Original Research

Estimation of Nutrient Losses from Open Fertigation Systems to Soil during Horticultural Plant Cultivation

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Abstract

The objective was the evaluation of nutrient losses to soil during horticultural plant cultivation in greenhouses where open fertigation systems are used. Losses were estimated by comparing the chemical composition of nutrient solution effluent from the drippers to the growing media with nutrient leakage from the media to the soil (called drainage or drainage waters) during soilless culture of tomato, cucumber, roses and gerbera. Largest losses were of potassium (up to 413 kg K/month/ha), nitrates (up to 231 kg NO_3-N/month/ha), calcium (up to 220 kg Ca /month/ha) and sulphur (up to 101 kg SO_4-S/month/ha). Smallest losses were of microelements (from 0.01 kg of Mn and Cu to 3.46 kg of Fe per month/ha). In Poland, the greatest horticultural pollution source for the environment is caused by the fertigation of tomato, whose cultivation area covers 2,500 ha, and whose production cycle lasts about 10 months. The least pollution arises from gerbera, which covers only about 90 ha. Sources of agricultural point pollution are generally attributed to animal farms. On the basis of the presented study the source of point pollution is not only assigned to typical agricultural production, but also to greenhouse production systems using soilless culture and open fertigation.

Keywords: nutrient losses, fertigation, soil pollution

Introduction

Fertigation, i.e. fertilization combined with irrigation, is an essential component of modern plant production that 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 is recirculated and, after disinfection, returns to the fertigation system and therefore it does not directly contaminate the environment. In the open system, there is an uncontrolled leakage of concentrated nutrient solutions to soil, and then to the ground or surface waters. The threat is significant because of usually very large amounts of fertilizers used for vegetable and ornamental plant fertigation in greenhouses. For example, for roses grown in soilless culture, a total of 2,990 kg N ha^{-1} was applied [7]. According to GUS [12], at present the annual average application of nitrogen in Poland is 70 kg N ha^{-1}. Thus, greenhouse fertigation represents a very large and potentially important loss of nutrients and source of environmental pollution. The objective of this work was therefore the evaluation of the extent of nutrient losses to soil during horticultural plant production in greenhouses where open fertigation systems are used.

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Material and Methods

All greenhouses were located in Poznań or in its surrounding areas. Estimation of nutrient losses to the soil was made by comparing chemical analysis of the nutrient solutions exuded from the drippers to the media with the analysis of drainage waters leaching from the medium to soil. Crops studied were: cherry tomato cv. Flavorino F1 (cultivated in coconut fibre) and gerbera cv. Amaretto, rose cv. Red Champ, cucumber cv. Milenium F1 and tomato cv. Cunero F1 (cultivated in rockwool). A full growing cycle of the production continued: 5 months - cocktail tomato, 10 months - small beef tomato, 6 months - cucumber, 12 months - gerbera and rose. Plant density was 5, 2.5, 2, 10 and 10 plants per square meter, respectively. Frequency of irrigation (always combined with fertilization) depended on the insolation measured with a calorie counter (Soltimer). Nutrient solutions were applied depending on plant needs: for tomato – 30-234, for cucumber – 30-200, for rose – 25-160 and for gerbera – 30-120 dm^3/m^2/month. According to the recommendations, in order to stabilize the concentration and the pH value of the solution in the root zone and in order to adjust the substrate moisture, the volume of nutrient solution must be higher than the nutritional requirements of plants [7]. During tomato and cucumber cultivations in rockwool there was a 30% overflow, while during cultivation of rose and gerbera in rockwool there was a 20% overflow. In the case of cherry tomato grown in coconut fibre, the applied effluent exceeded the nutritional requirements by 10%. Currently, overflow of 30-50% is recommended for soilless culture [3].

Samples of the supplied nutrient solution and samples of drainage from the medium slabs (day-and-night mean effluent), taken every second week from April to August (cucumber – to July) were analyzed. This is the period in which the greatest amount of nutrient solution is used for fertigation and, therefore, the greatest overflow is noted. In the solutions, the following concentrations of elements were determined: NH_4-N and NO_3-N (by micro-Kjeldahl analysis), P, B, Cl, SO_4-S (by colorimetric analysis), K, Ca, Na (by spectrophotometric analysis), Mg, Fe, Cu, Zn, Mn (by atomic absorption spectrophotometry); pH and electrical conductivity. Calculations shown in the later part of this paper were made on the basis of mean values.

Results and Discussion

The chemical composition of the nutrient solutions supplied to the plants is presented in Table 1. The solution with the highest concentration was supplied to tomato cv. Cunero F1 (EC 3.38 $mS \cdot cm^{-1}$), and that with the lowest to gerbera cv. Amaretto (EC 1.90 $mS \cdot cm^{-1}$). The chemical composition of nutrient solutions draining from the medium during cultivation and changes in the component concentration in relation to the applied nutrient are shown in Table 2.

Because of an insignificant amount of -NH_4-N in the drainage waters, the concentration of these cations is not shown in the tables. Changes in the concentration of components in the drainage water depended primarily on the species of plant and on the phase of plant growth or development. Concentrations of most macro and microelements in the drainage from slabs of inert media and from coconut fibre were higher than in the nutrient solution supplied to the media. The concentration of sodium increased most intensively (tomato, cucumber, gerbera). At the same time, the content of some components decreased, primarily the content of phosphorus and manganese. In consequence of these changes in ion concentration, the electrical conductivity of solutions (EC) increased. The scale of increase of nutrient solution concentration in root environment was: tomato (48-76%) > cucumber (64%) > rose (63%) > gerbera (33%). The pH of the solutions also increased (Fig. 1). Similar changes were also found for roses [2] and chrysanthemums [6]. This suggests that the basic cause of the increase in ion concentrations is a higher intensity of water uptake by plants rather than the uptake of mineral components [15]. Other authors believe that the ratio of the uptake rates of NO_3 , K and P, in comparison with the transpiration rate, decreased from May to September because the substrate temperature had a greater effect on nutrient uptake than on water absorption [9]. It should also be noted that there is a possibility of the release of alcalic elements (magnesium and sodium) from rockwool fibre [1]. One can suppose that, in some cases, the chemical properties of drainage waters may be influenced by the quality of water used for fertigation. Concentrations of nutrients found in the drainage from soilless cultures were many times higher than the mean concentrations of components in the drainage waters from typical agricultural areas. For example, in Wielkopolska, in drainage waters, there was 4.0 mg -NO_3-$N \cdot dm^{-3}$, while in the water from drainage ditches this value was as high as 6.56 mg NO_3-N. The decreasing concentration of ions in agricultural drainage waters was as follows: Ca > S-SO_4 > Cl > Mg > Na > K ≥ NO_3 > NH_4 ≥ PO_4. Moreover, ion concentrations in solutions from field drains is higher than that in solutions taken from drainage ditches [13].

Taking into consideration the minimal and the maximal monthly utilization of nutrient solution and the volume of overflow, the monthly deposition of elements transferred

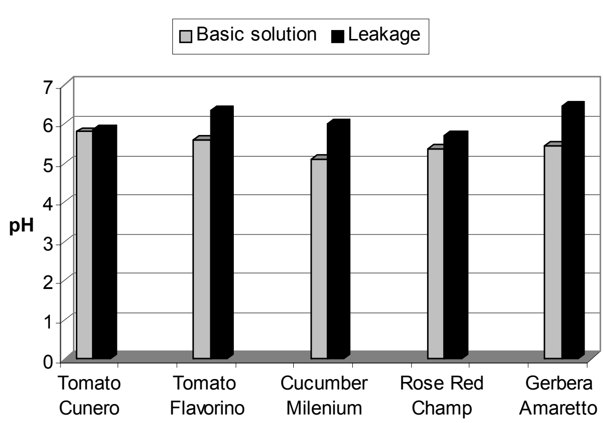

Fig. 1. Changes of nutrient solution pH.

Table 1. Chemical composition of the applied nutrient solutions for tomato, cucumber, rose and gerbera ($mg \cdot dm^{-1}$) grown in soilless culture (mean values).

Nutrient	Tomato Cunero F1	Tomato Flavorino F1	Cucumber Milenium F1	Rose Red Champ	Gerbera Amaretto
$N\text{-}NH_4$	3	12	1	1	5
$N\text{-}NO_3$	287	243	273	185	135
P	54	43	61	64	30
K	380	320	331	248	199
Ca	130	206	100	111	126
Mg	68	60	59	48	39
Na	18	30	33	13	28
Cl	9	34	36	2	53
$S\text{-}SO_4$	94	121	120	51	79
Fe	3.09	0.77	1.13	1.15	1.64
Mn	1.01	0.58	0.78	0.67	0.14
Cu	0.12	0.07	0.14	0.09	0.09
Zn	0.37	1.40	1.25	0.94	0.21
B	0.40	0.34	0.34	0.26	0.20
EC mS/cm	3.38	2.86	2.60	2.13	1.90
pH	5.80	5.60	5.10	5.36	5.45

Table 2. Mean content of components in the leakages from substrates ($mg \cdot dm^{-3}$) and changes in component concentration in relation to the applied nutrient (%).

Nutrient	Tomato Cunero F1		Tomato Flavorino F1		Cucumber Milenium F1		Rose Red Champ		Gerbera Amaretto	
	Leakage $mg \cdot dm^{-3}$	Increase or drop %	Leakage $mg \cdot dm^{-3}$	Increase or drop %	Leakage $mg \cdot dm^{-3}$	Increase or drop %	Leakage $mg \cdot dm^{-3}$	Increase or drop %	Leakage $mg \cdot dm^{-3}$	Increase or drop %
$N\text{-}NO_3$	327	+114	378	+156	385	+141	261	+141	162	+120
P	37	-69	38	-89	68	+112	51	-81	13	-45
K	588	+155	602	+188	562	+170	330	+133	217	+109
Ca	253	+195	470	+229	176	+176	170	+153	143	+114
Mg	81	+119	82	+135	74	+125	66	+139	55	+141
Na	47	+256	133	+441	85	+257	20	+158	52	+188
Cl	15	+167	63	+184	57	+159	1	-45	55	+104
$S\text{-}SO_4$	143	+153	193	+159	149	+124	81	+159	97	+123
Fe	4.93	+160	0.23	-30	0.81	-72	2.09	+181	1.72	+105
Mn	1.71	+170	0.07	-13	0.72	-93	1.57	+234	0.07	-50
Cu	0.35	+308	0.17	+233	0.22	+164	0.09	+109	0.12	+133
Zn	0.98	+269	0.55	-39	1.63	+131	2.19	+234	0.35	+167
B	0.50	+126	0.74	+218	0.61	+179	0.48	+186	0.36	+180
EC mS/cm	4.99	+148	5.04	+176	4.27	+164	3.47	+163	2.52	+133

Table 3. Ranges of monthly losses of nutrients during plant cultivation in soilless culture with the application of open fertigation systems.

Nutrient	Tomato Cunero F1	Tomato Flavorino F1	Cucumber Milenium F1	Rose Red Champ	Gerbera Amaretto
	Range (kg·ha^{-1})				
N-NO_3	30-230	23-177	35-231	13 -83	10-39
P	7-54	2-18	6-41	3-16	1-3
K	53-413	36-282	51-337	17-106	13 -52
Ca	23-178	28-220	16-106	9-54	9-34
Mg	7-57	5-38	7-44	3-21	3-13
Na	4-33	8-62	8-51	1-6	3-12
Cl	1-10	4-30	5-34	0.1-0.3	3-13
S-SO_4	13-101	12-90	13-90	4-24	6-24
Fe	0.44-3.46	0.01-0.11	0.07-0.49	0.10-0.67	0.10-0.41
Mn	0.15-1.20	0.01-0.03	0.07-0.43	0.08-0.50	0.01-0.02
Cu	0.03-0.25	0.01-0.08	0.02-0.13	0.01-0.03	0.01-0.03
Zn	0.09-0.69	0.03-0.26	0.15-0.98	0.11-0.70	0.02-0.08
B	0.05-0.35	0.04-0.35	0.06-0.37	0.02-0.16	0.02-0.09

with drainage waters was determined (Table 3). The largest amounts were of: K (up to 413 kg/month/ha), NO_3-N (up to 231 kg/month/ha), Ca (up to 220 kg/month/ha) and SO_4-S (up to 101 kg/month/ha). Distinctly lower were losses of Na (up to 62 kg/month/ha) and Cl (up to 34 kg/month/ha). Among microelements, the highest losses were of Fe (up to 3.46 kg/month/ha) and the smallest were of Cu (up to 0.25 kg/month/ha) and B (up to 0.37 kg/month/ha).

The literature dealing with environmental pollution caused by fertigation is not numerous and usually concerns N, P, K or total fertilizer volume. In an experiment with roses grown in an open soilless system, the mean leakage was 43% in the volume of the supplied nutrient solution. The total loss of N in drainage water was 2,000 kg ha^{-1}, which is about 60% of the supplied amount [7]. From 1 ha of rose cultivated in perlite or lapillus (volcanic rock) the average overflow was about 40%. The effluent of 2,000 m^3 contained 700 kg of nitrogen fertilizers [9]. In trial with roses grown in perlite and tuff, 44-76% of the supplied nutrients leached from the medium [16]. During the production of cucumbers grown in rockwool, nitrate leakage was 33-43% while phosphorus leakage amounted to 35-47% of the applied nutrients [22]. Cultivation in organic substrates was characterized by a smaller run-off. In an open system with tomatoes grown in peat, the leakage was only 10% and the amount of leached nitrate-nitrogen and phosphorus was less than 20% [22]. However, the input of nutrients from 1 ha of agricultural field crops is considerably smaller. For example, nitrogen rarely exceeds 140 kg N/ha/year [5, 10, 20], and magnesium 24 kg Mg/ha/year [14]. To combat too high nitrate leaching from agricultural soils, the European Commission has issued the Nitrate Directive [8]. This requires the elaboration of new recommendations of nutrient balance for field vegetable production [17].

A complete elimination of losses from soilless culture is unrealizable. A smaller application of nutrients and in consequence smaller losses to the soil can be obtained with the recirculation system. Taking into consideration the concentration of nutrients in the drainage waters, the recirculation of the whole volume of nutrient solution is impossible – a significant part must be mixed with pure water. The rest constitutes an unusable post-production waste. It has been shown that an increase of electrical conductivity of nutrient solution and an increase of sodium concentration are the most important parameters. They both determine the required dilution of drainage with water for its reuse [6, 18]. In comparison to an open system, because of recirculation, it is possible to reduce fertilizer losses by 15-65% [11, 18, 21] and water consumption by 15-35% [18, 21]. For example, during rose cultivation in rockwool with recirculation of nutrient solution, 265 kg N, 53 kg P, 429 kg K/ha/year were lost to soil in the drainage waters [2].

Conclusion

Sources of point pollution have previously been associated with animal farms [19]. On the basis of the presented study, greenhouse production systems using soilless culture and open fertigation should also be considered as a source of point pollution. In Poland, the cultivation of greenhouse tomatoes, because of its large acreage (2,500 ha) and length of production cycle, leads to the largest losses of fertilizers and, in consequence, the highest contamination of soil. On the other hand, the production of gerbera covers only 90 ha, and thus it causes the least pollution. A future policy might involve a law obliging growers to limit losses from soilless culture and decrease environmental point pollution. The EU CLOSYS project (CLOsed SYStem for water and nutrient management) aims to improve the sustainability of crop production by developing an automated fertilization management prototype for soilless crops, including the recirculation of drainage water, which delivers water and nutrients according to plant needs [3]. The change from an open system to a closed system saves both fertilizer and water. Moreover, it reduces soil and water pollution.

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