



## Salt gradients near roots of a rose plant by using a model system

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### Abstract

The ionic concentration of the nutrient solution absorbed by a plant may dramatically vary over a period of 24 hours ; yet, it is not common to modify the feeding solution at this short time scale. Any lasting discrepancy will generate concentration gradients at the root surface, possibly responsible for plant stress and stomatal closure, but such local gradients are diluted in the drainage flow and their intensity is usually underestimated. A direct evidence of salinity gradients was obtained by piling absorbing paper sheets directly in contact with the bare root system of a rose plant grown with a nutrient film technique (NFT). After a period of high transpiration rate, paper sheets exhibited very different salt contents at various distances from the root surface. These concentration gradients can be only alleviated by efficient washing through a high rate recycling of drainage solutions.

**Key words:** Saline gradients, rose plants, root surface, experiments.

### Introduction

Greenhouse soilless cultivation technique helps control most environmental factors of a plant, and in particular, it helps meeting its hydric and mineral requirements. Water and nutrients are accurately supplied by a feeding solution through drippers. To ensure water availability to the plant, one must also prevent water retention by the medium due to the osmotic pressure caused by excessive salinity<sup>1</sup>. For this reason, one should try to keep the composition of the mineral solution close to the actual needs of the plant at the shortest possible time scale.

It is known that nutrient and water uptake are not constant in time: they vary according to plant development stage, which is a slow variation, but they also vary according to the incident solar energy and to the saturation deficit of the air<sup>2</sup>. Thus, the pertinent time scale for adjusting plant nutrition may be short, but usual cultural techniques using a substrate like rockwool or perlite are not able to respond in such a short delay. It takes more than one day (in summer) and more than one week (in winter) to flush the medium with a new solution when operating with a 20% drainage rate<sup>3</sup>. As a result, roots are usually in contact with a nutrient solution that does not correspond to the instant requirements of the plant. This misadjustment generates salinity drifts in the medium which can be observed in the composition of the drainage water<sup>4</sup>. High levels of the concentration of the nutrient solution are responsible for plant stress<sup>5</sup> and have a negative effect on stomatal conductance and photosynthesis of rose leaves<sup>6-7</sup>. Photosynthesis affects not only flower yield but also plant osmotic pressure, thus leading to a quality decrease of flower stems<sup>8</sup>. In most cases, the mismatch between the electrical conductivity of the feeding solution and that of the drainage water does not exceed one or two mS/cm, and a correction on the fresh solution can be tempted to reduce this gap. However, this correction usually comes much too late and actual salinity gradients inside the

root medium are not correctly estimated from the mean drainage composition.

As the absorption concentration of the plant decreases with increasing transpiration<sup>9</sup>, a feeding solution which is kept invariant during this period generates ion accumulations in the vicinity of the roots<sup>10</sup>. The volume concerned by ionic accumulation around the roots is small compared with the whole root medium, since roots are thin filaments scattered in the medium. Therefore, measuring the concentration of the leachates which represent an average over the whole root volume gives little information on actual local gradients<sup>11</sup>.

The objective of this study is to have an idea on the variation of the concentration of the nutrient solution in the immediate vicinity of the root system of a rose plant, as rose is especially sensitive to salinity. Because, it is hard to measure the drift in concentration in the real system, a direct evidence of such local gradients has been searched and found by using a specific model system.

### Material and Methods

It is too difficult to isolate the tiny cylindrical volume directly in contact with a thin root. It is much easier to work with a planar root system. When a plant is grown in nutrient film technique (NFT), its free root system is nearly flat (see Figure 1) and can be pressed into a disc, so that the vicinity of the roots can be assimilated to successive plane layers at increasing distances from the roots.

**Principle of the method:** The root system of a plant grown in a nutrient film technique (NFT) channel was arranged as a thin disc maintained in contact with a porous medium by compression. The porous medium was made of successive independent porous paper layers that could be ultimately separated. The plant was fed by capillarity through the pile of

porous layers. A high salinity mineral solution was prepared according to the ionic balances recommended by Brun<sup>12</sup>, and the plant was placed under high relative humidity (60-65%) and low solar radiation (about 100 W.m<sup>-2</sup>) for three or four days. Then the plant was placed in conditions of high solar radiation (400 W.m<sup>-2</sup>) and low relative humidity (20-30%) to enhance transpiration. After two days of such conditions, the stratified medium was separated from the plant and disassembled. Successive layers of porous paper disks were extracted and analyzed. The observed compositions gave a direct measure of the actual concentration gradient close to the roots.

**Experimental set-up for measuring salt concentration levels in the roots medium:** In a first series of trials, we chose to work on barley seedlings to have an idea on the model system used to determine salt gradients in the presence of a plant without damaging root system. These seedlings were grown on a horizontal porous disc (a thin polymer material) placed inside a plastic cylinder and put in contact with water. With this method, the barley seeds developed a dense root system nearly planar. In a second series of trials, the measurements were carried on adult rose plants (*Rosa hybrida*, cv. Sweet Promise). In such a case, it was necessary to grow the plants first using the nutrient

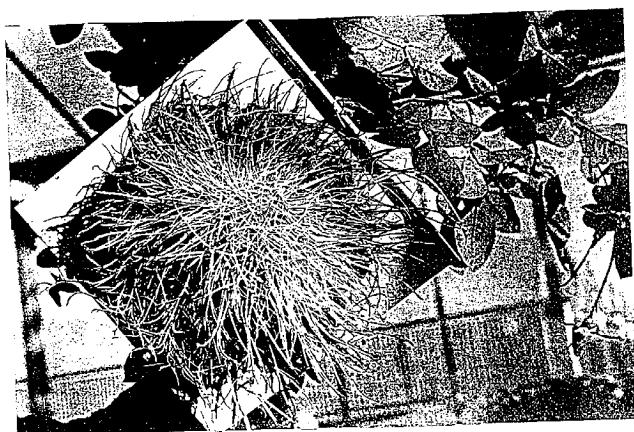


Figure 1. Bare root system of a rose plant after manipulation.

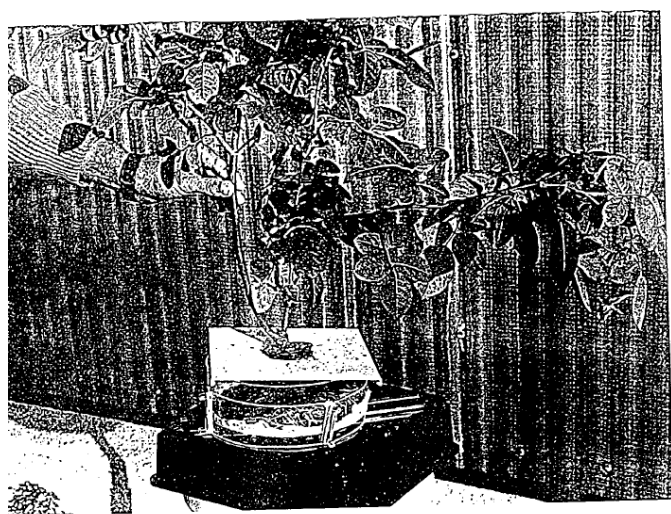


Figure 2. The cylinder in the top in presence of the rose plant.

film technique (NFT), so they could be moved without damaging the root system (see Figure 1). The root system was then carefully distributed on a plane porous surface (same thin polymer material of larger diameter). To insure a dense and plane root geometry and a good contact with the underlying medium, it was necessary to apply a pressure on the upper surface of the roots. In each case, the plants were fed from below by capillarity with a nutrient solution, and then acclimated under very mild climatic conditions implying low transpiration, during two days, a necessary delay for root adaptation. After this preparatory stage, the plants were placed on the top of a filter paper pile soaked with the same nutrient solution, and submitted during a few days in a greenhouse to strong solar radiation levels and low humidity to induce a strong transpiration demand.

**Technical details :** Circular filter paper sheets were specially designed to fit inside the plastic cylinder; the nutrient solution can only move up by capillarity through the filter pile to reach the root plane. Some of the circular filter sheets were pre-punctured and presented 6 mm diameter removable discs on their surface; such removable discs were made on every 5th filter sheet (thus at a 1 mm vertical distance). The plastic cylinder containing the filter paper pile and the barley plantlets was placed in a shallow tank filled with the nutrient solution. In the upper cylinder (see Figure 2), a porous membrane allowed to separate the bare root system from the absorbing paper and to define a precise root surface. The nutrient solution was prepared according to standard recommendations for the culture of rose plants and its concentration is indicated for each trial. The root medium was protected against radiation, heat and evaporation with the help of polystyrene and aluminum foils, to prevent any external effect on the composition of the feeding solution. To average out possible fluctuations of salt concentration on a given filter sheet, due to an uneven distribution of the roots system or some heterogeneity of the filter material, three discs were punctured in each sampling filter sheet. Figure 3 shows a sketch of the set-up in the case of a rose plant.

**Analysis of root medium concentrations :** After a few days of intense transpiration, the plants were separated from the filter-paper pile and the composition of the monodimensional root medium was examined in a very short period of time, to prevent diffusive re-equilibration in the medium. Thanks to the pre-punctured filter sheets, the extraction of root medium samples was very rapid. Each sample disc extracted from every fifth filter sheet was immediately placed in a psychrometer, to prevent further concentration modification by evaporation. Every filter sheet containing a disc sample was weighted in parallel, to check its degree of imbibition. Reliable psychrometric measurements required in fact to have identical (and weak) matrix retention pressures in the filter sheets. During the measurement process, the sample disc was introduced into a closed chamber in equilibrium with the ambient temperature. This ambient temperature was recorded. After cooling of the thermocouple contained in the room (by Peltier effect), this one had a temperature below that of the dew point and there was a condensation on the thermocouple. Then the temperature of the thermocouple increased gradually. When it reached the dew point, the condensation ceased. Become stable, the temperature

of the dew point corresponding to the sample was recorded. The final response in  $\text{mmol.kg}^{-1}$  is proportional to the difference of the two recorded temperatures. Indeed, this temperature difference characterizes the vapour pressure of the solution, which is a function of the salt concentration.

### Results and Discussion

As the salt concentration can vary on the surface of a given filter sheet ; the adopted value is the average over the results of measured concentrations of three different punctured discs present in each sampling filter sheet. During the experiments, the dispersion in weights of filter sheets did not exceed 10%, which is acceptable compared with the uncertainty of psychrometric measurements. For the measurements taken after one day of submissiveness of the plants to the conditions of intense radiation and low humidity, the variations of the concentration in the root medium were not significant. This was due to the period of adaptation of the plant to these conditions or to the weak salinity drift which we could not make in evidence.

In general, it was necessary to submit the plants to 2 or 3 days if intense transpiration. For each test, the salinity drift observed in the medium was then due to the lasting discrepancy between the concentration of the solution absorbed by the plant (called in short « absorption concentration ») and the concentration of the feeding solution.

The absorption concentration is calculated as follows :

$$C_{abs} = \frac{C_i M_i - C_f M_f}{T_r} \quad (1)$$

where  $C_i$  and  $M_i$  are the concentration and the mass of the feeding solution respectively, and where  $C_f$  and  $M_f$  are the concentration and the mass of the final solution respectively, and  $T_r$  is the transpiration rate measured as being the difference between initial and final mass of the nutritive solution. The measured maximum values of the solar radiation could reach  $500 \text{ W.m}^{-2}$  (at the end of May). It is useful to quote in each case the observed concentration absorption and the concentration of the feeding solution.

**Tests on barley:** In the first trial, a mass of 138 g of feeding solution with a concentration of  $92 \text{ mmol kg}^{-1}$  was submitted to a water loss of 40 g by transpiration. The concentration of the final solution was  $117 \text{ mmol kg}^{-1}$ . As a consequence, the absorption concentration taken up by the plants was  $30.75 \text{ mmol l}^{-1}$ , which is 3 times lower than the feeding solution. The concentration drift in the proximity of the root system as measured by the psychrometric tests on samples is shown in Figure 4 . The generated gradient raised the salinity by 30% at the root surface.

In the second trial the experiment was repeated with a lower irradiation but a longer period. A mass of 225 g of the same solution as in the first trial underwent a water loss of 66 g by transpiration and the final concentration was  $113 \text{ mmol kg}^{-1}$ . The observed absorption concentration was  $41.4 \text{ mmol l}^{-1}$ , which

was in fact higher than before. The concentration drift in the proximity of the root system as measured by the psychrometric tests on samples is shown in Figure 5, which shows that a weaker mismatch between offer and demand created weaker salinity peaks at the root surface.

**Application to Rosa hybrida (cv. Sweet Promise) :** In the first trial, a mass of 1648 g of fresh nutrient solution with  $93 \text{ mmol kg}^{-1}$  of concentration was placed in a tank to feed the bottom of the cultural system sketched in Figure 3. After 2 days of natural irradiation in a greenhouse, the rose plant lost 574 g of water by transpiration. The concentration of the final solution in the tank was equal to  $94 \text{ mmol kg}^{-1}$ . This corresponds to an absorption concentration of  $91.12 \text{ mmol l}^{-1}$ , not very different from the feeding solution. After measuring the concentration in the filter sheets at various positions, the saline gradient observed in the vicinity of the root surface is shown in Figure 6, which indicates that the saline peak was relatively moderate.

In the second trial, a mass of 1260 g of the same fresh nutrient solution was placed in the tank. After standing in a sunny ambiance, the rose plant lost 607 g of water. The concentration of the remaining solution increased to  $112 \text{ mmol kg}^{-1}$ . The absorption concentration was thus equal to  $72.56 \text{ mmol l}^{-1}$ , a value 22% smaller than that of the feeding solution. The saline gradient observed in the root medium is shown in Figure 7. The saline concentration observed at the contact with the root system was almost twice larger than that observable in the tank. In the third trial a 800 g initial mass of fresh nutrient solution was placed in the tank (Figure 3) and the rose plant was submitted to a sequence of 3 days of intense solar radiation. The transpiration process evacuated 440 g of pure water and the concentration of the remaining solution reached  $117 \text{ mmol kg}^{-1}$ . This corresponds to an absorption concentration equal to  $73.36 \text{ mmol l}^{-1}$ . After measuring the concentration of successive layers of filter paper sheets, the saline gradient built up in the root medium appeared as shown in Figure 8. The larger mismatch between the feeding and the absorbed solution created a much larger saline gradient, with a 4-fold concentration increase near the root surface. The salinity drift in the tank was far from representing the true concentration value felt by the plant roots.

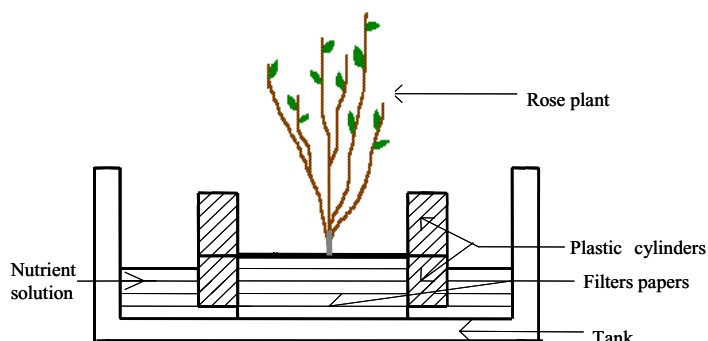


Figure 3. Sketch of the set-up in the case of a rose plant.

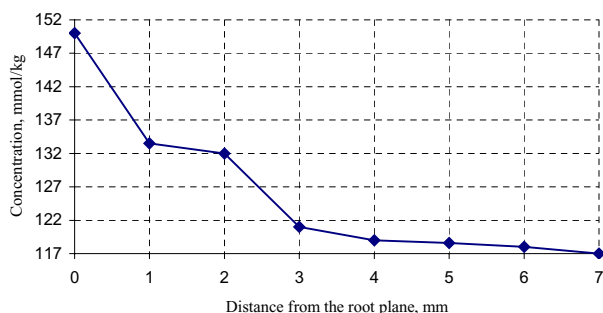


Figure 4. Concentration variation near the root plane in the first barley trial.

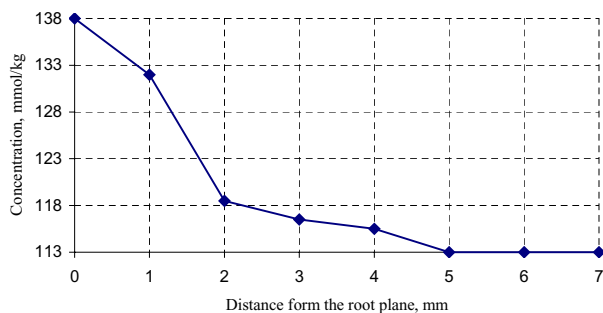


Figure 5. Concentration variation near the root plane in the second barley trial.

### Conclusions

Experimental evidence of possible concentration gradients in the vicinity of the root surface was obtained for barley and rose plants cultivated in porous media, with the help of a simple model system which makes the root medium geometry monodimensional. Such saline gradients result from a mismatch between the feeding solution and the actual solution absorbed by the plant. No gradient would take place in a liquid root medium like nutrient film technique (NFT), but most root media used in other soilless culture media are porous substrates.

The present experiments on rose plants showed that it is easy to build up a 4-fold concentration increase at the root surface with a relatively moderate (15%) mismatch in concentration of solutes. Most of all, one should be aware that salinity drifts observed in the feeding tanks (or equivalently in a rockwool substrate, for example) is very far from representing the actual salinity peak close to the root surface. This phenomenon is easy to reproduce quantitatively, provided one can estimate the surface area of active roots of a plant.

As a result, we can state that many cultural problems occurring in crops submitted to conditions of strong climatic demand and

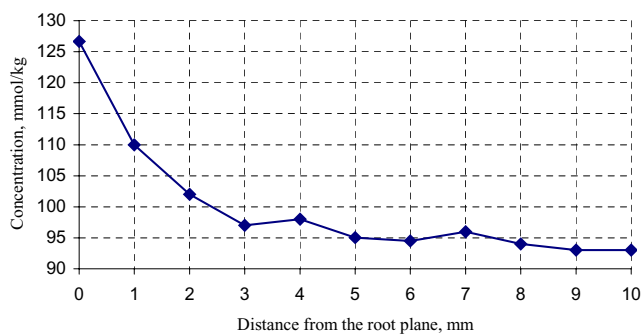


Figure 6. Concentration variation near the root plane in the first rose trial.

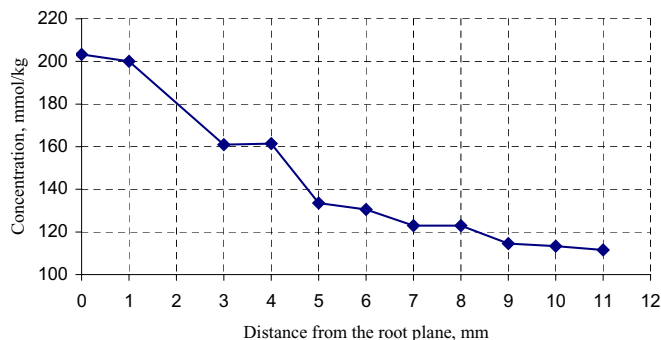


Figure 7. Concentration variation near the root plane in the second rose trial.

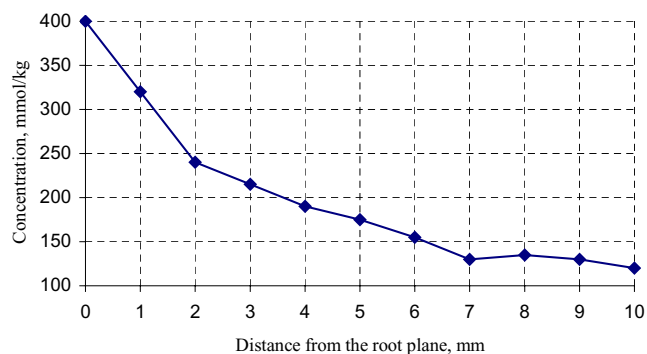


Figure 8. Concentration variation near the root plane in the third rose trial.

Table 1. Summary of the variables used.

Variable	Unit	Significance
$C_i$	$\text{mmol.kg}^{-1}$	Concentration of the feeding solution
$M_i$	kg	Mass of the feeding solution
$C_f$	$\text{mmol.kg}^{-1}$	Concentration of the final solution
$M_f$	kg	Mass of the final solution
$T_r$	kg	Rate of transpiration
$C_a$	$\text{mmol.kg}^{-1}$	Absorption concentration

high transpiration could be due to a saline stress resulting from local concentration peaks at the root surface. To prevent such salinity gradients, one could try to reduce the mismatch between offer (feeding solution) and demand (plant absorption); but this is difficult as the absorption concentration of the plant varies on a short time scale. It is easier to apply excessive volumes of feeding solution so that possible gradients are washed away. This is why leaching rates as large as 30% are applied in soilless crops grown with open drainage. However, such leaching rates can be sometimes insufficient, and in addition, they can generate pollution in the soil. The best answer to the problem is certainly offered by the technique of recirculating solution, now more and more common among professionals.

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