TRENDS IN FERTILIZERS AND FERTILIZATION

Intensive Greenhouse Tomato Production as a Model for Fertilizer Development Recommendations

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The S. Neaman Institute Press

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February 1990

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Acknowledgments:

The authors are thankful to:

Ms. Ricija Zak who participated in preparation of this report and specifically in calculations of the physico-chemical properties of fertilizer solutions.

Ms. Nili Tirosh for her very efficient and friendly help in computerized literature searches.

Negev Phosphates Ltd. for partial support of the project.

The Agronomy Department of Fertilizers and Chemicals for supplying information and organizing visits to growers.
The growers, extension workers and research institute personnel in Israel, Crete (Greece), Naaldvijk (The Netherlands), Littllehampton (UK), National Fertilizer Development Center, TVA (Alabama), Gainesville (Florida), Cornell University (NY).

CONTENTS

SUMMARY

A study of fertilization practices in intensively grown tomatoes, leading to a projection of future developments in fertilizer consumption of this crop, was initiated.

Targets of optimal fertilization strategy were defined:
- Maximize exportable fruit yield.
- Maximize fruit quality.
- Minimize environmental pollution with fertilizers.
- Minimize corrosion of the fertilizer distribution system.
- Minimize expenses on fertilizers.

Information was gathered by literature searches and by personal interviews and visits to research institutes and growers in Israel, Greece, Netherlands, England and USA. Relevant research results and fertilization practices in protected tomato cultures are reported.

Recommendations on rechecking of fertilization practices for greenhouse tomatoes grown in detached media in Israel were formulated:
- Ammonium / nitrate ratio in fertilizer formulations.
- Use of urea in fertilizer solutions.
- Levels of phosphates applied.
- Levels of sulphate applied.
- Simple iron salts vs. chelated iron application.
- Osmotic potential, expressed as electrical conductivity (EC), of the nutrient solution at various growth stages.
- Short term variations in nutrient solution concentration.
- Use of rain water for irrigating greenhouse crops.

A forecast on future demands of fertilizer compounds was formulated:

- A change from use of complex fertilizer solutions to application of single salts.
- An increase in the ratio of ammonium to nitrate in fertilizer formulations.
- In consequence of the above, a partial shift in use of potassium sources from potassium nitrate to phosphate, sulphate or chloride.(The last one is already partially used for maintaining the osmotic potential of the nutrient solution).

- Recent developments point toward a shift from the use of fertilizer salts to the use of very soluble and concentrated compounds such as caustic potash, nitric, phosphoric and sulphuric acids.

Electrical conductivity, pH and estimated prices of fertilizer solutions were calculated and presented in Addendum.

Introduction

The Samuel Neaman Institute (SNI Annual Report 1988/9) pursues a policy of inquiry and analysis designed to identify significant public policy problems, to determine possible courses of action to deal with the problems, and to evaluate the consequences of the identified courses of action

The Israeli fertilizer industry accounts for about 600 million dollars of fertilizer production and sale. Ninety per cent is exported and contributes an important source of foreign currency.

The SNI has therefore decided to carry out a pilot study on the future developments of the fertilizer industry and to evaluate the effects of world technological and ecological trends on the industry structure in Israel.

Developed agricultural systems are more concerned with the effects of agricultural inputs on pollution, than on increasing crop yields. Pesticides and fertilizers are considered to be the two main sources of agricultural pollution. A U.N. report states that there is a deterioration of drinking water quality world wide. Major emphasis is on toxic levels of nitrates in water and on eutrophication agents such as nitrogen and phosphates. Leaching of fertilizer elements into underground water in intensive agricultural systems indicates over-fertilization, caused probably by the cost of fertilizers, which is low relative to other production inputs. The British Ministry of Agriculture announced on May 9, 1989 that the Government will in the next year set up a scheme to control the leaching of nitrates from agricultural land into water resources. Restrictions on the use of nitrate fertilizers will be applied where nitrate concentrations in water resources exceed or are at risk of exceeding the European Community limit of 50 mg/1. In the same week the Dutch Ministry of Agriculture and Fisheries proposed substantial cuts in the consumption of fertilizers and other chemicals by the turn of the century. TVA reports on fertilizer elements run-offs and a consequent wide spread river pollution and lake eutrophication. In some high fertilizer using countries, such as for example Denmark, legislation limiting fertilizer use is contemplated. The nitrate level in many wells in Israel was found to be higher than the permissible U. S. standard.

We therefore face a conflict between high level of agricultural production and demands to safeguard the ecological balance. There is no doubt that in the long run high inputs of fertilizers are needed to maintain the high yields and high quality of crop varieties achieved by efforts of selection and breeding. These contradictory trends will force the food producing community to revise its fertilization strategies. It seems that the western societies are ready to pay a certain price for measures minimizing pollution.

Several ways of reducing ground water pollution by fertilizers are envisaged. One, probably valid in the more distant future is in biotechnology and genetic engineering techniques. There is a possibility of engineering crop varieties capable of more efficient utilization of nutrients, thus utilizing less soluble and less leachable compounds. Another possibility is in developing crop varieties capable of living in symbiosis with nitrogen fixing organisms such as is the case in leguminous plants. However, for the nearer future known fertilization techniques could be refined and adapted to the existing situation. Tailor-made fertilizers supplying all the nutrients according to crop rate of demand will be needed. This strategy requires evaluation of research already done. Additional work is needed for establishing optimal nutrient concentrations in the growth substrate in order to satisfy the optimal uptake of nutrients by plants and without leaving surpluses. In irrigated systems plant mineral nutrients can be applied at a controlled rate with the water. Soil solution testing or leaf analysis aiming at maintaining a predetermined level of nutrients is widely used.

The bulk of food production in the world is in extensive agricultural systems. In these systems the cost of fertilizers is high relative to other production inputs. Not withstanding, underground water pollution by fertilizers is a problem and solutions will be required.

In the first stage of our study we choose to review and formulate recommendations for a very intensive crop, namely tomatoes grown in greenhouses. In such a production system the problems are more acute than in less intensive ones. Therefore, we see the study of greenhouse tomatoes as a pilot study. Recommendations formulated for such an intensive crop may serve as a model for other intensive crops and later for extensive ones. In addition, greenhouse crops and especially tomatoes are gaining in importance as export crops fetching high prices in international markets. The export value in Israel at present is about 20 mil. $. Tomatoes are the major vegetable crop sold on the world markets. Formulation of fertilizer compounds for maximizing yields and quality and minimizing waste that will find its way eventually into the aquifers, should be important both to the fertilizer manufacturers and to the growers.

Environmental pressures for a radical change in fertilization practices may exist, but it seems unrealistic to expect that such changes will occur rapidly. The world-wide fertilizer industry has large scale investments in fertilizer plants and farmers in fertilization equipment. Closing the gap between environmental demands and increased fertilizer requirements may be easier achieved by introducing new methodology, such as complex fertilizers formulations, or delivery systems. This can be attained within the existing economic situation more easily than by restructuring the fertilizer industry and application equipment.

In the case of fertilization of very intensive greenhouse cultures, the saving in fertilizer inputs may not be very important, although it may be the narrow margin between profit and loss. However, the saving in water pollution may be very important. It seems that the days have passed when the general fertilization recommendation was to add at least 25% above the real crop demand just to be on the safe side.

Various fertilization practices have to be examined. For example it is customary in greenhouse cultures to apply the iron in a chelated form. This practice is justified if the plants are grown in a calcareous soil, but it is questionable and has to be rechecked in an artificial slightly acid growth medium. The price of chelated iron may comprise about 20% of the total fertilizers price.

Forms of nitrogen application have to be rechecked also. It is customary to apply nitrogen as ammonium nitrate and potassium nitrate. Such a combination of nitrogen compounds supplies much more nitrate than ammonium to the growth substrate. Recent research results indicate that a higher yield and better quality may be achieved by supplying a 1:1 ratio of nitrate to ammonium nitrogen. Thus, it may be of benefit to balance the nitrate applied as potassium nitrate with an ammonium salt, or to replace the potassium nitrate by an other compound of potassium such as sulphate or even chloride.

Quality and improved flavor of tomato fruits are important points in finding export markets ready to pay a premium price for the fruit. It seems that for development of desirable fruit flavor, the plant has to be under a stress condition. Stress may be generated by several means. Known strategies are development of stress by salinity conditions i. e. by applying irrigation water having a relatively high Electrical Conductivity. This can be achieved either by high fertilizer rates in the fertigation, or by adding salt such as potassium chloride to the water. Both ways are unfriendly from the environmental point of view. Stress may be imposed by pulse irrigation, allowing a relatively dry root zone between irrigation pulses. For such a strategy a fertilizer composition generating minimum osmotic pressure is necessary in order to minimize possible damage to roots during the dry interval.

Agrotechniques may improve fertilizer utilization. For example increasing plant population per area may replace limiting fertilizer amounts. However, other factors may enter, such as light intensity on the total canopy. Increased concentrations of carbon dioxide in the greenhouse atmosphere may improve fertilizer utilization by the crop.

The influence of fertilizers on shipping quality of greenhouse crops, especially tomatoes has been studied by various investigators. The marketing of the tomato crop in the U.S.A. is governed more by long distance (California or Mexico to East Coast) shipping logistic problems than by crop qualities determined by vine-ripening. The Israeli varieties picked vine-ripe have long shelf life and good taste and thus fetch premium prices on the US market.

Grower and National Targets in the Intensive Tomato Industry

Our projections for fertilizer development for greenhouse tomatoes are based on current fertilizer recommendations, on reported experimental results and on known or assumed crop, economic and environmental demands.

The optimal fertilizer composition should lead to the following results:
Maximize exportable fruit yield, aiming at seasonal tomato production gaps in target countries, when high prices can be expected.
Maximize fruit quality expressed as flavor, firmness, color, and prolonged shelf life.
Minimize underground and/or surface water pollution.
Minimize corrosion and/or clogging of the water and fertilizer supply and distribution systems.
Minimize expenses on fertilizer materials and applications.

There are, obviously, several approaches and not all of them may lead to the achievement of all the stated goals. Therefore, a first decision should be made on priorities. Taking the Israeli intensive tomato production and marketing as an example the following priorities in descending order are proposed:

1. Maximize fruit quality.

In a competitive market and with relatively high costs of transportation, where the Israeli producers cannot compete on the basis of bringing large quantities of fruits to the market, they have to serve the high quality and high price section of the export market.

2. Maximize exportable fruit yield.

Economic reasons dictate that mineral nutrients deficiencies should not restrict in any way high yield production.

3. Minimize pollution.

The awareness of polluting the underground or surface waters by fertilization practices in greenhouse crops is rather low today. The enlargement of areas under protected crops, some over very sensitive aquifers, and the possible use of excessive amounts of fertilizers will increase the pollution hazards. Fertilization practices will have to take this problem into account.

4. Minimize corrosion.

Corrosiveness and forming of precipitates may have considerable economic consequences in the maintenance of the irrigation and fertilizer distribution systems. However, it seems that it would not be too difficult to propose non-corrosive and non-precipitating fertilizer compositions and concentrations or additives preventing clogging and/or corrosion.

5. Minimize expenses.

Fertilization expenses are a small fraction of the total inputs in a greenhouse culture. Therefore, savings on fertilizer costs may not have a marked impact on its economics. Still, in some cases they may be the difference between profit and loss.

Methods of fertilizer application

Applying fertilizers with irrigation water is the regular practice in greenhouse cultures. This method of application enables a continuous supply to the root system of mineral nutrients at a predetermined concentration.

Supplying nutrients by slow-release fertilizers is considered. For the time being it seems that application of slow-release fertilizers has to be more expensive than the application of simple salts or acids. Applying commercially available slow-release fertilizers does not allow for regulating the nutrient supply according to the daily needs of plants. The rate of nutrient release is not synchronized with the rate of nutrient uptake.

There are some promising developments in controlled-release diffusion based fertilizers. This method allows for the rate of release to be predetermined according to plant requirements. However, even this development would not permit regulating nutrient supply after the fertilizer has been applied. Additional developments may be envisaged leading to controlled-release fertilizers responding to external signals. For example the release of mineral nutrients from a diffusion based fertilizer in close contact with a root could respond to changes in concentration gradients between the root and the fertilizer surfaces. In practice we do not know of such developments and they will probably not influence fertilizer markets in the forseeable future. However, there are first indications in this direction in work done in the USA on H^+ ion release from roots.

In view of the above we shall concentrate on ways and means of optimizing fertilizer application in irrigation water.

Maximizing yields by fertilization.

High yielding cultivars need an adequate supply of nutrients to express their yield potential. The decisive factor in an adequate nutrient supply is the nutrient concentration in the root medium and this is determined by the concentration in irrigation water. However, the relation between the concentration in irrigation water and that in the root medium is not a simple one. The factors that may influence it are the rate of nutrient uptake by the plant, rate of evapotranspiration and possible reactions such as precipitation or fixation by the growth medium. Fertilization practice should be governed by monitoring the nutrients concentration in the growth medium and adjusting it to some predetermined values. It seems that these values are known, although a rechecking would be helpful in establishing revised norms.

Nitrogen.

A concentration of about 200-250 mgN/1 of soil solution seems to be an adequate level. Fertilizer recommendations are based more or less on that level. Although, it should be noted that recommendations relate to the concentration in irrigation water and that does not have to be identical to the concentration obtained in the growth medium. Further, recommendations vary according to the growth stage. Lower concentrations are used at the beginning of the growing period and somewhat higher at the peak of the season. This may be due to a varying demand for optimal concentrations in the root substrate. On the other hand it may be assumed that the demand for optimum concentration does not vary appreciably with time. The need for varying the incoming concentrations arises from changes in uptake rates.

The form of nitrogen in the nutrient solutions influences changes in the pH of the solution upon N uptake by plant roots. Uptake of nitrate raises somewhat the pH of the solution, while uptake of ammonium lowers it considerably. Mixtures of nitrate and ammonium are in an intermediate position.

The current recommendations of applying nitrogen in irrigation water at the beginning of the growing period at the concentration of about 150 mgN/l and later at about 250 mgN/l seems to be sound. The prevailing practice is to supply the nitrogen as nitrates of potassium, magnesium and calcium and balance it by ammonium nitrate. There are indications that a balanced (1:1) supply of ammonium and nitrate nitrogen could be beneficial. It is recommended to recheck this issue. Assuming that the above assumption is acceptable, a change in the nitrogen fertilizer solution would be required. For example, nitrates of potassium and possibly of magnesium should be replaced by sulphates. Thus, the bulk of nitrogen would be applied as ammonium nitrate, nearly satisfying a balanced ammonium-nitrate nitrogen nutrition.

The proposed change would add sulphates to the nutrient solution. This compound is lacking in the prevailing composition of detached growth media in Israel.

Phosphates.

The amount of phosphate applied appears to be high. We recommend rechecking the levels of P application. It is known from numerous soil researches that a level of 1-4 mgP/1 soil solution is adequate for maximum plant growth. Similar values are derived from a graph presented in Marschner, 1986, (p. 49). The recommended concentrations in irrigation water are much higher. In soil cultures a fixation of phosphates may occur. Therefore, relatively high rates of P have to be applied in the incoming solution for achieving the desired and lower concentrations in the soil solution. The actual P rates will depend very much on the soil and no specific recommendations can be given, without a check in the field.

It is recommended to check on several typical soils the relation between the concentration of P in the incoming solution and that in the equilibrating soil solution. Working in sand or in other nearly inert media much phosphate fixation cannot be expected and therefore it is strongly recommended to recheck the required P concentration in irrigation water. As a first approximation a concentration of 10 mgP/1 should be tried. This is still about three times higher than the assumed necessary P level in the growth medium.

The level of soluble P in the growth medium solution will be influenced mainly by the pH and by the concentrations of Ca and Mg. There is no doubt that these have to be determined when deciding on the optimal P concentration in irrigation water. P inputs have been limited in several countries, because of eutrophication hazards. In soil-less media excess P will have to be sewaged and thus will create an environmental problem.

A number of P sources are in use. In Israel the most popular one is phosphoric acid. Other P sources are used throughout the world and these include potassium polyphosphate, monopotassium phosphate and ammonium phosphate.

Potassium.

Recommendations on K rates seem to be rather high, they go up to about 350 mgK/l. However, in view of the tomato plants large demand for potassium for ensuring high fruit quality, this high rate of application seems justified.

The potassium salt applied is irrelevant to potassium uptake by plants, but the accompanying anion may influence the root medium solution. For example sulphate may lower the pH of the solution more than chloride or nitrate. The choice of anion should be made according to the need of balancing anion inputs. Part of the potassium could be given as potassium phosphate. The other part of potassium requirements could be applied as a sulphate salt, or a nitrate and even potassium chloride could be considered. A highly concentrated and soluble compound is potassium hydroxide, which is growing in use in Europe.

Calcium and Magnesium.

The calcium concentration in irrigation water has to be augmented by a nitrate salt, because of the low solubility of other common calcium salts. The recommended Ca concentrations are similar to those used in Hoagland solution. Because of lack of better values those seem acceptable. Recommended magnesium concentrations are somewhat higher than those used in the Hoagland solution. This seems justified, taking into account the high concentrations of applied potassium. Magnesium could be added as a sulphate or as a nitrate salt. In a concentrated feeder solution, if mixed with calcium nitrate, it has to be in the nitrate form to prevent calcium precipitation.

Microelements.

A microelements solution has to be added, although the concentrations applied are minute. The cations, except iron, are applied as sulphates. Iron is mostly, including the Hoagland solution, applied in a chelated form. The possibility to apply it as a sulphate similar to other cations should be explored.

Finally, maximizing yields seems to be possible only by maintaining an adequate osmotic pressure in the rooting medium solution during most of the growth period. This has to be taken into account when formulating fertilizers solutions. Any nonessential cations and anions should be omitted.

Maximizing fruit quality by fertilization.

An ample supply of potassium with high availability of calcium and magnesium seem to be important factors in securing high fruit qualities, such as color, firmness and prolonged shelf life. A balanced ammonium-nitrate nitrogen nutrition may have some influence on these qualities.
The flavor of the fruit is a very important marketing

quality. It seems that the flavor in the fruit develops at the late stage of its growth under the influence of an increased osmotic pressure in the root environment, caused by a salt or drought stress.

The prevalent recommendations aimed at flavor development in the fruit are based on increasing the electrical conductivity of the water applied at the late stages of growth. An increased concentration of KCl or even the use of sea water are recommended. These means are claimed to be efficient in improving fruit flavor without impairing too much the final yield. We have some reservation to this practice. It seems that for a tomato plant, having an indefinite growth pattern, the definition of a late stage of growth is almost impossible. In addition, the surplus salts have to be leached out of the root zone and they finally may find their way into an aquifer, which will probably not be tolerated in the not too distant future. Obviously, alternative means for enhancing fruit flavor will have to be found. As a first thought, reducing of water applications at critical periods is proposed. That may induce a drought stress combined with a high osmotic pressure stress, because of the resulting temporary high concentration of mineral nutrients in the rooting medium. The use of high osmotic pressure fertilizers at critical periods could be possible.

Minimizing water pollution by fertilizers.

Strategies employed for minimizing osmotic pressure of the rooting medium solution discussed under the heading of Maximizing Yield will lead toward minimizing the pollution hazard of surface or/and underground water. Minimizing pollution hazards by means aimed at enhancing the fruit flavor were discussed above.

Minimizing corrosion and clogging.

The primary fertilizer solutions are rather concentrated and may have a low pH. For storing and mixing these solutions corrosion resistant materials are used. Fertilizer concentrations in the irrigation system are dilute and in most cases would not be corrosive, nor form precipitates. Clogging may occur by biological growth in the nutrient solution. Additives to the irrigation solution, non-toxic to plants such as for example, copper compounds could be used for preventing biological clogging. Low pH fertilizer solutions have an anticlogging effect.

Minimizing cost of fertilizers

This last item was assigned the lowest priority, because fertilizers costs are a small proportion of the total operation expenses of growing greenhouse tomatoes. Higher priced fertilizers may sometimes pay off by improving fruit quality or by reducing the salt concentration in the root zone. However, if an alternative is given, the lower cost fertilizer should be chosen.

Tables of fertilizer mixtures may be found in Addendum to this report.

Literature review

The review is aimed at scanning the literature on mineral nutrients rates and ratios applied mainly to tomatoes grown under protected environmental conditions. Rates of application are stated as kg/dunam (kg/du) wherever possible. Dunam is a unit in the metric system. It contains 1000 m^2= 0.1 hectar. This area measurement is used in Israel and through the Middle East. It is a convenient unit for glasshouse conditions.

Bar Yosef et al. (1980) concluded that the optimal N concentration in irrigation water during the main growth period should be 240 ppm.. Other nutrient ratios were kept constant throughout the experiment and there is no experimental evidence that those used are the optimal ones. Accordingly, parallel to the above N concentration, the P concentration is 35 ppm. and that of K 192 ppm..

Some other experiments showed similar optimal concentrations of N in irrigation water. Tsikalas and Manios (1984, 1985) received the highest yields of greenhouse tomatoes with an N concentration in irrigation water of 200 ppm..

Similarly, Papadopoulos (1987) growing tomatoes in 12 1 pots in a non-calcareous sandy loam soil, trickle irrigated and applying ammonium nitrate, monoammonium phosphate, potassium sulphate and micronutrients and N concentrations in irrigation water of 90, 180 and 270 ppm., found that the 180 ppm. N concentration was the optimal one. He explained that effect by nitrate concentrations in the soil solution. At the lowest application rate no nitrate was found in the soil solution. The second N level brought the nitrate - N level to around 100 mg N/1 and the higher level up to about 400 mg N/1. The accompanying EC (dS/m) was 2.0, 2.6 and 4.0. The lower application did not maintain an adequate level of N in the soil solution, while the higher one generated a high EC. It should be noted that the plants received a mixed ammonium - nitrate diet.

Magalhaes and Wilcox (1984) experiment gives an indirect evidence to the advantage of a mixed ammonium-nitrate nutrition over only nitrate nutrition.

Graifenberg et al.(1986) by comparing ratios of urea : NO3 : NH4 for greenhouse tomatoes, found that the highest yield was obtained at a 2:1:1 ratio. This indicates a beneficial effect on yield of a relatively high content of ammonia in the nitrogen nutrient mixture.

Kondo (1972) reports very similar results regarding the N level.

Similar to previous findings Oswiecimski (1981) growing tomatoes in 12 1 of peat found that the optimum nutrient solution content at full growth in mg/1 was N: 200-300, P: 22, K: 166-250 and Mg: 50. At early stages of growth 40% of the above concentrations were sufficient.

Borkowski and Szwonek (1984) found magnesium rates of 100-200 mg Mg/1 as optimal.

Orlov et al. found that by increasing recommended fertilizer rates by 30% increased yield and especially exportable yield.

Kirkby et al. (1981) found that nitrate reductase activity was stimulated by an increased supply of K in the nutrient medium. This indicates that if plants are not adequately supplied with potassium, nitrate reduction may be affected and hence also the nitrogen nutrition of the plant.

Huett and Dettmann (1988) state that on a physiological basis, N compared with other nutrients, has the greatest effect on growth rate and nutrient uptake rate and is therefore the most important nutrient to precisely control in order to achieve optimal nutrition. For achieving optimum nutrition conditions and thus maximum growth rate, a stable nutrient supply by regular replenishing of the nutrient solution is required. Optimum N levels for maximum fruit yields are between 250-450 mgN/l. The highest N level produced the firmest fruit with the highest dry matter and total soluble solids content. The highest demand for N and K occurs over the fruit growth period.

The K level should be reconsidered in view of Winsor and Adams (Glasshouse Crops, 1987) statement. The amounts of K required for production of evenly ripened and high quality fruit considerably exceed those required for maximum yields. However, it should be kept in mind that high K rates may induce Mg and Ca deficiencies and raise the EC.

The experimental evidence cited, points to the following optimal concentrations of nutrients in irrigation water for greenhouse tomatoes in sandy soils or in detached growing substrates, during the main growing season:

N: 200 - 300 mg/l
P: 20 -35 mg/l
K: 166 - 350 mg/l
Mg: 50 - 200 mg/l

Lower concentrations are required during the early stages of growth.

Optimization of levels of mineral nutrients applications is closely related to osmotic pressures generated by the salts in solution. Increasing osmotic pressure near to or beyond that prevalent in root cells impairs water and nutrient uptake by the roots and has a negative effect on plant growth and yield. In majority of researches electrical conductivity (EC) of the salt solutions, which is closely related to osmotic pressure, is measured.

In Bar-Yosef et al. (1980) work increasing the EC of soil extracts (1:1) above 0.5 dS/m decreased yield. Orlov et al. state that an increase of EC decreased yield and especially that of the exportable fruit size.

Aendekerk(1977) states maximal permissible levels of fertilizers in sprinkling irrigation to be for ammonium sulphate generating an EC of 1.9 dS/m and for other fertilizers an EC of 3 dS/m.

Kondo(1972) tested several N fertilizers given with irrigation water. At the 400 ppm. N application rate only urea did not increase appreciably the EC of the soil solution and only urea increased the N content of stems and leaves as the application rates increased from 50 to 400 ppm. N.

Summarizing the effect of osmotic pressure or of the EC of the growth substrate on yield, there is a variation in reported findings on the effect of EC values on yield. The critical EC value varies from 0.5 to 4.0 dS/m. We have to take into consideration that the reports are coming from growing areas with different light intensity, growth patterns and cultivars.

In a very intensive and high yielding culture like greenhouse tomatoes a high rate of mineral nutrients supply is necessary. This may be contradictory to the requirement of keeping the EC of the nutrient solution as low as possible. Obviously, fertilizer combinations should be sought maximizing the nutrient content in the solution and minimizing its EC.

Flavor of the tomato fruit is a very important attribute in successful marketing. The flavor is chemically not well defined. It is a function of sugar and acids concentrations, but additional compounds contribute to the flavor.

Mizrahi et al. (1988) worked on improving the flavor of greenhouse tomatoes grown on a coarse sand by applying saline solutions. It is known that saline treatment improves fruit quality in terms of color, flavor, concentration of soluble solids, sugars and acids. However, improvement in quality is usually accompanied by reduced yields, mainly as a result of small fruit size. They reasoned that if tomato plants were subjected to salinity application at a late stage of plant development, size loss could be minimized and fruit quality improved. Application of diluted sea water at 3 dS/m and at a late stage of growth did not reduce significantly the total and export quality yield, but improved quality over the control non saline treatment.

Orlov et al. found that although raising the EC of the nutrient solution decreased yield, it improved the fruit`s taste.

Muller - Haslach et al. (1986) found that the flavor (organoleptic) properties of greenhouse grown tomatoes increased slightly with increased rates of fertilizers.

Winsor (1968) found that high levels of K decreased ripening disorders, increased firmness and increased acidity, thus improving flavor of tomato fruit. High levels of Mg and N tended to show small improvements in fruit quality. P affected fruit quality adversely. Increase in the ionic concentration may possibly provide a common factor linking the K, N and Mg effects. However, it is stated that K has a unique position in this respect.

Karlen et al. (1983) working with various irrigation regimes, including frequent flooding, concluded that excess soil water in the root zone should be prevented. It causes stomatal closure and influences negatively the storage quality of fruit.

Bar Yosef et al. (1980) found that tomato fruit quality (blotchiness and firmness) was best at low rates of water application. R Frankel (personal communication) found that the fruit quality and flavor of tomato plants were improved by imposing from time to time drought stress by regulating pulse irrigation.

The above review indicates that development of desired flavor qualities in tomato fruit is a function of imposing a stress on the plant and of a high potassium content. It seems that the stress does not have to be continuous, nor at an early stage of growth. The stress may be generated by temporary drought conditions, or salinity of the root environment. These factors have to be taken into account while formulating the mineral nutrient solution composition.

Some non conventional ways are proposed for maintaining an ample flow of nutrients to the plants without causing an increased EC in the root environment.

Kulyukin and Litvinov (1984) grew tomatoes in polyethylene troughs receiving slow release fertilizers in the form of perforated plastic tubes containing KNO_3 + NH_4NO_3 or NH_4NO_3 + K_2SO_4 + $MgSO_4$. This method of fertilization reduced substrate solution concentration, increased yields, advanced earliness and improved fruit quality.

Mougou et al. (1981) received higher yields with a "9-month" slow release fertilizer than with a "4-month" one or with liquid fertilizer application.

On the other hand, Graifenberg and Linardakis (1983) comparing slow release fertilizers to fertilizers applied through the irrigation system found that both methods of application gave similar yields.

Tanew (1973) found that urea, ureaform and ammonium nitrate had similar effects on growth and fruit development. In soil cultures high levels of biuret had no harmful effects, but in sand culture 5% biuret depressed yields.

Additional nutrient supply by spraying the foliage may be another approach to enhanced nutrition without burdening the ionic environment of roots.

Spraying of tomato foliage by a "Wuxal" suspension of 0.2% concentration containing 10% N, 2% MgO, 15% CaO and microelements (No specification of compounds), increased significantly weight of fruit by 5 - 10 % and total yield by 10 - 20% (Gezerel, 1986).

Iron nutrition of tomato plants may be an important input item. It is well known that in an alkaline or calcareous substrate chelated iron compounds have advantage over soluble salts. However, in slightly acid media as are often used in tomato cultures, this advantage is not obvious. If chelated compounds are used, those with a lower binding energy to iron, for example EDTA, are preferable to those with a higher one (J.J. Mortvedt, personal communication).

Further, Sonneveld and Voogt (1985) compared Fe-chelates in a nutrient film system with glasshouse tomatoes. EDTA and HEEDTA were more effective than DTPA and EDDHA. Fe deficiency symptoms and yield reductions were observed at Fe levels below 10 µmol/1.

Additional data which may be of interest were found in the literature review.

Gibson and Pill (1983) state that tomato produce maximal growth at P concentrations of 0.1-0.3 µg/ml soil solution.

Oswiecimski (1981) quotes optimum nutrient content of fully developed tomato foliage in percentage: 0.3-0.7 N, 0.17-0.22 P, 2.9-4.6 K, 1.5-3.0 Ca and 0.4-1.0 Mg.

Nurzynski et al. (1980) comparing KCl, K_2SO_4 and KNO_3 on tomatoes grown on a peat substrate, received the highest yield and quality with KCl.

Kuckens and Kohl (1987) report that water enriched with CO2 to 0.1-2 g/l enhanced the solubility of nutrient salts.

REFERENCES

Aendekerk, G. L., 1977. Fertilizer application in greenhouses by way of sprinkling irrigation. Consulentschap voor de Tuinbouw, Boskoop, Netherlands. Bedrijfsontwikkeling 8 (1): 99-104

Bar-Yosef, B.; Sagiv, B.; Eliah, E., 1980. Fertilization and irrigation of winter tomatoes grown in glasshouse in the Besor area. Preliminary Report, Division of Scientific Publications, Bet Dagan (775): 90pp.

Borkowski, J.; Szwonek, E., 1978. Effects of different potassium fertilizer rates on glasshouse tomatoes. Roczniki Nauk Rolniczych, A 103 (4): 53-68.

Borkowski, J.; Szwonek, E., 1984. Effect of magnesium fertilization on the yield of greenhouse tomatoes, occurrence of blossom-end rot and plant nutritional status. Biuletyn Warzywniczy 27 9-31.

Dellacecca, V.; Mancini, L.; Motola, P.; Romano, M. 1987 The effect of fruit setting treatments and of fertigation on table tomatoes. Part 1. Colture Protette 16 (5): 51-56.

Gezerel, O., 1986. The effect of calcium-containing foliar fertilizers on tomato yields. Developement in Plant and Soil Sciences Vol. 22: 304-309.

Gibson, C. J.; Wallace, G.P., 1983. Effects of preplant phosphorus fertilization rate and of nitrate and ammonium liquid feeds on tomato grown in peat-vermiculite. Journal of the American Society for Horticultural Scienses 108 (6): 1007-1011.

Graifenberg, A.; Guistiniani, L.; Pestas, S; Du Jardin, P.,1986. Effectsof different nitrogen forms and combination on tomato plants grown in greenhouse. Acta Horticulturae 176: 83-91.

Graifenberg, A., Linardakis, D.; 1983. The effect of fertilizer and substrate on the feeding of greenhouse tomatoes. Colture Protette 12 (7): 37-44.

Huett, D.O. Dettmann E.B., 1988; Effect of nitrogen on growth, fruit quality and nutrient uptake of tomatoes grown in sand culture. Austral. J. Exper. Agric. 28:391-399.

Karlen, D.L. Sojka, R.E., Robbins M.L., 1983; Influence of excess soil water and N rates on leaf diffusive resistance and storage quality of tomato fruit. Commun in Soil Sci. Plant Anal. 14: 699-708.

Kirkby, E.A., Armstrong, M.J., Leggett, J.E. 1981. Potassium recirculation in tomato plants in relation to potassium supply. J. Plant Nutr. 3: 955-966.

Kondo, T., 1972 Supplying fertilizer solution for tomato plants. Bulletin of the Horticultural Research Station, B (Okitsu) (No. 12): 181-206.

Kostewicz, S. R.; Locascio, S. J. ,1977. Effect of production media, cultivar and fertilizer on yield of greenhouse tomatoes. Proceedings of the Florida State Horticultural Society 1976 89 129-131.

Kuckens, A.;Kohl, 1987. H. Method for qualitatively and quantitatively improving the fertilizing or leaf dressing of cultivated and ornamental plants in greenhouses, outdoors or agriculture. United States patent.

Kuliukin, A.N.; Litvinov, B.V., 1984. Growing cucumbers and tomatoes on a low volume peat substrate with slow release sources of nutrients. Izvestia Timiryazeveskoi Sel'skokhozyaistvennoi Akademii (3): 125-133.

Magalhaes, J. R.; Wilcox, G. E.,1984. Growth, free amino acids and mineral composition of tomato plants in relation to nitrogen form and growing media. Journal of the American Society for Horticultural Scienses 109 (3): 406-411.

Mougu, A. Zamiti A. Verlodt, H. 1981; Agronomic results of growing early tomatoes in a growing bag on a substrate of marine grass, Posidonia oceanica. Medel. Fac. Landboww., Rijksuniv. Gent 46:671-683.

Maher, M. J. 1976. Growth and nutrient content of a glasshouse tomato crop grown in peat. Scientia Horticulturae 4 (1): 23-26.

Marschner, H. 1986. Mineral Nutrition of Higher Plants. Academic Press, pp.674.

Muller-Haslach, W.; Arold, G; Kimmel, V.,1986. Effect of nutrient intensity on the quality of tomatoes. Bayerisches Landwirtschaftliches Jahrbuch, Sonderheft 63 (1): 81-104.

Nurzinski, J.; Uzika, Z; Mokrzecka, E., 1980. Effects of various kinds of potassium fertilizers on the yields and quality of greenhouse tomatoes. Acta Agrobotanica 33(2): 197-203.

Oswiecimski, W., 1981. Fertilization of greenhouse tomatoes with solutions of mineral fertilizers. Rolniczej w Warszawie, Ogrodnictwo (11): 7-24.

Papadopoulos,I.,1987. Nitrogen fertigation of greenhouse-grown tomato. Communications in Soil Science and Plant Analysis 18 (8):897-907.

Sonneveld, C.; Voogt, W., 1985. Studies on the application of iron to some glasshouse vegetables grown in soilless culture. Glasshouse Crops Research Station, Naaldwijk, Netherlands. Plant and Soil 85 (1): 55-64.

Spasov, S. P.; Kanazirska, V., 1978. Fertilization in early glasshouse tomato production. Gradinarska i Lozarska Nauka 15 (7/8): 122-128.

Tanew, S., Edelbauer, A. , Krisper, J.; 1973. The effect of form of nitrogen on the growth and yield of a glasshouse tomato variety. Bodenkultur 24: 155-165.

Tsikalas, P. E.; Manios, V. I., 1984. Tomato nutrition on growth bags in greenhouse. I. Effect on the yield. Proceedings of 3rd Conference on Protected Vegetables and Flowers.

Tsikalas, P.E.; Manios, V.I., 1985. Nutrition of tomatoes in growing-bags in greenhouse. I.Effect on productivity. Georgike Ereuna 9 (2): 279-289.

Winsor, G. ; Adams, P., 1987. Diagnosis of mineral disorders in plants. Glasshouse crops. Vol. 3. Her Majesty's Stationary Office 168 pp.

Fertilizer Practices in the Production of Intensively Grown Tomatoes

The following is based on information received while visiting glasshouse crops research centers.

Crete, Greece,
Demetrio Linardakis, Institute of Viticulture Vegetable Crops and Floriculture, Heraclion, Crete, 71110.

Tomatoes under cover in Crete are grown on an area of approx. 6000 dunam (see p. 17), mostly in soil cultures. The soils have mostly a loam texture, high in lime content, having a pH of 7 - 8 and EC of 1.0 - 1.5. The soils are defined as Rendzina and Terra rossa.

Tomatoes receive a basic fertilization as follows:

Superphosphate 20% P_2O_5	100 - 150 kg/du
Potassium sulphate	50 kg/du
Epsom salt, $MgSO_4.7H20$	50 - 100 kg/du

Additional fertilizers are applied with the irrigation water, which is mostly given in drip irrigation.

Density of planting is 1500 - 1700 plants/du.
2 - 3 L of water are applied per irrigation and per plant, which gives 3 - 5 m^3/du/irrigation.
Scheduling of irrigation is as follows:

September - October	3 irrig./week
November - February	1 - 2 "
March - May	3 "

The total amount of water is about 500 - 600 m^3/du/season.

The recommended concentrations of nutrients in irrigation water is:

N	120 ppm
K	150 - 180 "
P	40 - 50 "
Mg	10 - 15 "
Ca	The irrigation water contains presumably enough Ca

The above nutrients are supplied in the form of Potassium nitrate, Ammonium nitrate, Magnesium sulphate and Phosphoric acid. Monopotassium phosphate was introduced in the last year. It proved to be an excellent source of P and K. For the time being its price is prohibitive. It would be used widely and replace the phosphoric acid and partly the potassium nitrate if its price would be about 0.5 $/kg.

It seems that in many cases the growers apply higher quantities of nutrients than the recommended ones, especially so with K, which concentration is increased in the fruit forming period.

The recommended EC in the soil solution is 3 - 4 mmhos, but it may rise to 5 - 7 mmhos. If it is higher than 4 mmhos, leaching without fertilizers is recommended.
There are no environmental considerations.
The yields obtained vary from 10 - 14 t/du/season.

The Netherlands

Cees de Kreij, C. Sonneveld (head), Department of Plant nutrition and substrates, Glasshouse crops research station, 2670 AA Naaldwijk.

The area under glasshouse culture in the Netherlands is about 90,000 du, 50% in vegetables and 50% in flowers. There are about 12,000 du of tomatoes under glass, most grown in rockwool, some (very few) in polyphenol foam. 5.6 L of rockwool is used per plant.
Nutrition of glasshouse cultures is based on the Hoagland solution, with some modifications developed as a result of research and practical experience.

The K/Ca ratio seems to be of high importance for fruit quality. An optimum ratio of K:Ca = approx. 3:1 was found. (W. Voogt, The growth of beefsteak tomato as affected by K/Ca ratios in the nutrient solution. Acta Hortic. 222, 155-165 (1988)). However in the recommendations cited later the ratio is much narrower. The reason is that the plants can utilize K in the nutrient solution to its exhaustion, while the utilization of Ca is much lower.

Zn deficiency is getting critical with the use of plastic piping systems. A concentration of 4µmol Zn is the threshold deficiency value. 7 µmol seems to be an adequate concentration. (C. Sonneveld, S.S. de Bes, W. Vogt, Zinc uptake and distribution in tomatoes grown in rockwool. Soilless Cult. 2, 49-60 (1986)).

During the autumn and winter period a high EC of the nutrient solution is maintained. This salt stress is required to partially overcome the low light intensity stress and induce earlier flowering. The EC of the nutrient solution is maintained at 2.5 - 3.5 mmhos during most of the growing season. The pH may vary between 4.8 and 6.2.

The recommendation on the EC of the nutrient solution is based on research work, published in: C. Sonneveld and G.W.H. Welles; Yield and quality of rockwool-grown tomatoes as affected by variation in EC-value and climatic conditions. Plant and Soil 111, 37-42 (1988). The threshold value of EC in the root environment at which no yield depression occurred was found to be 2.5 dS/m. Higher EC values decreased yield by 5 to 7% per dS/m. At very high humidity a decrease of 10% was found for each dS/m. Under poor light conditions high EC values did not affect yields adversely. This finding leads to the conclusion that the EC-effect on yield is not only related to the length of a period over which a certain EC value is maintained, but is also related to the production level at that period. Fruit quality was improved by increased EC values. K contents in the leaves were increased and Ca and Mg contents were decreased.

The yield of tomatoes obtained per a growing season of 11 months is 45 t/du without artificial light and with artificial lightning 60 t/du.

The water consumption per season is 650 -700 m^3/du. Only about 20% of the applied water is lost by drainage.
There is a tendency to recycle the water and nutrients applied. In such a case the nutrient solution is tested every 2 weeks and individual nutrients added to replenish them to the required level. This is the reason that single fertilizer salts are preferred over ready composite solutions.

Recently, a growing tendency is noted for the use of highly soluble, highly nutrient-concentrated and relatively low priced compounds such as KOH, HNO_3, H_3PO_4, H_2SO_4. For example less than 150 g KNO_3 can be solubilized in 1 L of water, whereas 0.5 to 1.0 kg of KOH can be solubilized in 1 L water.

Urea is not recommended in nutrient solutions under conditions where it may be directly absorbed by plants. It has toxic effects unless hydrolised and subsequently oxidized outside of the plant. A concentration of 10 - 20 % of N as NH4 is allowed. Higher values tend to lower too much the pH of the rhizosphere.

Mono potassium phosphate is used and it is a good fertilizer. However, it may be replaced by KOH and H_3PO_4.

A computer program is available for calculating amounts of compounds required, according to recommendations and analytical results. (T. Breimer, C. Sonneveld and L. Spaans; A computerized program for fertigation of glasshouse crops. Acta Hort. 222, 43-50 (1988)).

It is <u>not</u> recommended to change the concentration and composition of the nutrient solution in short terms, for example apply at day time a full nutrient solution and at night only irrigation water. The main reason is that the availability of K is very dependent on the uniformity of supply. Therefore, it is essential to maintain a steady level of K supply at the roots. Erratic changes in the amount of K, such as may result from an attempt to manipulate the solution conductivity by flushing out with clear water, can result in K deficiency and poor fruit quality.

A great part of irrigation water is rain water collected from the glasshouse roofs.

The relatively small amount of drainage water, exhausted of nutrients, goes into the ground water, which is anyhow saline in the western parts of the country. Until now there are no environmental restrictions on effluent nutrient concentrations. The present level is monitored and within five years it should be reduced to one half of it and within the next five years to nil.

Ratios between uptake of nutrients and optimum application rates were calculated and they are tabulated in kg of nutrient per dunam and per growing season.

	Uptake	Apply about
N	60 - 100	200
P	15 - 18	35
K	120	160
Mg	10	

Fertilizers used:
S is applied mainly as K_2SO_4
P is applied mainly as KH_2PO_4
K is applied in the two above compounds and in KNO_3

In "Nutrient solutions for vegetables and flowers, 1988" the recommended composition of the nutrient solution for tomatoes and its accompanying root environment concentration is listed as follows:

Nutrient	Nutrient solution		Root environment	
	mmol/L	ppm	mmol/L	ppm
N-NO_3	14.0	196	17.0	238
P-H_2PO_4	1.0	31	0.5	15
S-SO_4	3.75	120	5.0	160
N-NH_4	1.25	17	<0.5	<7
K	8.75	342	7.0	274
Ca	4.25	170	7.0	281
Mg	2.0	49	3.5	85
	µmol/L		µmol/L	
Fe	15	0.8	15	0.8
Mn	10	0.5	7	0.4
Zn	5	0.3	7	0.5
B	30	0.3	50	0.5
Cu	0.75	0.05	0.7	0.04
Mo	0.5	0.05	-	-
	mS/cm (25 C)			
EC	2.3		3.0	

In "A method for calculating the composition of nutrient solutions for soilless cultures, by C. Sonneveld, 1989" the compositions of two typical major elements stock solutions are listed as follows:

1. Stock solution for rain water

Fertilizer	kg/m^3
Mono potassium phosphate	17.0
Calcium nitrate (cont. water)	70.2
Ammonium nitrate	2.8
Potassium nitrate	43.0
Magnesium sulphate	24.6

2. Stock solution for water containing 3 mmol HCO_3, 1 mmol Ca and 0.5 mmol Mg /L

Fertilizer	kg/m3
Phosphoric acid 75%	19.6
Nitric acid 65%	14.5
Calcium nitrate (cont. water)	48.6
Ammonium nitrate	8.4
Potassium nitrate	30.3
Potassium sulphate	34.9
Magnesium sulphate	12.3

Great Britain

Peter Adams, Institute of Horticultural Research, Worthing Road, Littlehampton, West Sussex BN17 6LP.

The glasshouses are scattered over large areas and not concentrated like in Holland. Therefore, at present there are no environmental constrictions on nutrients effluents.

Average yields are 40 t/du/year and aiming at 50 t. There is a yearly increase in yield of 3-4%, due to improved cultivars and fine tuning of the system. The area under heated glasshouse tomatoes is about 2000 du with a growing season of 11 month. The tomatoes are grown mostly in detached media, 10 l/plant.

The EC of the nutrient solution is maintained most of the time between 2.5 and 3.0 dS/m, but during the period of low light intensity it is brought up to 4.0 dS/m and to about 3.5 at the fruit ripening period. Stress concentrates acids and sugars in the fruit. A high level of K increases mainly acid production which is important for flavor development. Therefore salinity stress should be imposed with relatively high concentrations of K. However, in a recent work (P. Adams, Some responses of tomatoes grown in NFT to sodium chloride, Proc. 7th Intern. Congress on Soilless Culture, 59-71, (1989)) salinity induced by sodium chloride at a concentration of 22 mM and EC up to 4-5 dS/m increased yield and improved fruit quality by increased dry matter content, sugar content and acidity of the fruit. The response was ascribed to salinity and not to a specific sodium effect.

The EC of nutrient solutions may be manipulated by changing the concentration of nutrients. An example is given in: D.L.Smith, Rockwool in Horticulture, Grower Books, London, p. 108 (1987).:

Nutrient	EC dS/m			
ppm	2.0	3.0	4.0	5.0
NO_3-N	180	310	435	560
P	40	40	40	40
K	300	500	700	900
Ca	200	330	470	600
Mg	40	65	95	120

Drought stress may improve flavor, but it is not recommended. The severity of draught is difficult for regulating, because of the uneven supply of water to individual plants by drippers. A drought stress of more than one day may induce blossom end rot.

The lower limit for pH of the nutrient solution is about 4.5.

Nutrient solutions are monitored on their nutrients concentrations and they are often recirculated. Therefore compound solutions are not used. Rather, solutions of individual salts are prepared according to need. The use of highly concentrated solutions of KOH, HNO_3 etc. are at present not considered. Use of these compounds is hazardous from the safety point of view. If and after the Dutch develop safe handling procedures for these materials they may be considered in the U.K..

KH_2PO_4 is the major source of P. It is preferred over phosphoric acid, because of ease of handling and because the analysis of the acid varies. P concentration at the beginning of the growth season should be 40 ppm for good root development. Later a concentration of 30 ppm is sufficient. A high P level may have a negative effect on fruit quality. Additional sources of K are KNO_3 and K_2SO_4. The use of KNO_3 is somewhat restricted, because of the need to add Ca as $CaNO_3$ and the required K:N ratios which are at the beginning of the growing season 1.2:1 and when the fruit is formed 2.5:1. (P. Adams and D.M. Massey, Nutrient uptake by tomatoes from recirculating solutions, Proc. 6th Intern. Congr. on Soilless culture (1984)).

It is of interest to note that there is evidence that tomatoes grown under high light intensity have an increased potassium demand in relation to the other major nutrients.

Mg is supplied as a sulphate salt, mainly because the price of the nitrate is much higher than that of the sulphate. The concentration of Mg in the nutrient solution is maintained at 40 - 50 ppm, but a concentration of 70 - 80 ppm would be preferred for preventing Mg deficiency at high rates of K and

Ca supply. For example a K:Mg ratio of 350:70.

S is supplied mostly as K_2SO_4. A concentration of 70 - 120 ppm S should be maintained.

NH_4 - N should be below 10% of total N. Higher concentrations may induce Ca deficiency and with it blossom end rot.

Urea has toxic effects,especially at low rates of growth. At high growth rates the plant can tolerate relatively high urea concentrations.

Fe is applied in a chelated form. Roots exude HCO_3 and point concentrations may be high enough for precipitating Fe salts. Fe-citrate may be stable enough, but it increases the microbial population of the growth medium and is therefore not recommended. The concentration should be 12-15 ppm Fe until picking starts and be reduced to 5 ppm Fe later in the season.

Hoagland solution

For comparison, the composition of a modified Hoagland solution is given:
Macronutrients compounds: KNO_3, $Ca(NO_3)_2.4H_2O$, $NH_4H_2PO_4$, $MgSO_4.7H_2O$. In the nutrient solution the ratio of NO_3-N/NH_4-N is 7/1.
Micronutrient compounds: KCl, H_3BO_3, $MnSO_4.H_2O$, $ZnSO_4.7H_2O$, $CuSO_4.5H_2O$, H_2MoO_4, Fe-EDTA

The elemental composition of the nutrient solution is as follows:

Element	mM	ppm	Element	µM	ppm
N	16	224	Cl	50	1.77
K	6	235	B	25	0.27
Ca	4	160	Mn	2.0	0.11
P	2	62	Zn	2.0	0.13
S	1	32	Cu	0.5	0.03
Mg	1	24	Mo	0.5	0.05
			Fe	20	1.12

National Fertilizer Development Center, TVA, Muscle Shoals, Alabama

E. Sample, Norman Hargett, Jim Ransom, Robert Mikkelson, Bert Bock.

Monopotassium phosphate: Excellent fertilizer for glasshouse crops. It may substitute KNO_3, because of the nitrate content of the last one. Environmental considerations may reduce considerably the use of nitrate fertilizers. Foliar application of fertilizers may have its come back, again because of environmental considerations and there potassium phosphate may be an excellent source of both P and K. It is a good fertilizer for legumes, again because it does not contain nitrates. This compound can be used in drip irrigation in situations where irrigation water contains low concentrations of Ca and Mg. The product should be attractive to liquid manufacturers, who need highly soluble K sources. Liquid grades such as 13-13-13, 11-22-11, 7-14-14, 5-15-15 and others have been made satisfactorily. It seems that potassium phosphate is not produced in the USA and its use at present is very small.

Speciality fertilizers in the USA are about 8-9% of the total fertilizer market. Its marketing is increasing and is important, because of the decline in marketing of agricultural fertilizers. The income per unit of non-field crops is considerably higher than that per unit of field crops. Conrolled-release fertilizers are the primary speciality fertilizers. About 25% of non-farm fertilizers used are control-release. Speciality fertilizers are used in glasshouses, nurseries, golf courses, lawns, landscaping, etc.. Of the total market value of fertilizers in the USA of 1.6 bil.$, 34% is in fertilizers for non-agricultural uses.

Controlled release fertilizers contain mainly N as urea and some K. The major problem is the low predictability of release from these fertilizers. Several approaches for controlling the release of nutrients are tried. Thin polymer coating, 3% by weight of fertilizer and up, is used. Thickness of coating determines the rate of release. Other known coatings are sulphur coated urea and resin coated urea. Gel type fertilizers for delayed release of nutrients are in development. Various gels are used, such as Guar bean gel, polyacrilates gels and others. The gels slow down the diffusion of nutrients from fertilizer particles; mineralization of the gel releases the nutrients and it binds part of the N. Additions of urease inhibitors to the urea fertilizer is another approach of controlled release.

Urea binds strong acids, such as phosphoric, sulphuric and nitric in a mol ratio of about 1:1 to form solid, concentrated compounds. Urea-nitric acid is explosive and its handling needs development.

KNO_3 is used in fertilizer blending industry with additional sources of N and P. Chilean KNO_3 is in the fertilizer market.

Florida

S.J. Locascio, G. Hochmuth, Vegetable Crops Department, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Florida 32611.

Glasshouse tomatoes are grown in sand and in rockwool.

The pH of irrigation water is 7.1 - 7.8 and the EC 0.2 - 0.3 mmhos.

Plant population is about 2500 plants/dunam.

Recommended compounds for formulating the nutrient solution: $Ca(NO_3)_2.4H_2O$, NH_4NO_3, $MgSO_4.7H_2O$, KCl, H_3PO_4. Phosphoric acid is prefered over other P sources, because of its acidifying effect. Sometimes sulphuric acid is added for lowering the pH. KCl is the preferred K source.
The compounds for micronutrient solutions are: FeNaEDTA, $MnSO_4.4H_2O$, H_3BO_3, $NH_4Mo_7O_{24}.4H_2O$, $CuSO_4.5H_2O$, $ZnSO_4.7H_2O$.

The growers often do not follow the above recommendations and purchase ready mixed solutions from fertilizer companies. These solutions are often prepared from KH_2PO_4, K_2SO_4 and KNO_3.

The recommended nutrient concentration in irrigation water in Florida is lower than that recommended in Holland. It seems that the Dutch recommendations are too high for conditions of high light intensity and relatively high temperatures.

There are no specific recommendations for enhancing the fruit flavor.

The following are nutrient concentration for greenhouse tomatoes grown in rockwool. Lower concentrations of the major nutrients are given at the beginning of the growing season than after the first fruit set.

Nutrient	Concentration in ppm	
	Early	After 1st fruit set
N	80-100	140-160
P	30- 40	30- 40
K	120-150	200-225
Ca	150	180-200
Mg	40-50	
S	40	
Fe	2	
Mn	0.8	
Cu	0.15	
B	0.3	
Zn	0.15	
Mo	0.06	
pH	6.0-6.2	
EC	1.8	2.0

North-East U.S.

L.D. Topoleski, Department of Vegetable Crops, Cornell University, Ithaca, NY 14853-0327.

In the north-east states a very small area is under glasshouses and very little research is done on nutrition. Fertilizers are applied in form of ready compound solutions according to manufacturers recommendations.

It seems that in Ohio, Indiana and Pennsylvania glasshouse cultures are more developped. The contact address given is:
Dr. W.L. Bauerle, Dept. of Horticulture, Research and Development Center, Ohio State University, Wooster OH 44691.

Recommendations in Israel

Fertilizer recommendations for soil grown tomatoes (According to Omar Zaydan, Ministry of Agriculture Extension Service):

Basic dressing: Superphosphate (SSP) at a rate of 150 kg/du and KCl 50 kg/du.

Other fertilizers are applied in solution through drip irrigation. The fertilizer composition is varied during the growth period. Mostly solutions known as Shefer are used. First Shefer 7-3-7 and later Shefer 5-2-7. These solutions have a pH of about 3.5 and are composed of ammonium nitrate, potassium nitrate, phosphoric acid and micronutrients. The ratio of NO_3-N to NH_4-N is 3:2 in 7-3-7 and 7:3 in 5-2-7.

The rate of application varies with the season and is determined according to N concentration in irrigation water. At the beginning of the season the concentration is 100 ppm N, rising to 300 ppm N at the peak of the growth and late in

the season dropping to 150-200 ppm N.
Accordingly, the concentration of nutrients (mg/L) in the irrigation water at two growth periods is as follows|

	Start	Peak
N	100	300
P	19	52
K	83	348

It is estimated that the following total quantities of mineral nutrients are applied:

Basic dressing:

P	10	kg/du
K	25	kg/du

In solution:

N	100 - 200	kg/du
P	20 - 40	kg/du
K	80 - 160	kg/du

Detached medium cultures.

Values reported here are according to actual use in Habonim, closely following Extension Service recommendations.

Two tomato plants are grown per plastic container of 20 L and drip irrigated with a fertilizer solution. The growth medium is perlite. The amount of irrigation water is about 1000 m^3/du/year.

Fertilizers are fed into the irrigation water from three different containers: a Shefer solution, a Ca + Mg solution and a solution containing Koratin, Sequestrene and Bor.
The compounds are: H_3PO_4, KNO_3, NH_4NO_3, $Ca(NO_3)_2$, $Mg(NO_3)_2$.

The concentrations of nutrients in the irrigation water (mg/L) are:

	Start	Later
N	160	240
P	45-50	70
K	260	305
Ca	175 (incl. 80-100 in water)	
Mg	35-40 (incl. 15 in water)	

Micronutrients (Koratin) solution 200 cc./m^3 of water.
Sequestrene 20 g/m^3.
Bor solution 70 cc./m^3.

Dov Orlov (Negev) gives higher values at the peak season. According to him, the recommendations are: 350 mgN/L and 500-525 mgK/L. In addition, mixing of 100 g superphosphate (22% P_2O_5) into 10 L of substrate in detached cultures is recommended. We raised the possibility of using phosphogypsum instead of superphosphate, in quantities of 200-300 g per 10 L, supplying some of the required Ca, S and about 2-3 g of P. In Holland the recommended Ca:Mg ratio is 4:1, while in our water the ratio is about 1:1.

Discussion, Conclusions and Recommendations

Comments to tomato nutrition practices in Israel.

A nutrient balance for the peak growing season was calculated. The following conditions were assumed: Tomatoes are grown in a detached culture, irrigated with a commercially available fertilizer solution mixture (5-2-7). Calcium and magnesium nitrates solutions are added as necessary to the available irrigation water. The rate of irrigation is 5 m^3/du/day, or 35 m^3/du/week. 2500 plants/du are assumed. The nutrient uptake data, except those for S are taken from Huett and Dettmann (1988).

We are aware that the input and uptake conditions are not identical and that in practice variations occur in both.

Nutrient input and uptake calculations
for tomatoes in a detached culture
per week

Nutrient	Applied mg/L	Applied kg/d	Uptake kg/d
N	250	8.7	8.5
P	100	3.5	1.9
K	350	12.2	14.0
Ca	175	6.1	4.3
Mg	40	1.4	1.1
S	21	0.7	2.5 (estimated)

The above calculations indicate that according to the assumptions, some of the input values should be rechecked.

It should be kept in mind that growers in Holland attain much higher tomato yields than those in Israel. The growing season in Holland is longer than that in Israel, but part of it is under poor light conditions when the production rate is low. Taking into account the difference in growing season, the Israeli production level still lags behind the Dutch.

Nitrogen sources.

There are indications that a balanced supply of NH_4 and NO_3 is beneficial to yield production. However, a low proportion of ammonium in the fertilizer solution mixture is recommended both in Holland and in England. Rechecking of the applied ratio of NH_4-N/NO_3-N is recommended.

Urea is considered in general as a good nitrogen source. Its use for greenhouse tomatoes is not recommended in Holland and England. It seems justified to recheck this issue.

The level of N application seems to be in agreement with the plants requirements and with practices elsewhere.

Phosphates.

The level of P application in Israel seems to be above the plants requirements. There are some indications that excess P in the nutrient medium may have adverse effects on fruit quality. P not utilized by plants may be leached into the environment. Phosphates are known as a major source of eutrophication. Rechecking of levels of P application is recommended.

Potassium, Magnesium and Calcium

The levels of K and Mg application are high, but they are more or less in agreement with the plant requirements for these elements. Furthermore, they seem to be justified by a high demand for K to ensure fruit quality, especially under conditions of high light intensity. Parallel to raising the K level, a higher need for Mg arises.

A good supply of Ca is needed for preventing blossom end rot. Still, levels of Ca application seem to be high and it is recommended to recheck them.

Sulphate.

The solutions used in Israel do not contain enough sulphates and this situation should be corrected. The soil grown cultures receive sulphates with the basic dressing of SSP.

Iron.

Iron fertilization in detached cultures in the chelated form is a well accepted practice. Still, its application as sulphate or as citrate should be rechecked having in view the acidity of the nutrient solution.

Osmotic Potential.

The osmotic potential of the nutrient solution is expressed by its electrical conductivity (EC). Israeli growers tend to aim at a relatively low EC at the beginning of the season and raise it toward fruit formation and ripening. In order to maintain the lower EC, sometimes, the fertilizer solution applied during day time is flushed out at night.

Growers in Holland and England maintain a relatively high EC during the whole growing period, without impairing yield production. It seems that under low light intensity the plants are more tolerant to high EC values, than under high light intensity.

It is emphasized that changing nutrient concentrations at short time intervals may have an adverse effect on fruit yield and quality.
The attitude to EC values should be rechecked.

It should be noted that the nutrient concentrations recommended to growers in the southern part of Israel are higher than those in the northern areas of the country. This may be due to a higher light intensity in the south.

Finally, growers in Holland collect rain water from the glasshouse roofs and use it for irrigating the crops in the glasshouse. This practice should be considered, at least in the higher rainfall areas of Israel.

Forecast for fertilizer formulations demands.

The commercially available complex fertilizer solutions, such as for example "Shefer", take into account the prevailing fertilizer recommendations and are well suited to the present demand in Israel.

Sophistication of the protected cultures demands a close monitoring of the composition of the growth medium and its constant adjustment to the recommended nutrient levels. Such a nutrition regime cannot utilize well ready made nutrient mixtures. In fact, the prevailing practice in advanced growing systems is to use single salts for nutrient solution preparation.

In view of the above remarks, the Israeli grower may demand, in the near future, simple compounds instead of complex solutions. If our assumptions prove to be correct, we recommend to the industry to check the list of fertilizers to be marketed to growers of protected tomatoes and possibly other protected crops.

For balancing the ammonium-nitrate ratio, less nitrate and more ammonium salts will be used than is used today. Some reduction of nitrate usage may come by reducing the amounts of calcium nitrate applied. Applying magnesium in one solution with calcium necessitates its addition as a nitrate salt. Application of magnesium as a sulphate would cause precipitates. If the two nutrients could be applied separately, magnesium sulphate, which is cheaper than the nitrate, could be used. Additional reduction in nitrate application will come be reducing the use of potassium nitrate. It seems that an ammonium nitrate solution, possibly enriched with ammonia will be the major source of nitrogen.

Phosphate could be supplied as potassium phosphate, satisfying part of the potassium requirement, or as phosphoric acid. The last one is widely used in irrigation systems.

The potassium phosphate may supply a small part of the potassium demand. The major portion of potassium may come from sulphate or even chloride. Both compounds are cheaper than the nitrate salt.

On visits to greenhouses, a suggestion was raised that mixing of phosphogypsum into the growth substrate may be a source of both phosphates and sulphates. We suggest testing this idea. The possibility of contamination with Cadmium or radioactivity should be considered.

We believe that the above recommendations are logical and worthy of a trial. However, we are aware that the grower may choose mixtures and compounds according to company salesman recommendations, which are ready available, easy to use and according to his old and tried out habits.

Recent development in nutrient application in glasshouses in Holland indicates a radical change in fertilization technology. The Dutch growers are shifting from fertilizer salts to the use of highly concentrated, highly soluble acids and bases. Typically, these are caustic potash, nitric, phosphoric and sulphuric acids. It seems that the problems of high corrosiveness of these materials has been solved. This development may easily influence fertilizer marketing in Europe and eventually in Israel. Our fertilizer industry should be aware of these developments, because they may change fertilizer purchasing patterns in Israel and in export target countries.

Electrical conductivity, pH and price of fertilizer solutions, having the same nutrient concentration and differing in compounds used to produce the solution, are given in the following table. Nutrient concentrations and ratios used in this calculation are given as an example. Details of calculation procedures are presented in Addendum.

Nutrient concentration

mg/1

N	P	K	Mg	Ca
250	50	350	30	210

	1	2	3	4	5	6	7	8
Ca(NO3)2	676	676	676	676	676	676	676	676
K2SO4	781	781	781	781	503	781	781	--
KNO3	--	--	--	--	--	--	--	897
NH4NO3	384	--	--	384	384	320	256	--
(NH4)2SO4	--	--	634	--	--	--	--	48
H3PO4	158	581	158	--	--	--	--	--
KH2PO4	--	--	--	219	--	--	--	--
K2HPO4	--	--	--	--	280	--	--	--
NH4H2PO4	--	--	--	--	--	185	--	185
(NH4)2HPO4	--	--	--	--	--	--	213	--
UREA	--	288	--	--	--	--	--	--
S	162	162	162	162	111	162	162	29
EC	2.19	2.20	2.34	2.34	2.20	2.34	2.29	2.09
pH	6.5	6.4	7.8	7.8	8.3	7.8	8.3	7.9
PRICE $/m3	0.83	0.82	0.82	0.83	0.81	0.74	0.74	0.90

Results of calculations in the above table reveal several interesting facts. For example, a very low sulphate concentration is found in the formulation based on potassium nitrate and monoammonium phosphate (formulation 8). This composition gives the lowest EC values. The differences between the various formulations in EC values are rather small. High pH values are obtained in presence of dibasic phosphates. The lowest priced formulations are composed of potassium sulphate, ammonium nitrate and ammonium phosphate. The highest priced is the one containing potassium nitrate.

Similar calculations were done for single salts and for mixed fertilizer solutions. These calculations may help in deciding on the most suitable fertilizer combination. Tables presenting these calculations are given in the Addendum.

Addendum

Physical-chemical properties of fertilizer solutions.

Physical-chemical properties of fertilizer solutions were calculated. The ionic strength (IS) and pH were computed by the GEOCHEM program. The electrical conductivity (EC) was calculated from the equation: $IS = 0.0144*EC$. The osmotic pressure (OP) was calculated from the equation: $OP = 0.036*EC$.
For UREA the osmotic pressure was calculated from the equation: $P*V = N*R*T$, where P = osmotic pressure, N = number of moles of solute in volume V, $R = 0.082$ and T = abs. temperature. EC and IS for urea were calculated from the above equations. Urea in solution does not generate electrical conductivity, but it develops osmotic pressure. Because of practical considerations osmotic pressure of fertilizer solutions is not measured nor stated. Instead, electrical conductivity is measured and in fact the osmotic pressures of fertilizer solutions are compared according to it. Therefore we decided to calculate some kind of equivalent to EC for urea.

In the following table the calculated properties of compounds commonly used in fertilizer solutions preparation are listed.

Physical-chemical properties and prices of fertilizer solutions

	Mmol/L	mg/L	EC dS/m	pH	$/t	$/ 100M	solu. g/L
NH4Cl	1.0	14N	3.47E-2	7.0	250	1.34	297
	10.0	140N	3.47E-1	6.8			
KNO3	1.0	14N 39K	6.94E-2	7.2	400	4.04	316
	10.0	140N 390K	6.90E-1	7.0			
NH4NO3	1.0	28N	6.94E-2	6.0	150	1.20	1183
	10.0	280N	6.94E-1	5.5			
HNO3	1.0	14N	6.94E-2	3.0	350	2.37	infi
	10.0	140N	6.94E-1	2.0	95%		
NH4OH	1.0	14N	6.94E-2	6.0	120	0.42	26
	10.0	140N	6.94E-1	5.5			
K2SO4	1.0	78K 32S	2.08E-1	7.0	200	3.48	12
	10.0	780K 320S	1.97E-1	7.0			
KCl	1.0	39K	6.94E-2	7.2	100	0.74	347
	10.0	390K	6.90E-1	7.0			
Ca(NO3)2	1.0	40Ca 14N	2.09E-1	7.0	750	12.3	1020
	10.0	400Ca 140N	2.01	6.9			
MgCl2	1.0	24Mg	2.09E-1	7.0	100	0.95	567
	10.0	240Mg	2.04	6.8			
MgSO4	1.0	24Mg 32S	2.56E-1	7.0	200	2.40	260
	10.0	240Mg 320S	2.215	6.9			

Mg(NO3)2	1.0	24Mg 28N	2.08E-1	7.0	400	5.92	200
	10.0	240Mg 280N	2.07				
KH2PO4	1.0	39K 31P	7.06E-2	5.1	500	6.80	330
	10.0	390K 310P	6.93E-1	4.6			
K2HPO4	1.0	78K 31P	2.05E-1	9.0	500	8.75	v.s.
	10.0	780K 310P	1.92	9.2			
H3PO4	1.0	31P	6.13E-2	3.1	450	7.11	
	10.0	310P	3.88E-1	2.3	62%		
MgHPO4	1.0	24Mg 31P	1.94E-1	8.1			sl.s
	10.0	240Mg 310P	1.20	7.8			
Mg(H2PO4)2	1.0	24Mg 62P	2.02E-1	4.7			
	10.0	240Mg 620P	1.75	4.2			
NH4H2PO4	1.0	14N 31P	3.50E-2	5.1	180	2.07	227
	10.0	140N 310P	3.47E-1	4.7			
(NH4)2HPO4	1.0	28N 31P	6.46E-2	7.8	200	2.64	575
	10.0	280N 310P	6.52E-1	7.8			
(NH4)2SO4	1.0	28N 32S	1.39E-1	5.3	60	0.79	706
	10.0	280N 320S	1.38	4.5			
NH4H3P2O7	1.0	14N 62P	6.11E-2	3.1			
	10.0	140N 620P	4.60E-1	2.8			
(NH4)2H2P2O7	1.0	28N 62P	6.97E-2	4.9			
	10.0	280N 620P	6.93E-2	4.5			
(NH4)3HP2O7	1.0	42N 62P	1.11E-1	7.6			
	10.0	420N 620P	1.17	7.5			

(NH4)4P207	1.0	56N 62P	1.34E-1	8.0			
	10.0	560N 620P	4.18	8.1			
NH4H4P3010	1.0	14N 93P	9.62E-2	2.8			
	10.0	140N 930P	8.00E-1	1.9			
(NH4)2H3P301	1.0	28N 93P	1.00E-1	3.1			
	10.0	280N 930P	8.96E-1	2.2			
(NH4)3H2P301	1.0	42N 93P	1.05E-1	4.9			
	10.0	420N 930P	1.05	4.5			
(NH4)4HP3010	1.0	56N 93P	1.50E-1	7.2			
	10.0	560N 930P	1.59	7.0			
(NH4)5P3010	1.0	70N 93P	1.78E-1	7.6			
	10.0	700N 930P	6.44	8.0			
KH3P207	1.0	39K 62P	1.78E-1	3.1			
	10.0	390K 620P	1.26	2.5			
K2H2P207	1.0	78K 62P	2.11E-1	4.9			
	10.0	780K 620P	2.09	4.5			
K3HP207	1.0	117K 62P	4.17E-1	7.8			
	10.0	1170K 620P	4.11	7.3			
K4P207	1.0	156K 62P	6.12E-1	9.9	700	23.1	s.
	10.0	1560K 620P	5.52	10			
KH4P3010	1.0	39K 93P	3.76E-1	2.7			
	10.0	390K 930P	2.98	1.9			

K2H3P3010	1.0	78K 93P	3.94E-1	3.0			
	10.0	780K 930P	3.46	2.2			
K3H2P3010	1.0	117K 93P	4.24E-1	4.6			
	10.0	1170K 930P	4.20	4.0			
K4HP3010	1.0	156K 93P	6.88E-1	7.3			
	10.0	1560K 930P	6.80	6.7			
K5P3010	1.0	195K 93P	8.82E-1	9.7			
	10.0	1950K 930P	8.13	9.7			
UREA	1.0	28N	6.67E-1	7.0	160	0.96	
	10.0	280N	2.71	7.0			

Fertilizer solutions formulations

Examples of several combinations of fertilizers at various concentrations in water were chosen and the resulting EC and pH of each combination were calculated as described earlier. Each table represents one set of nutrient concentrations in irrigation water achieved with six different combinations of fertilizers. Nutrient concentrations, except sulphur, in mg/L or g/m^3 are presented at the head of the table. Sulphur (as SO_4) concentrations vary according to fertilizer combinations and they are recorded in the table at the end of the list of fertilizers. The figures in the rows adjacent to the fertilizer give the amounts of fertilizer in mg/L in solution. Prices of fertilizers in 1 m^3 of solutions were calculated according to listings in "Chemical Marketing Reporter" of May 8, 1989. (* The price for $KH_4P_3O_{10}$ is not included). This prices are shown only for comparative purposes. They may vary from country to country and from time to time. The prices in Israel are mostly higher than those listed. At the bottom of each table the calculated electrical

conductivity (EC) in dS/m, the pH and the price in $ are given.

The first group of tables presents calculations done for solutions in pure water, that initially does not contain any salts. Obviously, this is only a theoretical information.
The second group of tables presents calculations of fertilizer solutions in water containing ions in equivalent concentrations to the National Carrier water. In these solutions the amount of ions present initially in the water were taken into account when calculating the amounts to be added.

The molecular weights of fertilizer compounds used in the calculations are listed as follows:

$Ca(NO_3)_2$	$MgSO_4$	K_2SO_4	KNO_3	NH_4OH	H_3PO_4	$NH_4H_2PO_4$	$KH_4P_3O_{10}$
164	120	174	100	35	98	115	296

Fertilizer solutions in pure water

Summary of nutrient concentrations
mg/L

	N	P	K	Mg	Ca
A	140	10	250	30	150
B	200	40	300	50	200
C	250	80	350	80	300

D 250 10 300 50 200

Nutrient concentration A
mg/L

N	P	K	Mg	Ca
140	10	250	30	150

	1	2	3	4	5	6
Ca(NO3)2	615	615	615	615	615	615
MgSO4	148	148	148	148	148	148
K2SO4	557	557	557	--	341	539
KNO3	--	--	--	640	250	--
NH4OH	88	--	--	--	--	112
NH4NO3	--	114	100	--	--	--
H3PO4	31	--	31	--	--	--
NH4H2PO4	--	37	--	37	--	--
KH4P3O10	--	--	--	--	32	32
S	142	142	142	39	102	139
EC	1.55	1.58	1.58	1.49	1.51	1.52
pH	3.6	5.6	3.6	2.9	3.7	9.7
PRICE ($/m3)	.63	.63	.64	.73	.66 *	.61 *

Nutrient concentration B

mg/L

N	P	K	Mg	Ca
200	40	300	50	200

	1	2	3	4	5	6
$Ca(NO_3)_2$	820	820	820	820	820	820
$MgSO_4$	247	247	247	247	247	247
K_2SO_4	670	670	670	--	--	632
KNO_3	--	--	--	769	726	--
NH_4OH	150	--	--	--	--	150
NH_4NO_3	--	240	171	--	--	--
H_3PO_4	126	--	126	--	--	--
$NH_4H_2PO_4$	--	148	--	148	--	--
$KH_4P_3O_{10}$	--	--	--	--	127	127
S	189	189	189	66	66	182
EC	1.91	1.87	2.10	1.96	1.98	1.65
pH	8.6	8.5	3.0	4.4	3.1	9.2
PRICE ($/m3)	.91	.86	.92	1.00	.96 *	.81 *

Nutrient concentration C
mg/L

N	P	K	Mg	Ca
250	80	350	80	300

	1	2	3	4	5	6
Ca(NO3)2	1230	1230	1230	1230	1230	1230
MgSO4	395	395	395	395	395	395
K2SO4	781	781	781	781	710	710
KNO3	--	--	--	--	--	--
NH4OH	100	--	--	--	--	100
NH4NO3	--	--	114	--	--	--
H3PO4	279	--	279	--	--	--
NH4H2PO4	--	298	--	298	--	--
KH4P3O10	--	--	--	--	255	255
S	249	249	249	249	236	236
EC	2.76	2.77	3.00	2.77	2.66	2.53
pH	5.7	4.7	2.8	4.7	2.9	5.5
PRICE ($/m3)	1.38	1.21	1.38	1.21	1.14 *	1.15 *

Nutrient concentration D
mg/L

N	P	K	Mg	Ca
250	10	300	50	200

	1	2	3	4	5	6
Ca(NO3)2	820	820	820	820	820	820
MgSO4	247	247	247	247	247	247
K2SO4	670	670	670	--	--	670
KNO3	--	--	--	769	769	--
NH4OH	275	--	--	--	--	275
NH4NO3	--	314	--	--	--	--
H3PO4	31	--	31	--	--	--
NH4H2PO4	--	37	--	37	--	--
KH4P3O10	--	--	--	--	32	32
S	189	189	189	66	66	189
EC	1.99	2.17	1.97	1.97	1.97	2.01
pH	9.8	3.7	3.5	4.5	3.7	10.1
PRICE ($/m3)	.85	.85	.82	.98	.98 *	.83 *

Fertilizer solutions
in water equivalent to the National Carrier

Concentrations of nutrients in these calculations are the same as those calculated in pure water. However, for calculating the amounts of Ca and Mg to be added, concentrations of these nutrients in the water are taken into account.

The pH of the final solution was calculated assuming a partial pressure pCO2=3.5.

Ion concentrations in the water of the national carrier vary with location and time of sampling. An arbitrary composition was taken as an example.

Ion concentration in the National Carrier water:

Ca	Mg	Cl	K	Na	HCO3	SO4
			mg/L			
45	30	220	5	110	140	55

EC = 0.990 ; pH = 8.0

Nutrient concentration A-M

mg/L

N	P	K	Mg	Ca
140	10	250	30	150

	1	2	3	4	5	6	7
Ca(NO3)2	430	430	430	430	430	430	430
K2SO4	557	557	557	126	126	557	557
KNO3	--	--	475	475	--	--	--
HNO3	150	--	--	--	--	--	--
NH4OH	83	--	--	--	--	166	166
NH4NO3	--	190	190	--	--	--	--
H3PO4	31	--	31	--	--	--	31
NH4H2PO4	--	37	--	37	--	--	--
KH4P3O10	--	--	--	--	33	33	--
UREA	--	--	--	--	--	--	--
S	121	121	121	43	43	121	121
EC	1.85	1.85	1.85	1.73	1.74	1.69	1.69
pH	8.3	8.3	8.3	8.4	8.5	9.4	9.3
PRICE $/m3	0.54	0.48	0.49	0.56	0.55 *	0.47 *	0.49

Nutrient concentration B-M

mg/L

N	P	K	Mg	Ca
200	40	300	50	200

	1	2	3	4	5	6	7
$Ca(NO_3)_2$	636	636	636	636	636	636	636
$MgSO_4$	98	98	98	98	98	98	98
K_2SO_4	670	670	670	386	386	670	670
KNO_3	--	--	--	325	325	--	--
HNO_3	205	--	--	--	--	--	--
NH_4OH	114	--	--	--	--	228	228
NH_4NO_3	--	260	260	--	--	--	--
H_3PO_4	126	--	126	--	--	--	126
$NH_4H_2PO_4$	--	148	--	148	--	--	--
$KH_4P_3O_{10}$	--	--	--	--	127	127	--
UREA	--	--	--	98	98	--	--
S(ppm)	168	168	168	115	115	168	168
EC	2.33	2.33	2.33	2.24	2.26	2.26	2.19
pH	7.0	7.0	7.0	7.0	8.2	9.3	9.4
PRICE \$/m3	0.81	0.69	0.76	0.75	0.72	0.66	0.75

Nutrient concentration C-M

mg/L

N	P	K	Mg	Ca
250	80	350	80	300

	1	2	3	4	5	6	7
Ca(NO3)2	1045	1045	1045	1045	1045	1045	1045
MgSO4	247	247	247	2477	247	247	247
K2SO4	781	781	781	558	558	781	558
KNO3	--	--	--	255	255	--	255
HNO3	161	--	--	--	--	--	--
NH4OH	89	--	--	--	--	179	89
NH4NO3	--	204	204	--	--	--	--
H3PO4	253	--	253	--	--	--	--
NH4H2PO4	--	298	--	298	--	--	--
KH4P3010	--	--	--	--	255	255	--
UREA	--	--	--	77	77	--	--
S(ppm)	228	228	228	187	187	228	187
EC	3.11	3.11	3.11	3.05	3.02	3.02	2.89
pH	3.7	3.7	3.7	3.7	4.6	8.6	8.3
PRICE $/m3	1.24	1.07	1.20	1.11	1.06 *	1.01 *	1.24

Nutrient Concentration D-M
mg/L

N	P	K	Mg	Ca
250	10	300	50	200

	1	2	3	4	5	6	7
Ca(NO3)2	636	636	636	636	636	636	636
MgSO4	98	98	98	987	98	98	98
K2SO4	670	670	670	219	219	670	670
KNO3	--	--	--	505	505	--	--
HNO3	318	--	--	--	--	--	--
NH4OH	177	--	--	--	--	354	354
NH4NO3	--	404	404	--	--	--	--
H3PO4	31	--	31	--	--	--	31
NH4H2PO4	--	37	--	37	--	--	--
KH4P3O10	--	--	--	--	33	33	--
UREA	--	--	--	151	151	--	--
S(ppm)	125	125	125	85	85	125	125
EC	2.44	2.44	2.44	2.31	2.33	2.28	2.26
pH	8.2	8.2	8.2	8.4	8.5	9.7	9.6
PRICE $/m3	0.77	0.70	0.71	0.77	0.77 *	0.67 *	0.69

Nutrient concentration E-M

mg/L

N	P	K	Mg	Ca	S
240	70	305	30	175	18

	Ca(NO3)2	KNO3	NH4NO3	H3PO4
mg/L	533	782	114	221

EC = 1.81 ; pH = 5.2

PRICE: 0.89 $/m3

Nutrient concentration F-M

mg/L

N	P	K	Mg	Ca	S
160	50	260	30	175	153

	Ca(NO3)2	KNO3	K2SO4	NH4NO3	H3PO4
mg/L	533	246	365	98	158

EC = 2.04 ; pH = 6.5

PRICE: 0.70 $/m3

Nutrient concentration G-M

mg/L

N	P	K	Mg	Ca
250	50	350	50	150

	Ca(NO3)2	KOH	MgSO4	NH4NO3	H3PO4
mg/L	430	502	100	504	158

EC = 1.91 ; pH = 6.5

PRICE: 0.96 $/m3

Nutrient concentration H-M

mg/L				
N	P	K	Mg	Ca
250	50	350	50	150

	Ca(NO3)2	KOH	MgSO4	HNO3	H3PO4
mg/L	430	502	100	795	158

EC = 2.00 ; pH = 2.8

PRICE: 1.02 $/m3

Comparative osmotic pressures expressed as EC of fertilizers solutions providing equivalent amounts of a nutrient

N - 200 mg/L

Fertilizer Compound	mg/L	mmol/L		E. C. dS/m
NH4NO3	571	7.14		0.50
Urea	435	7.25		0.25
(NH4)2SO4	952	7.21		1.00
KNO3	921	9.20	(0.64)	
(NH4)2SO4	338	2.56	(0.36)	1.00
NH4H2PO4	185	1.61	(0.06)	
NH4NO3	507	6.34	(0.44)	0.50
(NH4)2HPO4	213	1.61	(0.10)	
NH4NO3	443	5.54	(0.38)	0.48

P - 50 mg/L

H3PO4	161	1.64	0.10
KH2PO4	227	1.67	0.12
K2HPO4	278	1.60	0.33
NH4H2PO4	185	1.61	0.06
(NH4)2HPO4	213	1.61	0.10

				K - 350 mg/L
K2SO4	778	4.47		0.93
KNO3	921	9.12		0.63
KH2PO4	227	1.67	(0.12)	
K2SO4	636	3.65	(0.76)	0.88
K2HPO4	278	1.60	(0.33)	
K2SO4	500	2.87	(0.60)	0.99

Remarks to the Report

The report was discussed at a round table meeting attended by agronomists and researchers from the fertilizer industry, growers, extension agrnomists and researchers from the Technion, on December 12, 1989. Some of the remarks are listed in the following:

The participants at the meeting expressed appreciation for the content and the form of the report.

J. Martinez, grower from moshav Habonim: Costs of fertilizers: Income from 1 du of greenhouse tomatoes was in the last season 41,000 IS and expenses on fertilizers were 4,000 IS. Any cost reduction in fertilizers would be significant. 30-40% or more of the applied fertilizer are lost in drainage.

O. Zaydan, Ministry of Agriculture Extension Service: A shift to single nutrients and recycling of water require control systems. Those are too costly for a small scale grower, such as are most growers in Israel.

Written remarks were received after reading the report. The authors are thankful for these remarks. They undoubtedly improve the value of the report. The remarks were given in Hebrew. They are presented in the following in a somewhat abridged and free English translation.

Y. Nizani, Haifa Chemicals Ltd.: A model was developed calculating the amounts of chlorides accumulating in the growth medium under defined water quality, drainage and plant uptake conditions. For example,it was assumed that half of the potassium requirement is supplied by potassium sulphate and phosphate and the other half by potassium chloride instead of potassium nitrate and that the irrigation water is of good quality. Under such conditions 23 mmol Cl/L will accumulate in the growth medium within one month, assuming a 30% drainage and 64 mmol Cl/L with no drainage. The optimal concentration of Cl in tomato growth media is 5-10 mmol/L.

S. Sharon, Fertilizers and Chemicals Ltd.:
Corrosion: On the long run, it is simpler and cheaper to install corrosion resistant materials in the fertilizer distribution system, than to choose fertilizers according to their corrosiveness.

The use of copper compounds for preventing clogging may induce, within a short period of time, toxic levels of copper in the growth medium.

Composition of the fertilizer solution: Compound solutions are satisfactory and it is not advisable to change the nutrient composition very often, especially in an inert growth medium, where reactions are minimized. Although, in a recycling system corrections of nutrient composition by single compounds are necessary.

Nitrogen: The ratio of ammonium to nitrate nitrogen and the use of urea should be thoroughly checked, prior to any recommendations of changing the prevailing practices.
Phosphates: Practical experience and experimental work indicate that the levels of P application are definitely not

too high. There is no danger of eutrophication of waters by phosphates in the Negev and Arava areas of Israel, because of the considerable depth of the aquifer

Potassium: Use of potassium sulphate may supply the sulphate, where needed, but its use may disturb the balance with calcium and magnesium. The use of potassium chloride will not be advised under our conditions, unless rain water is used for irrigation.

Microelements: In calcareous soils the more expensive chelate EDDHA has to be used, while in inert growth media the cheaper EDTA is effective enough.

Electrical conductivity: A small difference in EC may be significant, especially with irrigation water having a relatively high EC.