitrate content in butterhead lettuce*. Ann. UMCS Lubin, Sect. EEE, Suppl., 8: 189-195. (in Polish)

STĘPOWSKA A., NOWAK J. S. 2006. *Straw substrates for lettuce cultivation*. Acta Agroph., 7(4): 1003-1014. (in Polish)