Potassium Management of Vegetables Under Intensive Growth Conditions

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Abstract

The importance of adequate potassium fertilization under intensive vegetable production in greenhouses is illustrated by comparing the available quantities with the total demand. To promote quality, fertilisation levels are high, therefore, the effects of K supply on yield may not be expected. Potassium has a positive effect on keeping quality of tomato, sweet pepper and cucumber and additionally on taste of tomatoes. K enhances blossom-end rot (BER) in tomato, sweet pepper and eggplant, as it goes for tipburn in lettuce. Gold speck and black spot in tomato and sweet pepper respectively are enhanced by reduction of K supply. The uptake of K by fruit crops change rapidly and increase strongly during fruit development, together with a dramatic decrease in Ca uptake. For crops grown in soilless culture (hydroponics), nutrient solutions should be adapted to the uptake ratios of K : Ca : Mg of individual crops and desired accumulation rates for Ca and Mg. Closed growing systems open possibilities for complete nutrient management.

Introduction

Growing crops in a protected environment like greenhouses, is the most intensive method of horticulture. Presently, over 60 % of the crops are grown in soilless culture (hydroponics) in the Netherlands. For fruit vegetables, almost 100 % of the area are grown soilless. This system opens the possibility of full control over the irrigation and nutrient supply. This especially applies to the closed growing systems, in which the run off water is re-used. The change over to these systems is forced by the government to reduce the emission of N and P to the environment. However, the small volume of substrate means low buffering capacity and give rise to uncontrolled variations and instabilities in the nutrient composition in the root environment. Crops absorb potassium in the highest quantities (by weight) and it is for several reasons that this element needs special attention in this intensive cropping systems. As these systems are capital intensive, maximum yield and quality are required, and K plays an essential role in both aspects. Moreover, the demand for K fluctuates strongly according to the stage of growth, which is particularly the case for fruit vegetables. A review is given on the significance of K for yield and quality for vegetable crops, especially fruit vegetables. The implications of the control of the optimum K status in the nutrient solutions have been discussed.

Potassium Supply in Intensive Greenhouse Production

There are several differences between field-grown vegetables and crops grown under protection. Elevated temperatures and the exclusion of precipitation and other climatic influences allow higher growth rates with higher yields, which impose a high need for nutrients. It is evident that K fertilization is essential, for even in high fertile alluvial soils like in the Netherlands, the natural K supply from soil minerals is insufficient. Especially long term vegetable crops like tomato absorb such high quantities of minerals that it is impossible to supply those quantities as base dressing with fertilizers, because the osmotic pressure in the soil solution would increase to detrimental levels (Sonneveld, 1979; Sonneveld and Voogt, 1981). Additional side dressings or fertigation is essential for such crops. The total buffer of K in the root volume is of secondary importance in greenhouse soils and evidentially negligible for hydroponic systems. This is demonstrated by the results of calculations, listed in **Table 1**.

Table 1. Quantities of available K in different growing systems in comparison with the total K demand of a long-term tomato crop yielding 50 kg m^{-2}.

	Growing system		
	Greenhouse Soil	***Rockwool Slab***	***Nutrient film technique***
Substrate volume (l m^{-2})	300	15	2
K concentration (m mol l^{-1})	4*	8	8
Total demand (kg ha^{-1})	1750	1750	1750
Total direct available (kg ha^{-1})	600**	40	6
% of total demand	34	2	< 1

Source: Sonneveld (1990) and de Kreij et al. (1999)
*Based on 1:2 by volume extraction
**Referring to the readily available potassium as is determined by the 1:2 volume extract.

Apart from the supply of fertiliser K to match crop requirements, K fertilizers are often used to increase the osmotic pressure of the soil solution (Roorda van Eysinga, 1996b; Sonneveld and Voogt, 1981). As greenhouse crops in northern latitudes are grown during the long periods of the year under poor light conditions, the osmotic pressure of the soil solution is used as a tool to prevent lush growth and to improve fruit quality.

Potassium Supply and Yield of Crops

A lot of experimental work on the effects of K fertilization on the yield of glasshouse vegetables have been reported in the past, showing the significance of K fertilization (Roorda van Eysinga, 1966a & 1996b; Sonneveld and Voogt, 1981). Potassium fertilisation influences the total yield only when the K status of the soil is low (**Figure 1**). As the common practice of fertiliser recommendation is intended to keep the levels of nutrients in the soil on defined guide values using continuous fertigation, yield responses to K fertilisation are rare for crops grown in greenhouse soils (Sonneveld and Voogt, 1981). Glasshouse production of crops is capital intensive and costs of

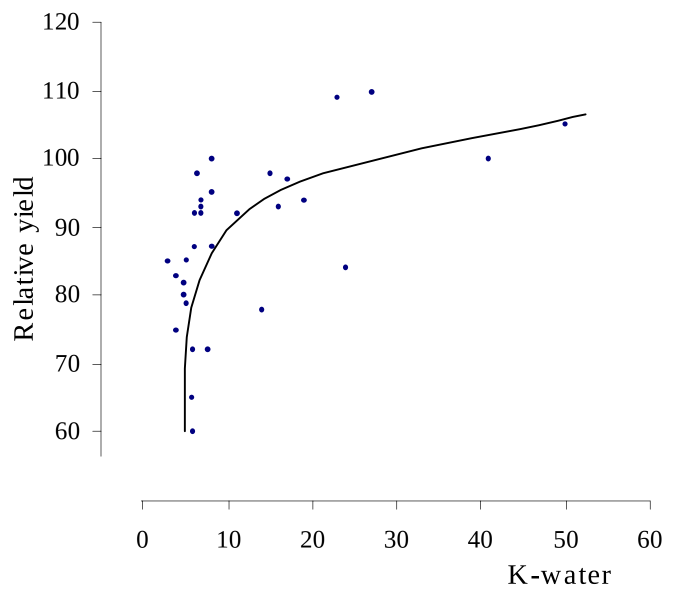

Figure 1. Relation between the content of water-soluble K (mg K/100g dry soil) estimated in soil samples just before starting the experiment and the relative yield *(from Roorda van Eysinga, 1966).*

fertilizer hardly affect the total production costs. It is common practice to apply fertilizers at or even above the rates at which maximal productions can be obtained. This practice has a big drawback of low fertilisers use efficiency and high potential losses of nutrients to the environment. Recent investigations showed that on an average only 45 % of the K supplied are absorbed by the crop (Voogt and Korsten, 1996). The effects of K nutrition in hydroponics on crop yields has been reported by Sonneveld and Voogt (1981), Voogt (1988), and Kreij (1999). From the results it is evident that shortage of K supply has a detrimental effect on yield. Very high supply of K increases the osmotic pressure too much and induces salinity problems (Sonneveld, 1979; Sonneveld and Mook, 1983; Sonneveld and Welles, 1988).

Potassium Supply and Quality of Crops

Product quality is a complex matter and has various aspects, which are affected by many factors. Concerning plant nutrition, potassium plays an important role (Windsor, 1979; Janse, 1985; Martin-Prével, 1989)). Intensive research has been done in recent years to investigate the effects of K on fruit quality of cucumber, tomatoes, eggplant and sweet pepper grown in hydroponics, showing the significance of K in the nutrition of these crops (Sonneveld and Voogt, 1985; Voogt, 1987; Sonneveld and Welles, 1988; Bakker, 1989; Kreij, 1996 & 1999). However, a complication in these studies is that increased K supply involves enlargement of the total ion concentration (EC level). At the same time the osmotic pressure is increased, which in itself has a clear effect on yield and quality (Sonneveld and van den Burg, 1991). The effect of K nutrition should, therefore, be studied by taking in to consideration the total ion concentration (EC). It is therefore important to study the effects of K nutrition in relation to other cations, mainly Ca and Mg in general and Na under saline irrigation water. An illustration of the impact of K nutrition, in relation to Ca and Mg on fruit quality of tomato is shown in **Figure 2**. Increasing K/Ca ratio resulted in improvement of the keeping quality, and factors affecting flavour such as sugar and acid content (not shown). However, the per cent of fruits with blossom-end rot (BER) was also higher. A remarkable phenomenon is the incidence in gold speck on tomato fruits. This phenomenon is connected with Ca accumulation and Ca-oxalate crystallisation (Kreij *et al.*, 1992). Increased gold speck often reduced the shelf life (Janse, 1988), probably due to increased respiration and transpiration of the fruit. Increasing K/Ca ratio reduced gold speck. In this experiment, the increase in K was associated with decrease in Ca, hence it was difficult to distinguish whether K or Ca causes these effects. A clear interaction was found between the K/Ca ratio and the Mg level, with shelf life in particular. The reduction in shelf life by decreasing K/Ca ratios was more pronounced at low Mg levels. Increasing Mg concentration enhances the incidence of BER and reduces gold speck incidence (**Figure 2**).

Similar results were found with sweet pepper (Benzioni and Golden, 1992; Krey *et al.*, 1999), where increased K levels led to a dramatic increase of BER. It was also observed that K had a stronger antagonistic effect on the Ca uptake than that of Na. Fruit cracking in sweet pepper was reduced by increasing K levels (Kreij *et al.*, 1999).

Physiologically, the black spot in sweet pepper is the same phenomenon as gold speck in tomato. There is evidence that in sweet pepper the incidence of black spot is enhanced by decreasing K : Ca ratios (Voogt, 1985). In Egg-plant, BER was increased with increasing K : Ca ratios (Bakker *et al.*, 1989). Significant effects of K on fruit quality were found only on shelf life of

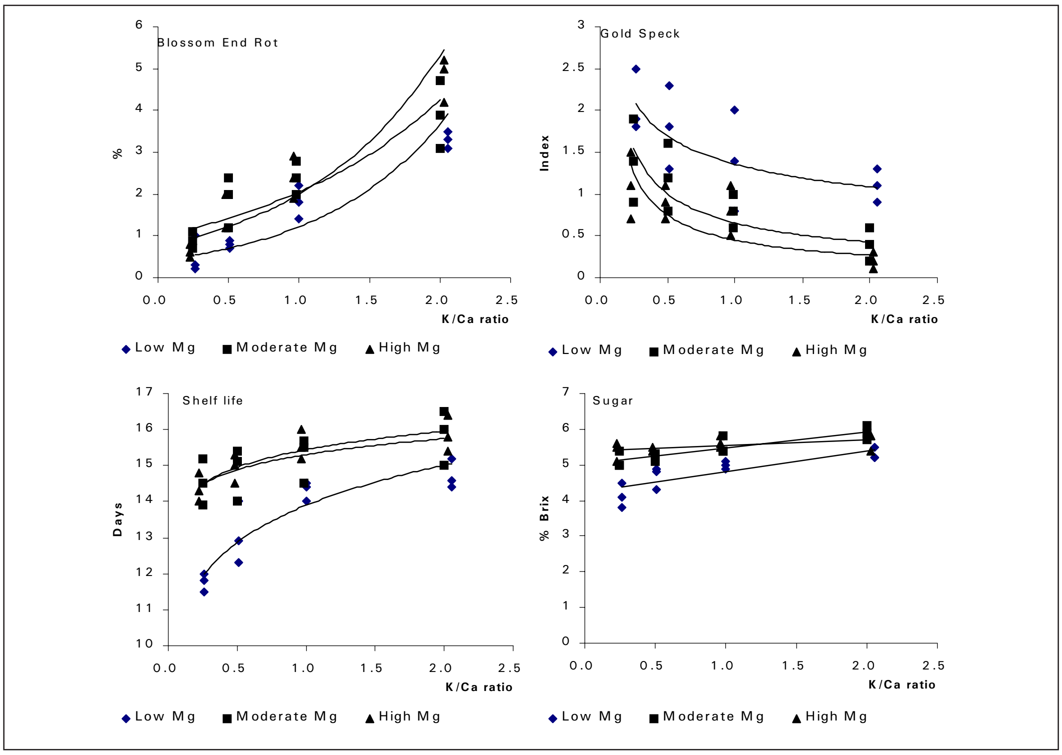

Figure 2. Relations between the K/Ca ratio in the root environment and the percentage of blossom-end rot fruits, the goldspeck index, shelf life and sugar content of fruits of rockwool grown tomato, at three Mg levels (*adapted from Voogt, 1987b*).

cucumber. Increasing K supply led to darker green fruits (Janse, 1985; Bakker and Sonneveld, 1988), which resulted in longer shelf life. Since self life is determined by the decline in colour, darker fruits have a longer shelf life. In terms of other quality indices, no significant effect of K supply was found. For other fruit vegetables such as cucurbitaceae, melon and courgette, no response on fruit quality was found (Sonneveld and Voogt, 1985). Increase in K : Ca ratio in the nutrient supply increased the tipburn of lettuce slightly (Voogt, 1988). However contradictory effects have been reported by Sonneveld and Mook (1983), who found a positive response of the K supply on the Ca distribution to inner leaves of lettuce heads. Iceberg lettuce showed higher head firmness and improved keeping quality with increased K levels in soil (Maaswinkel and van den Bos, 1987).

Potassium uptake

A large quantity of data has been collected on the K uptake of several crops. It is obvious that the absolute K uptake depends on the total dry matter production, which is further, related to the length of the growing period. Close relationships between yield and K uptake have been found for tomato, cucumber and pepper (**Figure 3**).

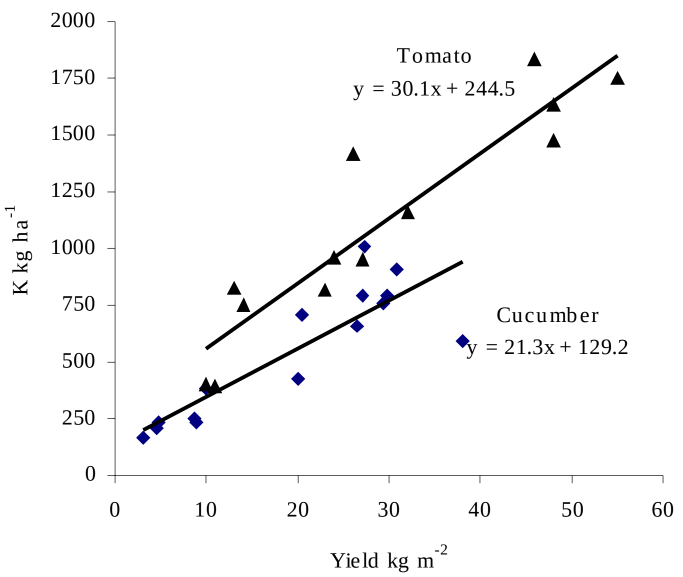

Figure 3. Relationships between the yield of tomato expressed as kg m^{-2} and the absorption of nutrients expressed as kg ha^{-1} *(adapted from Sonneveld, 1997)*

Striking differences in total K uptake were found between crops, compared on basis of a year round growing cycle (**Table 2**).

Table 2. Total yield, total dry matter production and K uptake of crops based on a year round growing period (tomato, cucumber, sweet pepper), or year round cropping cycle (radish, lettuce, chrysanthemum).

Crop	*Total yield*	*Total dry matter*	*Total K*
		kg m^{-2} yr^{-1}	
Tomato	50	3.8	1750
Cucumber	65	3.0	1500
Sweet pepper	25	2.5	1500
Radish	25	1.2	900
Lettuce	23	1.2	1200
Chrysanthemum	16	2.1	1100

Source: Sonneveld (1997), Voogt (1993), Voogt and Korsten (1996)

For individual crops it was found that time of the year and climatical conditions have a significant effect, and differences between cultivars are sometimes quite large (**Table 3**)

Table 3. Potassium contents of young fully grown laminae of tomato, cucumber and egg-plant grown under high- and low humidity conditions (m mol kg dry matter^{-1})

Crop	*High humidity*	*Low humidity*
Tomato crop 1	1394	1535
Tomato crop 2	1336	1532
Cucumber	865	937
Sweet pepper	1452	1410
Egg-plant	1299	1624

Source: Bakker and Sonneveld (1988), Bakker et al. (1989), Kreij (1996 & 1999)

The uptake of K by crops grown under conditions with low humidity was high. This was probably due to the result of the lower transpiration of the laminae and reduced K accumulation due to transport by mass flow (Adams, 1984; Bakker and Sonneveld, 1988).

Potassium Uptake Concentration

The K uptake is strongly related to the uptake of water (Adams, 1984). The K uptake expressed on the basis of water uptake is called uptake concentration. The uptake concentration differs for crops, stage of growth and growing conditions. In **Table 4,** the uptake concentrations of K for a number of crops are listed. The differences between the crops are large, which could be related to differences in dry matter production and in water use efficiency. Sonneveld and Van den Bos (1995) demonstrated the effect of the time of the year in radish. The absolute uptake of K in summer and winter was more or less the same, however the water uptake was three to four times higher in summer than in winter therefore the uptake concentration was higher in winter than in summer by the same factor. Similar effect but to some less extent was found in tomato (Voogt, 1993).

Table 4. Uptake concentrations of K in some horticultural crops, expressed as mmol l^{-1} and in per cent of the total sum of ions in mmol l^{-1}.

Crop	*K*	*%*
Cucumber	6.6	27
Lettuce	8.7	40
Radish (summer)	4.5	28
Radish (winter)	16.5	27
Sweet pepper	4.5	25
Tomato	6.5	31
Rose	1.9	21

Source: Sonneveld (1997), Voogt (1988, 1993) and Sonneveld and van den Bos (1999)

The K uptake is not constant during the growing period of a crop. The total uptake is more or less determined by the growth, but the uptake of specific nutrients also depends on stage of growth. It has been observed that in tomato the uptake of K changes considerably depending upon the fruit load (Voogt, 1988 & 1993). The uptake of K increases rapidly from the time of third fruit cluster swelling and reaches maximum at the swelling of 10th cluster. At the same time the uptake of Ca and to a less extent of Mg decreased. The uptake of K, Ca and Mg in a long-term tomato crop is shown in **Figure 4.**

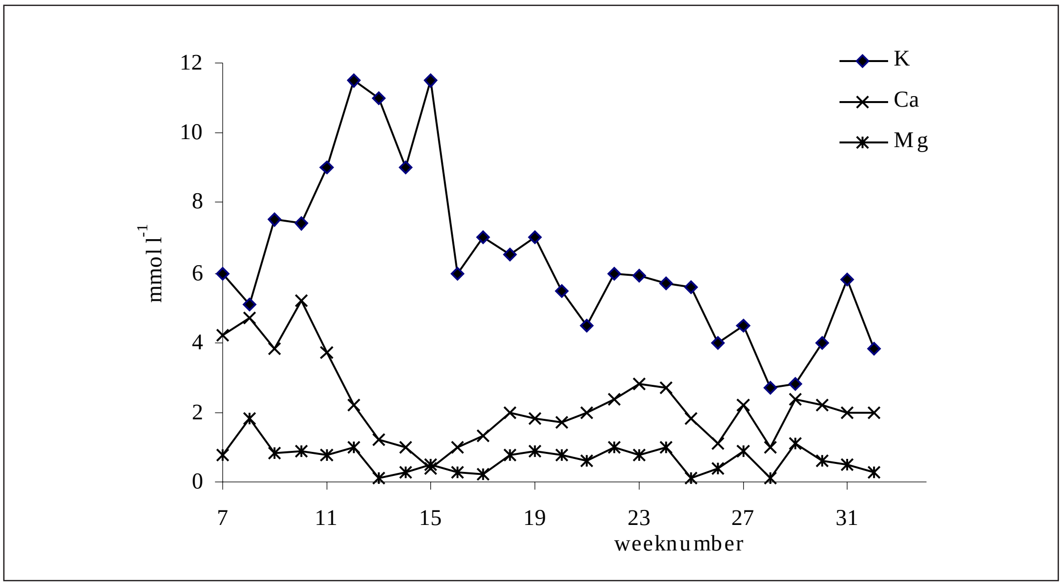

Figure 4. Uptake of K, Ca and Mg of a year round crop of tomato in a closed growing system, planted in week 1, first yield in week14, expressed in mmol l^{-1}. *(from Voogt, 1997).*

The total distribution of the major elements in the plant for tomato and cucumber is listed in **Table 5**. From the data it is clear that for tomato a significant fraction of the absorbed K is partitioned to fruits. For K, the fraction is even higher than is for the total dry matter. However, the fraction of Ca in fruits is dramatically lower compared to K. The transition from vegetative to generative development will therefore cause a change in K/Ca ratio in the uptake. In addition, this effect is probably intensified by the fact that during the period of increased fruit load, the Ca uptake is reduced by the restricted root growth (Noordwijk, 1990). For cucumber, the differences in Ca quantities in plant parts are much smaller, which explain the minor changing in K/Ca

Table 5. Per cent distributions of dry matter, K, Ca and Mg in aboveground plant parts of a tomato and a cucumber crop

Parameters	*Tomato*			*Cucumber*		
	Leaf	*Stem*	*Fruit*	*Leaf*	*Stem*	*Fruit*
Dry matter	20.3	13.6	61.8	28.1	13.9	58.0
K	18.5	10.8	65.6	22.5	11.2	66.3
Ca	75.7	15.1	5.2	56.2	23.8	20.0
Mg	50.3	15.0	29.8	44.2	19.1	36.9

Source: Voogt (1993), Roorda van Eysinga and Van Haeff (1964) and Voogt (unpublished data) ratio (Voogt, unpublished data). Similar changes in uptake ratio of K/Ca were observed with butterhead lettuce in small buffered growing media as NFT during the period of head formation (Voogt, 1988). The unfolded leaves and the inner parts of the head of lettuce show K/Ca ratios comparable to those in leaves and fruits of tomatoes, respectively (Sonneveld and Mook, 1983). Thus, with respect to the uptake of K and Ca, lettuce (butterhead and iceberg) behaves like a fruit crop.

Fertiliser Applications

In the Dutch horticultural practice, the method of target values for the root environment has been developed (Breimer *et al.*, 1987). These target values are established for each crop and derived from experimental work, expressing the optimum concentration for K in the soil solution. The high quantities of K absorbed by the intensive horticulture systems necessitate an adequate K supply. The supply of nutrients by means of fertigation has now become common practice. For crops grown in soil, mixed fertilizers are sometimes used, but nutrient solutions, prepared with single fertilizers are mainly used. In hydroponics, only nutrient solutions are recommended and used (Kreij *et al.* (1999). With respect to individual elements such as K, the total concentration as well as the ratio with other nutrients are important. Furthermore, it is important to distinguish between the composition of the nutrient solution to be supplied to a crop and the composition of the root environment. Like in hydroponics, it is the solution in the rockwool slab or in other growing media, or in soil the soil solution. Target values for the root environment are derived from experimental data. The actual concentration in the root environment, however, may vary between certain boundary values, which are 0.66 and 1.66 times the target value for most crops (Kreij *et al.*, 1999). The nutrient solution to be supplied is calculated in such a way that the target values for the root environment will be reached. It is obvious however, that during the growing cycle of many crops, the target values for the root environment will not be reached or exceeded, due to changing in uptake ratios. Adjustment of the standard nutrient solution is than necessary

Nutrient adjustments

Concerning the composition of nutrient solutions for hydroponic systems, the following aspects should be taken into account. Firstly, the composition of a nutrient solution must reflect the uptake ratios of individual element by the crop. As the demand between crops differ, the basic compositions of nutrients solutions are crop specific (Kreij *et al.*, 1999). Secondly, the uptake of certain elements differs widely.

This is particular the case for Ca and Mg, the absorption of which are more difficult than K and $NO_{3.}$ Sufficient uptake of these elements, necessitates relatively accumulation of Ca and Mg in the root environment, whilst K may deplete to a certain extent. Ca and Mg should therefore be present in relatively higher ratios to K than the mere uptake ratio of the crop. Thirdly, the growing system is important. In systems with free drainage of water, part of the nutrient solution in the root environment will be leached, which undo to a certain extent the raised Ca and Mg concentrations in the root environment. The higher the leaching fractions, the more the eventual ratios of cations in the root environment are shifted towards the original ratios in the nutrient solution supplied, so the ratios in the nutrient solution must be corrected for the leaching fraction (Voogt and Sonneveld, 1997). In closed systems, however, the loss of nutrients from the root environment is brought to a minimum. For those systems, the mutual ratios of the elements in the nutrient solution must correspond with the ratios of the uptake, otherwise it will lead to either accumulation or depletion of certain elements. The effect of shifting of K/Ca ratios in the root environment as the result of the differences in supplied ratios is illustrated in **Figure 5**.

Practical Implications

Since the available quantity of K in the root environment is limited and analysis of the root environment are usually not done too often, effective control of crop nutrition in soilless culture can only be achieved by choosing the right nutrient solution. It is important that the ionic composition of the nutrient solution is well designed and tailored to the requirements of the crop, the growing system and adjusted for the presence of ions in the irrigation water. The nutrient solution can be transformed into fertiliser solutions, according to the method described by Kreij *et al.* (1999). For K, mono potassium phosphate and potassium sulphate is adjusted in such a way so that it meets the required amounts of H_2PO_4 and SO_4. The remaining quantity of K is settled by KNO_3. In case of tomato crops, Cl is part of the nutrient solution and KCl is used. Adjustments because of crop stage are achieved by using standard guidelines. The minor adjustments are carried out through the

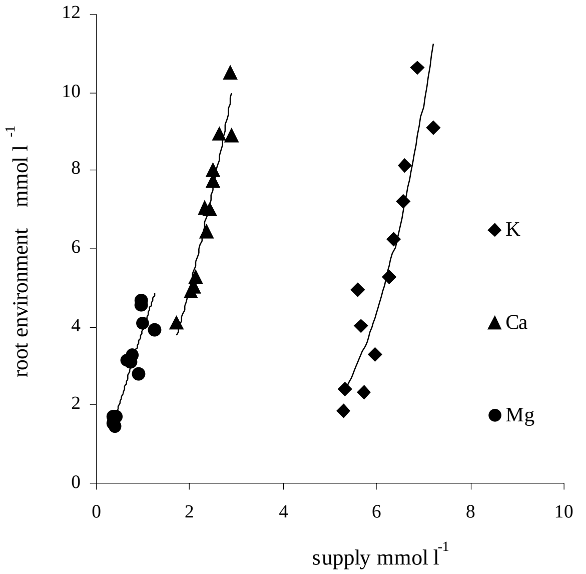

Figure 5. Relationship between the average K, Ca and Mg concentrations supplied and the average concentrations in the root environment (rockwool slab) of a long term tomato crop grown in rockwool with reuse of drainage water *(derived from Voogt, 1987)*

analysis of the root environment. In essence these modifications are done by changing the mutual ratios of cations, or anions if necessary and are easy to accomplish by exchanging the quantities of two or three fertilisers.

Conclusions and Remarks

Potassium plays an important role in yield and quality. Depending on the definition of quality however, one can choose for improving quality in terms of storage quality or taste, either by increasing K supply or to reduce the risk of physiological Ca disorders, by reducing K supply. For crops like tomato and sweet pepper, the K supply seems like walking a tightrope, with possibilities of improving storage quality at one hand and keeping the risk of BER, gold speck or black spot on the other. This contradiction seems to make it impossible to grow crops susceptible for Ca disorders under conditions of getting both a maximum storage quality and a high percentage of first grade fruits. However, growing vegetables in greenhouses has the possibilities for efficient control on the environment and on the manipulation of the Ca transport and distribution in the plant to avoid Ca stress, together with high quality vegetable production (Adams and Holder, 1992; Kreij, 1996; Bakker and Sonneveld, 1988). Such manipulation of the nutrient uptake requires adequate supply of nutrients and continuous control of the nutrient status of the root environment. Next to it is the development of closed systems, either to minimise the contamination of ground and surface waters, or for conservation of water in arid regions. The K demand of crops can fluctuate highly and control on the composition of the nutrient solution can easily be lost. Although Voogt and Sonneveld (1997) presented rough guidelines to anticipate these fluctuations for tomatoes, development of accurate nutrient uptake models is essential. Together with continuous, on-line measurement of the nutrient concentrations in these closed systems will open the possibility of really full control of crop nutrition. However, ionselective sensors, which are in development for quite a few years (Gieling *et al.*, 1988) are still not operational.

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