# THE SELECTIVE CAPACITY OF PLANTS FOR IONS AND ITS IMPORTANCE FOR THE COMPOSITION AND TREATMENT OF THE NUTRIENT SOLUTION

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## Introduction

In the 20 minutes speaking time it is impossible to offer a detailed and complete view on the newer discoveries about the selective capacity of plants for ions. Here it is only possible to give a summary, but still, this may be sufficient for explaining the importance of this phenomenon for giving a better light on the composition and treatment of the nutrient solution.

## The selective capacity of plants for ions

Proceeding on the assumption that all of you have acqaintance with the method of expressing the mutual ratios between three magnitudes in one point in an equilateral triangle, I may suffice to show you some examples, using the mutual ratios between the ions in my universal nutrient solution (Steiner, 1961, 1968 & 1972). All mutual ratios in this article are calculated from the amounts in milli-equivalents.

In figure 1 the mutual ratio between the anions nitrate, phosphate and sulfate as 60 : 5 : 35 is given in one point. The phosphate always is calculated as $H_2PO_4^-$. In figure 2 the mutual ratio between the cations potassium, calcium and magnesium as 35 : 45 : 20 is given in one point. These two triangles may be placed one on top of the other as shown in figure 3, where a circle represents the mutual ratio between the anions, and a cross the mutual ratio between the cations.

Now I summarize the results of five years experiments with lettuce and seven years experiments with tomatoes, all in pure water culture, using different mutual ratios between the ions.

In figure 4 we see the original composition of the nutrient solutions with three different mutual ratios between the anions (circles), three different ratios between potassium and calcium at a constant magnesium proportion (crosses), and five different mutual ratios between magnesium and the sum of potassium and calcium, at a constant mutual ratio between potassium and calcium (stars). The combination S for the anions and for the cations represents my universal nutrient solution.

Lettuce and tomato plants have been growing on all combinations between the circles and crosses in figure 4 at 0.7 atm. osmotic pressure. At the same total ion concentration the universal anion ratio S has been combined with all magnesium proportions (stars) for lettuce only. The universal combination S 'circle' and S 'cross' was used for lettuce at 0.48, 0.72, 1.08 and 1.62 atm. osmotic pressure and for tomatoes at 0.18, 0.36, 0.72 and 1.08 atm. All experiments have been carried out at least in triplicate with at least nine plants in each repetition, and with exception of the magnesium proportions, at least three repetitions in several seasons of the year.

The composition of the nutrient solutions is kept as constant as

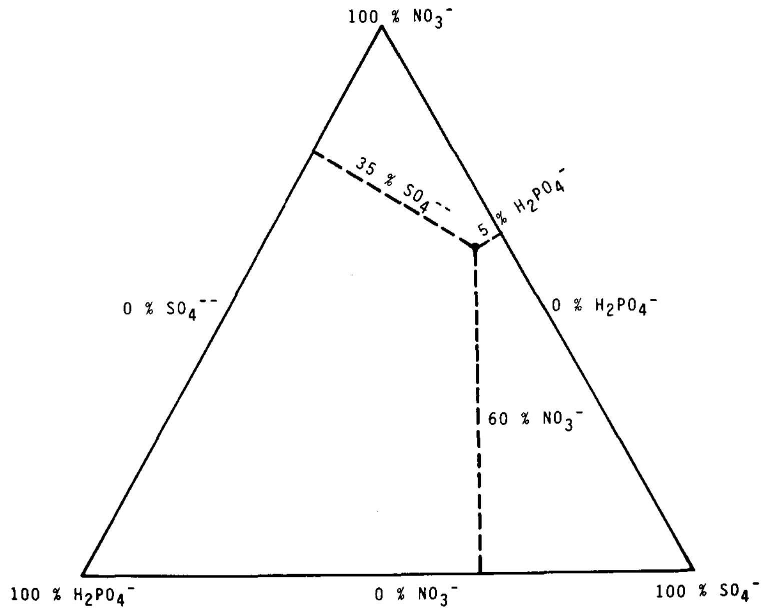


Figure 1 - The mutual ratio between the anions (based on equivalents) in Steiner's universal nutrient solution

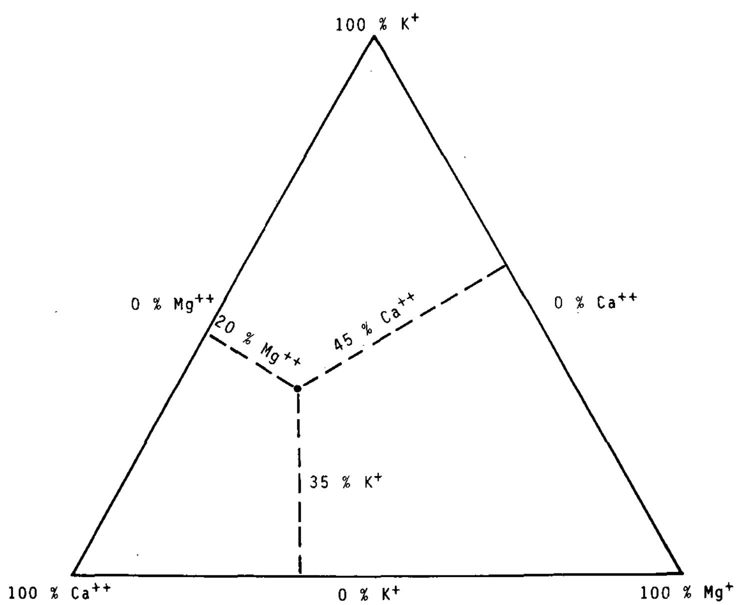


Figure 2 - The mutual ratio between the cations (based on equivalents) in Steiner's universal nutrient solution

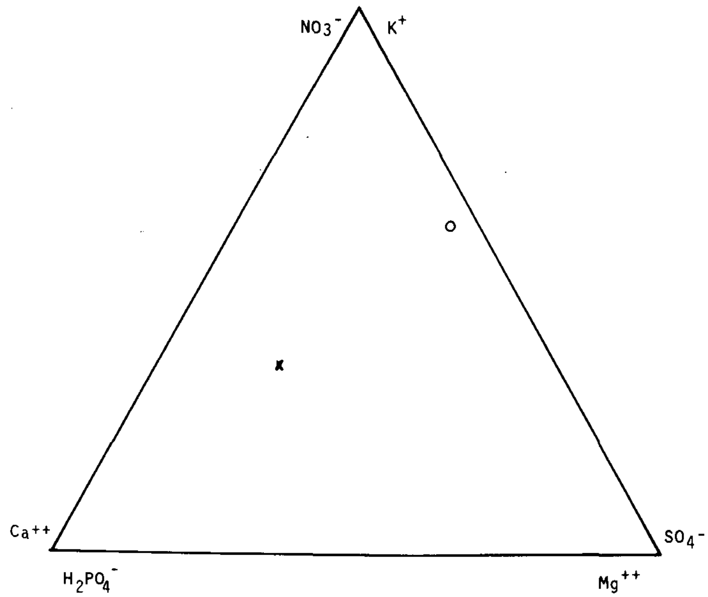


Figure 3 - The mutual ratio between the anions (circle) and the mutual ratio between the cations (cross) in Steiner's universal nutrient solution

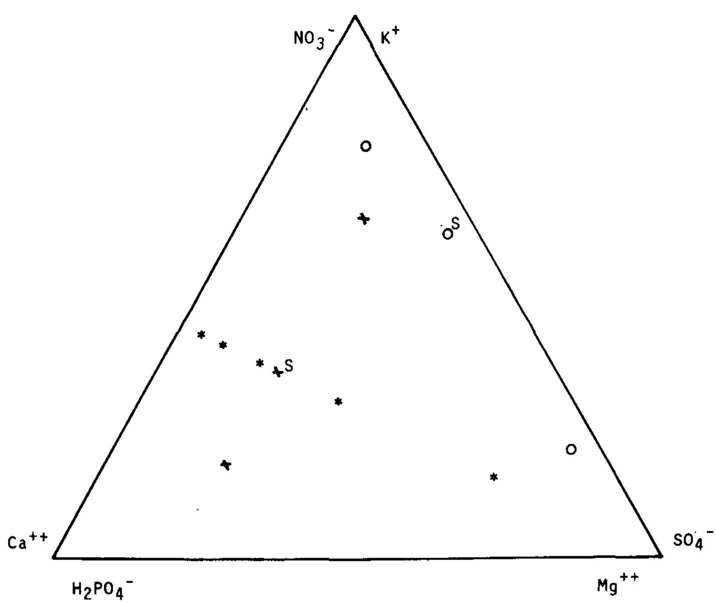


Figure 4 - Original mutual ratios between the ions in the nutrient solutions

o mutual ratios between the anions
x mutual ratios between K and Ca; Mg proportion constant
* mutual ratios (K + Ca) : Mg; K : Ca constant

possible by using large quantities of nutrient solution for one plant (15 litres for one lettuce plant, 35 litres for one tomato plant) which already gives a strong buffer, and by frequent analyses of the solutions and replacement of used ions. But of course, there still are some deviations during the experiments. Nevertheless, the mutual ratio between the ions never exceeded the encircled areas given in figure 5, where the original mutual ratios are given as circles, crosses and stars, as in figure 4. We may conclude that all mutual ratios during all experiments have been sufficiently constant, and specially there are strong significant differences between all mutual ratios taken into consideration.

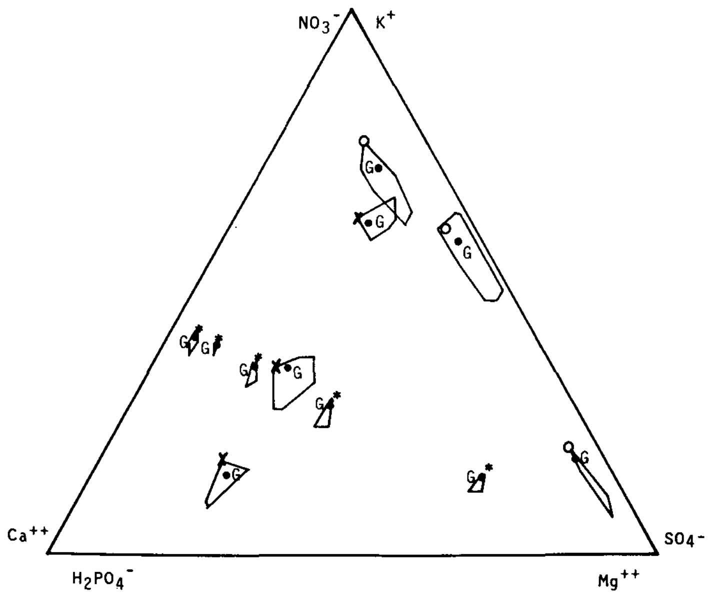


Figure 5 - a. maximum deviations in the mutual ratios between the ions in the nutrient solutions (encircled areas)

o original mutual anion ratios
x original mutual ratios K : Ca; Mg proportion constant
* original mutual ratios (K + Ca) : Mg; K : Ca constant

b. geometric means of the mutual ratios between the ions in the nutrient solutions, dots, signed G

For bringing the mutual ratios between the ions consumed by the plants, in the same triangle with the mutual ratios in the solutions, we need a more simple view on the mutual ratios between the ions in the nutrient solutions. For this reason we need one mean point for each area of ratios in the solutions, which only may be calculated by the geometric means, not as the arithmatic means (Hoveyn, 1978). These geometric means are given in figure 5 as a dot in each area. In figure 6 the geometric means of each mutual ratio between the ions in the nutrient solutions are given as circles for the anions, and crosses and stars for the cations as before in figure 4 for the original mutual ratios.

All lettuce and tomato plants have been analyzed for N, P, S, K, Ca and Mg for determining the mutual ratios in which the ions are taken up by the plants.

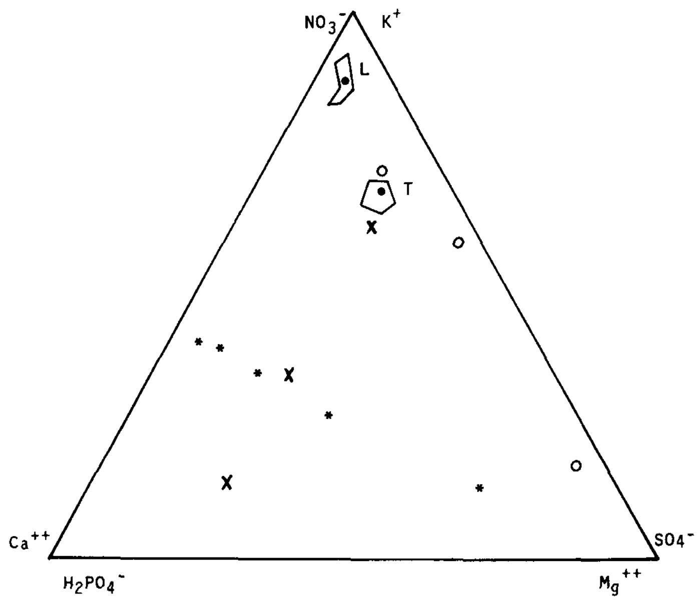


Figure 6 - The mutual ratios between the anions absorbed by lettuce and tomato plants

In the plants (encircled areas)

- L lettuce
- T tomato plants
- • geometric means

In the solutions (geometric means)

- O mutual anion ratios
- x mutual ratios K : Ca; Mg proportion constant
- * mutual ratios (K + Ca) : Mg; K : Ca constant

Now we come to the remarkable discovery that the mutual ratio between the anions taken up by lettuce plants, without any exception, lies within the encircled area L in figure 6, irrespective of the widely divergent mutual anion ratios and mutual cation ratios in the nutrient solutions. It does not matter if there is about 70 % or only 15 % nitrate portion in the anions in the nutrient solution and whatsoever mutual ratio between the cations; even a 64 % magnesium portion in the cations and at an osmotic pressure varying from 0.48 to 1.62 atm., lettuce plants absorb the anions nitrate, phosphate and sulfate, in a very specific mutual ratio. Even the deviations in uptake from the geometric means, given as a dot in figure 6, may be attributed to analytical errors.

We come to the same remarkable discovery for the anions taken up by tomato plants, only here we have not yet investigated the magnesium influence (the stars in figure 6). The mutual ratio between the anions taken up by tomato plants, lies without any exception within the encircled area T in figure 6, irrespective of the widely divergent mutual anion ratios and mutual cation ratios in the nutrient solutions. Only here, a total ion concentration as low as 0.18 and 0.36 atm. osmotic pressure, gave some less portion in the uptake of phosphate (from 12 % to 7 % of the anions), mainly in favour of the sulfate uptake (from 20 % to 27 % of the anions). Here we see some influence of the physical factor 'osmotic pressure'.

We see that the extremely strong selection goes in different ways for lettuce and tomato plants (areas L and T in figure 6).

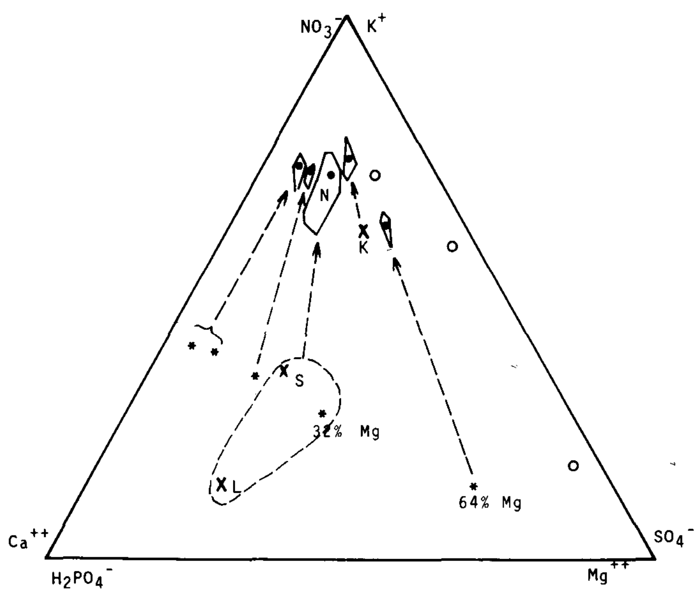


Figure 7 - The mutual ratios between the cations absorbed by lettuce

In the plants (encircled areas)

- ● geometric means

In the solutions (geometric means)

- o mutual anion ratios
- × mutual ratios K : Ca; Mg proportion constant
- * mutual ratios (K + Ca) : Mg; K : Ca constant

Now the cation uptake. Here, we also have a strong selective capacity, but not as distinctly as for the anions; here there is less resistance against extreme mutual ratios between the cations in the nutrient solution.

All mutual ratios between the cations in lettuce plants, without any exception lie within the encircled areas in figure 7, where the geometric means of the mutual ratios between the anions in the nutrient solution are given as circles, and between the cations as crosses and stars, exactly as in figure 6. 'Low' and 'normal' potassium in the solution (crosses L and S) and 32 % magnesium, all give the mutual ratio of the uptake in area N. An extremely high potassium proportion in the solution (cross K), gives some more potassium uptake. Relatively less magnesium in the solution gives some lower magnesium uptake and the extremely high portion of 64 % of the cations as magnesium in the solution gives a serious higher magnesium uptake. Total ion concentrations, varying from 0.48 to 1.62 atm. osmotic pressure did not give any significant difference in the mutual ratio between the cations taken up by lettuce.

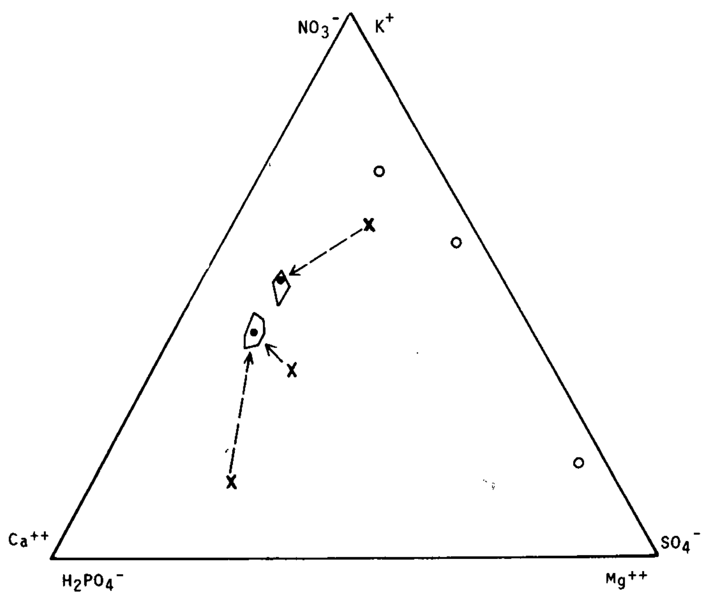


Figure 8 - The mutual ratios between the cations absorbed by tomatoes

In the plants (encircled areas)

- ● geometric means

In the solution (geometric means)

- o mutual anion ratios
- x mutual ratios K : Ca; Mg proportion constant

With tomatoes the magnesium influence is not yet investigated. Figure 8 shows the mutual ratios between the cations taken up by tomato plants from the given mutual ratios in the nutrient solutions. Only the extremely high proportion of potassium in the solution gives a higher portion of potassium in the tomato plants, but still plants have a strong resistance.

For tomatoes the total ion concentration has a significant influence on the mutual ratio between the cations taken up, mainly on the ratio potassium : calcium. From the very low osmotic pressure of 0.18 atm. (that means only about 0.5 g total salts per litre !) to 1.08 atm. (3 g total salts per litre) the potassium portion of the cations rose from 39 % to 49 %, mainly at the expense of calcium (35 % to 28 %).

Thus, we did not find any influence of the total ion concentration on the direction of selecting the anions and cations by lettuce plants, but a real influence for tomato plants.

For the sake of completeness I have to mention that all mutual ratios in the plants, given in the triangles, are based on the experiments with various mutual ratios in the nutrient solutions, all at a total ion concentration of 0.72 atm. osmotic pressure. The results of the ion uptake at other total ion concentrations are only given as percentages in the text, and not surveyed in the triangles !

Also for the cations we see that the selection goes in a quite other direction for lettuce than tomato plants (compare the figures 7 and 8). Although not yet explicitly investigated for other kinds of plants, from scattered data in the literature we have strong indications that each kind of plant has its own direction of selecting the ions in certain mutual ratios.

We found that younger and older lettuce plants, all have the same direction of selecting the ions . For tomatoes there is a difference between the first vegetative growing period and the more generative production period. The direction of selecting the ions is also slightly different for tomatoes under various climate conditions (temperature, light intensity and possibly day length). In this lecture it would take too much time to give details (details about the selective capacity of tomato plants partly published, Steiner 1973).

<u>The influence of the mutual ratio between the ions in the nutrient solution on the production</u>

The production results are also very impressive. For lettuce all treatments mentioned did not give significant differences in the production, except the extremely high magnesium proportion in the solution. Here we got a 13 % reduction in the production. The lowest total ion concentration of 0.48 atm. osmotic pressure gave 9 % less production, but we have not yet calculated the significance of this figure. But surely, all other treatments, including the extremely high potassium portion in the solution which gave some higher potassium portion in the plants, did not give any reduction in the production.

With tomato plants, only the extremely high potassium portion caused a reduction in the production of 7 %. Only here, we have not yet investigated the extremely high magnesium portion in the solution. For the sake of completeness we have to mention that in other experiments we used the extremely high portion of nitrate at 86 % of the anions for tomato plants. This resulted in a significant reduction of only 9 % in the production of tomatoes (Steiner, 1966).

As a general conclusion we may say that plants, in any case lettuce and tomato plants, not only have a strong capacity for selecting the ions in a certain direction adequate for that kind of plant, but that even if extreme mutual ratios in the nutrient solution cause a deviation in the uptake as desired by the plant, this only has a relatively small influence on the production. Nevertheless, it is important to give plants the opportunity to absorb the ions in a mutual ratio as they wish to do according to their typical nature.

## The importance of the selective capacity for ions for the composition and treatment of the nutrient solution

Now, what does this all mean for the practical application of water culture systems ? To explain this I have to go back into the history of soilless culture. For nearly all crops there were special compositions of the nutrient solution; we found over 300 recipes for nutrient solutions for tomatoes, roses, wheat, potatoes, etc., etc., sometimes more than 50 recipes for one crop (Ebbinge Wubben & Steiner, 1948; Steiner, 1972). During the culture the solutions were regularly analyzed and the original composition was as good as possible redressed by adding salts to the nutrient solution.

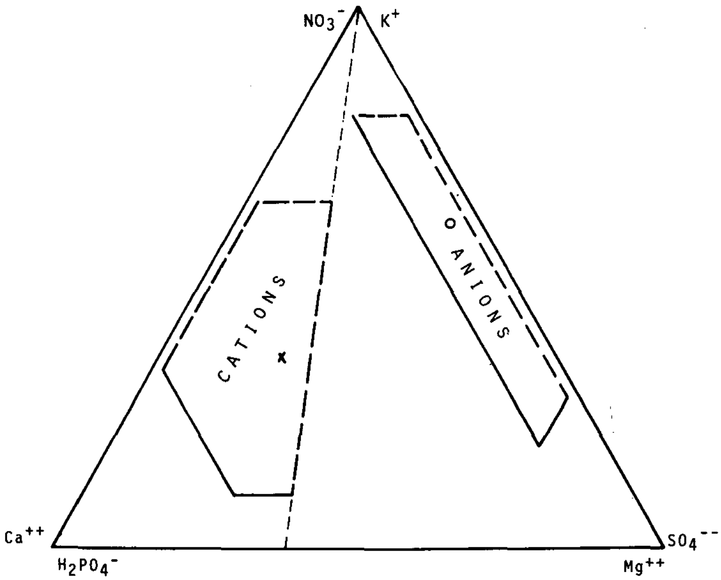


Figure 9 - The composition of Steiner's universal nutrient solution (**o** and **x**) and the favourable areas for plant production

solid lines = precipitation limits at 0.7 atm. osmotic pressure and $p_H$ 6.5

broken lines = physiological limits

Already in the sixties I proved that for all plants, except some special calcifuges like Ericaceae, we may use one and the very same composition, realized in my universal nutrient solution, given in figure 9 with a circle for the mutual ratio between the anions and a cross for the mutual ratio between the cations, and moreover that any composition within the encircled areas in figure 9, does not give any reduction in growth and production of plants. It was proved for tomatoes, cucumbers, elm-tree, reed, willow-tree, potatoes, and many other plants.

For the sake of completeness I have to say that solid lines represent the limits for a precipitate at a total ion concentration of 0.7 atm. osmotic pressure and $p_H$ 6.5, and broken lines are the physiological limits for a normal growth and production. Only for calcifuge plants the mutual ratio between calcium and magnesium has to be more in favour of magnesium (Steiner, 1969).

Still the prevailing idea was that we had to maintain the composition within the given areas in figure 9 by additions based on analyses of the nutrient solution. However, using relatively small quantities of nutrient solutions per plant, as in nutrient film systems and with cultures in rockwool, people started to apply always the original composition for additions during the culture, only controlled for the total ion concentration with a conductivity meter.

If the mutual ratio between the ions added to the nutrient solution during the culture, was strongly different from the mutual ratio in which the plants absorbed the ions, there was an accumulation of certain ions in the nutrient solution. In most cases, still the plants themselves saved the culture by their strong selective capacity. Only in extreme cases the nutrient solution became too much out of balance, that means the mutual ratios stepped across the favourable areas given in figure 9. This has given a lot of problems with nutrient film systems and in the beginning also with cultures in rockwool.

But still, we may add salts to the nutrient solution, controlled by the electrical conductivity if we only add as good as possible the ions in the same mutual ratio as they are consumed by the plants.

This means that we have to leave the old idea that we have to force the plant to consume certain quantities of e.g. potassium and calcium, e.g. in a mutual ratio 1 : 1, for which we have to offer a relatively high calcium : potassium ratio, e.g. 2 : 1, based on the old idea that for bivalent ions we have to offer more for reaching the desired uptake than for univalent ions. Now we know that the plants themselves can select the favourable ratio from widely different ratios in the nutrient solution. This gives us the possibility to add the ions in the mutual ratio as the plants consume them.

I can not yet prove it completely, but I have strong indications that if we offer the ions in the mutual ratio the plants like to absorb them, it saves energy for the plant, that means that a plant has to spend more energy if the ions are offered in a mutual ratio, strongly deviating from the mutual ratio the plant likes to consume them. And plants can only produce this energy by burning assimilates in the roots at the cost of production, thus at the cost of the profit of the grower.

This all means that we still return to a special composition of the nutrient solution for each kind of plant, but now based on a good knowledge of what happens. Based on this knowledge we can leave the method of trial and error for finding a favourable composition of the nutrients solution, and of the nutrients to be added during a culture for a special kind of crop, only controlled by the electrical conductivity. These values can be found by analyzing well growing and good producing plants. And we already experienced that for the changing direction of selecting the ions by young and older tomato plants, it is not necessary to change the composition of the solution for replenishment.

Now, Sonneveld and Voogt already proved that for cucumbers and tomatoes in rockwool it is possible to add one and the same composition of the nutrient solution to the rockwool during the whole culture period. Of course, for security the nutrient solution in the rockwool is frequently analyzed. If there comes a real deviation in the composition of the nutrient solution in the rockwool, mainly caused by deviations in the climate, giving a change in the mutual ratio between the consumed ions, it is possible to offer a solution with a slightly different composition for replenishment. This happens rarely, but if it happens it is only necessary to offer the substitute solution for a very short period.

## General conclusion

The general conclusion is that based on the chemical composition (all material analyzed as inorganic elements) of a well growing and well producing crop, it is possible to compose a nutrient solution, which also may be used for continuous replenishment, only controlled by the osmotic pressure of the nutrient solution. Still the composition has to be followed weekly or fortnightly by analyses. But still if there are relatively small deviations in the chemical composition of the nutrient solution, the plants themselves have the 'mechanism' to select the ions in a mutual ratio favourable for their growth and development.

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