Nutrient Concentrations of Plant Tissues of Greenhouse Crops as Affected by the EC of the External Nutrient Solution

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Abstract

This paper reports osmotic effects from a series of experiments where greenhouse crops were grown in substrates with different EC values of the nutrient solution. Results of yield characteristics were published elsewhere: in the present paper, the nutrient uptake in relation to the EC will be discussed in the light of growth of lily, lettuce and kohlrabi. The crops were grown in substrates within a circulation system and thus, the water absorption of the crops could be precisely determined. The nutrient absorption was determined by tissue analysis. For lettuce whole heads were sampled and analysed; for lily, bulbs and leaves and for kohlrabi, tubers and leaves were sampled and analysed separately.

The results showed a strong increase of plant nutrient concentrations in the EC-domain until the optimum growth response of the crops. Higher EC values did not affect the plant nutrient dry matter concentrations seriously, except for K concentrations of the lily crop. Calculations showed that the K concentration in the plant sap played an important role in the osmotic adjustment of the different crops to high external concentrations. The uptake concentrations of the different crops were presented and discussed in relation to the EC value in the external solution. External nutrient concentrations and plant nutrient concentrations in relation to optimum yield are presented. Calculations are made of the nutrient efficiency of a system with drainage to waste compared with a system with reuse of drainage water.

INTRODUCTION

Results of a study of osmotic effects on greenhouse crops grown in substrate (Sonneveld et al., 2004) outlined the relationships between the yields of a series of crops and osmotic potentials in the external solution. In the experiments, differences in the osmotic potential of the external solution were achieved by addition of nutrients. In the present paper results of nutrient uptake in three crops, in relation to the osmotic potential of the external solution, will be discussed. These include a tuber crop, a leaf crop and a bulb crop, represented by kohlrabi, lettuce and lily, respectively.

METHODS AND MATERIALS

The crops were grown in sand and as well in granulated rock wool substrates placed in a 0.15 m thick layer in basins with a size of 0.8 m x 1.6 m. Nutrient solutions of different concentrations were prepared and added with the aid of a sprinkler system. The irrigation time, the quantity of water and the concentration of nutrients in the water were varied according to the crop, the growing conditions and the osmotic potential aimed at. The leaching fraction in the growing system was focused on 0.25 and 0.50 and the drainage water was reused in the system.

Six treatments were laid out in four parallel-randomized blocks in which the EC in the substrate solution roughly varied between 1 and 8 dS m^{-1}. The composition of the nutrient solutions used was tuned to the need of the crop according to the recommendations for growers (Sonneveld and Straver, 1994). The different EC values were achieved by addition of various amounts of major elements. NH_4 and P, however, were kept constant, since NH_4 may influence the pH of the nutrient solution (Sonneveld, 1991) and P can become toxic to some crops (Howell and Bernhard, 1961), when added with too high concentrations. The rough composition of the nutrient solution as used related to an EC value of 1.8 dS m^{-1} was following: in mmol L^{-1} NH_4 1.0–1.3, K 6.0–7.5, Ca 2.8–3.3, Mg 0.8–1.5, NO_3 12.6–13.5, SO_4 0.8–1.5, H_2PO_4 1.0–1.3 and in µmol L^{-1} Fe 10–60, Mn 0–20, B 15–30, Cu 0.25–0.75, Mo 0.5–0.75. Sufficient Zn was available in the primary water, either rain water or desalinated water. The average EC of this water was 0.15 dS m^{-1} and the concentrations of Na and Cl were about 0.6 mmol L^{-1}. The kohlrabi crop cv. Quickstar was grown between Feb.-Apr., 1991; the lettuce between cv. Cortina Jun.-Jul., 1992; and lily cvs. Connecticut King and Star Gazer between Feb.-Jun., 1995. Both cultivars of lily were grown in the same experimental plots; thus part of the calculations could not be made for the cultivars separately. In such cases average values of both cultivars are given. The planting density was 20.3, 18.8 and 56.2 plants per m^2 for kohlrabi, lettuce and lily respectively, in agreement with horticulture practices in The Netherlands.

The concentrations of nutrients and the EC in the root environment were estimated by measurement of these parameters in the solution supplied and in the drainage water. The quantities of water supplied and drained out were recorded and used for calculation of the water absorption of the crop.

Tissue samples were gathered at the end of the cropping periods and analysed for major nutrients, as well as Na and Cl. For kohlrabi tubers and tops, and for lilies bulbs and tops were gathered separately. With lettuce, representative tissue samples were taken from whole heads. The samples of the lily bulbs grown in the rock wool could not be cleaned sufficiently from these fibres and thus were not analysed. All other samples were dried at 80°C, ground and extracted by total destruction (acid digestion) to determine the element concentrations.

At the beginning of the experiments, small kohlrabi plants in rock wool plugs were set out, and with lettuce small plants in peat cubes were used. The quantities of nutrients brought in with these materials were very small and considered neglected for the purpose of calculations. For lily young bulbs were planted out and tissue analysis showed that 5 to 45% of the nutrients absorbed by the crop were already available in the bulbs used at the start. These quantities were taken into account in the calculations of the nutrient uptake.

RESULTS AND DISCUSSION

The relationships between the yields of the crops and EC values in the root environment are shown in Fig. 1. A function of an exponential model showed the best relationship between the EC and the yield characteristics (Sonneveld et al., 2004). The maximum yield was obtained at EC values of 2.3, 2.7, 0.5 and 1.1 for kohlrabi, lettuce, lily cv. Connecticut King and lily cv. Star Gazer respectively.

The water use in the experiments, covering the absorption by the crop and the evaporation by the substrate surface, was not different for the EC values of the kohlrabi and the lettuce and amounted on average 109 and 100 L m^{-2} respectively. The water use of the lily decreased from 325 till 229 L m^{-2} with increasing EC in the root environment from 1.2 to 6.0. This reduction in water use of 30% is in agreement with the previously reported growth reduction in this range, which was also about 30% (Sonneveld et al., 2004). The fact that kohlrabi and lettuce did not show differences in water use with increasing EC can be explained by the type of canopy formed by these crops. Both crops quickly form a closed canopy over the total area, even when there is a moderate growth reduction. In such cases the transpiration is related to the area covered. Lily, however, has an open canopy in which the transpiration will be related to the total leaf area. These results contradict the (still) generally held believe that the principal factor associated with growth reduction of crops by salinity is water availability, and support conclusions of previous workers such as Lagerwerff and Eagle (1961), and Maas and Nieman (1978), who concluded that the plants adjust for the water availability.

Tissue analysis between the crops grown in sand and those grown in rock wool showed no significant differences, and so the overall data will be discussed. The quantity of nutrients absorbed by the crops, and the nutrient concentrations in the dry matter of the plant tissues for kohlrabi and lettuce were often lowest at the treatment with the lowest EC of 1.2 dS m^{-1} in the root environment. The insufficient supply of nutrients at this EC level lowered the yield of the kohlrabi by around 60% and lettuce by around 20% in comparison with the optimum growth level. The uptake of nutrients for lily, even at the lowest EC of 1.2 dS m^{-1}, was apparently sufficient, because the maximum growth response was already obtained at this low level. Increasing EC values from the optimum up to the highest level of about 6 dS m^{-1} resulted in almost no increase in the nutrient concentrations of the dry matter for kohlrabi and lettuce. For lily occasional increases in nutrient concentrations were found in the dry matter of the tops as well in those of the bulbs; mainly for K, and to a lesser extent also for N. The quantities of nutrients absorbed by kohlrabi and lettuce with increasing external concentrations above the optimum stayed more or less stable, whilst for lily the quantities of nutrients absorbed tended to decrease with increasing external concentrations.

The uptake concentrations, defined as the ratio between the quantities of nutrients and water absorbed by the crop, were calculated and listed in Table 1. The lowest uptake concentrations for kohlrabi and lettuce are found at the lowest EC value. For lily, the uptake concentration of K at the lowest EC was below that for the other treatments. Furthermore, increasing external concentrations scarcely affected the uptake concentrations of the nutrients of the crops. These stable uptake concentrations for kohlrabi and lettuce with increasing external concentration above the optimum supply correspond to the stable absorption of water and nutrients under these conditions. In the case of lily it may be explained by the decrease of the absorption of both the quantity of water and nutrients, with increasing external concentrations. From the data in Table 1 mean uptake concentrations will be calculated. From these calculations for kohlrabi and lettuce the data at the lowest EC value was excluded, since this treatment gave yields below the optimum. For lily the higher uptake concentrations of K at the higher external concentrations were excluded, for these are apparently resulted from luxurious uptake, which means absorption of nutrients in excess of that required for optimal growth and plant function. Therefore, the uptake concentration of K for lily was calculated from the data found at the lowest two external concentrations, excluding in this way on the one hand luxurious uptake and on the other possible sub-optimal uptake.

In Table 2, the calculated average uptake concentration at optimum growth conditions are given. For lettuce the optimum uptake concentrations are much lower than those found by Voogt (1988). This can be explained by the high transpiration rate during the growth of the lettuce crop. The present results were obtained during full summer, where transpiration is high, thus decreasing the uptake concentration. Comparable effects of the transpiration rate on uptake concentrations have been found for radish (Sonneveld and Van den Bos, 1995).

The extra K uptake at high EC values with lily offers the plant an osmotic escape from the high external EC values. It increases the K concentration of the plant sap to about 60 mmol L^{-1}, which is equivalent with an osmotic pressure (OP) of about 120 kPa. This may be compared to the increase of the OP in the external solution, estimated at 160 kPa. Comparable effects can be calculated for both of the other crops, despite not showing an increased K concentration in the dry matter. Kohlrabi and lettuce, however, showed and increase in dry matter content with increased external concentration above the optimum level, which was not seen in the lily crop (Fig. 2). This increased dry matter content was also associated with an increase in the K concentration in the plant sap of kohlrabi and lettuce (Fig. 3), from around 25 till 50 mmol L^{-1} (OP 50 till 100 kPa), while the OP of the external solution from optimal till the highest values increased to about 130 kPa. Thus, the increased K concentrations in the plant sap contribute substantially to the osmotic escape for all crops under investigation. This may be especially true for K because this is the only nutrient element more or less total soluble in the plant sap (Sonneveld and De Bes, 1983). Other work has indicated also that individual crops may adapt to low external osmotic potentials differently and that osmotic adjustments are often complex and not yet fully understood (Yeo and Flowers, 1984; Greenway and Munns, 1980).

The concentrations of the different ions in the root environment at optimum production levels are given in Table 3. They were calculated from the average concentrations in the solution supplied and those in the drainage water. The solution supplied was the mix of this fresh solution added to replenish the absorption of the crop and the reused drainage water. Na and Cl remained from the irrigation water used. This was mainly rain water containing about 0.5 mmol NaCl per litre (Sonneveld and Heinen, 1997). The uptake of Na by most crops is low; thus even with the low levels indicated above, some accumulation occurs with reuse of drainage water.

The quantities of drainage water were measured and analysed. With this data the fractions of nutrients drained to waste, as opposed to that not reused, could be calculated. These fractions found at the optimum EC level for the different crops are listed in Table 4. Relatively most nutrients are drained out with the high leaching fraction with the lily crop. Furthermore, the output to waste for N and K is relatively lowest, because the concentrations of those nutrients in the root environment are relatively low in comparison to the uptake. P concentrations in the drainage to waste may be low because of precipitation of this element with high pH values in the root environment. The ratio between the external concentrations and the uptake concentration for Na, and the divalent ions is higher than for the other ions. Over time, an unbalanced nutrient solution in the root environment will occur in a closed system. This demonstrates the need of adjustment of the application of nutrients in closed systems. On the other hand, some nutrients like Ca and Mg need accumulation in the root environment, to ensure a sufficient uptake by plants.

In Table 5, the nutrient concentrations of the dry matter of plant tissues at optimum production level are listed. The concentrations found at this level for the tops of the plants are in agreement with the values given by De Kreij et al. (1992), except for the N concentration of the lilies. The concentration of about 1500 mmol kg^{-1} dry matter mentioned in Table 5 is lower than the limits of 2000–2860 given by De Kreij et al. (1992).

CONCLUSIONS

Increased EC values in the root environment resulting from increased concentrations of nutrients above the level necessary for optimum growth response decreased the fresh and the dry weight of kohlrabi, lettuce and lily. The total dry matter production of kohlrabi and lettuce was less effected by the increased nutrient concentrations than the marketable fresh yield production.

The water absorption of the kohlrabi and the lettuce crops was not affected by the increased EC in the root environment and this of lily was reduced in agreement with the growth reduction of the crop.

The nutrient concentrations in the dry matter were hardly affected by increased nutrient concentrations in the external solution above the level necessary for optimum production. However, in lily some luxurious K uptake was found by an increased EC value. The uptake concentrations also were stable in the range from the optimum until the highest EC values realised in the experiment. For lily, however, an increased uptake concentration was found for K.

The K absorption seemed to be an important factor in the osmotic adjustment of the crops under discussion. All crops substantially increased their internal osmotic potential by an increased K concentration in the plant sap. With kohlrabi and lettuce this was realised merely by increased dry matter concentrations of the plant, a mechanism not evident with lily. This crop realised the higher K concentration in the plant sap by extra absorption of this element on dry matter basis, thus the extra absorption at increased external osmotic potentials may not simply described as a luxurious phenomenon, because it is a necessity for osmotic adjustment.

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Tables

Table 1. Uptake concentrations of the crops (mmol L^{-1}) in relation to the concentration of the nutrient solution in the substrate (EC_{ss}), calculated from the data of tissue analysis.

EC_{ss}	Nutrients							
	Na	K	Ca	Mg	N	Cl	P	S
				Kohlrabi				
1.3	0.2	3.2	0.9	0.2	4.9	0.3	0.4	0.7
2.2	0.4	5.5	1.6	0.5	10.2	0.4	0.6	1.0
3.2	0.5	5.6	1.8	0.6	10.9	0.4	0.6	1.0
4.2	0.4	5.5	1.7	0.6	10.8	0.5	0.6	1.0
4.9	0.3	5.5	1.6	0.5	10.8	0.4	0.5	1.0
6.0	0.2	5.6	1.8	0.5	10.4	0.4	0.5	0.9
				Lettuce				
1.2	0.2	3.6	0.4	0.2	5.0	0.5	0.4	0.2
2.2	0.2	4.4	0.5	0.3	7.0	0.3	0.4	0.2
3.4	0.2	4.7	0.5	0.3	7.6	0.3	0.4	0.2
4.6	0.2	5.1	0.6	0.4	7.7	0.4	0.4	0.2
5.8	0.2	4.7	0.6	0.4	7.2	0.3	0.4	0.2
6.6	0.1	4.4	0.6	0.3	6.8	0.3	0.3	0.2
				Lily				
1.2	0.3	2.3	0.8	0.3	4.0	0.2	0.3	0.2
2.2	0.2	2.8	0.8	0.3	4.1	0.2	0.2	0.2
3.2	0.1	3.2	0.7	0.3	4.0	0.2	0.2	0.2
4.2	0.1	3.0	0.7	0.3	3.7	0.1	0.2	0.2
5.1	0.1	3.2	0.7	0.3	3.7	0.1	0.2	0.2
6.0	0.1	3.2	0.7	0.2	3.6	0.1	0.1	0.2

Table 2. Uptake concentrations at optimum production level, expressed as mmol L^{-1} of water absorbed by the crops.

Crops	Na	K	Ca	Mg	N	Cl	P	S
Kohlrabi	0.36	5.54	1.70	0.54	10.62	0.42	0.56	0.98
Lettuce	0.18	4.66	0.56	0.34	7.26	0.32	0.38	0.20
Lily	0.18	2.55	0.74	0.28	3.85	0.15	0.20	0.20

Table 3. Concentrations of nutrients in the root environment at optimum production of the crops, expressed as mmol L^{-1}.

Crops	Na	K	Ca	Mg	N	Cl	P	S	EC
Kohlrabi	2.6	4.8	4.8	2.4	9.2	0.6	0.6	5.4	2.3
Lettuce	2.4	8.0	5.8	3.0	14.6	0.6	0.6	4.3	2.7
Lily	1.4	2.4	2.4	1.2	5.8	0.4	0.9	1.5	1.1

Table 4. Fractions of nutrients and water drained to waste at optimal nutrient concentrations in the root environment, without reuse of the drainage water.

Crops	Na	K	Ca	Mg	N	Cl	P	S	Water
Kohlrabi	0.41	0.12	0.30	0.31	0.12	0.23	0.04	0.48	0.19
Lettuce	0.40	0.20	0.37	0.42	0.22	0.34	0.03	0.41	0.24
Lily	0.54	0.26	0.54	0.55	0.35	0.44	0.25	0.70	0.35

Table 5. Concentrations of nutrients of plant tissues (mmol kg^{-1} dry matter) grown at optimum values in the external solution.

Crops		Nutrients					
Type	Plant part	K	Ca	Mg	N	P	S
Kohlrabi	Top	1806	842	215	3398	157	404
	Tuber	1395	129	96	2496	178	178
Lettuce	Head	2405	266	164	3777	223	93
Lily CK*	Top	796	224	108	1546	105	58
	Bulb**	531	109	66	1078	107	55
Lily SG*	Top	803	214	96	1484	68	38
	Bulb**	591	60	41	1091	77	14

* Cultivars: Connecticut King (CK) and Star Gazer (SG); **Data of sand grown bulbs.

Figures

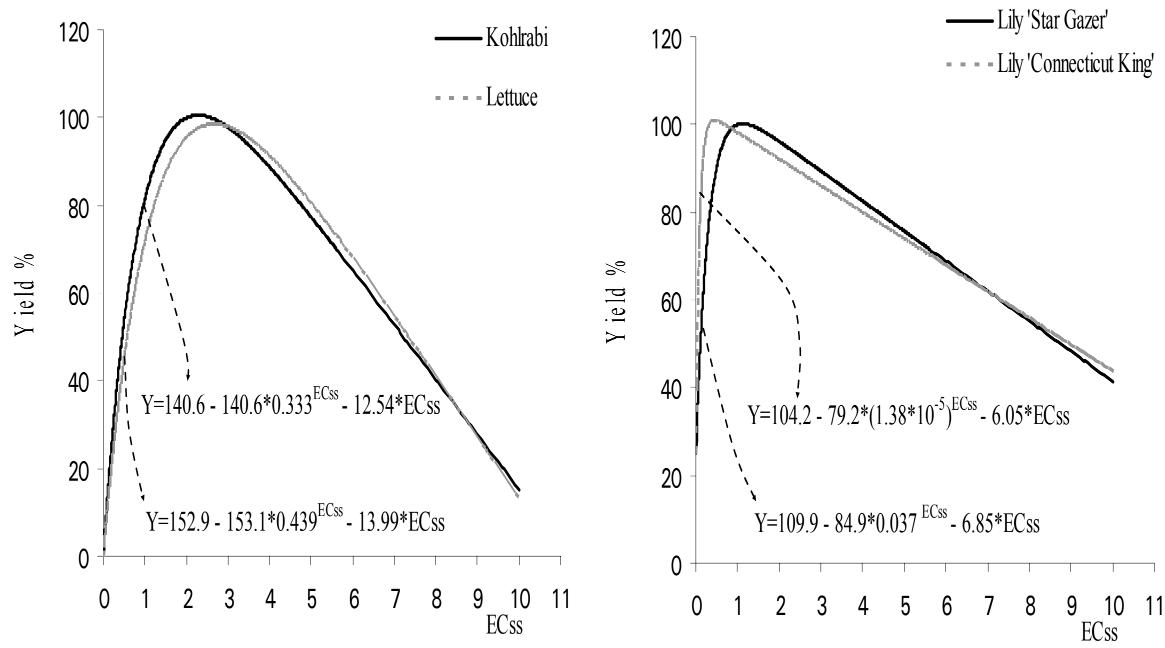

Fig. 1. Relationships between the EC in the root environment (EC_{ss}) and the relative (%) marketable fresh yields of the crops under discussion (Sonneveld et al., 2004). The functions adjusted were of the model Yield% = A + $BQ^{EC_{ss}}$ + C EC_{ss}.

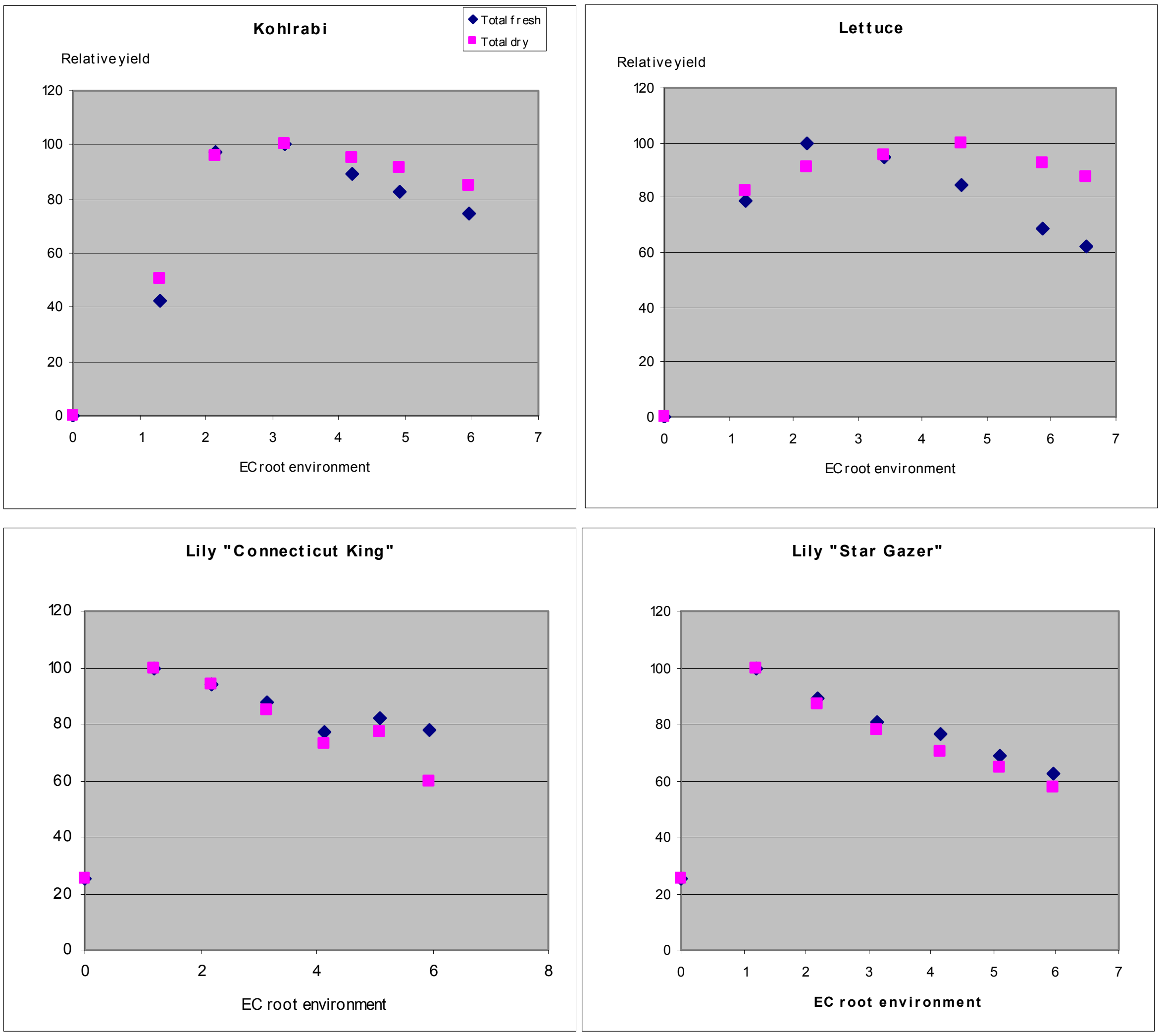

Fig. 2. Relationship between the EC (dS m^{-1}) in the root environment and the relative (%) total fresh and total dry matter productions of different crops.

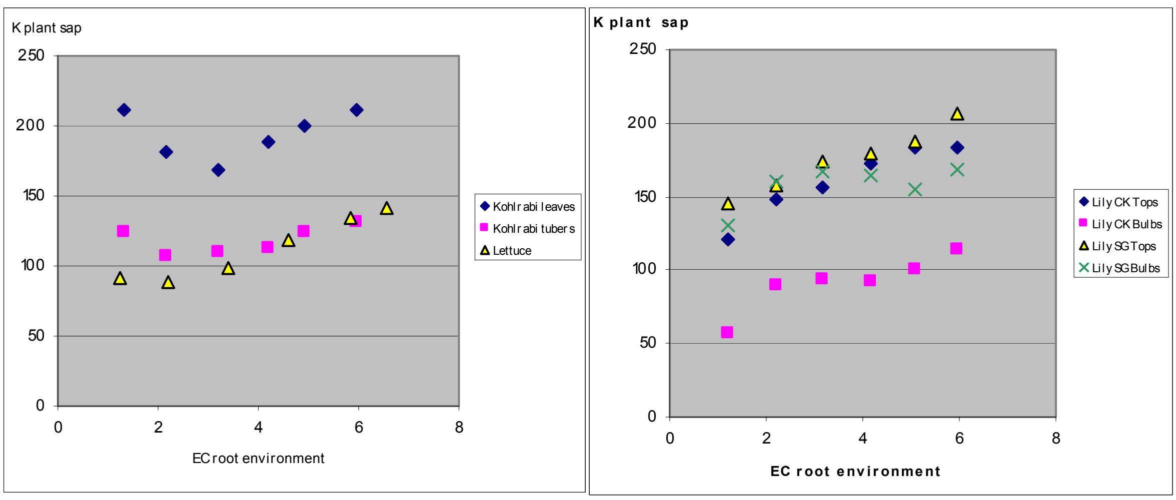

Fig. 3. Relationship between the EC (dS m^{-1}) in the root environment and the K concentration in the plant sap (mmol L^{-1}).