J. Elementol. 2008, 13(2): 189–198

THE EFFECT OF NUTRIENT SOLUTION PH ON PHOSPHORUS AVAILABILITY IN SOILLESS CULTURE OF TOMATO

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Abstract

Greenhouse experiments with tomato were conducted in the years 2004-2006. The aim was to study the effect of nutrient solution pH on the availability of phosphorus in soilless culture of tomato. Tomato plants were grown on mats made of shredded rye straw, and on slabs of peat and rockwool. The plants were fertilized with a standard nutrient solution of different pH: 4.5, 5.0, 5.5, 6.0 and 6.5. Such different pH levels of the nutrient solution used in soilless culture modified the pH of the root growth zone. This effect was more evident in rockwool than in the organic media (especially straw). The phosphorus content in the root zone was closely associated with the pH value of the supplied nutrient solution and the kind of growing medium. Considerably lower concentrations of phosphorus were recorded in the organic media (straw, peat) than in rockwool. As the pH level of the nutrient solution increased, so did the pH of the root zone, whereas the amount of available P-PO_4 decreased. The course of these changes was similar in all the substrates. However, the dynamics of the changes was weaker in the organic media. With an increase in the pH of the nutrient solution, the average phosphorus content in tomato leaves decreased. The P-PO_4 concentration was higher in the leaves of tomato plants growing in rockwool compared to those in the organic media. A significantly higher marketable yield was obtained from tomato plants cultivated in rockwool than in the organic media. For all the growing media, the highest yield of tomatoes was obtained after feeding the plants with the nutrient solution of pH 5.5.

Key words: pH, nutrient solution, phosphorus, straw, peat, rockwool.

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WPŁYW ODCZYNU POŻYWKI NA DOSTĘPNOŚĆ FOSFORU W BEZGLEBOWEJ UPRAWIE POMIDORA

Abstrakt

Badania prowadzono w warunkach szklarniowych w latach 2004-2006. Celem badań było określenie wpływu odczynu pożywki na dostępność fosforu w bezglebowej uprawie pomidora w podłożach organicznych i inertnym. Uprawę prowadzono w matach wykonanych z rozdrobnionej słomy żytniej, w workach z torfem oraz w wełnie mineralnej. Rośliny nawożono standardowymi roztworami pożywek o zróżnicowanym odczynie (pH): – 4,5, 5,0, 5,5, 6,0, 6,5. Zróżnicowany odczyn pożywki stosowanej do upraw bezglebowych na podłożach organicznych, szczególnie na słomie, w mniejszym stopniu modyfikował pH środowiska korzeniowego niż na wełnie mineralnej. Zawartość dostępnego fosforu w środowisku korzeniowym była ściśle związana z odczynem dozowanej pożywki oraz podłożem uprawowym. Zdecydowanie mniejsze zawartości dostępnego fosforu oznaczano w podłożach organicznych (słoma, torf) w porównaniu z wełną mineralną. Wraz ze wzrostem pH pożywki, wzrastało pH środowiska korzeniowego oraz malała zawartość dostępnego fosforu. Przebieg tych zmian był podobny zarówno w podłożach inertnym, jak i organicznych. Tempo tych zmian było wolniejsze w podłożach organicznych. Wraz ze wzrostem pH stosowanych pożywek malała średnia zawartość fosforu w liściach pomidora. Wyższą zawartość $P\text{-}PO_4$ w liściach pomidora stwierdzono na wełnie mineralnej. Na wełnie mineralnej uzyskano istotnie wyższy plon handlowy pomidora w porównaniu z plonem z podłoży organicznych. Najlepsze plonowanie pomidora, niezależnie od stosowanych podłoży, stwierdzono w przypadku stosowania pożywki o pH 5,5.

Słowa kluczowe: pH, pożywka, fosfor, słoma, torf, wełna mineralna.

INTRODUCTION

In soilless culture of tomato, mineral, organic and inert growing media are used. The pH of the root zone affects the availability of nutrients taken up by plants (NELSON 1991). In organic-mineral substrates, the effect of pH is greater than in soil (PETERSEN 1982, quoted by NELSON 1991). According to many authors, nutrient solution used to cultivate tomato in rockwool should have a pH of 5.5-6.0 (SONNEVELD 1991, MICHAŁOJĆ, NURZYŃSKI 2002, KOMOSA et al. 2004, DYŚKO, KOWALCZYK 2005, KOWALCZYK, KANISZEWSKI 2005). In inert substrates, the availability of some nutrients depends directly on the pH of the root zone. In soilless cultures with organic substrates, the pH of the nutrient solution is modified not only by the plants and the changes in the surrounding environment (as is the case of inert substrates), but also by the organic matter of the substrate used. BADORA (2002) reports that the specific adsorption of molybdate, phosphate and sulphate ions decreases as the pH increases, whereas their immobilization occurs in an acidic environment. The pH of a growing medium has the greatest influence on the availability of phosphorus, manganese and iron (KOWALCZYK, KANISZEWSKI 2005, KOWALCZYK et al. 2006). Phosphorus is an element which occurs in forms that are strongly dependent on environment pH. In the root zone, active phosphorus can be found as

PO_4^{-3}, HPO_4^{-2}, and $H_2PO_4^-$ ions. Most phosphorus is taken up by plants in the form of the two latter ions. The largest amounts of phosphorus available to plants grown on inert substrates are present in nutrient solutions that are slightly acidic (pH 5.0). In alkaline and highly acidic solutions, retardation takes place, i.e. a decrease in the concentration of available ions. A literature review indicates that the experimental work on the effect of nutrient solution pH has involved mainly inert substrates, and there have been no reports concerning organic growing media.

The aim of this work was to determine the effect of nutrient solution pH on the availability of phosphorus in soilless culture of tomato grown in organic and inert substrates.

MATERIAL AND METHODS

The work was carried out under greenhouse conditions in the years 2004–2006. The experiment was set up in a two-factorial design, in an independent system with four replications. The experimental factors included:

a) growth substrates – peat, rye straw, rockwool;
b) pH of nutrient solution – pH of 4.5, 5.0, 5.5, 6.0, 6.5.

Shredded rye straw was used to make cultivation mats in the shape of 100 cm long x 20 cm wide x 10 cm thick slabs. Mats of the same dimensions were also made of peat. The inert substrate used in the experiment was 'Grodan-Master' rockwool in 100x20x7.5 cm slabs. Each slab of a substrate was used to grow 3 tomato plants of cultivar Blitz F_1. The experimental plot size was 3 m^2. The plants were planted in a permanent place of cultivation in early April and grown in an extended cycle until mid-October. The required pH of the nutrient solution was obtained by adding to water 65% HNO_3 and 33% HCl. The amount of acid needed to bring the nutrient solution to the required pH level was determined on the basis of a water acidification curve, with the nitric acid used to fix the pH at 6.5, while the other acidification levels were achieved with the hydrochloric acid (so as not to vary the nitrogen content in the experimental combinations). After seedlings had been planted, regular fertigation was carried out, adjusted to climatic conditions and plant growth stage. For irrigation, water of the following composition was used (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^{o}dH. Parameters of the applied nutrient solution: pH 4.5-6.5, depending on the combination; EC 2.0--3.0 $mS \cdot cm^{-1}$; composition ($mg \cdot dm^{-3}$): 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. While growing the tomato plants, the concentration of the nutrient solution was maintained at EC = 2.3-2.8 $mS \cdot cm^{-1}$ when the weather was sunny, at EC = 3.0 $mS \cdot cm^{-1}$ when it was cloudy with low light levels, and at EC = 2.7-3.0 $mS \cdot cm^{-1}$ during vigorous plant growth and harvest. During the initial period of plant growth, until the third or fourth fruit cluster had set, the nitrogen content in the nutrient solution was at a level of 260 $mg \cdot dm^{-3}$. Then the level of nitrogen was lowered to 200 $mg \cdot dm^{-3}$. Tomato fruits were picked twice a week. Marketable fruit yield was recorded.

Samples of the solutions from cultivation mats were analysed for phosphorus content once every fortnight. The samples for chemical analyses were taken after the second watering cycle from in between two plants in the centre of the mat. Chemical analyses for phosphorus content in the leaves were carried out 3 times during the cultivation period: when the third cluster was in flower, at the time of picking the third fruit cluster, and 2 weeks before the end of cultivation. For that purpose, the fifth leaf from the top of the plant was taken as a sample. pH was measured with an ORION pH meter, while $P\text{-}PO_4$ concentration was determined by means of an Atom Scan 16 plasma spectrometer. The results were processed statistically using the variance analysis method. Mean values were compared with Newman-Keuls test at p=0.05. The changes in phosphorus concentration in the cultivation mats and its dependence on pH were determined using the methods of correlation and linear and parabolic regression (PIELAT, VISCARDI 1988).

RESULTS AND DISCUSSION

The pH value of the nutrient solution delivered to the tomato plants had an effect on the pH changes in the root zone during the cultivation period. The average pH values presented in Table 1, which represent the samples of the nutrient solution taken from the cultivation mats, are a general indicator of the response of the root environment to the application of the nutrient solution at different pH levels. There was a weaker response to the variations in pH of the supplied nutrient solution in organic substrates, straw in particular. Because of its very good buffering properties, straw maintained in the root zone a high pH level with very little variation. In the peat substrate, the changes in pH were also very small, as both low and high pH levels of the nutrient solution only slightly changed the pH of the root zone only. In rockwool, however, the changes in pH of the root zone depended on the pH of the nutrient solution. Low pH of the applied nutrient solution (pH 4.5) was found to maintain the pH in the root zone at a level of 5.8, whereas high pH (6.5) sustained a level of 7.5.

The available phosphorus content was very closely associated with the pH of the nutrient solution being supplied and the growing medium used (Figures 1-5). Regardless of the pH value of the applied nutrient

Table 1

The effect of pH of nutrient solution on the pH of root zone of tomato (2004-2006)

pH of nutrient solution	pH of root zone		
	straw	peat	rockwool
4.5	7.1	6.4	5.8
5.0	7.4	6.5	6.0
5.5	7.5	6.7	6.2
6.0	7.6	6.9	6.7
6.5	7.8	7.2	7.5

solution, the least variation in the available phosphorus content was found in the solution taken from the cultivation mats made of straw. Over the whole period of tomato cultivation in straw, the least amounts of phosphorus were measured when the nutrient solution had a pH of 6.5. The dynamics of the changes in the phosphorus content in straw was described by rectilinear regression lines. With the nutrient solution of pH 4.5, the phosphorus content in the solution sampled from the straw mats increased during the cultivation period, whereas at pH 6.5 it showed a downward trend throughout the whole period of cultivation. A comparison of the substrates used in the experiment reveals that the least amounts of available phosphorus were found in straw. Compared to straw, there was greater availability of phosphorus in the peat substrate. In this substrate, the highest phosphorus amounts were measured when the pH of the nutrient

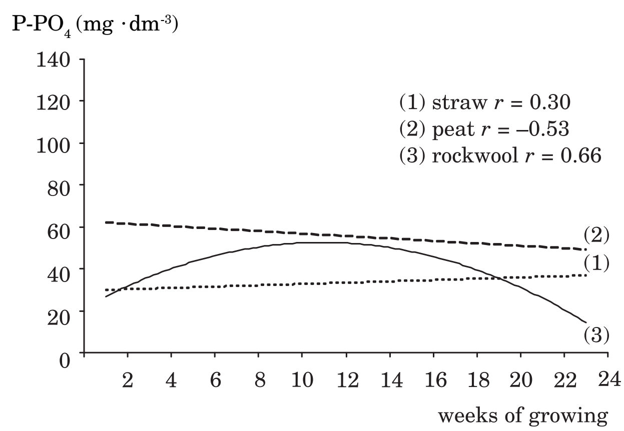

Fig. 1. Changes of $P\text{-}PO_4$ concentrations in root zone of tomato at pH 4.5 of the nutrient solution

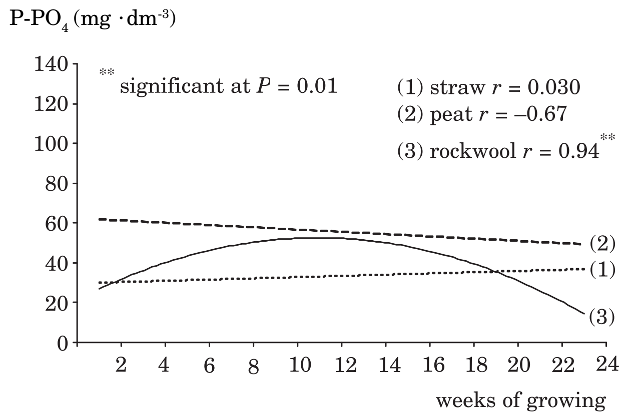

Fig. 2. Changes of P-PO_4 concentrations in root zone of tomato at pH 5.0 of the nutrient solution

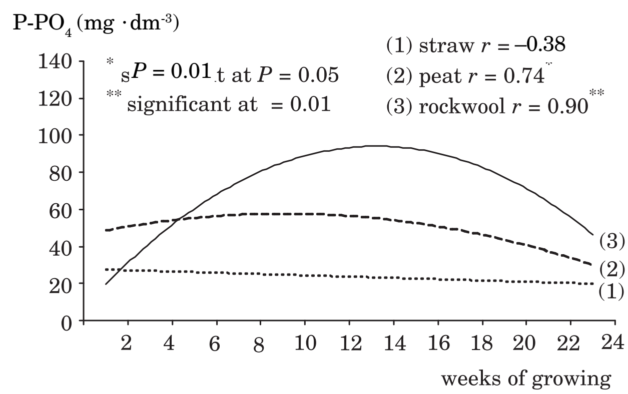

Fig. 3. Changes of P-PO_4 concentrations in root zone of tomato at pH 5.5 of the nutrient solution

solution was 4.5, and the lowest when the solution pH was 6.5. The changes in the phosphorus concentration in the root zone in the peat substrate proceeded in a similar way for the nutrient solutions with pH 4.5, 6.0, and 6.5, and were represented by a straight line. In contrast, the changes for pH 5.0 and 5.5 were described by a parabolic curve. It should be noted that the course of the changes in the phosphorus content did not depend on the stage of cultivation at the pH levels used and was of no statistical significance. When the pH of the applied nutrient solution was 6.5, the highest availability of phosphorus in all the substrates used was found in peat. In rockwool, the pH of the nutrient solution significantly changed the amounts of phosphorus available to plants. The resulting parabolic regression lines clearly demonstrate a significant relationship be-

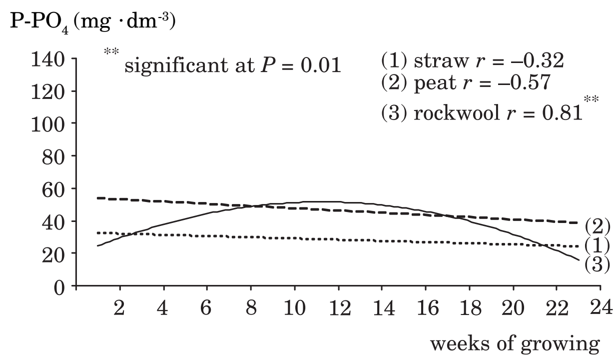

Fig. 4. Changes of P-PO_4 concentrations in root zone of tomato at pH 6.0 of the nutrient solution

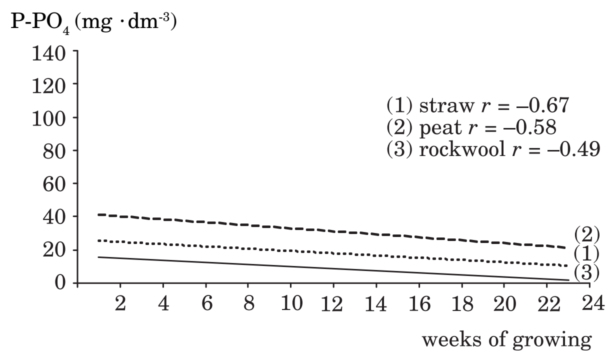

Fig. 5. Changes of P-PO_4 concentrations in root zone of tomato at pH 6.5 of the nutrient solution

tween phosphorus concentration in the root zone and plant development stage when the nutrient solution was used at pH 5.0, 5.5, and 6.0. At these pH levels, the highest amounts of available phosphorus were found in the middle of the plant cultivation period. At pH 4.5, the trend curve for the phosphorus content in rockwool was similar to the curves obtained at pH 5.0, 5.5 and 6.0, but the changes were not proven statistically. The lowest concentrations of phosphorus in rockwool were recorded when the pH of the applied nutrient solution was 6.5. At pH 6.5, the phosphorus content in the various cultivation mats (straw, peat, rockwool) can be described by 3 parallel straight lines displaced, on average, by about 15 mg P-PO_4·dm^{-3} relative to each other, with the lowest values recorded for rockwool, and the highest for peat. When the nutrient solution was supplied at pH 6.5, higher levels of phosphorus in the growth substrates were measured at the beginning of the cultivation period, and then, as the plants developed, these values decreased. MICHAŁOJĆ and NURZYŃSKI (2002), and KOWALCZYK and KANISZEWSKI (2005) during the cultivation of tomatoes on rockwool, also found a significant drop in the levels of phosphorus in the root zone at high pH values of the nutrient solution. In the experiments by De Rijck and Schrevens (1999) with pure nutrient solutions, the effect of pH on phosphorus levels was rectilinear in character.

The pH of the supplied nutrient solution, as well as the kind of substrate, produced significant variations in the nutritional status of tomato plants in respect of phosphorus (Table 2). With increasing pH of the nutrient solution, the average phosphorus content in the tomato plants fell. Similar results were obtained by Komosa et al. (2004), and Kowalczyk, Kaniszewski (2005) while growing tomatoes in rockwool at different pH values of the nutrient solution. The highest levels of phosphorus were obtained in the plants grown on rockwool. The lowest phosphorus content of 3.3 $g \cdot kg^{-1}$ d.w. was found while growing tomatoes on peat supplied with the nutrient solution of pH 6.5. According to Adams (1996), a concentration of $P<0.2\%$ d.w. in the leaves indicates phosphorus deficiency in the plant.

Table 2

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

pH of nutrient solution	Growing medium			
	straw	peat	rockwool	*x*
4.5	4.20	3.83	5.47	4.50 *a*
5.0	3.90	4.07	5.33	4.43 *a*
5.5	3.73	3.60	4.80	4.04 *ab*
6.0	3.77	3.60	4.63	4.00 *ab*
6.5	4.07	3.30	4.07	3.81 *b*
x	3.93 ^{b}	3.68 *b*	4.86 *a*	-

Means followed by the same letter are not significantly different at $p = 0.05$.

On the basis of the experimental results it was concluded that both the pH of the applied nutrient solution and the kind of substrate used had a significant effect on the size of the marketable yield of tomatoes (Table 3). However, no evidence of a combined effect of solution pH and the type of substrate was found in this respect. The highest marketable yield was obtained when tomatoes were grown on rockwool. This yield was significantly higher than the yields obtained from cultures on the organic substrates (straw, peat). Comparing the different pH values of the supplied nutrient solution, irrespective of the kind of a substrate used, the highest marketable yield was obtained at pH 5.5. The marketable yield obtained with the nutrient solution of pH 5.5 was significantly higher in relation to the yield obtained at pH 6.5, but it did not differ significantly from the yields obtained at pH 4.5, 5.0, and 6.0. Similar re-

Table 3

The effect of pH of nutrient solution and type of growing medium on marketable yield of tomato cv. Blitz F1 (2004-2006)

pH of nutrient solution	Yield (kg·m^{-2})			
	straw	peat	rockwool	x
4.5	39.97	38.31	45.63	41.30 *ab*
5.0	37.14	40.84	46.14	41.38 *ab*
5.5	41.58	41.87	47.53	43.66 *a*
6.0	39.01	40.87	45.32	41.73 *ab*
6.5	36.47	38.25	39.23	37.98 *b*
x	38.83 *b*	40.03 *b*	44.77 *a*	41.21

Means followed by the same letter are not significantly different at $p = 0.05$.

sults were obtained by CHOHURA et al. (2004) while studying the effects of solution pH (at the same levels as in this experiment) on tomato cultures grown only on rockwool. KOWALCZYK (2003), who cultivated tomato on rockwool, obtained a significantly lower marketable yield after using a nutrient solution with a high pH value (pH 6.5). In the experiments by WILLUMSEN (1980) with tomato aquacultures, different pH levels (4.5–6.5) of the nutrient solution were not found to have an effect on marketable yield. However, nutrient solution pH of 4.5 was found to reduce fruit size.

CONCLUSIONS

1. Different pH levels of the nutrient solution used in soilless cultures with organic growing media, particularly straw, modified the pH of the root zone to a lesser extent than in an inert substrate (rockwool).

2. The concentration of available phosphorus in the root zone was closely associated with the pH level of the applied nutrient solution and the kind of a cultivation substrate used. Less available phosphorus was found in organic substrates (straw, peat), more in rockwool.

3. With an increase in pH of the applied nutrient solution, there was a drop in the average phosphorus content in leaves of tomato plants. Higher phosphorus levels in leaves were found in tomato cultures set up on rockwool than those on organic substrates.

4. Irrespective of the kind of substrate used, the best yielding of tomato plants was obtained at pH 5.5 of the nutrient solution. A significantly higher marketable yield was obtained from plants growing on rockwool than on organic substrates.

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