J. Agr. Sci. Tech. (2018) Vol. 20: 121-128

Contamination of Shallow Groundwater by the Soilless Tomato Culture

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ABSTRACT

Fertilization of plants in greenhouse soilless cultivation is used in a closed system with recirculating nutrient solution or in an open system where the excess of nutrient solution is discharged into the soil or sewage. In Poland, most of basic greenhouse vegetables are grown in the open soilless system. The excess of highly concentrated nutrient solution leaking from growing slabs causes contamination of soil and shallow groundwater. The aim of the study was to monitor component changes in nutrient solution and nitrate nitrogen in the plant root zone, drainage water, as well as in shallow groundwater present in arable lands in the immediate vicinity of the soilless tomato culture. The study was conducted in 2013 - 2015 and compared tomato cultivated in Rockwool versus biodegradable organic substrate. Changes of nutrient content including N-NO_3 in the root zone and drainage water depended on the type of the substrate in which tomato plant was cultivated as well as on the plant growth stage. Higher content of nitrate nitrogen in the root zone and drainage water was found in tomatoes grown in Rockwool compared to the organic substrate. The peak content of N–NO_3 (117 mg dm^{-3}) was detected in the groundwater present directly under the soilless tomato culture and it decreased proportionally to the distance from the greenhouse.

Keywords: Drainage water, Nitrate nitrogen, Nutrient solution, Organic substrate.

INTRODUCTION

The soilless cultivation is currently the most common method of vegetable production in greenhouses and this trend increases annually. This technology ensures high quality and quantity of yields and it enables production of a single plant species without a need of crop rotation and soil decontamination. In general, cultivations on mineral and organic substrates dominate among the soilless cultivation methods. The modern cultivation of tomato is conducted with a limited-to-minimum amount of substrate typically consisting of Rockwool i.e. mineral wool (Sonneveld, 1991; Komosa, 2002). Fertilization in soilless substrate technologies takes place either in an open- or closed-system. In open-systems, the excess of nutrient solution used to maintain the proper concentration of nutrients in the growing slabs is discharged in an uncontrolled way to the greenhouse soil and/or sewage. In a closed-system, the drainage water is collected and re-used for fertilization after appropriate treatment. In Poland, nearly the entire soilless cultivation of tomato is carried out in open fertilization systems (Dyśko and Kowalczyk, 2005) and similar is true in Mediterranean countries (Munoz *et al*., 2008; Thompson *et al*., 2013). Nutrient solution in the root zone of plants and drainage water are richer in nutrients compared to nutrient solution delivered to plants. The highest concentration of nutrients in those solutions occurs in fully yielding of tomato during the summer months (Dyśko and Kowalczyk, 2005). In the soilless cultivation,

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[DOR: 20.1001.1.16807073.2018.20.1.8.0]

approximately 70% of the delivered nutrient solution is used up by plants, whereas 30% is utilized for rinsing of the growing slabs. In the investigations of Benoit and Ceustermans (1995), five tons of fertilizers, including microelements in a chelated form, leaks to the greenhouse soil from one hectare of tomato cultivation in 20% of effluent of drainage water. According to Malorgio *et al*. (2001), in cultivation of roses conducted in an open fertilization system, 2,123 m^3 ha^{-1} of fertilizer solution (containing 1,477 kg of nitrogen) is uncontrollably discharged to the greenhouse soil annually. Our study of an open tomato cultivation system (in Rockwool) demonstrated that the consumption of nutrient solution between early April and late September reached 10,220 m^3 ha^{-1} while the overflow was 3,082 m^3 ha^{-1} (Dyśko, 2007). Moreover, the consumption of nutrients amounted to 9.5 t ha^{-1}, 4.7 t ha^{-1} of which, containing more than 1,000 kg of nitrogen, was uncontrollably leaked with drainage water into the soil. Cultivation in greenhouses and related soilless culture has a relatively small share in the total area used for agriculture. Yet, they are heavily concentrated in the vicinity of large cities and/or predominate in certain regions of the country. Thus, at those locations they can significantly contribute to the deterioration of the environment and increase the toxicological exposure to the residing population.

Using an open-system of tomato greenhouse cultivation, we aimed to monitor changes of the total content of the components and nitrate nitrogen in the dosing nutrient solution and in the plant root zone as well as in the drainage water and the shallow groundwater directly under the greenhouse and its vicinity.

MATERIALS AND METHODS

The study was conducted in an experimental greenhouse at the Institute of Horticulture in Skierniewice, Poland. The area of the greenhouse is 252 m^2, where extended cultivation of tomato in soilless system has been conducted for the last 14 years. The area adjacent to the greenhouse is covered with grass.

The greenhouse tomato cultivation was executed in an open-system of fertilization using: (a) Rockwool, and (b) Biodegradable organic substrates. The growing slabs of biodegradable substrate were made from waste organic materials of fibrous structure (sheep's wool, cotton, long fiber coconut, garneted pine sawdust and flax shives). (Figure1).

Chemical analyses of the nutrient solution from growing slabs, drainage water, and shallow groundwater were carried out once a

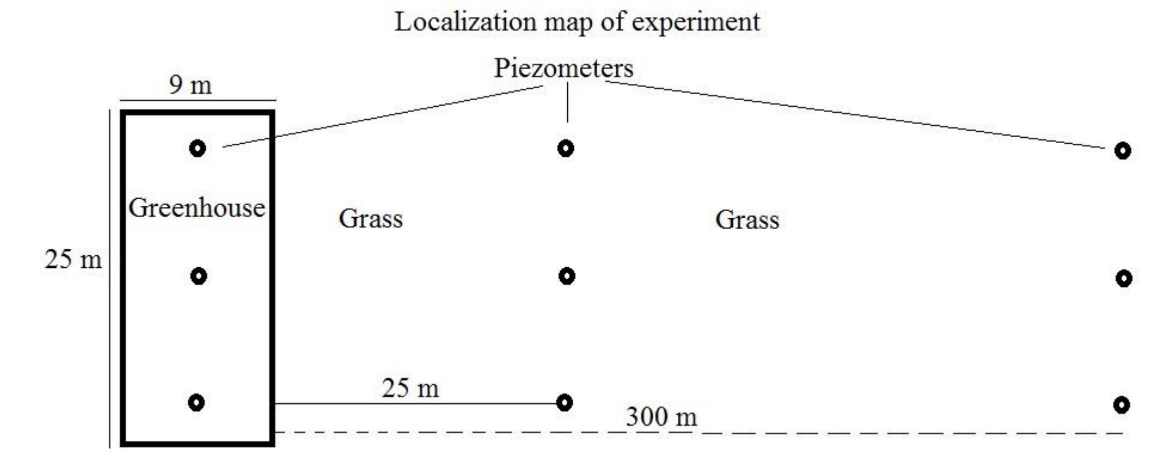


Figure1. Localization of piezometers.

[DOR: 20.1001.1.16807073.2018.20.1.8.0]

month during the tomato cultivation period (April 2013–October 2015); with four replicates per each collection. The nutrient solution was collected from growing slabs by using a medical syringe in the constant distance of 10 seats between the sampled plant sites, in the half length of each slab. Sampling of the nutrient solution was performed after the second irrigation cycle. Characteristic of the irrigation water and standard concentrations of nutrients are shown in Table 1.

The nutrient solution was prepared on the basis of fertilizers N:P:K:Mg - 9:4.5:30:3.5, N::P:K:Mg -10:4:25:4.4, while microelement solution contained : Fe- 1.42, Mn- 0.54, Cu – 0.1, B- 0.20, Mo – 0.03%., chelated iron – 2.7%, calcium nitrate, potassium sulfate, magnesium sulfate and nitric acid. The samples of drainage water from slabs after daily leachate were gathered in plastic containers. The samples of groundwater were collected from 9 piezometers located in the greenhouse and at the distances of 25 and 300 meters away. The content of N-NO_3 was determined colorimetrically with a Sanplus flow autoanalyzer (Skolar), and the *EC* conductometrically with sampler directly in nutrient solution.

The greenhouse soil used was similar to Luvisols soils made of a typical clay boulder. The groundwater level in the piezometers located in the greenhouse and 25 meters away, ranged from 210 to 260 cm, while its level in piezometers located 300 meters from the greenhouse ranged from 70 to 120 cm below the ground. The depth of the groundwater depended on the rainfall volume and the overflow level of the growing slabs. Arithmetic means and standard deviations were calculated for the examined features including *EC* and N-NO_3.

RESULTS AND DISCUSSION

EC and N-NO_3 Content in the Root Zone and Drainage Water

The electrical conductivity is the basic physical indicator determining the

Table 1. Characteristic of the irrigation water a and concentration of the nutrient solution during the tomato crop.

	pH	EC	mg dm^{-3}														
			HCO_3	NO_3	NH_4	P	K	Ca	Mg	Cl	S-SO_4	Fe	Mn	Cu	Zn	Bo	Mo
water	7.2	0.56	349	0.25	0.05	0,05	2.72	101	15	12.9	33.5	0.042	0.022	0.020	1.658	0.025	-
nutrient solution	5.5	3.0	50	220	10	60	320	210	60	20	120	2.1	0.8	0.15	1.9	0.3	0.07

concentration of all nutrients in a solution. The plants grown on biodegradable and inert substrates were fertilized with the same amount of nutrient solution and with the same concentration of nutrients. The type of substrates differentiated the concentration of nutrients both in the root zone and in the leachates from growing slabs (Figure 2, Table 2).

The higher concentration of nutrients was apparent in the Grodan rockwool in comparison to Biopot organic substrate, in the first four months of tomato cultivation. In the same observation period, the peak *EC* difference reached 2 mS cm^{-1} (i.e. higher in Grodan). In the subsequent observation/cultivation period, the concentration of nutrients was similar in both substrates. The type of substrate affected electrical conductivity primarily in the root zone, and to a lesser extent in the drainage water. Much higher nutrient content in the first period of tomato cultivation was recorded in overflows originating from rockwool, whereas less nutrient content was measured from biodegradable substrate. Starting from the second cultivation month, the drainage water formed in both types of substrates contained similar concentration of nutrients.

The changes of nitrate nitrogen in the root zone of plants and in the collected drainage water are shown in Figure 3 and Tables 2 and 3.

The $N\text{-}NO_3$ content in the root zone and drainage water collected from Grodan rockwool was similar and ranged between 300–520 mg dm^{-3}. In the biodegradable Biopot and its overflows, the $N\text{-}NO_3$ content was significantly lower (by about 1000% at the peak difference) than analogous cultivation on rockwool. The $N\text{-}NO_3$ content in the Biopot slabs was very low and ranged from 20 to 65 mg dm^{-3} in the first three months of cultivation. In contrast, the $N\text{-}NO_3$ content in the drainage water from Biopot was much higher and averaged 200 mg dm^{-3} during the same period.

Beginning from the third cultivation month, the nitrate nitrogen concentration in the root zone and leachates began to increase. In June, the gradually increasing nitrate nitrogen concentration reached a similar level in both substrates and its further rise remained similar until the end of cultivation/observation period. Compared to Rockwool, in biodegradable organic substrates relatively smaller quantities of nitrate nitrogen were recorded both in the root zone and leachates. This effect was likely due to the immobilization of nitrogen by microbial activity in the substrate. Similar findings were reported by other authors (Handreck, 1993; Hardgrave and Harriman, 1995; Kowalczyk and Dyśko, 2006; Gruda *et.al*., 2000; Gruda and Schnitzler, 1997) who studied multiple organic substrates in various methods of cultivation. Furthermore, Uronen (1995) demonstrated that the leakage of drainage water from the peat substrate was smaller and contained less nitrogen in comparison to rockwool. Using an open system of fertilization in the tomato cultivation, Breś (2009) showed that the $N\text{-}NO_3$ content in drainage water averaged 327 mg dm^{-3}, while the loss of nitrogen reached 231 kg of $N\text{-}NO_3$ $month^{-1}$ ha^{-1}. According to Kleiber (2012), the greatest environmental pollution is caused by an intense cultivation of tomato, in which the nitrogen loss can reach up to 245 kg of $N\text{-}NO_3$ $month^{-1}$ ha^{-1}.

EC and $N\text{-}NO_3$ Content in the Shallow Groundwater

Chemical analyses of water samples were carried out to assess the impact of soilless tomato cultivation on the quality of the shallow groundwater. The water samples were collected from piezometers installed in the greenhouse and its surroundings at the distance of 25 and 300 m. The concentration of mineral components (EC) and the $N\text{-}NO_3$ content are shown in Figures 4 (a-b) and in Table 4.

We demonstrate that the groundwater sampled from under the greenhouse contained a higher concentration of mineral components i.e. *EC*, in comparison to waters sampled on the surroundings of the greenhouse. Chemical analysis of the groundwater showed similarly

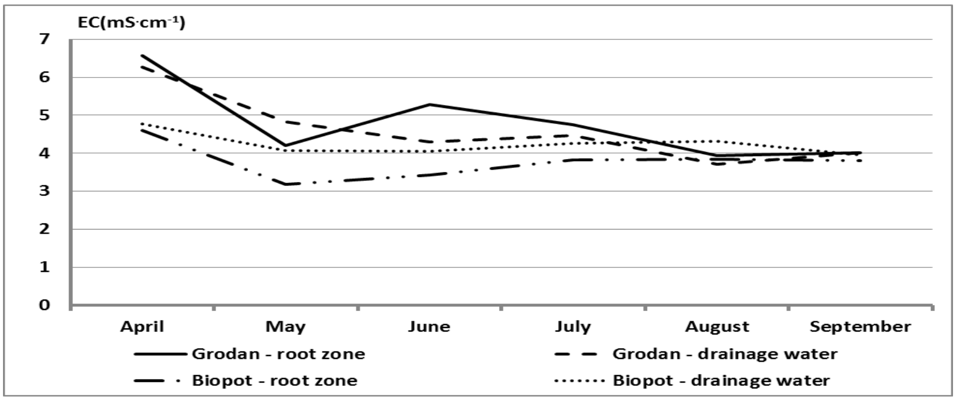


Figure 2. The influence of the type of substrate on the Electrical Conductivity (EC) of the nutrient solution collected from the root zone and drainage water.

Table 2. The influence of the type of substrates on the *EC* and N-NO_3 contents in the nutrient solution collected from the root zone.

Indicator	Grodan			Biopot		
	Mean	Min-Max	Standard deviation	Mean	Min-Max	Standard deviation
EC (mS cm^{-1})	4.35	3.42-6.56	0.91	3.63	2.77-4.86	0.66
N-NO_3 (mg dm^{--3})	361	300-521	66.22	158.0	0.05-404	151.60

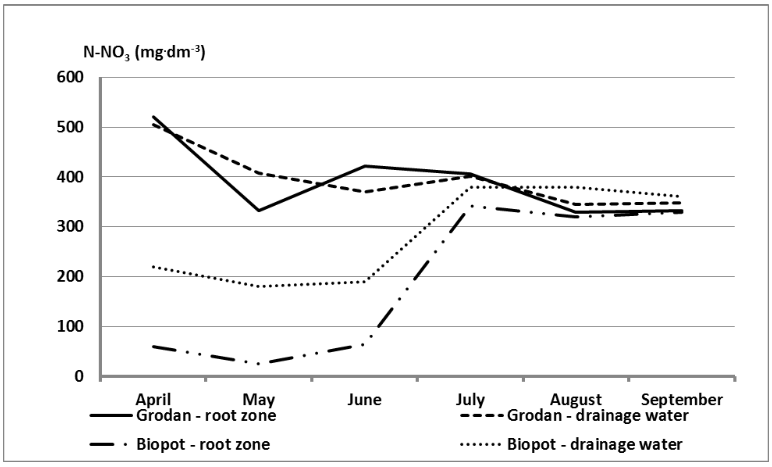


Figure 3. The influence of the substrate type on the content of N-NO_3 in the nutrient solution collected from the root zone and drainage water.

Table 3. The influence of the type of substrate on the *EC* and N-NO_3 contents in the drainage water.

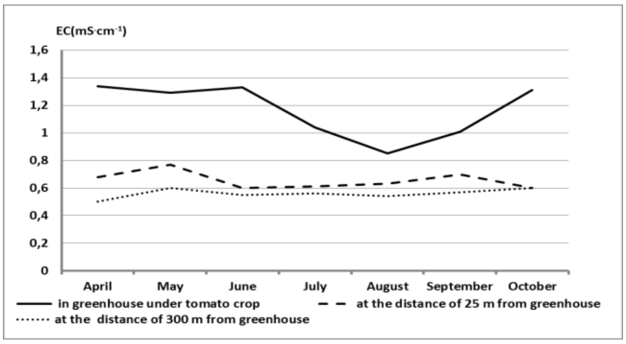
Indicator	Grodan			Biopot		
	Mean	Min-Max	Standard deviation	Mean	Min-Max	Standard deviation
EC (mS cm^{-1})	4.54	3.53-6.27	0.74	4.21	2.80-5.64	0.60
N-NO_3 (mg dm^{-3})	382	317-505	54.71	240	0.05-458	141.50

Table 4. The influence of the drainage water from a tomato soilless culture on the quality of the shallow groundwater

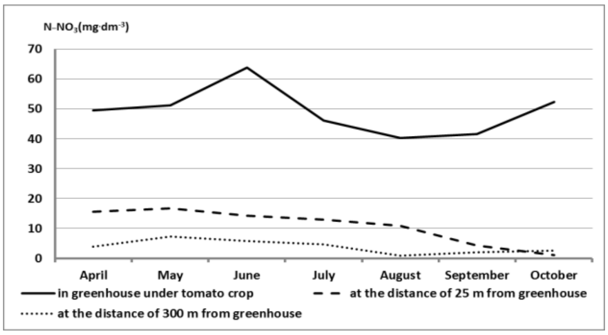
Indicator	Greenhouse			25 m distance			300 m distance		
	Mean	Min-Max	Standard deviation	Mean	Min-Max	Standard deviation	Mean	Min-Max	Standard deviation
EC (mS cm^{-1})	1.12	0.64-2.22	0.40	0.65	0.23-1.08	0.19	0.57	0.17-0.80	0.15
$N\text{-}NO_3$ (mg dm^{-3})	43.86	14.5-117.0	26.36	13.43	2.8-22.6	5.55	5.65	0.73-14.40	4.97

low *EC* values in samples collected from piezometers at 300 m (mean of 0.57 mS cm^{-1}) and at 25 m distance (average of 0.65 mS cm^{-1}). The average electrical conductivity of the groundwater gathered from under the greenhouse was 1.12 mS cm^{-1} and was markedly higher compared to the *EC* of water sampled at 25 and 300 m-distance. , respectively, at about 42 and 44%. The groundwater sampled from under the greenhouse and its piezometer was supplied by rainwater and drainage waters from soilless cultivations which infiltrated into the soil and drained into the groundwater.

Agriculture is considered as one of the main sources of water pollution with nitrogen compounds. As a source of nitrogen in soilless cultivation, nitrate forms of nutrients, which are very well dissolved in water but can easily be leached into groundwater, are primarily used in preparation of nutrient solutions. The average concentration of nitrate nitrogen in the groundwater collected from under the greenhouse approximated 48 mg of $N\text{-}NO_3$ dm^{-3}. The content changes were high and ranged from 14.5 to 117 mg of $N\text{-}NO_3$ dm^{-3}. The highest content of $N\text{-}NO_3$ in the groundwater from under-the-greenhouse was recorded in June and the lowest in August (regardless of the collection year). The content of $N\text{-}NO_3$ decreased proportionally to the distance of leakage of the fertilizer nutrients to the soil. The concentration of nitrate nitrogen was very low reaching only 5.68 mg of $N\text{-}NO_3$ dm^{-3} at the 300 m-distance sampling point. The course of changes of $N\text{-}NO_3$ content was relatively regular in the groundwater in area adjacent to the greenhouse. It followed two curves separated from each other by the value of 10 mg of $N\text{-}NO_3$ dm^{-3}. At the final stage of cultivation (September-October), the concentration curves gradually approached each other, and in the end of the growth period, they were nearly superimposable. Migration of nitrogen (in the form of $N\text{-}NO_3$) due to the better solubility of its compounds depended largely on the hydrological and soil conditions and was associated mainly with elution. The studies conducted by Komosa (2002) and Kowalczyk *et al*. (2013) in areas with a high share of soilless cultivation (particularly tomato), demonstrated pollution



(a)



(b)

Figure 4. The influence of the drainage water from a greenhouse soilless culture (a) on *EC* changes in the groundwater, (b) on the content of $N\text{-}NO_3$ in the groundwater.

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with nutrients and ballast components not only in the groundwater but also in the deeper water layers. The peak concentration of nitrate nitrogen in those waters reached even 128 mg dm^{-3}.

CONCLUSIONS

Changes in the nutrients including N- in the root zone and drainage water depended on the type of substrate in which tomato was cultivated. The higher EC and nitrate nitrogen content in the root zone and drainage water were found in tomatoes grown in the Rockwool compared to the organic substrate. The groundwater collected from under the soilless cultivated plants i.e. under-the-greenhouse samples, exhibited higher contamination with nutrient elements than shallow groundwater collected at 25 and 300 m-distance, i.e. surroundings of the greenhouse samples. The content of N-NO3 was the highest in the groundwater collected from under the soilless tomato cultivation: it reached 117 mg dm-3 and decreased proportionally to the distance away from the greenhouse. The tomato soilless culture in organic substrates is environmentally safer given that its drainage water contains less nutrient elements (especially N-NO3) than the drainage water from the soilless cultivation in Rockwool.

ACKNOWLEDGEMENTS

This study was conducted with the participation of the LIFE+ financial instrument of the EU and co-financed by the National Fund for Environmental Protection and Water Management.

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آلودگی آب زیر زمینی کم عمق در اثر کشت بدون خاک گوجه فرنگی

ج. دیکسوی و س. کانیزوسکی

چکیده

کوددهی گیاهان در گلخانه های کشت بدون خاک یا در سامانه های بسته است که در آنها محلول غذایی بازچرخانده می شود یا در سامانه های باز که در آن ها محلول غذایی اضافی به خاک یا فاضلاب تخلیه می شود. در لهستان، بیشتر گلخانه های اصلی تولید سبزیجات سامانه باز بدون خاک را به کار می گیرند. در این گلخانه ها، محلول غذایی اضافی و بسیار غلیظ که از قطعات پیش ساخته بستر رشد (slab) به بیرون نشت می کند موجب آلودگی خاک و آب زیرزمینی کم عمق می شود. هدف پژوهش حاضر پایش تغییرات مواد در محلول غذایی و مقدار نیتروژن نیتراته در ریشه گاه گیاه، آب زهکشی، و نیز در آب زیرزمینی کم عمق اراضی کشت شده درنزدیکی بلافصل محل کشت بدون خاک گوجه فرنگی بود. این پژوهش در سال های ۲۰۱۵-۲۰۱۳ انجام شد و در آن گوجه فرنگی دربستر رشد ساخته شده از Rockwool با بستر ساخته شده از مواد آلی زیست-پوسیدنی مقایسه شد. تغییرات محتوای مواد غذایی شامل نیتروژن نیتراته در ریشه گاه و آب زهکشی به نوع بستر رشد گوجه فرنگی و نیز به مرحله رشد گیاه بستگی داشت. نتایج نشان داد که مقدار نیتروژن نیتراته در آب زهکش و ریشه گاه گوجه فرنگی در بستر Rockwool در مقایسه با بستر مواد آلی بیشتر بود. مقدار بیشینه نیتروژن نیتراته (۱۱۷ میلی گرم در دسی متر مکعب) در آب زیر زمینی واقع در زیر محل کشت گوجه فرنگی بدون خاک بود و مقدار آن متناسب با دور شدن از محل گلخانه کم می شد.

[DOR: 20.1001.1.16807073.2018.20.1.8.0]