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THE INFLUENCE OF THE CHEMICAL COMPOSITION OF A NUTRIENT SOLUTION ON THE PRODUCTION OF TOMATO PLANTS

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INTRODUCTION

The experiment was designed to show the influence of different chemical compositions of a nutrient solution on the production of tomatoes. The chemical composition of the nutrient solution used was described earlier [4].

It was considered important that the composition of each nutrient solution remained constant during the experiment. Ideally a method providing a continuous flow of a fresh solution in a waterculture was desirable [3]. However, for statistical reasons, it was desirable to replicate the experiment three times with at least 5 plants in each replicate. It was necessary to compare at least 10 different compositions in the nutrient solution. A continuous-flow method was hardly possible on such a large scale. Therefore a method was chosen which used the same solution for a longer time. To prevent large fluctuations in the composition of the solution, a large quantity of nutrient solution is used (60 litres for 5 plants). Loss of water by free evaporation and by plant uptake was replaced daily by demineralized water and all the nutrient solutions were completely renewed as soon as the nitrate concentration of one solution was reduced to 80 per cent of the original.

For practical reasons the experiments have been carried out in gravel culture according to the system of Filippo [1].

The original investigation was made in 1962. In 1963 the experiments were repeated using the same design and again, in 1964, with some modifications in the nutrient solutions for the vegetative and fruiting periods of growth.

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THE ORIGINAL COMPOSITION OF THE NUTRIENT SOLUTIONS

The chemical composition of a nutrient solution depends on the concentration of the composing ions, on the total ion concentration expressed as osmotic value and on the acidity expressed as pH.

For simplicity the experiments were all conducted at the same osmotic value and pH of the nutrient solution.

An osmotic value 0.71 atm at 15°C resulting in 30 mg ions a litre under complete dissociation, was chosen. Earlier experiments showed this concentration suitable for a glasshouse crop of tomatoes at the Research Station starting in March–April. The experiment was started on 7 March.

Experiments with tomatoes in gravel culture provided good results with a nutrient solution of pH 6.5 ± 0.3. A higher pH will restrict the possibility of obtaining many ion-combinations by precipitation of $CaHPO_4$ as the percentage HPO_4^- of the total phosphate concentration increases with a higher pH as shown by the dissociation curve in Fig. 1. Also the same dissociation curve shows that the lower the pH the less OH^- or H^+ ions are needed for disturbing the equilibrium $H_2PO_4^-$: HPO_4^- and HCO_3^- : H_2CO_3 so below

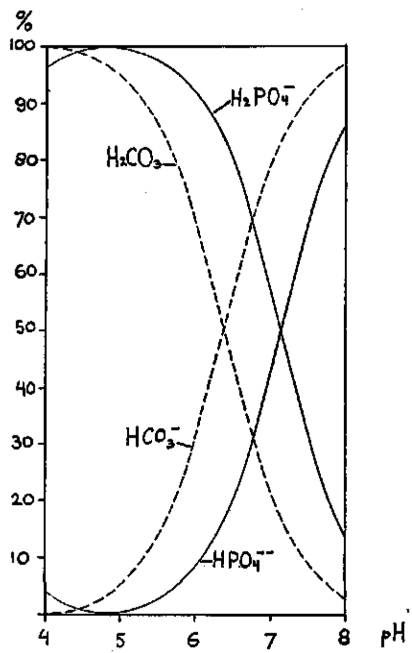

Fig. 1. Phosphate and carbonate dissociation curves at 18°C and 25°C.

pH 6.0 a very low stabilizing effect on the pH exists. For the phosphate this will be valid until pH 3.5 where the influence of the percentage H_3PO_4 will be as a stabilizer. For these reasons pH 6.5 $\pm$ 0.1 was chosen.

With 0.71 atm osmotic value and pH 6.5 $\pm$ 0.1, the only variable factors are the nutritional ions themselves.

In a earlier publication [4] the author considered whether a certain absolute concentration of the individual ions in a nutrient solution, or their relative proportions were the determining factors for a crop grown under given environmental conditions. As this is an essential question here, the argument for working with relative proportions will be repeated.

Let us assume that the concentrations of the individual ions are critical and that in a particular experiment optimum concentrations have been found corresponding to a K^+, b Ca^{++} and c Mg^{++} per litre. This gives the ratio of $K^+ : Ca^{++} : Mg^{++}$ as a : b : c. However, this ratio may also be expressed as a/n : b/n : c/n, provided the value of a + b + c is given. Thus the optimum composition may be expressed in terms of both a sum and a ratio. Even if the individual ion-concentrations are considered to be critical, the relative proportions of the different ions may also be considered in the same way, provided the total ion-concentration is included.

In these experiments there was already a fixed total ion-concentration of 30 mg ions a litre, so it was possible to use relative proportions of the individual ions, provided that a suitable equilibrium between the total cations and total anions for the desired pH 6.5 was chosen. As this ratio was fixed by pH variations could only be made in either the relative cation or in the relative anion ratio. The variations in these experiments were further restricted to the 3 main cations K^+, Ca^{++} and Mg^{++} and the 3 main anions NO_3^-, $H_2PO_4^-$ and SO_4^{--}. For the sake of simplicity no NH_4^+ was used, since tomatoes grow well in the absence of this ion.

Using a triangular system for the cations and for the anions, all possible combinations were made. To restrict the number of plots in the experiments only the $NO_3^- : (H_2PO_4^- + SO_4^{--})$ ratio and the $K^+ : (Ca^{++} + Mg^{++})$ ratio were changed. This means that the $H_2PO_4^- : SO_4^{--}$ ratio and the $Ca^{++} : Mg^{++}$ ratio remained constant. For $Ca^{++} : Mg^{++}$ the equivalent ratio 3 : 1 was chosen, because it was found to be suitable in earlier experiments (Fig 2). For K^+ 3 levels were used, respectively 66.8, 33.7 and 22.4 per cent of the total cations in equivalents. Very low phosphate concentrations

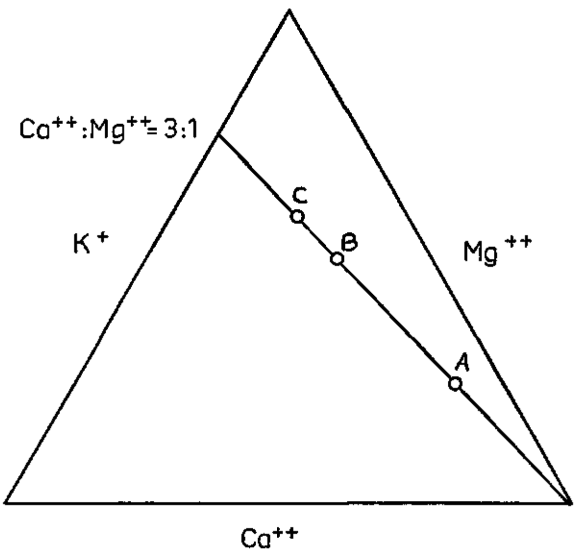

Fig. 2. The original equivalent cation ratio.
A = 66.8% K^+, B = 33.7% K^+, C = 22.4% K^+.

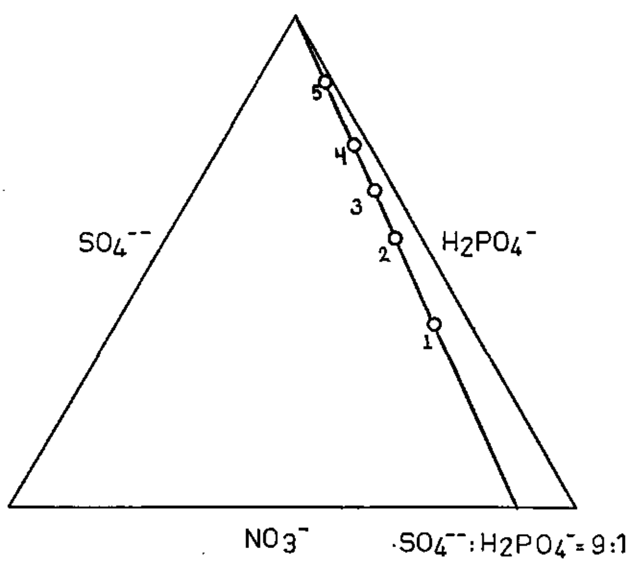

Fig. 3. The original equivalent anion ratio.
1 = 36.3% NO_3^-, 2 = 54.4% NO_3^-, 3 = 63.1% NO_3^-,
4 = 72.5% NO_3^-, 5 = 86.0% NO_3^-.

were chosen to avoid precipitation with the cations. In this experiment $H_2PO_4^-$: SO_4^{--} as 1 : 9 was chosen (Fig. 3). For NO_3^- 5 levels were used, respectively 36.3, 54.4, 63.1, 72.5 and 86.0 per cent of the total anions in equivalents. These 3 cation ratios and 5 anion ratios gave 15 different combinations of which the combinations b1, c1 and c2 are unobtainable by precipitation. Based on the method published earlier [4] the following 12 compositions were made (Table 1), resulting in the required total ion-concentration of 30 mg ions a litre and pH 6.5 $\pm$ 0.1. Table 2 shows the nutrient solutions.

TABLE 1

me/l	K^+	Ca^{++}	Mg^{++}	NO_3^-	$H_2PO_4^-$	SO_4^-
a1	13.097	4.882	1.627	6.945	1.219	10.969
a2	12.409	4.625	1.542	9.930	0.832	7.491
a3	12.100	4.510	1.503	11.269	0.659	5.931
a4	11.781	4.392	1.464	12.652	0.480	4.319
a5	11.348	4.230	1.410	14.531	0.237	2.129
b2	6.993	10.334	3.424	11.038	0.925	8.327
b3	6.797	10.044	3.328	12.497	0.731	6.577
b4	6.595	9.746	3.229	13.997	0.531	4.778
b5	6.323	9.343	3.096	16.023	0.261	2.348
c3	4.701	12.236	4.051	12.981	0.759	6.832
c4	4.555	11.856	3.925	14.524	0.551	4.958
c5	4.358	11.343	3.755	16.605	0.270	2.433

TABLE 2

The nutrient solutions of these compositions were made as follows:							
ml stock-solution per litre nutr. sol.	KH_2PO_4 1N	$Ca(NO_3)_2$ 5N	$MgSO_4$ 2N	$Mg(NO_3)_2$ 2N	KNO_3 2N	K_2SO_4 1N	KOH 0.1N
a1	1.219	0.976	0.814	—	1.032	9.342	4.730
a2	0.832	0.925	0.771	—	2.653	5.949	3.230
a3	0.659	0.902	0.752	—	3.380	4.428	2.540
a4	0.480	0.878	0.732	—	4.130	2.855	1.860
a5	0.237	0.846	0.705	—	5.151	0.719	0.910
b2	0.925	2.067	1.712	—	0.352	4.903	4.610
b3	0.731	2.009	1.664	—	1.227	3.249	3.640
b4	0.531	1.949	1.615	—	2.126	1.549	2.640
b5	0.261	1.869	1.174	0.374	2.966	—	1.300
c3	0.759	2.447	2.026	—	0.373	2.781	4.160
c4	0.551	2.371	1.963	—	1.334	1.033	3.030
c5	0.270	2.269	1.217	0.661	1.970	—	1.480

In 1962 demineralized water was used of at least 150.000Ω cm/cm². In 1963 the same method was followed for the nutrients but the solutions were made with tap water after deducting the quantities of elements in this tap water. This gave the same compositions except for an addition of sodium and chloride from the tap water. In 1964 all the original solutions were as in 1963.

Micro-elements were given per litre as follows:

Fe, 2.5 mg as Fe-EDTA; Mn, 2.0 mg as $MnSO_4.4$ aq.; Cu, 0.02 mg as $CuSO_4.5$ aq.; Zn, 0.1 mg as $ZnSO_4.7$ aq.; Mo, 0.05 mg as $Na_2MoO_4.2$ aq.; B, 0.5 mg as H_3BO_3.

The A–Z solution with trace elements by Hoagland [2] was used except for the trace elements mentioned above.

The gravel-culture installation

The installation consisted of 40 asbest cementos troughs sized 180 × 20 × 20 cm inside, painted with bitumen asphalt and filled with glacial gravel from the Rhine, sized 12–15 mm ∅. Underneath each trough a similar trough was placed as a tank for the nutrient solution (Fig. 4). Each combination had a

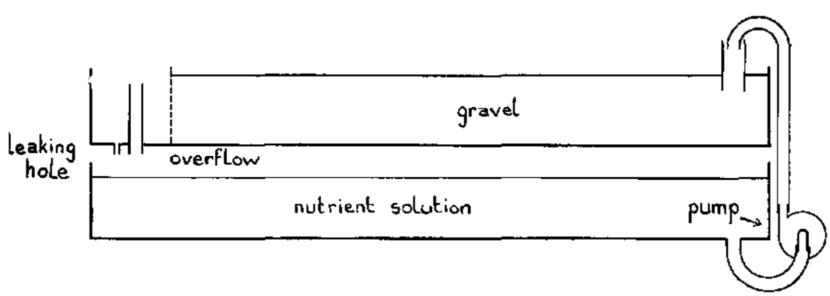

Fig. 4. Gravel-culture system Filippo.

small pump which conveyed the nutrient solution from the tank to the far end of the trough above the culture bed, where it fell on the gravel. The solution flowed through the gravel to the outlet end above the reservoir. On this side the bed had a small opening in the bottom – the leaking hole. The output of the pump was 10 litres a minute and the leaking hole was so adjusted that 5 litres a minute drained back into the tank; 5 litres per minute were supplied to the culture bed and remained there. Next to the leaking hole there was an overflow, the upper run of which was adjusted to the desired irrigation level of 2 cm underneath the surface of the gravel. As soon as this desired irrigation height was reached the surplus solution flowed back through the overflow into the tank. After 10 minutes the motor of the pump was automatically switched off and the nutrient solution in the culture bed was able to drain back completely into the tank by the leaking hole. This automatic system also guaranteed an excellent aeration of the nutrient solution. This method of gravel culture is the Netherlands system, now called system

Filippo by the inventor, the late Dr. H. Filippo [1]. All the culture beds were irrigated three times a day. The culture beds were situated in a glasshouse with central heating. There were 4 plots to avoid border effects with the lighting and 36 plots for the experiments with 12 nutrient solutions in triplicate, arranged as shown in Fig. 5.

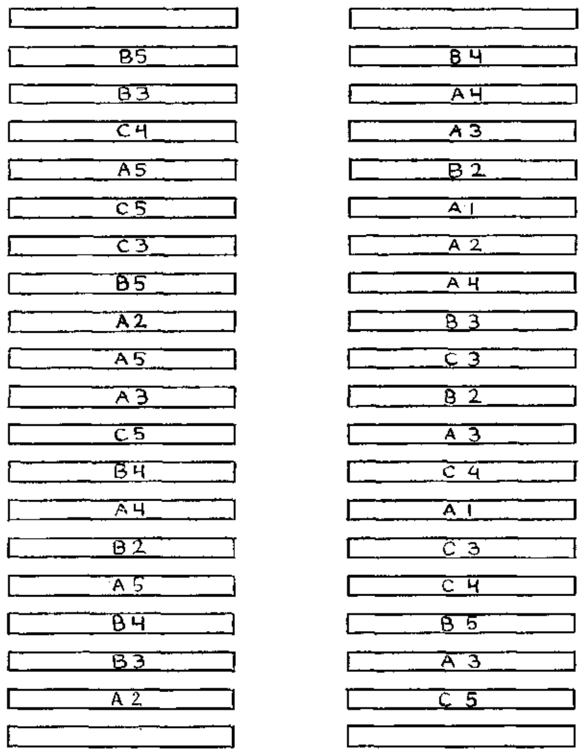

Fig. 5. The situation of the gravel-culture beds in the glasshouse.

RESULTS

The crop

On the 14th of February 1962 seeds of the cultivar 'Glorie' an Ailsa Craig type of *Lycopersicum esculentum* L. were sown in coarse riversand. On the 7th of March when the plants reached a height of about 3 cm they were planted out in the gravel-culture installation, 5 plants in each culture bed. The distance between the rows was alternately 85 and 55 cm and 30 cm between the plants in each row. Each plant had 12 litres of gravel for its roots. Calculated on the total area of the glasshouse, there were 4.2 plants per square meter. All plants were topped on the same day and at the same height, resulting in 7 to 8 trusses a plant. The experiment ended on the 3rd of September 1962. Plant disease control measures were employed.

The same procedure was followed in 1963, except that growth started much earlier. The sowing-date was the 20th of December 1962, and the plants were planted out on 10th of January 1963. Plants were also topped on the same date and at the same height, now resulting in only 5 to 6 trusses. The experiment ended on the 10th of July 1963. Virus-free seed was used and plants remained virus-free until the end of the experiment.

For the 1964 experiment the sowing-date was the 23rd of December 1963 and the planting-date was the 6th of January 1964. Plants were also topped at 5 to 6 trusses and the experiment ended at the 3rd of July 1964. The experiment also started with virus-free seed but it was not possible to keep the crop virus-free throughout the experiment.

The composition of the nutrient solutions during the experiments

All tanks in the experimental installation were filled with 60 litres of nutrient solution of the original composition desired for each plot. Loss of water by free evaporation and by plant uptake was replaced daily by demineralized water. Based on test samples all nutrient solutions were renewed completely as soon as the nitrate concentration of one solution was diminished to 80 per cent of the original level, with a minimum frequency of every 14 days. This occurred every 10 to 14 days during the first 2 months of each experiment, after that every week.

In 1962 the final composition of each solution at the moment of renewal was analyzed for NO_3^-, $H_2PO_4^-$, K^+ and $Ca^{++} + Mg^{++}$ together. The results showed that the final composition did not deviate much from the original. For 1963 complete analyses were made of the final composition each time. Based on this the maximum deviation from the original relative ratios has been calculated. The results are given in Fig. 6. However, the average deviations were much smaller. In 1964 only test-samples have been taken as controls. These indicate that the average composition of the nutrient solutions was very near to the original composition. Nevertheless the spread of the ratios as seen in Fig. 6 are such that the points B and C standing for 2 cation ratios cannot clearly be distinguished as factors causing different effects.

In 1962 and 1963 the 12 different compositions were used through-

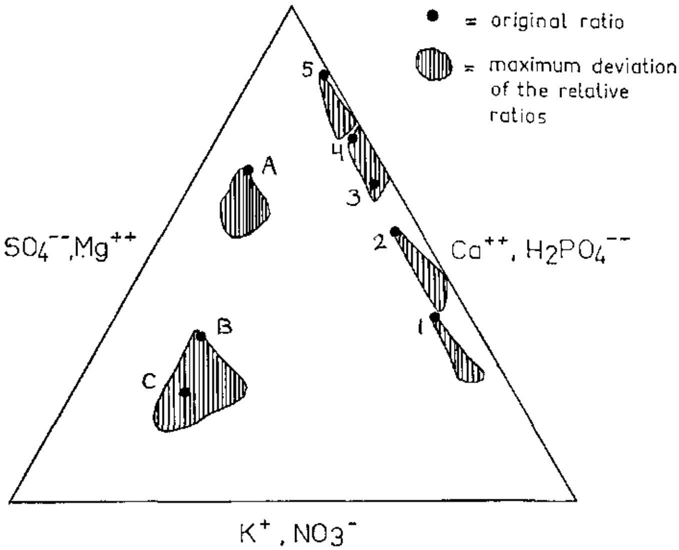

Fig. 6. Ion ratios in the nutrient solutions 1963.
1 to 5 are anion ratios, a to c are cation ratios.

out the whole experiment. As the results showed that combination C3 was the best for vegetative growth, this solution was applied to all plots in 1964 until the third truss was starting to flower. Then the 12 different compositions were used in the experiment for the later growth and fruiting.

The influence of the ion composition on tomato production

Commercially both the quantity and the quality of the tomato-fruit produced are important. Early production which yields high prices is vital to the economy of Dutch growers of hothouse tomatoes But the total yield, which is readily measured, is also very important

For 1963 and 1964 the yield up to May 31 was chosen as an indication of earliness. In 1962 the sowing date was 7 weeks later than in 1963 and 1964 but, as crop development is much quicker later in the year, the yield up to June 29, 1962 was used.

All yields are recorded per square meter of the whole area of the glasshouse.

Yields are summarized as in Table 3.

The variation in the production per individual plant was high for the early production; this results in a co-efficient of variation of

TABLE 3

1962									
Early production until 29-6-62					Total production in 1962				
kg/m2	a	b	c	Total	kg/m2	a	b	c	Total
1	1.787				1	10.779			
2	2.106	1.758			2	10.675	11.204		
3	1.942	2.200	2.327	6.469	3	11.645	11.822	12.084	35.551
4	2.193	2.142	2.050	6.385	4	11.189	11.959	12.436	35.584
5	1.061	0.935	1.161	3.157	5	10.159	10.865	9.923	30.947
Total	5.196	5.277	5.538	16.011	Total	32.993	34.646	34.443	102.082
1963									
Early production until 31-5-63					Total production in 1963				
kg/m2	a	b	c	Total	kg/m2	a	b	c	Total
1	2.019				1	9.088			
2	1.991	2.399			2	9.875	9.647		
3	1.436	1.737	2.074	5.247	3	8.338	9.565	10.114	28.017
4	1.549	1.934	2.180	5.663	4	9.854	10.195	9.594	29.643
5	1.319	1.643	1.413	4.375	5	8.792	9.330	9.191	27.313
Total	4.304	5.314	5.667	15.285	Total	26.984	29.090	28.899	84.973
1964									
Early production until 30-5-64					Total production in 1964				
kg/m2	a	b	c	Total	kg/m2	a	b	c	Total
1	2.213				1	8.269			
2	2.372	2.382			2	9.112	8.552		
3	2.255	2.194	2.272	6.721	3	8.326	8.054	8.903	25.283
4	2.025	2.362	2.333	6.720	4	8.694	8.559	8.397	25.650
5	2.039	1.962	1.957	5.958	5	7.763	7.891	7.655	23.309
Total	6.319	6.518	6.562	19.399	Total	24.783	24.504	24.955	74.242

27.0 per cent for 1962, 24.1 per cent for 1963 and 20.9 per cent for 1964, probably due to differences in heredity. For the total production the variation in the individual plants was much smaller; the co-efficient of variation was, respectively 7.4, 6.1 and 7.3 per cent.

In general the total production was comparable with a good yield of hothouse tomatoes in the Netherlands. It is clear that the total production was somewhat higher in 1962 since the early production of 1963 and 1964 is usually obtained at the expense of the total production. Also in general it may be concluded that any differences in production are small between the different treatments.

For the anion ratios, which depend on a variation in the NO_3^- and SO_4^{--} content, there is no significant difference in earliness or total production between the combinations 1, 2, 3 and 4. Combination 5 with the highest NO_3^- and the lowest SO_4^{--} content, is later and lower in total production than the other 4 combinations. For 1962 this holds true with a probability of 99 per cent for both earliness and total production; for 1963 with a probability of 93 per cent for earliness but with no significant difference in total production; for 1964 there is only a small and insignificant influence of combination 5 on the early production, which is in agreement with the fact that all combinations received the same nutrient solution in 1964 until the third truss was starting to flower; however, the total production of combination 5 is also lower in 1964 with a probability of 98 per cent.

It may be concluded that earliness and total production diminished for the highest N-level (= lowest S-level) but the differences are small. The other N-levels did not give any significant difference.

It was mentioned earlier that the cation ratios b and c are not clearly distinguished in the experiment. They show no difference in yield. In 1962 combination b and c with less K^+ and more Ca^{++} were higher in total production than combination a with a probability of 83 per cent. The earliness they showed was not statistical significant. For 1963 combination b and c were better than a with a probability of 95 per cent for earliness and 98 per cent for total production. In 1964, when the ion-combinations are applied in a later stage of development, there were no differences at all.

It may be concluded that earliness and total production are better with the combinations b and c (less K^+, more Ca^{++}) than with combination a, but again the differences are small. The different ion-combinations applied in a later stage, when the third truss started to flower, did not give any difference in production.

Quality of the tomatoes is very difficult to determine. Indeed, it is not even known which factors such as amino-acids, sugars, acids like citric acid, volatile elements, *etc.* in the tomato itself have an influence on the taste. The only measuring-rod is the outward appearance. Severe reduction in quality may result from blossom-end rot and blotching ripening. In this experiment no reduction in quality was seen except some incidental blotching ripening caused by extremely hot days.

In this experiment only a few ion combinations have been investigated. But when it is realized that the distance between the points b and c together and point a which quantities result in a factor 2 for the K^+ content, a marked influence of this change in nutrition can be expected. The same is valid for the NO_3^- content, varying from 7 me for point 1 to over 16 me for point 5. Some significant differences in crop production have been found but they were very small. The conclusion is that composition of the nutrient solution may influence tomato yields, but differences will usually be very small, except of course under extreme circumstances such as with starvation solutions.

Attention should be drawn to the fact these experiments concern tomatoes. Other crops are possibly more sensitive. Tomato roots are more tolerant to unbalanced nutrient solutions than tobacco roots [5]. Moreover, it must be pointed out that the results obtained are only valid for a nutrient solution in which all nutrients are completely dissociated and in an active state. In soil different results may be obtained.

SUMMARY

The influence of 12 combinations of 5 different relative anion ratios and 3 different relative cation ratios in a nutrient solution on the production of tomato plants has been investigated in gravel culture during the years 1962, 1963 and 1964.

There were 5 N levels, respectively 36.3%, 54.4%, 63.1%, 72.5% and 86.0% of the total anions in equivalents and 3 K levels, respectively 66.8%, 33.7% and 22.4% of the total cations in equivalents.

Although differences were small, there was a significant reduction of earliness and total production for the highest N level. The other N levels showed no difference.

Earliness and total production were significantly better with the lower K levels, but again differences were small.

The influence of the composition of the nutrient solution on the production of the tomato plant was shown to be very small.

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