J. Elementol. 2008, 13(2): 245–254

EFFECT OF NUTRIENT SOLUTION pH REGULATED WITH HYDROCHLORIC ACID ON THE CONCENTRATION OF Cl^- IONS IN THE ROOT ZONE IN SOILLESS CULTURE OF TOMATO

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Abstract

The experiment was carried out in a greenhouse in the years 2004-2006. Tomato plants of *cv.* Blitz F_1 were fertilized with a nutrient solution of different pH: 4.5, 5.0, 5.5, 6.0 and 6.5. The required nutrient solution pH was obtained by adding adequate amounts of 65% HNO_3 and 33% HCl. Nitric acid was used to adjust the nutrient solution's acidity to pH 6.5. Lower pH levels were obtained adding hydrochloric acid. The amount of the acid needed to adjust the nutrient solution pH to a required level was determined against a water acidification curve. Tomato plants were grown on organic media (peat and rye straw) and an inert medium (rockwool). Changes in the Cl^- concentration in the root zone during the cultivation period depended on the kind of substrate and the concentration of chlorides in the applied nutrient solution. In the straw substrate, irrespective of the applied nutrient solution pH, higher concentrations of Cl^- occurred in the early stages of cultivation. The concentration of chlorides in peat and rockwool increased during the tomato cultivation period at all of the applied pH levels of the nutrient solution. More chloride ions accumulated in the growth substrates when the nutrient solution has lower pH. Higher Cl^- concentration was a result of larger doses of hydrochloric acid. However, when pH is regulated with hydrochloric acid, the permissible chloride concentration levels in the applied nutrient solution and in the root zone of tomato plants are not exceeded. As the concentration of chlorides in the nutrient solution increases, so does the Cl^- content in leaves of tomato plants.

Key words: chloride, pH, hydrochloric acid, straw, peat, rockwool.

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WPŁYW pH POŻYWKI REGULOWANEGO KWASEM CHLOROWODOROWYM NA ZAWARTOŚĆ JONÓW Cl^- W STREFIE KORZENIOWEJ W BEZGLEBOWEJ UPRAWIE POMIDORA

Abstrakt

Badania prowadzono w latach 2004-2006 w warunkach szklarniowych. Pomidory odmiany Blitz F_1 nawożono pożywką o zróżnicowanym odczynie (pH): 4,5, 5,0, 5,5, 6,0, 6,5. Wymagany odczyn pożywki stosując dodatek 65% HNO_3 oraz 33% HCl. Ilość kwasu potrzebnego do doprowadzenia pożywki do wymaganego odczynu ustalono na podstawie krzywej zakwaszenia wody, do pH 6,5 za pomocą kwasu azotowego, a dalsze zakwaszenie za pomocą kwasu chlorowodorowego. Pomidory uprawiano w podłożach organicznych (torf, słoma) oraz inertnym (wełna mineralna). Przebieg zmian stężenia Cl^- w strefie korzeniowej w czasie uprawy pomidora zależał od rodzaju podłoża oraz zawartości chlorków w dozowanych pożywkach. W podłożu ze słomy, niezależnie od pH stosowanej pożywki, większe zawartości Cl^- oznaczano w początkowym okresie uprawy pomidora. Zawartość chlorków w torfie i wełnie mineralnej w przypadku wszystkich badanych poziomów pH wzrastała w trakcie uprawy. Większą akumulację jonów Cl^- w badanych podłożach stwierdzono po zastosowaniu pożywek o niższych poziomach pH, w których zawartość chlorków wynikająca z większej dawki kwasu solnego, była wyższa. Regulacja odczynu kwasem chlorowodorowym nie powodowała przekroczenia dopuszczalnych stężeń Cl^- w pożywce oraz strefie korzeniowej pomidora. Wraz ze wzrostem koncentracji chlorków w pożywce wzrastała zawartość Cl^- w liściach pomidora.

Słowa kluczowe: chlorki, pH, kwas chlorowodorowy, słoma, torf, wełna mineralna.

INTRODUCTION

Chlorine plays an important role in many physiological processes in plants (e.g. it affects photosynthesis and water balance) and, although it is considered to be a microelement, the average concentration of chlorine in plants is 2-20 $mg \cdot g^{-1}$ of dry weight, which is a concentration typical of macroelements (MARSCHNER 1995). For the optimal growth of most plant species, however, the demand for chlorine delivered in fertilizers is only 0.2-0.4 $mg \cdot g^{-1}$ d.w. (MARSCHNER 1995). Plants take up chlorine from a variety of sources: fertilizers, atmospheric precipitation, irrigation waters or polluted air. Consequently, toxic amounts of this element are more widespread than its deficiency. Optimum concentrations of chlorine in hydroponic nutrient solutions have not yet been established precisely. Until recently, the recommended concentration of Cl^- ions in nutrient solutions for growing tomatoes in rockwool was 35 ppm in the applied solution and 70 ppm in the root zone. The latest reports suggest that proper fertilization of tomato plants requires chlorine concentrations of 50 ppm in the nutrient solution delivered to the plants and 100 ppm in their root zone, even though the tolerance limit for chlorides in tomato is much higher (JAROSZ 2006). According to NURZYŃSKI and MICHAŁOJĆ (1998), the maximum concentration of Cl^- ions in the root zone that will not affect the growth and yielding of tomato plants can be as high as 1300 $mg \cdot dm^{-3}$. To obtain the required pH level of a nutrient solution, nitric and phosphoric acids as well as modifications in the concentration of NH_4^+ ions are most often used (WILLUMSEN 1980). In adjusting the pH of a nutrient solution, nitric acid can be partly replaced with hydrochloric acid (especially when there are some problems reducing the amount of nitrogen in the solution), which is also a source of Cl^- for plants. PAPADOPOULOS and PARARAJASINHAM (1998), who compared the use of nitric, phosphoric and hydrochloric acids in the NFT method of growing tomatoes, obtained the best yield improvement after stabilizing the nutrient solution pH by means of hydrochloric acid.

The aim of the experiment was to determine the effect of a nutrient solution pH adjusted with hydrochloric acid on the chlorides concentration in the root zone and in tomato plants grown in inert and organic media.

MATERIAL AND METHODS

The experimental work was conducted in 2004-2006, in a greenhouse of the Institute of Vegetable Crops in Skierniewice. The experiment was carried out on Blitz F_1 greenhouse variety of tomato grown on Grodan Master rockwool mats measuring 100 x 20 x 7.5 cm, and on mats of the same size made of shredded rye straw and peat substrate. The experiment was set up in a two-factorial design, in an independent system with four replications. On each experimental plot 6 plants were grown. The plants were planted in their permanent place of cultivation at the beginning of April and grown in an extended cycle until mid-October. Nutrient solution pH levels of 4.5, 5.0, 5.5, 6.0 and 6.5 were obtained by adding nitric and hydrochloric acids to water. The amount of acid needed to fix the required pH level was calculated on the basis of a water acidification curve. Concentrated nitric acid (65%) was used to adjust the pH of the nutrient solution to 6.5, whereas the lower pH values were achieved with 33% hydrochloric acid. The water used for irrigation had the following parameters: composition in $mg \cdot dm^{-3}$ – HCO_3 – 349, N-NO_3 – 0.25, N-NH_4 – 0.05, P – 0.05, K – 2.72, Ca – 101, Mg – 15.0, Na – 10.5, Cl – 12.9, S-SO_4 – 33.5, Fe – 0.042, Mn – 0.022, Cu – 0.020, Zn – 1.680, B – 0.025; EC – 0.56 $mS \cdot cm^{-1}$; pH – 7.2; total hardness – 17.6°dH. In the nutrient solution of pH 6.5, the concentration of chlorides was a result of their presence in the water used for irrigation and ranged from 12 to 25 $mg \cdot dm^{-3}$. The concentration of chlorides in the nutrient solution whose pH was adjusted with HCl was 138 $mg \cdot dm^{-3}$ at pH 4.5, 130 $mg \cdot dm^{-3}$ at pH 5.0, 114 $mg \cdot dm^{-3}$ at pH 5.5, and 60 $mg \cdot dm^{-3}$ at pH 6.0. The amounts of nutrients were as follows (in $mg \cdot dm^{-3}$): N – 200-260, P – 40, K – 220-380, Mg – 60-80, Ca – 180-200, S-SO_4 – 80, Fe – 2.5, Mn – 0.8, B – 0.43, Zn – 0.33, Cu – 0.1, Mo – 0.05.

The chemical analyses for chloride concentration in the solutions taken from the cultivation mats were carried out once a fortnight. For this purpose, samples of the nutrient solution were taken from between two plants in the centre of the mat after the second watering cycle. The chemical analyses for chloride content in leaves of the tomato plants were carried out 3 times over the cultivation period: during the flowering of the third cluster, while picking fruits from the third cluster, and 2 weeks before the end of the cultivation period. For these analyses, the fifth fully-developed leaf, counting from the top of the plant, was taken as a sample. pH was measured with an ORION pH meter; Cl^- concentration in the solution was determined with an ion analyser with a selective chloride electrode, and the chloride content in the plants was determined using the HPLC method. The experimental results were evaluated statistically with an analysis of variance. Mean values were compared with Newman-Keuls test at P=0.05. Changes in the concentration of chlorides in the cultivation mats and their dependence on pH were determined by the methods of correlation and linear and parabolic regression (PIELAT, VISCARDI 1988).

RESULTS AND DISCUSSION

The chemical analyses of the solutions taken from the cultivation mats revealed that the changes in pH in the root zone depended on the pH level of the nutrient solution being supplied, the growing medium and the plant development stage. How the pH of the root zone was changing, depending on the pH of the nutrient solution and the kind of substrate used, can be seen in Figures 1–3. The cultivation of tomatoes on straw, using the nutrient solution of low pH, i.e. pH 4.5, 5.0, and 5.5, caused the pH in the root zone to fall significantly, whereas at the higher pH levels of 6.0 and 6.5, the pH in the root zone was high and did not change much over the entire period of cultivation. As for the peat mats, when the nutrient solution was supplied at the higher pH values of 6.5, 6.0 and 5.5, there was a significant increase in the pH value in the root zone during the cultivation period (Figure 2). The nutrient solution pH levels of 4.5 and 5.0 did not produce significant modifications in the pH level of the root growth environment. In rockwool, the nutrient solution pH levels of 5.0, 5.5 and 6.0 significantly lowered the root zone pH during cultivation. However, supplying the nutrient solution at a pH close to neutral (pH 6.5) or acidic (pH 4.5) did not cause a significant decrease in the pH of the root zone (Figure 3). The organic growing media, in comparison with rockwool, did not respond so much to the different pH levels of the nutrient solution because of their high sorptive capacity and some buffering properties. According to DECHNIK and WIATER (2002), organic matter has a stabilizing effect on soil pH.

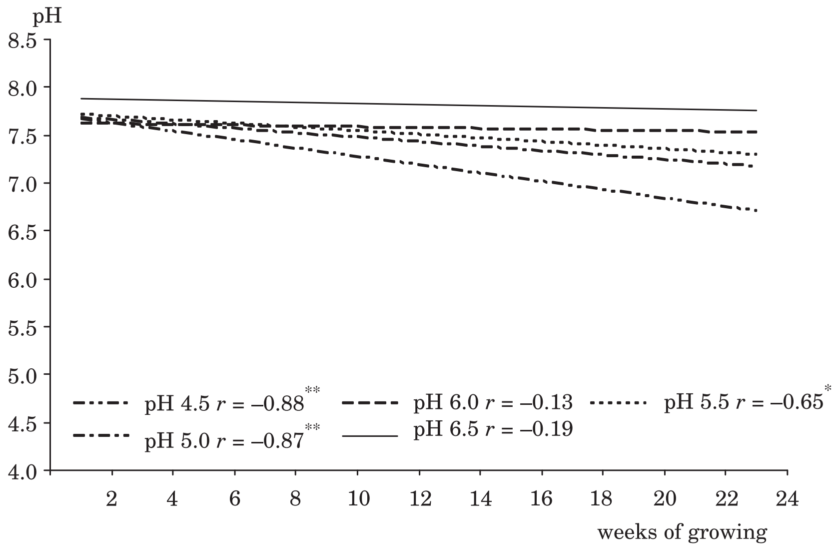

Fig. 1. Changes of pH in the root zone of tomato grown on straw medium depending on pH of the nutrient solution (* significant at $P = 0.05$, **significant at $P = 0.01$)

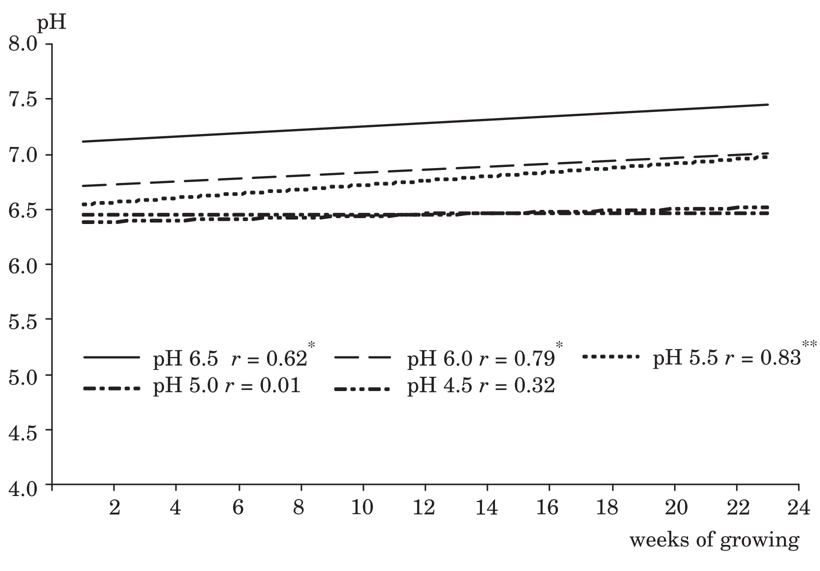

Fig. 2. Changes of pH in the root zone of tomato grown on peat medium depending on pH of the nutrient solution (* significant at $P = 0.05$, **significant at $P = 0.01$)

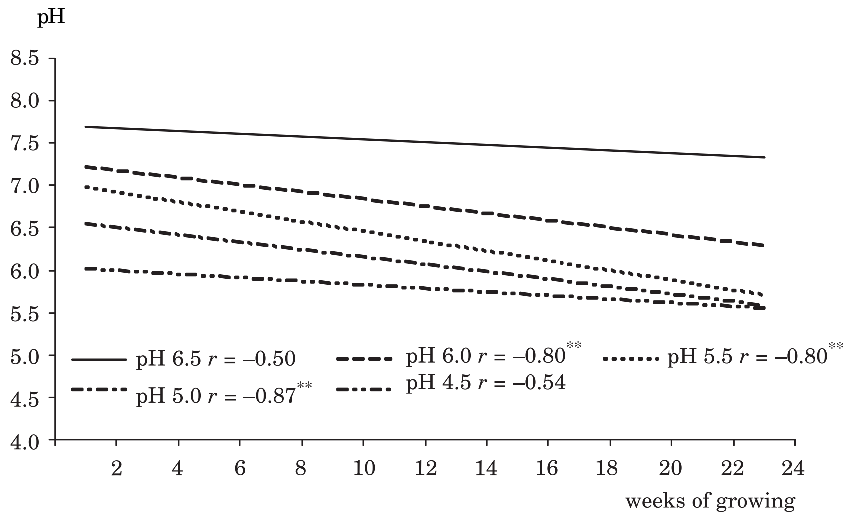

Fig. 3. Changes of pH in the root zone of tomato grown on rockwool depending on pH of the nutrient solution (* significant at P = 0.05, **significant at P = 0.01)

Changes in the Cl^- concentration in the root zone during the cultivation period depended on the kind of substrate and the concentration of chlorides in the nutrient solution supplied to plants. In the substrate made of straw, the highest Cl^- concentrations were measured in the early stages of cultivation (Figure 4). Even at pH 6.5 of the nutrient solution not adjusted with hydrochloric acid, the Cl^- concentration was high (around 200 $mg \cdot dm^{-3}$ Cl^-). With time, the concentration of chlorides in the straw substrate decreased. For the first 12 weeks of the cultivation, the Cl^- concentration in the root zone stayed at a similar level when the nutrient solution was supplied at pH 4.5, 5.0 and 5.5. Later, however, the Cl^- concentration showed more variation, increasing at pH 4.5 and falling at pH 5.5. The changes over time in the concentration of chlorides in the root zone in the straw substrate followed parabolic regression curves, which were significant at all of the applied nutrient solution pH values. Higher chloride concentration in the root zone in the initial stages of cultivation was caused by the leaching of chlorides from the straw. Straw of cereal crops is rich in chlorides, on average 0.90% in dry matter (HOUBA, UITTENBOGAARD 1994).

In the cultivation of tomatoes on peat and rockwool, lower concentrations of chlorides in the root zone, in all the cases, were found during the early stages of cultivation (Figures 5 and 6). With time, the concentration of chlorides in these substrates increased. In the experiments by NURZYŃSKI and MICHAŁOJĆ (1998) with tomatoes growing on rockwool, the concentration of chlorides during the vegetative period also increased, reaching 450 $mg \cdot dm^{-3}$ at

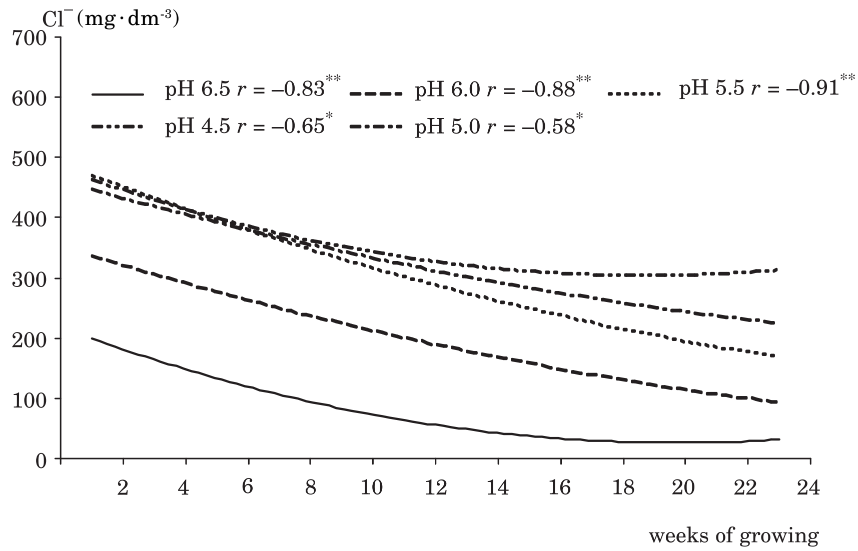

Fig. 4. Changes of the chlorides concentration the root zone of tomato grown on straw medium depending on pH of the nutrient solution (* significant at $P = 0.05$, **significant at $P = 0.01$)

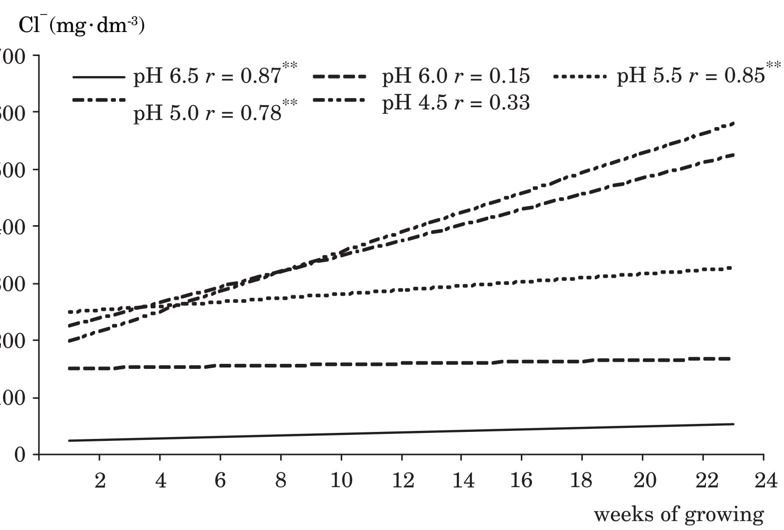

Fig. 5. Changes of the chlorides concentration in the root zone of tomato grown on peat depending on pH of the nutrient solution (* significant at $P = 0.05$, **significant at $P = 0.01$)

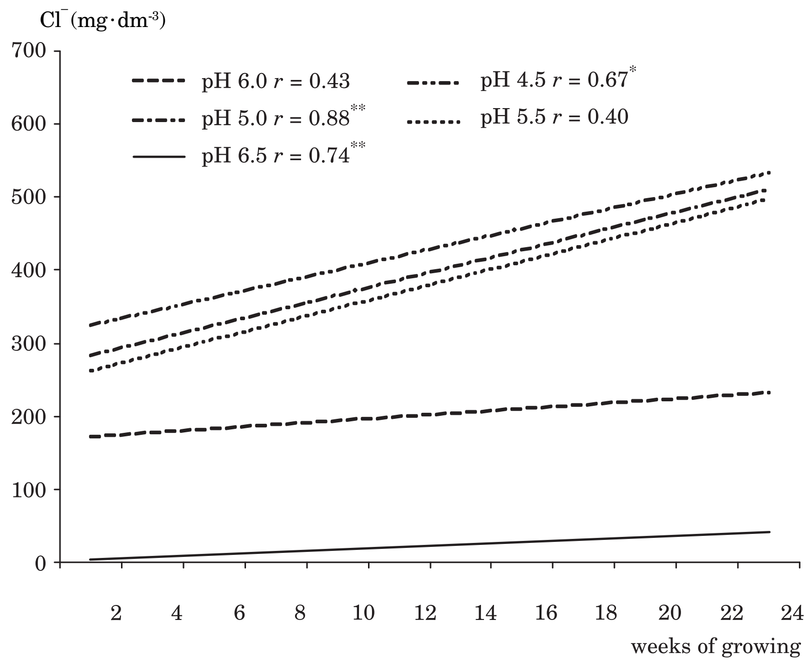

Fig. 6. Changes of the chlorides concentration in the root zone of tomato grown on rockwool depending on pH of the nutrient solution (* significant at P = 0.05, **significant at P = 0.01)

the peak of fruiting. More Cl^- ions accumulated in the root zone when the nutrient solution was supplied at the lower pH values, carrying higher concentrations of chlorides, which was due to the larger doses of hydrochloric acid used for fixing pH. The concentration of chloride ions in the straw substrate, after using the nutrient solution at pH 4.5, 5.0 and 5.5, fell significantly in the course of cultivation, and the regression trend lines obtained for these pH values were not significantly different from one another (Figure 4). Therefore, the pH of the nutrient solution, in this range, was not found to have an effect on the concentration of chloride ions in the root zone. In contrast, with tomatoes grown on rockwool, supplying the nutrient solution at pH 4.5 and 5.0 resulted in a significant increase in the Cl^- concentration in the substrate (Figure 6). However, the resulting regression lines for the changes in Cl^- concentration with time, analogously to straw, did not differ significantly from one other. In the peat substrate, the trend lines for chloride concentration changes were not significantly different only for pH 4.5 and 5.0 (Figure 5). Lowering the pH of the nutrient solution from 5.5 to 4.5 does not require as much hydrochloric acid as, say, adjusting from pH 6.5 to 5.5. This is a consequence of the non-linear (logarithmic) nature of the relationship between the pH value and the concentration of H^+ ions. The Cl^- concentration in all the substrates and at all the pH levels used did not exceed the value of 750 mg $Cl^- \cdot dm^{-3}$ given by Adams and Bailey-Anguish (1988), and quoted by Papadopoulos and Pararajasinham (1998) and Nukaya et al. (1991). In the experiments by Jarosz (2006), the Cl^- concentration in a nutrient solution used for growing tomatoes was 120 $mg \cdot dm^{-3}$, whereas the average chloride concentration in the root zone was at a level similar to our results, reaching 427 $mg \cdot dm^{-3}$ in rockwool, and 396 $mg \cdot dm^{-3}$ in peat. This means that by using hydrochloric acid to regulate the pH of a nutrient solution, the permissible chloride concentrations in the solutions used to fertigate tomato plants are not exceeded. The use of hydrochloric acid to adjust nutrient solution pH, and at the same time the Cl^- concentration in the root zone, had a significant effect on the chloride content in tomato leaves (Table 1). A significantly higher Cl^- content (10.0 $g \cdot kg^{-1}$ d.w., on average) was found in the leaves of tomato plants fertilized at pH 4.5–5.5 of the nutrient solution. The average chloride content in the leaves taken from the treatment where HCl was not used (pH 6.5), was 5.53 g $Cl^- \cdot kg^{-1}$ d.w. The growing media used in the experiment did not have a significant effect on the chloride content in leaves of tomato plants. Nurzyński and Michałojć (1998), and Chapagain and Wiesman (2004), using KCl and $MgCl_2$ to fertilize tomato plants in soilless culture, also found that as the chloride concentration in the substrate increased, the chloride content in tomato plants also increased.

Table 1

The effect of nutrient solution pH on the content of chlorides in leaves ($g \cdot kg^{-1}$ d.m.) of tomato (2004–2006)

pH	Growing medium			
	peat	straw	rockwool	*x*
4.5	10.8	11.2	8.80	10.3 *a*
5.0	10.4	10.3	7.77	9.45 *a*
5.5	10.2	12.1	10.2	10.8 *a*
6.0	6.44	7.86	7.92	7.41 *b*
6.5	3.92	5.87	6.79	5.53 *c*
x	8.34 *a*	9.44 *a*	8.29 *a*	-

Means with the same latter are not significant at $P = 0.05$.

CONCLUSIONS

1. Changes in Cl^- concentration in the root zone during cultivation of tomato depended on the kind of substrate and the concentration of chlorides in the nutrient solution supplied to the plants.

2. In the substrate made of straw, irrespective of the pH level of the nutrient solution being used, higher Cl^- concentrations were measured in the initial stages of tomato cultivation.

3. The concentration of chlorides in peat and rockwool increased in the course of tomato cultivation at all of the applied pH levels of the nutrient solution.

4. Adjusting pH by means of hydrochloric acid did not result in exceeding the permissible Cl^- concentration levels in the nutrient solution or the root zone of tomato plants.

5. As the chloride concentration in the nutrient solution increased, so did the Cl^- content in leaves of tomato plants.

REFERENCES

CHAPAGAIN B. P., WIESMAN Z. 2004. *Effect of potassium, magnesium chloride in the fertigation solution as partial source of potassium on growth, yield and quality of greenhouse tomato*. Sci. Hort., 99: 279-288.

DECHNIK I., WIATER J. 2002. *Kształtowanie wartości wskaźników zakwaszenia gleb nawożonych uciążliwymi opadami organicznymi.* Zesz. Probl. Post. Nauk Rol., 482: 121-129.

HOUBA V. J. G., UITTENBOGAARD J. 1994. *Chemical composition of various plant species.* Dep. of Soil and Plant Nutrition – Wageningen Agricultural University, pp. 226.

JAROSZ Z. 2006. *Effect of different types of potassium fertilization on the yielding of greenhouse tomatoes grown in various substrates*. Acta Sci. Pol. Hort. Cult., 5(I): 3-9.

MARSCHNER H. 1995. *Mineral nutrition of higher plants*. Second Ed. Acad. Press. London, 889 pp.

NUKAYA A., VOOGT W., SONNEVELD C. 1991. *Effects of NO_3, SO_4 and Cl ratios on tomatoes grown in rercirulating system*. Acta Hort., 294: 297-304.

NURZYŃSKI J., MICHAŁOJĆ Z. 1998. *Plonowanie pomidora uprawianego na wełnie mineralnej w zależności od nawożenia potasowego.* Zesz. Nauk. AR Kraków, 333: 235-239.

PAPADOPOULOS A. P., PARARAJASINGHAM S. 1998. *Effects of controlling pH with hydrochloric acid on the growth, yield and fruit quality of greenhouse tomato grown by nutrient film technique*. Hort Technol., 8(2): 193-198.

PIELAT H., VISCARDI T. 1988. *Regresja paraboliczna*. Inst. Warzywnictwa, Skierniewice.

WILLUMSEN J. 1980. *pH of the flowing nutrient solution*. Acta Hort., 98: 191-199.