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POLLUTION OF THE NATURAL ENVIRONMENT IN INTENSIVE CULTURES UNDER GREENHOUSES

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Abstract: The last two decades have brought a significant modernization in methods of cultivation in greenhouses. Soilless cultures, isolated from soils, have become a common practice, similarly as fertigation (fertilization + irrigation) installations, although most of them are applied in the open system (with no recirculation), where excess nutrient solution is removed straight to soil. This situation was the reason why it was decided to conduct studies, extended over a period of many years, on the estimation of environmental pollution caused by discharged drainage waters containing mineral fertilizers in economically important cultures in Poland (anthurium, tomato, cucumber). On the basis of the chemical composition of drainage waters and amounts of nutrient solution spillway from culture beds data were estimated concerning pollution of the soil medium by the nutrient solution. The level of pollution was dependent on nutrient requirements of crops and the length of the vegetation period. The highest environmental pollution is caused by intensive tomato growing (in kg·month·ha^{-1}): N-NO_3 (up to 245), K (up to 402), Ca (up to 145) and S-SO_4 (up to 102). A lesser threat is posed by metal microelements: Fe (up to 2.69), Mn (up to 0.19), Zn (up to 0.52) and Cu (up to 0.09). Lower contamination of the natural environment is generated in cultures with lower nutrient requirements (anthurium) and in the case of culture on organic substrates. With an increase in ecological awareness of producers recirculation systems should be implemented in the production practice, in which drainage waters do not migrate directly to soil, but are repeatedly used to feed crops.

INTRODUCTION

The last two decades – thanks to technical progress and considerable investments in the development of greenhouse facilities – have brought a significant increase in the intensity of culture in greenhouses. The total area of such cultures is 5290 ha, of which 45.4% comprises tomato cultures [1]. A vast majority of intensive cultures under cover is run in the open cycle with no recirculation of nutrient solution. Unfortunately, only few farms are equipped with systems collecting drainage waters spillway from culture beds. These waters may be used to feed other cultures (the closed system with no recirculation) or should be used in a given culture, after being disinfected and enriched with missing nutrients (the closed system with recirculation of the nutrient solution). Together with drainage waters discharged to soil huge amounts of mineral fertilizers migrate to soil. In the case of certain nutrients they may reach as much as 400 kg·month^{-1} [2, 3], causing significant contamination of soil under greenhouse facilities.

The aim of studies extended over a period of many years was to estimate the effect of applied open fertigation systems on the amounts of nutrients removed to soil in the case of soilless cultures of the crop plants which are economically important in Poland, i.e. anthurium, tomato and cucumber.

MATERIAL AND METHODS

Vegetation experiments lasting for several years were conducted in greenhouses, in which the following plant species were grown: anthurium (object I, object II), tomato (object III, object IV) and cucumber (object V). This study comprised estimations of the adverse effect of the application of open fertigation systems on environmental pollution. For this purpose comparisons were made for chemical compositions of nutrient solutions applied dropwise on crops in soilless cultures with nutrient solutions to the root medium (or leaking from cultivation mats with the so-called drainage waters), which in intensive cultivation systems migrate directly to the soil and groundwaters (10−30% applied nutrient solution), causing their contamination. The examined farms were equipped with systems collecting drainage waters; however, in horticultural practice less than 1% of farms have such systems – in this way nutrient solution, leaking from root systems of crops, contaminates soil. Analyses were conducted using the following cultivars: anthurium (*Anthurium cultorum* Schott) cv. “Tropical”, “President”, “Midori”, “Choco”, “Baron” and “Pistache”; tomato (*Lycopersicon esculentum* Mill.) cv. “Emotion F1” and “Caronte F1”; and cucumber (*Cucumis sativus* L.) cv. “Colonel F1”.

The species were selected on the basis of the economic importance of a given species and the length of the vegetation period. Anthurium is an epiphyte with relatively low nutrient requirements. Poland is a leading anthurium producer on the European market (ranking 2nd in Europe) – with expanded clay cultivation systems predominating. The total cultivated area is over 50 ha. Cucumbers and tomatoes have significantly higher nutrient requirements. The area of tomato cultivation under cover is approx. 2,400 ha, while for cucumber it is approx. 1,300 ha. These vegetables from intensive Polish cultures are commercially available practically almost throughout the year. The length of the vegetation period for each of the analyzed species varied, for anthurium it was all-year round, for tomatoes it was 7 months and for cucumber it was 4 months.

Plants were grown on different substrates: expanded clay (anthurium), rockwool (tomato) and sawdust (cucumber). Cultivation measures were performed in accordance with the current recommendations for the examined species. Plant density was 14, 2.5, 1.7 plants·m^{-2}, for anthurium, tomato and cucumber, respectively. The time and frequency of fertigation depended on the vegetation period and weather conditions. Anthurium was fed with 2−5 dm^3 nutrient solution per 1 m^2. In the case of tomato the doses of nutrient solution ranged from 2.5−8.75 dm^{-3}·m^{-2}, while for cucumber it was 2.55–5.95 dm^{-3}·m^{-2}. In the case of analyzed cultures the spillway of nutrient solution was 20, 30, 10%, respectively.

Prior to the establishment of experiments chemical analyses of waters were performed, on the basis of which nutrient solutions for plant fertigation were prepared. Their composition was as follows (in mg·dm^{-3}): (anthurium I) NH_4 trace (tr.); N-NO_3 1.0; P 0.8; K 2.4; Ca 58.1; Mg 20.3; S-SO_4 7.9; Fe 0.015; Mn 0.025; Zn 0.358; B 0.008;

Cu tr.; pH 6.69; EC 0.59 mS·cm^{-1}; (anthurium II) – two water sources: well water (a) and rain water (b): (a) N-NH_4 tr.; N-NO_3 2.2; P 1.2; K 1.3; Ca 141.4; Mg 8.1; S-SO_4 98.7; Fe 0.678; Mn 0.322; Zn 0.034; B 0.020; Cu 0.002; pH 7.46; EC 0.934 mS·cm^{-1}; (b) N-NH_4 and N-NO_3 tr.; P 0.2; K 0.2; Ca 5.0; Mg 0.1; S-SO_4 0.4; Fe 0.062; Mn 0.022; Zn 0.933; B 0.003; Cu 0.005; pH 6.46; EC 0.060 mS·cm^{-1}; (tomato I, II) N-NH_4 tr.; N-NO_3 3.7; P-PO_4 0.3; K 1.8; Ca 57.3; Mg 13.4; S-SO_4 58.3; Fe 0.080; Mn 0.080; Zn 1.648; B 0.011; Cu tr.; Mo tr.; pH 7.05; EC 0.737 mS·cm^{-1}; (cucumber): N-NO_3 5.7; P 0.6; K 8.3; Ca 42.2; Mg 17.6; S-SO_4 23.0; Fe 0.06; Mn 0.04; Zn 1.12; pH 7.09; EC 0.43 mS·cm^{-1}. The samples of nutrient solutions were collected in the case of anthurium every 2 months, while for tomato and cucumber every month.

Nutrient solution samples of 1 dm^3 were collected directly at dripping lines, while from the root medium drained drainage water was collected. Chemical analysis of water, nutrient solution, and drainage water was conducted directly in the analyzed solutions (without their stabilization) using the following methods: N-NH_4 and N-NO_3 – by distillation according to Bremner as modified by Starck [Breś *et al.* 2]; P – colorimetrically with ammonium vanadium molybdate; K, Ca, Na – by flame photometry; Cl – by nephelometry with $AgNO_3$; S-SO_4 – by nephelometry with $BaCl_2$; B – by colorimetry with curcumin; Mg, Fe, Mn, Zn, Cu – by atomic absorption spectrometry (AAS); EC – by conductometry; pH – by potentiometry.

RESULTS AND DISCUSSION

The mean chemical composition of nutrient solutions applied in vegetation experiments is presented in Table 1. It was dependent on the plant species (Table 1). The highest EC (Electrical conductivity; 3.03−3.04 mS·cm^{-1}), reflecting nutrient contents, was used in tomato growing, while it was markedly lower in the case of anthurium (EC 1.46−1.56 mS·cm^{-1}). The reaction of applied nutrient solutions was slightly acid, at pH within the range of 5.61−6.29.

In drainage waters, mainly as a consequence of transpiration predominating over nutrient uptake by plants, as well as retrogradation of certain components (e.g. iron, manganese), changes took place in the chemical composition of nutrient solutions (Table 1). In the case of tomato and cucumber it had a higher EC in relation to the nutrient solution applied for plants, while an opposite trend was observed in the case of anthurium. Relative changes in the chemical composition in the root medium in relation to the nutrient solution applied on plants are presented in Fig. 1.

In the case of both analyzed anthurium cultures, among other things as a consequence of cyclic application of crown sprinkling, diluting drainage waters, EC of nutrient solutions was reduced (by 14 and 2%) in relation to the nutrient solution applied on plants. In the case of vegetable crops a marked increase was recorded in the salinity of drainage waters. Concentrations of most macro- and microelements in nutrient solutions of the root medium were higher than those applied on plants dropwise. Components, whose content increased the most in the case of all the analyzed species, were sodium (18−97%) and chlorides (8−57%). In the case of anthurium the greatest reductions were found for the contents of phosphorus (29−69%) and metal microelements, i.e. iron (38−64%), manganese (43-84%) and zinc (37−74%).

A similar trend, as that observed for the analyzed vegetable crops, for an increase in salinity of nutrient solutions in the root medium, was found, among others, for lettuce

Table 1. Mean chemical composition of nutrient solutions used in fertigation and drainage waters

Nutrient ($mg \cdot dm^{-3}$)	Anturium I [26, 27, 28; mod.]	Anturium II [26, 27, 28; mod.]	Tomato I	Tomato II	Cucumber
Nutrient solution					
$N\text{-}NO_3$	106.3	100.3	229.2	217.7	204.0
P	47.8	34.6	50.9	48.6	53.1
K	213.1	176.9	446.3	294.7	323.1
Ca	40.0	88.6	139.2	86.1	123.7
Mg	36.5	31.8	63.9	67.1	57.4
$S\text{-}SO_4$	52.0	89.9	115.5	114.6	73.2
Na	13.8	22.8	31.0	36.0	23.1
Cl	15.2	24.3	35.5	37.8	19.6
Fe	1.46	1.90	4.36	1.80	1.98
Mn	0.31	0.28	0.51	0.30	0.75
Zn	0.34	0.41	0.64	0.44	1.12
Cu	0.09	0.11	0.06	0.07	0.10
pH	6.29	5.65	5.61	5.81	5.63
EC ($mS \cdot cm^{-1}$)	1.46	1.56	3.04	3.03	2.47
Drainage water					
$N\text{-}NO_3$	84.0	88.1	301.6	310.7	173.1
P	14.9	24.6	54.3	50.9	48.9
K	144.8	143.7	401.7	510.9	442.6
Ca	60.1	121.8	183.6	142.1	154.1
Mg	40.0	31.4	70.5	75.2	68.5
$S\text{-}SO_4$	57.2	106.4	129.5	124.0	81.1
Na	21.9	26.9	61.2	63.9	42.9
Cl	16.4	28.9	55.8	44.3	30.6
Fe	0.90	0.68	3.41	2.08	2.13
Mn	0.05	0.16	0.18	0.24	0.69
Zn	0.09	0.26	0.66	0.63	1.57
Cu	0.09	0.10	0.07	0.11	0.16
pH	6.70	5.90	5.72	6.20	6.89
EC ($mS \cdot cm^{-1}$)	1.26	1.53	3.77	3.94	3.38

[4], cucumber [5], tomato [6], chrysanthemums [7] and roses [8]. In open fertigation systems these nutrient solutions are removed with the so-called spillway directly to soil and groundwaters. In the case of areas with intensively developed horticultural cultivation systems in greenhouses the salinity of waters (expressed in EC units) may occasionally markedly exceed the salinity of nutrient solutions applied in fertigation of

species sensitive to salinity, such as anthurium or orchids [9]. Maximum salinity reported by that author was 1.97 mS·cm^{-1}, while EC of the nutrient solution applied in this study was 1.46−1.56 mS·cm^{-1}. Water of such poor quality should be disqualified from use in growing of plants in substrates of limited volume. However, poor quality water (with EC up to 3 mS·cm^{-1}) is occasionally used in the irrigation of outdoor vegetable cultures, e.g. in Spain (data collected by the author). Paradoxically, the quality of waters used in the preparation of nutrient solutions in fertigation systems is of key importance for the success of these cultures [10, 11]. Membrane techniques are very effective method of chemical water cleaning [12]. Approximately 70% of well waters in the Wielkopolska region may not be used in fertigation, due to the inadequate chemical composition [13]. This situation is frequently observed in regions with intensively developed greenhouse horticulture.

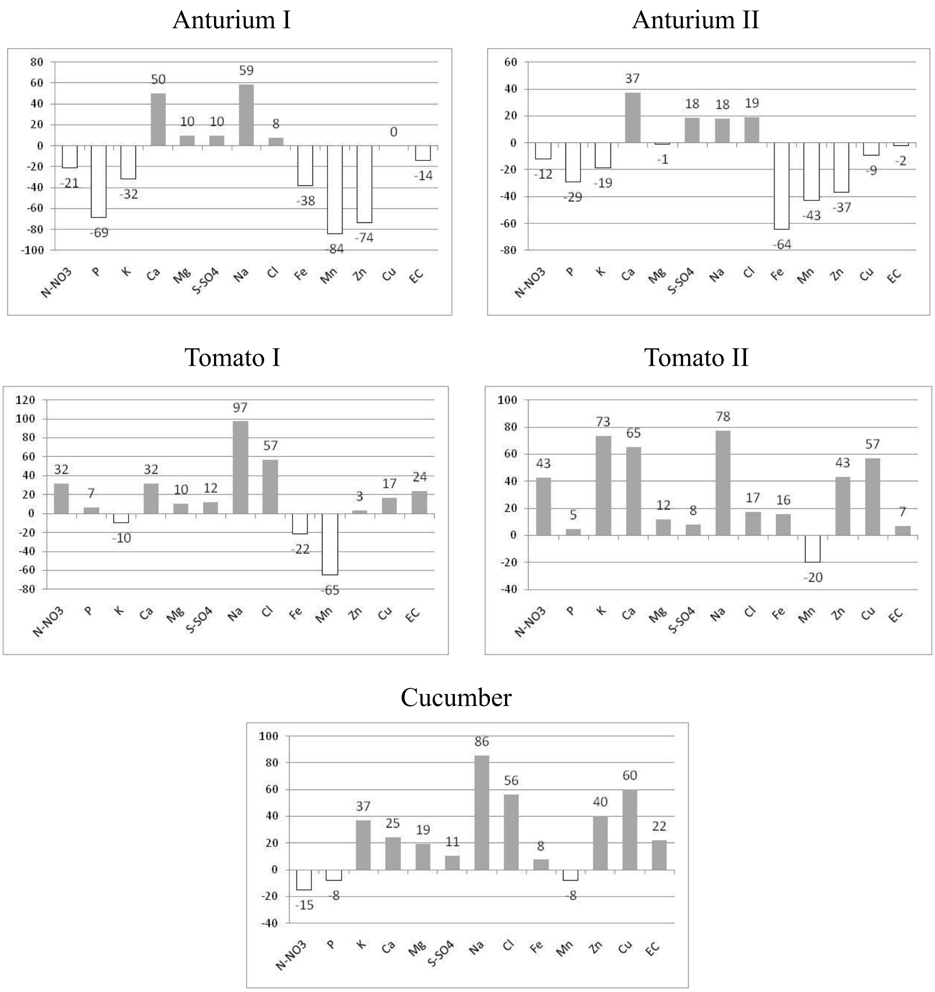

Fig. 1. Relative changes in the chemical composition of drainage waters in relation to nutrient solution applied on plants (in %).

On the basis of information of the chemical composition of drainage waters and the volume of spillway, the threat for the natural environment posed by discharged mineral fertilizers was assessed (Table 2). Most monthly nutrient discharge levels were dependent on the species, length of the vegetation period and the substrate applied. In the case of anthurium grown on expanded clay the greatest amounts of K (up to 43 kg·month·ha^{-1}), Ca (up to 37 kg·month·ha^{-1}), S-SO_4 (up to 32 kg·month·ha^{-1}) and N-NO_3 (up to 26 kg·month·ha^{-1}) were leached, at similar amounts of P, Mg, Na and Cl. Leached amounts of microelements were markedly lower (up to 0.27 kg·month·ha^{-1} in the case of iron). Similar levels of nutrients are leached with drainage waters in the cultivation of gerbera in rockwool, amounting to: N 10−39, K 13−52, Mg 3−13 and Na 3−12.5 (in kg·month·ha^{-1}) [2].

In the case of tomato grown in rockwool the amounts of nutrients leaking from culture mats were markedly higher. These respective levels were as follows (in kg·month·ha^{-1}): K up to 316−402; N-NO_3 up to 238−245; Ca up to 112−145, S-SO_4 up to 98−102 and Mg up to 56−59. They were much lower for microelements, not exceeding 2.69 kg in the case of iron. Amounts of bulk components (sodium and chlorides) in the case of anthurium and cucumber were up to 9 kg·month·ha^{-1}, while for tomato it was up to 50 kg·month·ha^{-1}. Similar data concerning contamination of the natural environment with discharged drainage waters from open fertigation systems were reported early [2]. The biggest problem was related with potassium (up to 413 kg·month·ha^{-1}), nitrates (up to 231 kg·month·ha^{-1}), calcium (up to 220 kg·month·ha^{-1}) and sulfur (up to 101 kg·month·ha^{-1}). The use of open fertigation systems causes serious soil contamination with nutrients – particularly N-NO_3, which, as a result of a lack of physico-chemical sorption on the sorption complex, is easily leached deeper into the soil profile [14].

Table 2. Estimated ranges of monthly nutrient discharge levels in cultures using open fertigation systems (in kg·ha^{-1})

Nutrient	Anturium I	Anturium II	Tomato I	Tomato I	Cucumber
N-NO_3	10–25	11–26	68–238	70–245	13–31
P	2–4	3–7	12– 43	11–40	4–9
K	17–43	17–43	90–316	115–402	34–79
Ca	7–18	15–37	41–145	32–112	12–28
Mg	5–12	4–9	16–56	17–59	5–12
S-SO_4	7–17	13–32	29–102	28–98	6–15
Na	2–7	3–8	14–48	14–50	3–8
Cl	2–6	4–9	13–44	10–35	2–5
Fe	0.11–0.27	0.08–0.20	0.77–2.69	0.47–1.64	0.16–0.38
Mn	0.01–0.02	0.02–0.05	0.04–0.14	0.05–0.19	0.05–0.12
Zn	0.01–0.03	0.03–0.08	0.15–0.52	0.14–0.50	0.12–0.28
Cu	0.01–0.03	0.01–0.03	0.02–0.06	0.02–0.09	0.01–0.03

One of the methods used to eliminate discharges of drainage waters to soil consists in the application of closed fertilization systems. They are divided into systems with no recirculation of the nutrient solution and those with recirculation of the nutrient solution. In the systems of nutrient solution recirculation, after disinfection and supplementation of insufficient levels of nutrients the solution is re-used in feeding a particular culture. These systems make it possible to save significant amounts of used fertilizers and water, as well as ensure their more efficient utilization [15]. There are several methods facilitating efficient disinfection of the nutrient solution, such as thermal disinfection [16, 17, 18], application of UV radiation [13, 19, 20], filtration of the nutrient solution using reverse osmosis or other membrane systems [15, 21], application of hydrogen peroxide [15], application of ozone [21] consisting in 1-hour exposure of the nutrient solution to ozone, iodination [22, 23].

At present it seems practically impossible to completely eliminate nutrient solution discharge to soil. However, it may be minimized thanks to research and development works on more advanced crop cultivation systems. In Poland, studies have been conducted on the preparation and practical implementation of systems with recirculation of nutrient solutions in which harvested yields would be similar to those obtained in cultures with no recirculation of nutrient solution [24]. The problem of environmental pollution caused by intensive horticultural cultivation systems has been acknowledged by the government of Holland, which passed the Agricultural Structure Memorandum and approved several plans, such as e.g. the National Environmental Policy Plan and the Multi-Year Protection Plan, concerning a reduction of environmental pollution thanks to the elimination of uncontrolled emissions of solutions of fertilizers and pesticides to soil and surface waters [25].

CONCLUDING REMARKS

An intensive plant cultivation in greenhouses, conducted over a period of many years using open fertigation systems with no recirculation of the nutrient solution, generates huge discharges of mineral fertilizers, which eventually may contaminate deep water intakes. It seems necessary to intensify implementation works on the application in horticultural practice recirculation system, which are more expensive in terms of installation costs (e.g. due to the necessity of using drainage water tanks, nutrient solution disinfection systems, systems enriching nutrient solution to the assumed pH and EC), but at the same time they are more eco-friendly than the open systems.

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ZANIECZYSZCZENIE ŚRODOWISKA NATURALNEGO W INTENSYWNYCH UPRAWACH SZKLARNIOWYCH

Ostatnie dwie dekady przyniosły istotną modernizację metod upraw pod osłonami. Do powszechnego stosowania weszły uprawy bezglebowe (ang. soilless) odizolowane od gleby i instalacje fertygacji (nawożenie + nawadnianie) – większość prowadzona niestety w systemie otwartym (bez recyrkulacji), gdzie nadmiar pożywki

usuwany jest wprost do gleby. Sytuacja ta była powodem do przeprowadzenia wieloletnich badań dotyczących oszacowania zanieczyszczenia środowiska naturalnego przez zrzuty wód drenarskich zawierających nawozy mineralne w uprawach o istotnym znaczeniu gospodarczym w Polsce (anturium, pomidor, ogórek). Na podstawie znajomości składu chemicznego wód drenarskich oraz ilości wyciekającej z zagonów uprawnych pożywki określono szacunkowe dane dotyczące zanieczyszczenia przez nie środowiska glebowego. Było ono uzależnione od wymagań pokarmowych roślin oraz długości okresu wegetacji. Największe zanieczyszczenie środowiska powodowane jest przez intensywne uprawy pomidora (w kg·miesiąc·ha^{-1}): N-NO_3 (do 245), K (do 402), Ca (do 145) S-SO_4 (do 102). Mniejsze zagrożenie stanowią mikroelementy metaliczne: Fe (do 2,69), Mn (do 0,19), Zn (do 0,52), Cu (do 0,09). Mniejsze skażenie środowiska generowane jest w uprawach o mniejszych wymaganiach pokarmowych (anturium) oraz w przypadku upraw w podłożach organicznych. Wraz ze wzrostem świadomości ekologicznej producentów, powinno wdrażać się do praktyki produkcyjnej układy recyrkulacyjne, w których wody drenarskie nie migrują wprost do gleby, a są ponownie wykorzystywane w żywieniu roślin.