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Effect of fertigation on soil pollution during greenhouse plant cultivation

Włodzimierz Breś*, Tomasz Trelka

Poznań University of Life Sciences, Poland
Department of Plant Nutrition

*Corresponding author's e-mail: wbnaw@up.poznan.pl

Keywords: drainage water, nutrient losses, open fertigation system.

Abstract: The aim of study was to investigate the effect of nutrient solution leakage during plant cultivation in greenhouse on soil pollution. Investigations were conducted in horticultural farms in the Wielkopolskie province (Greater Poland), specializing in soilless plant cultivation in greenhouse. In the first farm located on sandy soil tomato has been grown since its establishment (Object A). Prior to the beginning of crop culture soil samples were collected for analyses at every 0.2 m layer, to the depth of one meter. Successive samples were taken also in autumn after the completion of 1, 2, 3 and 7 culture cycles. For comparison, research was also conducted in a greenhouse located on loamy sand/sandy loam soil used for 8 years for tomato culture (Object B). In all these facilities plants in rockwool were grown and the fertigation in an open system was provided. Chemical analyzes showed the dynamics of soil properties changes and vertical distribution of cations and anions within the soil profile. Increased content of almost all nutrients and particularly of $S\text{-}SO_4$, P, K, Zn, $N\text{-}NH_4$, $N\text{-}NO_3$ in the soil profile in object A and $S\text{-}SO_4$, K, P, $N\text{-}NO_3$ in the soli profile in object B were recorded. The results showed that the degradation rate of the soil environment as a result of open fertigation system application depends primarily on the duration of greenhouse operation. However, explicit changes in the chemical properties of soils were observed already after the first growth cycle. Smaller doses of fertilizers and water, and in consequence reduction of nutrients losses may be achieved by closed fertigation systems.

Introduction

Soilless plant culture is a great technological achievement, since it makes it possible to obtain significantly higher yields than in the traditional cultivation system. This method consists in plant growing in natural or artificial substrates with no contact with soil. An essential component of this technology is fertigation, i.e. fertilization combined with irrigation. Fertigation can be carried out in an open or closed system. In the open system, an excess of the applied nutrient solution exudes to the soil. In the closed system, the excess of nutrient solution after disinfection returns to the fertigation system (recirculation) and therefore does not contaminate the environment. There is also the closed system with no recirculation – drainage waters spillway from culture beds is collected in tanks and nutrient solution may be utilized to feed other cultures (Kleiber 2012). In the open system, there is an uncontrolled leakage of concentrated nutrient solutions to soil,which results in environment al pollution. The problem of excessive amounts of nutrients penetrating to soil was indicated first in the countries with very intensive cultivation of horticultural plants – in the Netherlands (Van Os 1999) and in the Mediterranean Basin (Castilla 2002). At present this threat appears worldwide with the development of greenhouse-based plant production.

Specific chemical composition of drainage waters and the total load of individual nutrients entering the soil were already estimated (Breś 2009, Kleiber 2012). However, little information is available on the effect of fertigation on the chemical composition of soil. Also the dynamics of chemical properties changes of the soil is also unknown. In Poland, tomato culture accounts for approx. 45–50% area in greenhouses and plastic tunnels. Only few farms are equipped with closed systems facilitating reuse of drainage waters. For this reason the aim of this study was to investigate soil pollution as the effect of nutrient solution leakage during soilless culture of tomato.

Material and methods

Investigations were conducted in 2 horticultural farms in the Wielkopolskie province (Greater Poland), specializing in greenhouse plant culture. In the first farm located in Pleszew community tomato has been grown since its establishment in spring 2004 (Object A). Prior to the beginning of crop culture soil samples were collected for chemical analyses at every 20 cm layer to the depth of one meter. Successive samples were taken in autumn after the completion of 1, 2, 3 and 7 growing cycles. Each time the culture was run in rockwool from February to November using an open fertigation system. Samples were always taken in three randomly selected places by drilling with a soil auger under rockwool slabs. For comparison investigations were also conducted in a greenhouse located in Wloszakowice community (Object B). The soil samples were collected before the first growing cycle (2004) and after 8 growing cycles of tomato cultivation (2011). The plants were also cultivated in rockwool using an open fertigation system. The macroelements and sodium were extracted from the soil samples with 0,03 M CH_3COOH (Nowosielski 1998). The modified Lindsey solution was used for the extraction of microelements (IUNG 1983). The following elements were determined: N-NH_4 and N-NO_3 by the distillation method as modified by Starck (Nowosielski 1998), P, SO_4-S by colorimetric analysis, K, Ca, Na by spectrophotometric analysis, and Mg, Fe, Cu, Mn by atomic absorption spectrophotometry (AAS). Electrical conductivity and pH values were measured as well. Soil texture was determined by the sedimentation method (Mocek at al. 2010).

Results and discussion

The results of soil texture determinations are shown in Table 1. The soil from object A can be classified as a sandy soil, whereas the soil from object B as a loamy sand/sandy loamy soil (depending on the soil layer). Characteristic properties of sandy soils include a low exchange capacity, limited water holding capacity, but high water percolation. Soils with the amendment of loam have a higher exchange capacity and water holding capacity, but lower water percolation (Brady at al. 2009).

Table 1. Texture of soils in investigated greenhouses

Depth cm	Object	
	A	B
0–20	Loamy sand	Loamy sand
20–40	Sand	Loamy sand
40–60	Sand	Sandy loam
60–80	Sand	Sandy loam
80–100	Sand	Sandy loam

Vertical distribution of nutrients in the soil profile (mean content in subsequent soil layer) in relation to the duration of greenhouse operation (object A) are presented in Figs 1–2. The increase of nutrients contents in soil profile during seven years of monitoring was very high: S-SO_4 2164%, P 684%, K 666%, Zn 572%, N-NH_4 461%, N-NO_3 326%, Mg 325%, Ca 283%, Mn 215%, Na 203%. Electrical conductivity also grew (633%) (Fig. 3). At the same time a reduction of iron content was recorded (-56%). Changes of nutrients content in the soil during the study occurred with varying intensity. Steady increase was observed in the case of N-NH_4, N-NO_3, Ca, Mg, Na, Zn, while the decline in the case of Fe. Sudden changes in the content of K, S-SO_4, EC (after first growth cycle) and P, Mn (after third growth cycle) were observed. To measure the strength and direction of the linear relationship between variables correlation coefficient were calculated (Table 2). The content of N-NH_4, N-NO_3, P, K, Ca, Mg, Na, S-SO_4, Mn, Zn in the soil was strongly positively correlated to the duration of greenhouse operation; in the case of Fe and pH of soil, a strong negative correlation was found. With the exception of manganese, the depth at which soil samples were collected was of a low importance. This is due to the soil texture homogeneity in the soil profile and the free movement of drainage waters through sandy soils.

The influence of duration of greenhouse operation was confirmed in object B. After 8 years of tomato cultivation in the open fertigation system the contents of nitrates, phosphorus, potassium, calcium, magnesium, sulfates and manganese in greenhouse soil were drastically greater than those in the soil profile before tomato growing (Table 3). The contents of sodium and zinc increased to a lesser extent. However, the iron content slightly decreased.

In all soil profiles (objects A and B) a slight decrease of soil pH was noted. This process was caused by the application of HNO_3 to acidification of nutrient solution. Soil pH decrease can be caused by nitrification, oxidation of organic sulfur, oxidation of iron or manganese and anaerobic decomposition of organic substance (Brady at al. 2009), but in this case the use of HNO_3 as a nutrient solution component was most essential. Acidification of soil in greenhouses with traditional vegetables cultivation was indicated by Yu et al. (2010). The authors explained this process by nitrification of N-NH_4 applied at high rates in fertilization.

The use of open fertigation systems causes serious environment contamination particularly with N-NO_3, which, as a result of a lack of physicochemical sorption on the sorption complex, is easily leached deeper into the soil profile (Breś 2010). For this reason N-NO_3 content in the tested soils was relatively slight, despite the fact that the concentration of N-NO_3 in drainage waters was markedly higher than in nutrient solutions supplied to plants (Table 4). Higher nitrate concentrations in leakage confirm the results of previously published studies (Branas 2005, Thompson at al. 2013). During the traditional culture system in greenhouse the translocation of nitrogen is less intensive: 83% N-NO_3 originating from mineral fertilizers were detected at a depth of 60–100 cm, while 77% N-NH_4 were accumulated in the upper soil horizon (0–60 cm) (Thompson at al. 2007).

New technologies allow to cultivate the plants in greenhouses almost all year round. In the presented study tomato was grown in greenhouses for approx. 10 months/year. At this time drainage waters discharged to soil large amounts of mineral fertilizers. On average, 30% applied volume of nutrient solutions penetrate to soil; however, on hot days a 50% overflow is recommended (Brajeul at al. 2005). This practice is aimed at the reduction of salt accumulation, prevention of nutrient imbalances in root zone (rockwool slabs) or the provision of irrigation uniformity throughout the irrigation zone (Schröder at al. 2002).

The amounts of nutrients leaking during soilless tomato cultivation estimated in earlier investigations (Breś 2009) were as follows: up to 413 kg K · month · ha^{-1}, up to 231kg N-NO^3 · month · ha^{-1}, up to 220 kg Ca · month · ha^{-1} and up to 101 kg S-SO^4 · month · ha^{-1}. Distinctly lower losses were recorded for Na (up to 62 kg kg · month · ha^{-1}) and Cl (up to 34 kg kg · month · ha^{-1}). Among microelements, the highest

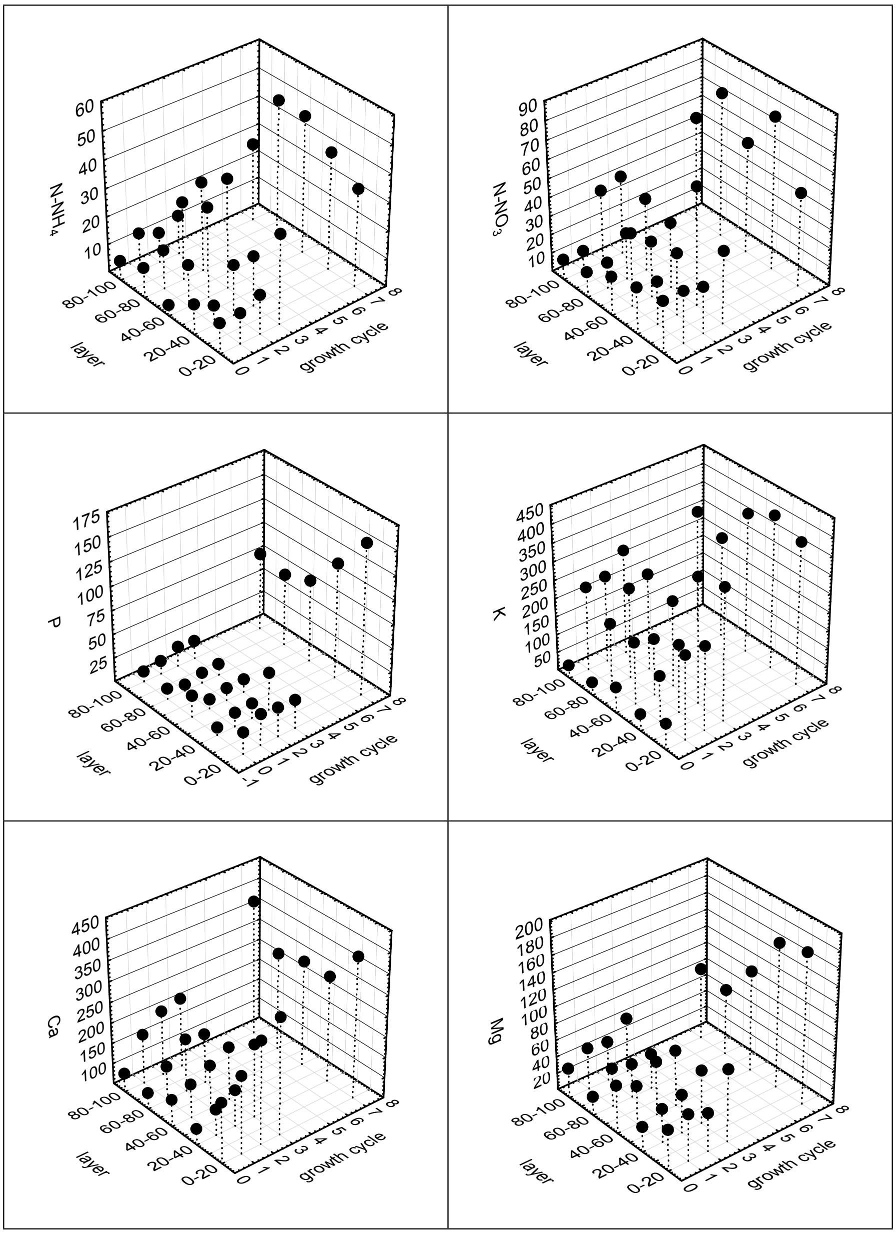

Fig. 1. Relationship between duration of greenhouse A operation (0 – before first growth season and after 1,2,3...growth cycles), depth of soil sampling (cm) and nutrient content in the soil profile in object A (mg · dm^{-3})

losses were found for Fe (up to 3.46 kg kg · month · ha^{-1}) and the smallest for Cu (up to 0.25 kg kg · month · ha^{-1}) and B (up to 0.37 kg kg · month · ha^{-1}). The scale of the pollution confirmed also the results of research published in 2012 (Branas 2005). Annual losses of 850 kg N, 80 kg P and 850 kg K ha^{-1} have been reported for Swedish tomato nurseries (Hansson 2003). It was also estimated that in Mediterranean conditions 300–350 kg N and 125–300 kg P are lost per ha and year (Marcelis at al. 2000). On the basis of the presented studies, greenhouse production systems using soilless culture and open fertigation should be considered as a source of point pollution.

Drainage waters leaching from soilless culture pose a real threat to ground water quality. The soil is not able to capture all leaking components, as sorption complex has a limited exchange capacity. After its saturation cations are no longer retained by the soil. Unfortunately, dominating in Wielkopolska province sandy soils have small exchange capacity. This affects the acceleration of groundwater pollution.

Environmental pollution during greenhouse crop culture is a phenomenon observed in many countries. This problem has been reported in Spain, Italy, Morocco (Cuervo at al. 2012, Pardossi at al. 2004), Northern Ireland (Jordan at al. 2005), Sweden (Hansson 2003), Turkey (Merica 20011), China (Hu at al. 2012, Min at al. 2011) and Colombia (Cuervo at al. 20120). The presented results indicate that this problem is also found in Poland. Similarly as in other countries, this was not only related with horticulture. Gross nitrogen balance in Poland for the years 2009–2011 showed a surplus of about 80 kg N · ha^{-1} of agriculturally utilized area. The highest surplus of nitrogen was recorded in north-western Poland, particularly in the Wielkopolskie (Greater Poalnd) and Kujawsko-Pomorskie (Kuyavian-Pomeranian) provinces, which may raise some concern of environmental pollution (GUS 2012).

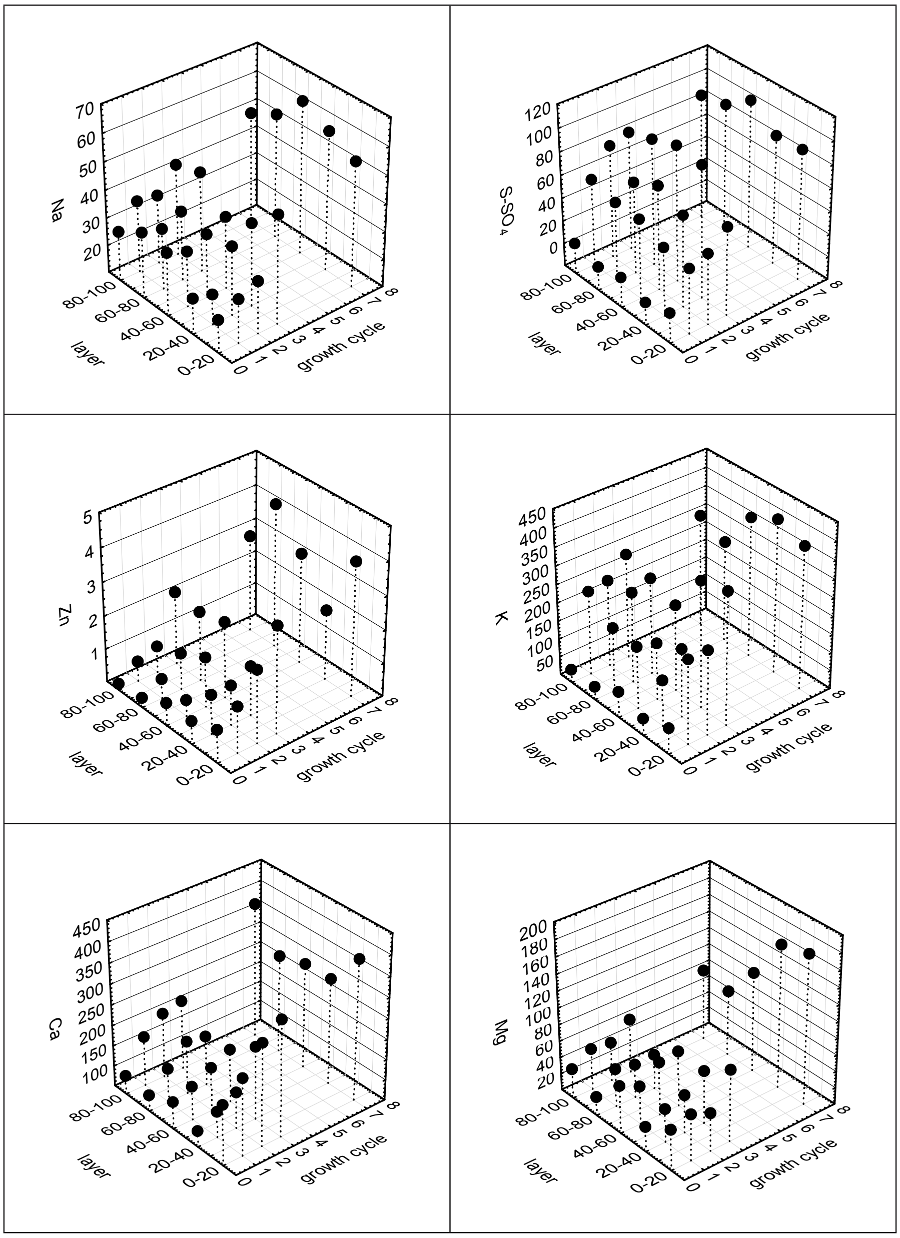

Fig. 2. Relationship between duration of greenhouse A operation (0 – before first growth season and after 1,2,3...growth cycles), depth of soil sampling (cm) and nutrient content in the soil profile (mg · dm^{-3}) or pH of soil

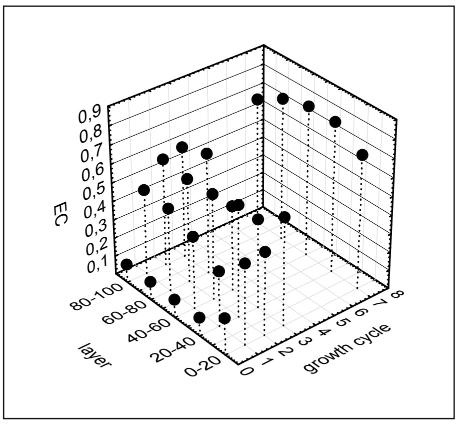

Fig. 3. Relationship between duration of greenhouse A operation (0 – before first growth season and after 1,2,3... growth cycles), depth of soil sampling (cm) and electrical conductivity (EC mS · cm^{-1})

Conclusions

The presented analyses showed that the degradation rate of the soil environment as a result of open fertigation system application depends primarily on the duration of greenhouse operation. Explicit changes in the chemical properties of soils were detectable already after the first growth cycle. It is not possible to completely eliminate losses from soilless culture. Lower application rates of nutrients and in consequence smaller losses to the soil may be provided by closed fertigation systems. These systems increase considerably water and nutrient use efficiency in cultivated plants and minimize environmental pollution. Thanks to the application of nutrient solution recirculation it is possible to reduce water consumption by 15–35% and to limit nutrient solution losses by 15–67% (Merica at al. 2011, Giuffrida at al. 2003, Pardossi at al. 2006, Sonneveld at al. 2009). However, the commercial application of these systems is limited, as their management is more

Table 2. Correlation coefficient between nutrients content in the soil and duration of greenhouse operation or vertical distribution of nutrients in the soil profile in object A (p = 0,05)

$N\text{-}NH_4$	$N\text{-}NO_3$	P	K	Ca	Mg	Na	$S\text{-}SO_4$	Fe	Mn	Zn	pH	EC
Mean nutrients content in the soil to duration of greenhouse operation												
0.84	**0.86**	**0.85**	**0.83**	**0.83**	**0.82**	**0.91**	**0.82**	**-0.72**	**0.78**	**0.87**	**-0.90**	**0.86**
Mean nutrients content in the soil to vertical distribution of nutrients in the soil profile												
-0.04	-0.12	-0.25	-0.13	-0.2	-0.29	0.11	0.14	0.10	**-0.40**	-0.21	0.04	0.04

Numbers in bold – correlation coefficient statistically significant

Table 3. Influence of nutrient solution leaching during 8 years of tomato cultivation on chemical properties of greenhouse soil in object B (mg · dm^{-3})

Depth cm	$N\text{-}NH_4$	$N\text{-}NO_3$	P	K	Ca	Mg	Na	$S\text{-}SO_4$	Zn	Mn	Fe	pH	EC
	The soil in the new greenhouse												
0–20	< 5	30	8	27	320	72	21	3	26	6	99	7.83	0.07
20–40	< 5	24	7	57	315	82	21	< 1	21	10	120	7.84	0.06
40–60	< 5	15	15	57	168	59	17	< 1	11	6	130	7.76	0.05
60–80	< 5	17	14	94	84	44	15	< 1	10	5	152	7.71	0.04
80–100	< 5	12	10	169	95	51	13	< 1	12	4	132	7.63	0.06
The soil after 8 years of greenhouse utilization													
0–20	7	168	127	574	410	367	25	459	43	32	103	6.53	1.19
20–40	14	161	171	520	440	364	27	462	37	43	106	6.68	1.37
40–60	14	165	193	610	360	368	23	548	37	36	105	6.69	1.46
60–80	18	109	183	631	362	231	21	485	34	32	102	6.76	1.16
80–100	21	102	166	691	320	263	23	368	23	23	112	6.68	0.98

Table 4. Example of chemical composition of applied standard nutrient solution used for fertigation of tomato and drainage water leaching from rockwool to the soil

Nutrient solutions	$N\text{-}NH_4$	$N\text{-}NO_3$	P	K	Ca	Mg	Na	$S\text{-}SO_4$	Fe	Mn	Cu	Zn	EC mS · cm^{-1}	pH
	mg · dm^{-3}													
Standard solution	18	193	40	340	170	50	< 60	120	0.84	0.54	0.05	0.33	3.00	5.5
Leakage	1.5	368	58	482	253	80	80	165	6.95	1.75	0.25	2.11	5.09	5.7

difficult compared with open fertigation systems (Pardossi at al. 2006, Magan at al. 2008, Gallardo at al. 2009). Appropriate procedures have already been developed (Savvas 2002, Massa at al. 2010, Bamsey at al. 2012). In the Netherlands, the law requires, since 2000, the use of closed systems or recycling of the nutrient solution in 100% of cultivated areas to mitigate pollution, particularly of surface waters (Van Os 1999, Runia at al. 2001). In the Mediterranean countries, the law states that the leachates from soilless culture systems (SCS) should be treated as industrial discharge and that for crops grown in nitrate vulnerable zones, one must apply irrigation scheduling methods that allow for maximum water use efficiency (Marfá 2000). Poland has the Environmental Protection Law (2001), but too high investment costs associated with the introduction of new technologies pose an obstacle to farmers. In many countries the problem of uncontrolled leakage of nutrient solutions during greenhouse plant cultivation is still not resolved.

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Wpływ fertygacji na zanieczyszczenie gleb podczas uprawy roślin w obiektach szklarniowych

Celem pracy było zbadanie wpływu wyciekającej pożywki podczas uprawy roślin w obiektach szklarniowych na zanieczyszczenie gleby. Badania prowadzono w gospodarstwach ogrodniczych na terenie województwa wielkopolskiego, specjalizujących się w bezglebowej uprawie roślin. W pierwszej z nich, zlokalizowanej na glebie piaszczystej, od początku specjalizowano się w uprawie pomidorów (obiekt A). Przed rozpoczęciem pierwszego cyklu uprawy pobierano próby gleby do analiz chemicznych z kolejnych warstw co 0,2 m, aż do głębokości jednego metra. Kolejne próby pobierano co roku jesienią po zakończeniu 1, 2, 3 i 7 cyklu uprawy. Każdy cykl trwał około 10 miesięcy. Dla porównania przeprowadzono także badania w szklarni zlokalizowanej na glebie gliniasto-piaszczystej, w której uprawiono pomidory przez 8 lat (Obiekt B). W obu obiektach rośliny uprawiano w wełnie mineralnej z wykorzystaniem otwartego systemu fertygacyjnego. Wyniki analiz chemicznych pozwoliły zobrazować dynamikę zmian oraz pionowe rozmieszczenie kationów i anionów w profilu glebowym. Stwierdzono wzrost zawartości niemal wszystkich składników, a szczególnie $S\text{-}SO_4$, P, K, Zn, $N\text{-}NH_4$, $N\text{-}NO_3$ w profilu glebowym obiektu A oraz $S\text{-}SO_4$, K, P, $N\text{-}NO_3$ w profilu glebowym obiektu B. Intensywność degradacji środowiska glebowego spowodowanego stosowaniem otwartych systemów fertygacyjnych zależy przede wszystkim od długości użytkowania szklarni, jednak wyraźne zmiany właściwości chemicznych gleb stwierdzano już po pierwszym cyklu uprawy roślin. Mniejsze zużycie nawozów i wody, a w konsekwencji mniejsze straty składników, można uzyskać stosując zamknięte systemy fertygacyjne.