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Development of tomato plants growing on nutrient solution containing ammonium salts in the presence of various doses of potassium

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Abstract

In all the experiments the best development of tomato plants was observed when nutrient solutions containing 1/3 of full doses of potassium were applied (i.e. when the N : K ratio = 0.84). On the other hand, the poorest development of plants was observed in combinations with 1/100 of the full potassium dose. Tenfold doses of potassium added to the nutrient solution depressed markedly plant growth, particularly at pH 7.6. The supply of potassium in the nutrient solution was correlated with the nitrogen, potassium and calcium amounts absorbed by the plants.

INTRODUCTION

The experiments performed with barley and sunflower by Haeder and Mengel (1970) have revealed that increased amounts of nitrogen in the nutrient solution strongly stimulate the absorption of potassium by the plants. At the same time, the height of the dose of nitrogen in the nutrient solution, as well as its form play an essential role in that process. However, the question whether the ammonium or the nitrate form of nitrogen is more beneficial to the plants received various answers. Some studies revealed that in the presence of nitrate, potassium is more intensively absorbed and in higher doses (Ehrendorfer 1964; Cunningham and Karim, 1965; Steineck, 1966, 1967), whereas the results obtained by Klemm (1966) revealed a slightly higher consumption of potassium when the plants received ammonium nitrogen. Potassium was found by Kirkby and Mengel (1967) in experiments with tomatoes to give the highest potassium level in all parts of plants receiving ammonium nitrogen, and the lowest when fertilizing with nitrate. Moreover, the studies of Klemm (1966, 1967) stressed the fact that one of the essential factors of regular growth and development of fertilized plants is the maintenance of an appropriate ratio between nitrogen and potassium in the nutrient solution. His studies revealed that, when nitrate is supplied, the uptake of potassium and the increment of fresh mass increase with growing concentration of nitrogen in the nutrient solution. However, in cultures in ammonium nutrient solution, the increasing concentration of ammonium ions stimulated absorption of potassium merely up to the moment when in the nutrient the concentrations of nitrogen and potassium reached an equal level (N : K ratio = 1). A further increase of nitrogen concentration in the solution limited potassium absorption by the plants and lowered their crop. Klemm (1967) changed in the given nutrient solution both the level of nitrogen and that of potassium (1967).

In view of the results obtained by Klemm it was decided to examine how increasing amounts of potassium, at a stable ammonium nitrogen level, affect the increment of fresh mass. Changes of potassium amount in the nutrient solution induce changes of the K : Ca ratio, therefore studies of the content of K and Ca in the plants were undertaken to elucidate whether there exists any connection between the amount of those elements and plants growth.

The studies of Stabrowska and Paściak (1971) on the growth of tomatoes fed a nitrate or an ammonium nutrient solution in the presence of various forms of iron ($FeCl_3$, $Fe_2(SO_4)_3$, iron citrate and iron versenate) and different amounts of iron (doses: 1/1, 1/10, 1/20 and 1/100), revealed that, in cultures of aired tomatoes, from among the examined iron salts, both in nitrate and in ammonium form, the most beneficial is iron citrate. Moreover, it was noted that in ammoniu cultures, in combination with smaller doses of iron citrate (1/10 and 1/100 of full dose) and iron versenate (1/20 and 1/100 of full dose), the plants with high P : : Fe ratio were small and chlorotic. It also resulted from observation of the plants that this did was not due to iron deficiency. Outward symptoms indicated rather potassium deficiency which, according to the authors (Stabrowska and Paściak, 1971), could have been induced by too high a concentration of ammonium ions (nutrient solution containing 0,952 g $(NH_4)_2SO_4$ per 1 l. of solution). Therefore, in order to obtain a good growth of the plants a lower concentration of ammonium salts is presently applied together with iron citrate. In the investigations, such a range of pH was used in which the ammonium ion was sufficiently absorbed by the plants.

METHODS

The experiments were carried out on water cultures in a glasshouse without air conditioning, under natural light in April, May and June in 1972. Tomatoes of the variety Stonor, and a nutrient ammonium solution of the following composition were used: $(NH_4)_2SO_4$ — 0.236 g, $(NH_4)_2HPO_4$ — 0.142 g, $MgSO_4 \cdot 7H_2O$ — 0.578 g, $CaCO_3$ — 0.475 g, K_2SO_4 — 0.589 g, iron citrate — 0.206 g per 1 l water (distilled). $CaCO_3$ was added as buffer to the solution. Moreover, to 1 l of nutrient solution, 1 ml of concentrated solution of microelements was added, composed of: $MnCl_2 \cdot 4H_2O$ — 0.350 g, H_3BO_3 — 0.500 g, $ZnSO_4 \cdot 7H_2O$ — 0.050 g, $CuSO_4 \cdot 5H_2O$ — 0.050 g, $Al_2(SO_4)_3 \cdot 18H_2O$ — 0.050 g, $NiSO_4 \cdot 7H_2O$ — 0.050 g, $Co(NO_3)_2 \cdot 6H_2O$ — — 0.050 g, LiCl — 0.025 g, KBr — 0.025 g, KJ — 0.025 g, $SnCl_2 \cdot 2H_2O$ — 0.025 g, $H_2MoO_4 \cdot H_2O$ — 0.025 g per 1 l of bidistilled water. Besides, in each experiment the nutrient solutions were differentiated as to the amount of potassium. The following eight combinations of nutrient solution were applied: (1) containing a full dose of K in the form of K_2SO_4, (2) with a double dose of K, (3) with a threefold dose of K, (4) with a tenfold dose of K, (5) with one third the full dose of K, (6) with one half the full dose, (7) with 1/10 of full dose, (8) with 1/100 of full dose of K.

The control was a nutrient solution with a full dose of K (0.589 g K_2SO_4 per 1 l. of solution).

Three experiments were performed, in which nutrient solution with different pH was used, namely, 5.6, 6.6 and 7.6. Each initial pH was adjusted by means of 0.1 N HCl, or 0.1 N NaOH. After 24 hr the pH of the solution was measured again, and the solution was distributed into vessels of 10 cm diameter, 16 cm high of 800 ml capacity. All the vessels were protected from light (wrapped first in black and then in white paper).

Into thus prepared vessels were transferred one-week tomato seedlings, earlier germinated in roasted sand. Seedlings for the experiment were selected from among plants of approximately equal size, with two well developed leaves. The seedlings were then soaked in the nutrient solution up to the rootneck and fixed with cottonwool in the cardboard apertures of the paraffinated lids.

At the start four seedlings grew in each vessel. During the experiment, after the first five days, the weakest of the four seedlings was eliminated, the plants were aerated twice daily and the nutrient solution was stirred at the same time by pouring it from one vessel into another. The evaporated water was replaced by freshly distilled water. Every combination included six simultaneous replications, each involving three plants in one vessel.

During the vegetation season of the plants their growth and development were observed, and the ambient temperature and course of the weather were recorded. The experiment was terminated when distinct differences in growth between the particular combinations coulde be noted, (after about three weeks). Then the final pH of the nutrient solution was measured, and the tomato plants well rinsed with distilled water were placed between filter paper, killed at 100°C and dried up to constant weight at 60° C.

The dry weight of the plants was assumed as measure of their growth.

Total nitrogen, potassium and calcium were determined in the plants.

After drying and comminution, the dry plant mass from six replications of a given combination was pooled together. From the thus prepared material 30 g were digested in concentrated H_2SO_4 with addition of salicylic acid in a proportion of 60 mg of salicylic acid to 100 ml of concentrated H_2SO_4. In the digested sample total nitrogen was determined by means of the Parnas-Wagner device by the Kjeldahl method.

In a 500-mg sample digested in a mixture of concentrated nitric, sulphuric and perchloric acids, potassium and calcium were determined with a flame photometer.

The confidence interval for the data referring to the dry mass was calculated by the method of independent variables.

COURSE OF EXPERIMENTS AND RESULTS

I. Experiment with nutrient solution with pH 5.6 (20 April—12 May).

The tomatoes were raised on an ammonium nutrient solution 5,6 pH, with various doses of K added (dosage given in Methods). During the vegetation season the weather was mostly cloudy, and the temperature oscillated between 16° and 28° C. After one week of vegetation differences in the size of the seedlings were already visible. These differences became more pronounced with time.

At the end of the experiments the plants in the combination with 1/3 of the full K dose were the largest, intensely green with a well developed root system. Tomatoes of the combination with a 1/100 dose of K exhibited the poorest growth. The plants were pale-green the lowest leaves were yellow and characteristically rolled up like in plants deficient in potassium.

The habit of plants from the combination with a tenfold increased dose of K was different from the remaining ones. Their leaves were smaller, yellowish, and dried up at the ends. The growth apices were underdeveloped, and the root system of these plants was short, scarce and with few capillary roots. These symptoms are typical for calcium deficiency.

After three weeks of vegetation, the experiment was ended. The dry mass of the plants as well as the amount of absorbed nitrogen, potassium and calcium are shown in Table 1. The final pH of the nutrient solutions did not show any particular change (pH 5.4—5.6).

It was established in the analyses that the amount of absorbed nitrogen and calcium in the particular combinations follows the curve of dry mass of plants. The largest amount both of nitrogen and calcium was taken up by plants in the combination with 1/3 of the K dose, the least by plants in the combinations with 1/100 K.

The smallest amount of absorbed potassium could be observed in plants growing on a 1/100 concentration of K in the nutrient solution. Further, with the increase of K in the nutrient solution to 1/3 of the dose, its uptake drastically rose. A further increase of potassium level in the solution had no stronger effect on the increase of potassium absorption in the plants, on the contrary — a tenfold dose of K in the nutrient slightly inhibited the absorption of this component in the plants.

The percent of nitrogen and calcium in the dry mass has a similar course as their coresponding uptake by the plants. The per cent of potassium in the dry mass increases with increasing concentration in the nutrient solution, whereas the amount of potassium absorbed by the plants rose only up to the moment of increase of its level in the nutrient solution to 1/3 of the dose (Table 1).

Table 1

The development of tomato plants growing on nutrient solution containing ammonium salts of pH 5,6 with reference to different doses of potassium. Expt. April 20 — May 20

Doses of potassium	Average weight of dry mass of 3 plants (from one jar) in mg	Elements absorbed by 3 plants (from one jar) in mg			Percent of particular elements in dry mass (from one jar)		
		N	K	Ca	N	K	Ca
1/100	195.5	10.10	0.88	0.18	5.11	0.45	0.09
1/10	296.5	21.10	2.88	0.47	7.11	0.97	0.15
1/3	483.2	38.88	13.90	0.79	8.04	2.87	0.16
1/2	318.2	24.60	13.70	0.65	7.73	4.30	0.20
1/1	319.3	23.86	13.10	0.59	7.47	4.10	0.18
2/1	290.5	17.45	12.90	0.57	6.00	4.44	0.19
3/1	265.6	13.73	12.00	0.49	5.59	4.88	0.19
10/1	245.2	12.11	11.70	0.25	4.93	4.77	0.10
Confidence interval (P=0.05)	10.3	—	—	—	—	—	—

Initial pH of nutrient solution: 5.6; final pH of nutrient solution 5.4—5.6

II. Experiment with nutrient solution of 6.6 pH (25 May — 17 June)

A similar experiment was performed on an ammonium nutrient solution of 6.6 pH. During the vegetation phase of the plants most days were sunny and hot, with a temperature of 22° to 30° C. In this experiment the plants grew very intensively and had dark green leaves. Their root system was well developed. Visually the growth of the plants was similar in the combination with 1/3 and 1/2 of the K dose, but the dry mass of plants in the combination with 1/3 of the dose of K was the largest as compared with all the remaining combinations (the differences in increase of dry mass are significant).

Similarly as in the previous experiment the weakest growth of the tomatoes was noted in the combination with 1/100 of the K dose. The difference in size between plants in this combination and those receiving a full dose was very large. In combinations with full, double and three-fold dose of K the height of tomatoes was almost equal (Table 2).

Table 2

The development of tomato plants growing on nutrient solution containing ammonium salts of pH 6.6 with reference to different doses of potassium. Expt. May 25 — June 17

Doses of potassium	Average weight of dry mass of 3 plants (from one jar) in mg	Elements absorbed by 3 plants (from one jar)			Percent of particular elements in dry mass (from one jar)		
		N	K	Ca	N	K	Ca
1/100	134.3	9.18	0.40	0.28	6.83	0.29	0.20
1/10	567.0	30.99	14.50	1.22	5.46	2.55	0.21
1/3	888.3	45.00	24.90	1.87	5.06	2.80	0.21
1/2	853.2	42.49	29.00	1.50	4.98	3.39	0.18
1/1	787.0	40.67	29.70	1.49	5.00	3.77	0.18
2/1	778.0	37.82	31.70	1.31	4.79	4.02	0.16
3/1	771.5	37.80	31.90	1.29	4.89	4.13	0.16
10/1	695.3	36.39	33.80	0.97	5.23	4.86	0.13
Confidence interval (P=0.05)	5.09	—	—	—	—	—	—

Initial pH of nutrient solution: 6.6; final pH of nutrient solution 5.8—6.6 (pH 5.8 in combination with 1/3 of K doses)

Tomatoes in the combination with a tenfold dose of K presented symptoms of calcium deficiency, analogically as in the first experiment. The determination of dry mass in this experiment confirmed the observations made during the vegetation.

The final pH of the nutrient solutions in particular combinations showed some differences. The lowest acidification of the nutrient solution was noted in the combination with 1/100 dose of K (pH 6.6—6.2). A higher acidification of the nutrient was noted in the remaining combinations (pH 6.4—5.8). pH 5.8 was recorded in the nutrient solution with 1/3 of K dose, i.e. when growth of the tomatoes was most intensive.

The amounts of nitrogen and calcium absorbed by the plants were similar as in the previous experiments.

A different picture is presented by the per cent of nitrogen and calcium in the corresponding dry mass. The highest per cent of nitrogen in the dry mass was noted in the combination with 1/100 of K dose, whereas in the remaining combinations this per cent remains more or less at the same level. On the other hand, the calcium per cent in dry mass in combinations with 1/100, 1/10 and 1/3 of K is almost identical. The calcium per cent slightly diminishes in the plants with the increase of K concentration in the nutrient solution.

The lowest amount of potassium absorbed by the plants as well as its per cent in the dry mass were noted in the combination with 1/100 of the K dose. Further, with the increase of the K dose in the nutrient solution, its uptake by the plant and its per cent in the dry mass increase.

III. Experiment with nutrient solution of 7.6 pH (19 June — 10 July)

In this experiment the differentiation of potassium doses was the same as in both the earlier ones, but the pH of the nutrient solutions was adjusted at 7.6 pH. During vegetation there was a prevalence of hot and sunny days. The temperature oscillated between 26° and 34° C. In these experiments the growth of the plants was distinctly weaker than in the previous ones.

Similarly as in the previous experiments the smallest growth of tomatoes occurred in the combination receiving 1/3 of the K dose, and it was poorest in the combination with 1/100 of K dose.

Table 3

The development of tomato plants growing on nutrient solution containing ammonium salts of pH 7.6 with reference to different doses of potassium. Expt. June 19 — July 10

Doses of potassium	Average weight of dry mass of 3 plants (from one jar) in mg	Elements absorbed by 3 plants (from one jar) in mg			Percent of particular elements in dry mass (from one jar)		
		N	K	Ca	N	K	Ca
1/100	94.2	5.56	0.61	0.08	5.90	0.64	0.08
1/10	295.6	17.05	4.40	0.49	5.76	1.48	0.16
1/3	543.5	32.43	16.30	0.95	5.96	2.99	0.19
1/2	464.8	24.32	15.60	0.81	5.23	2.64	0.20
1/1	432.2	23.77	15.20	0.72	5.49	2.89	0.18
2/1	421.5	21.64	12.50	0.69	5.13	3.60	0.17
3/1	366.3	19.17	12.20	0.62	5.23	4.25	0.18
10/1	110.3	5.11	5.60	0.09	4.63	5.16	0.08
Confidence interval (P=0.05)	7.54	—	—	—	—	—	—

Initial pH of nutrient solution: 7.6; final pH of nutrient solution 6.5—6.6.

In contradistinction to the two previous experiments the growth of the plants in the combination with a tenfold dose of K was four times weaker than in the combination with a full K dose. The seedlings were pale green, with poorly developed growth apices. The roots were short and slimy. The hot days induced a high water evaporation from the nutrient solutions. The water deficiency was supplemented by freshly distilled water. In the third week of vegetation drying up of lower leaves was observed in all combinations. The final pH of the nutrient solutions changed from 7.6 to 6.6 pH (Table 3).

The course of nitrogen, potassium and calcium absorption by the plants was similar as in the first combination. The per cent of nitrogen in the dry mass of all the combinations remained more or less at the same level. On the other hand, the per cent of calcium was analogous to that in the first experiment, and the potassium percent to that in both the previous experiments.

DISCUSSION

Considering the difficulty of realizing a very extensive experiment, which would comprise three pH levels, three experiments were performed at various times. Each experiment is complete and has been discussed separately. Their results cannot be compared directly. However, a similarity of trend could be noticed in the weight of dry mass in dependence on the potassium dose in all three experiments. The dose of 1/3 of the potassium full dose proved optimal in each of the three experiments. In the nutrient solution with 1/3 of the K dose, the N : K ratio was the nearest to unity (N : K = 0.84). These observations are confirmed by earlier studies of Klemm (1966, 1967), who ascertained the best development of barley on an ammonium nutrient solution containing nitrogen and potassium in equal amounts (N : K = 1). Further, in all cases of lowered potassium level in the nutrient solution a distinct retardment of plant growth, even to the point of occurrence in them of potassium deficiency appeared. In the first place, the lower leaves of the tomatoes were characteristically rolled. The gradual increase of potassium level in the nutrient solution limited in a much lower measure the increase of plant mass, and only a tenfold increase of the K dose in the nutrient solution decidedly inhibited tomato growth, especially at pH 7.6. Such a high concentration in the nutrient solution strongly limited the absorption of calcium, what brought about typical symptoms of deficit of that component in the plants. The strongest symptoms occurred in plants on pH 6.7 solutions. The growth apices perished, and the roots were slimy and had no capillary excrescences (Tables 1, 2 and 3).

Moreover, a correlation was observed between the intensity of growth and final acidification of the nutrient solution. In all experiments the widest changes in nutrient solution pH occurred in the combination with 1/3 of the K dose, i.e. when the plant growth was most vigorous. his could be explained by the rapidity of absorption and utilization of ammonium ions. These phenomena have already been stressed much earlier by Prianishnikov (1951).

It was shown by analyses in all experiments that, in dependence on the potassium doses, the amount of nitrogen absorbed by the plants runs a similar course as dry mass changes. Similar dynamics was noted in the amount of potassium absorbed by plants growing at 5.6 and 7.6 pH. Amount of potassium taken up by plants on nutrient solutions of 6.6 pH is different, namely, with the increase in potassium concentration of the nutrient solution its level rises in the plants. Moreover, in contrast to the prior experiments, the highest amount of absorbed potassium was established in plants growing on a nutrient solution containing a 10-fold dose of that component. Maybe the high concentration of K in the nutrient solution of 6.6 pH favours accumulation of this element in the plants.

In comparison to potassium concentration the amount of calcium in dry mass of all plants is rather low especially at a ten-fold concentration of potassium in the nutrient medium. The high level of K in the nutrient solution probably hinders calcium absorption by the plants.

It is worth of noting that in all the experiments the potassium per cent in the dry mass of plants increases with the rise of its concentration in the nutrient solution, whereas as regards the amount of potassium consumed, this dependence was noted only in experiments in which a nutrient solution of 6.6 pH was used. Both the amounts of nitrogen and calcium absorbed by the plants and their per cent in dry mass exhibit symilar dynamics.

It should be also stressed that changes of potassium doses in the nutrient solution induce changes in the amount of other ions which affect growth. In the experiments performed the highest growth of tomatoes occurred in nutrient solutions with K : Mg ratio = 3 : 1. Similar results have been obtained earlier by Steiner (1961) according to whom, for tomato growth, the ratio K : Mg = 5 : 2 is optimal. The worst result in plant growth occurred at K : Mg = 30 : 1 (combination with a tenfold dose of K). These observations are in agreement with earlier studies of Mulder and Bakema (1956) who claim that high doses of K have an inhibitory action on Mg ions absorption by plants, and on their growth.

The experiments permit the following conclusions:

1. In the presence of ammonium salts, tomatoes grow best when the ration of N : K approximates unity.

2. Very intensive plant growth induces a high acidification of the ammonium nutrient solution.

3. Increasing concentrations of potassium stimulate the growth of tomatoes up to the moment of balance between concentration of potassium and nitrogen in the nutrient solution. A further increase of potassium concentration inhibits the increase in plant mass.

4. A correlation was noted between the doses of potassium in the nutrient solution and nitrogen, potassium and calcium uptake. At the same time, the potassium per cent in the dry mass of plants increases with the rise of its concentration in the nutrient solution, while for the amount of potassium absorbed by the plants this dependence occurs only at pH 6.6. On the other hand, the amounts of nitrogen and calcium absorbed by the plants and their per cent in dry mass exibit similar dynamics to the changes in dry mass.

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Wzrost pomidorów na pożywce amonowej w obecności różnych ilości potasu

Streszczenie

Przeprowadzono badania nad wzrostem pomidorów na pożywce amonowej w zależności od różnych dawek potasu. Wykonano trzy doświadczenia metodą kultur wodnych na pożywce o pH 5.6, 6.6 i 7.6. W każdym doświadczeniu zastosowano następujące dawki potasu: 1 — pełna dawka K w formie K_2SO_4; 2 — podwójna dawka K; 3 — potrójna dawka K; 4 — 10-krotna dawka K; 5 — 1/3 K; 6 — 1/2 K; 7 — 1/10 K i 8 — 1/100 K; — Kontrolą była pełna dawka K (0,589 g K_2SO_4 na litr roztworu).

We wszystkich trzech doświadczeniach zauważono podobieństwo trendu ciężarów suchej masy w zależności od dawki potasu. Okazało się bowiem, że dawka 1/3 potasu w każdym z doświadczeń była dawką optymalną. Nadto stwierdzono, że w pożywce z 1/3 dawki K stosunek N : K był najbardziej zbliżony do jedności (N : K = 0.84). Spostrzeżenia te potwierdziły wcześniejsze obserwacje Klemma (1966; 1967), który stwierdził najlepszy wzrost jęczmienia na pożywce amonowej zawierającej azot i potas w równych ilościach (N : K = 1). Następnie we wszystkich przypadkach wraz z obniżeniem poziomu potasu w pożywce zaobserwowano wyraźne zahamowanie wzrostu roślin, aż do wystąpienia u nich objawów niedoboru tego pierwiastka. Natomiast stopniowe zwiększenie potasu w pożywce nie dało tak wyraźnego efektu. Dopiero 10-krotne zwiększenie dawki K w pożywce zahamowało wyraźnie wzrost siewek pomidorów, łącznie z wystąpieniem typowych objawów niedostatku tego składnika, szczególnie przy pH 7,6. Ponadto zaobserwowano, że we wszystkich doświadczeniach największe zmiany pH pożywki nastąpiły w kombinacji z 1/3 dawki K, czyli tam gdzie był najbujniejszy wzrost roślin. Zjawisko to jest zgodne z wcześniejszymi spostrzeżeniami Prianisznikowa (1951).

Analizy roślin wszystkich doświadczeń wykazały, że występuje zależność pomiędzy dawkami potasu w pożywce a pobieraniem potasu, wapnia i azotu przez rośliny. Zauważono bowiem, iż zarówno ilości azotu i wapnia pobrane przez rośliny, jak ich procenty w suchej masie kształtują się podobnie jak odpowiednie suche masy. Natomiast w przypadku potasu zaobserwowano nieco odmienny układ, a mianowicie: procent potasu w suchej masie rośnie wraz ze zwiększeniem jego stężenia w pożywce, podczas gdy przy ilości potasu pobranego przez rośliny zależność ta zachodzi tylko w doświadczeniu z pożywką o pH 6,6. Przy pH 5,6 i 7,6 ilość potasu pobranego przez rośliny kształtuje się analogicznie jak odpowiednia sucha masa.