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WATER DEMAND OF CARROTS AS AFFECTED BY THE NUTRIENT, SALINITY AND AERATION STATUS OF THE SOIL

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Abstract

The water requirement of carrots as affected by salinity, nutrient supply and soil aeration was investigated in a groundwater-influenced silty soil under field and growth chamber conditions. The predominant factor controlling the evapotranspiration coefficient (amount of water used/unit biomass produced) was the nutrient level of the soil. Soil salinity and soil aeration had a lesser impact with respect to the evapotranspiration coefficient. Under optimum conditions and favourable nutrient supply, evapotranspiration coefficients amounted to 300-400 L kg^{-1} storage root dry weight (RDW). The evapotranspiration coefficients remained unchanged up to salt concentrations of 16 mS/cm in the soil solution. At higher salt concentrations, the evapotranspiration coefficients increased to 600-700 L kg^{-1} RDW. Low nutrient levels increased the evapotranspiration coefficients to values significantly higher than 1000 L kg^{-1} RDW. Evapotranspiration efficiency, the reciprocal value of the evapotranspiration coefficient, was strongly decreased by low nutrient levels associated with increased salinity and/or insufficient soil aeration. Evapotranspiration coefficients were essentially constant at high yield levels.

1. Introduction

Most water-requirement studies have concentrated on the climatic factors that influence water use for crop production (Hanks, 1983). The water requirement of a plant is influenced frequently by additional factors such as nutrient supply, salinity and impeded aeration. Relatively little is known about the influence of various salinity levels, nutrient and oxygen levels and their interactions on water use efficiency.

Therefore, the influence of various salinity, nutrient and soil aeration levels on water demand and evapotranspiration efficiency of carrots (Daucus carota L., var Nandor) were investigated under field and growth chamber conditions.

Water demand and evapotranspiration efficiency are usually evaluated on the basis of the plant's reaction to water supplies which vary temporally and quantitatively.

A different approach was chosen for our experiments. The ability of the experimental soil to transport water was sufficiently high so as to create non-limiting conditions for supplying water to the plants. The investigated system allowed for the quantification of water demand as being a function of growth stage, soil nutrient level, soil salinity and soil aeration status of the soil.

2. Material and methods

Soil columns, 0.25 m in diameter, with groundwater depths of 0.5, 1.0 and 1.5 m (growth chamber experiments) and of 0.6, 0.9, 1.2 m (field experiments) were homogeneously packed with a silty soil to a bulk density of 1.32 g cm^{-3}. The composition of the soil was: clay 9.1 %, silt 59.5 %, sand 31.4 %, $CaCO_3$ 8 % and organic matter 0.85 %. The parameters measured were: electrical conductivity EC_{se} (13.7 mS cm^{-1}), cation exchange capacity (4.8 cmol kg^{-1}), pH (8.2) and saturated hydraulic conductivity (8 cm d^{-1}).

Non-saline conditions were obtained by leaching the soil with tap water and the desired salinity levels by percolating the soil with salt solutions. Differences in soil aeration resulted from different groundwater depths.

Soil water suction was measured by means of tensiometers and salt concentrations were determined with salinity sensors. The groundwater was maintained at a constant level by a float regulator.

A float maintained a constant groundwater level. Water was supplied from calibrated bottles on which the evapotranspirational loss of water could be read. The plants depended entirely on water supply from the groundwater by means of capillary rise in the growth chamber experiments. The electrical conductivity of the groundwater was 2.6 mS cm^{-1}. Two additional groundwater salt concentrations of 1.18 and 3.34 mS cm^{-1} were investigated in the first experiment.

In the field, the soil columns were buried in the soil so that the upper surface was at the same level as the surrounding soil. An outlet 0.5 cm above the groundwater level permitted the collection of the drainage water.

Fifty seeds were planted in each soil column. In the field experiment, the surrounding terrain was also cultivated with carrots. Twenty days later the number of plants was reduced to ten plants per column.

Plant growth was related to soil solution salt concentration averaged over depth and time.

Long term average temperatures and relative humidities of the field site were simulated in the growth chamber. The average daily mean temperatures were 11.0, 15.2 and 18.2 °C for the month of April, May and June, respectively. Relative humidity and photon flux density did not differ between months and their values were 64 % and 579 $\mu mol \cdot s^{-1} m^{-2}$, respectively. The monthly averages of temperature and relative humidity measured in the field were 18.5, 23.5, 19.4, 15.3 and 9.5 °C, respectively, and 58, 55, 66, 70 and 76 %, respectively, for the months of June, July, August, September and October.

3. Results

3.1. Water use as affected by high salinity levels and low nutrient levels

Before the beginning of the experiment the top twenty centimeters of the strongly salinized soil were leached with tap water. Different groundwater concentrations did not influence the growth and the water use of plants due to the low capillary rise of groundwater.

Storage root dry weight (RDW) increased with increasing evapotranspiration (ET). The following regression equation was determined: RDW = -21.48 + 1.65 * ET (r^2=0.631). A closer correlation was found between the soil salt concentration and the evapotranspiration coefficient (ETC), defined as amount of water used per unit dry weight produced. With increasing salt concentration, RDW decreased linearly, whereas there was a linear increase in ETC (figure 1). Increasing the salt concentration of the soil solution from 12 to 18 mS cm^{-1} increased the evapotranspiration coefficient more than threefold from 475 L kg^{-1} to 1468 L kg^{-1} RDW.

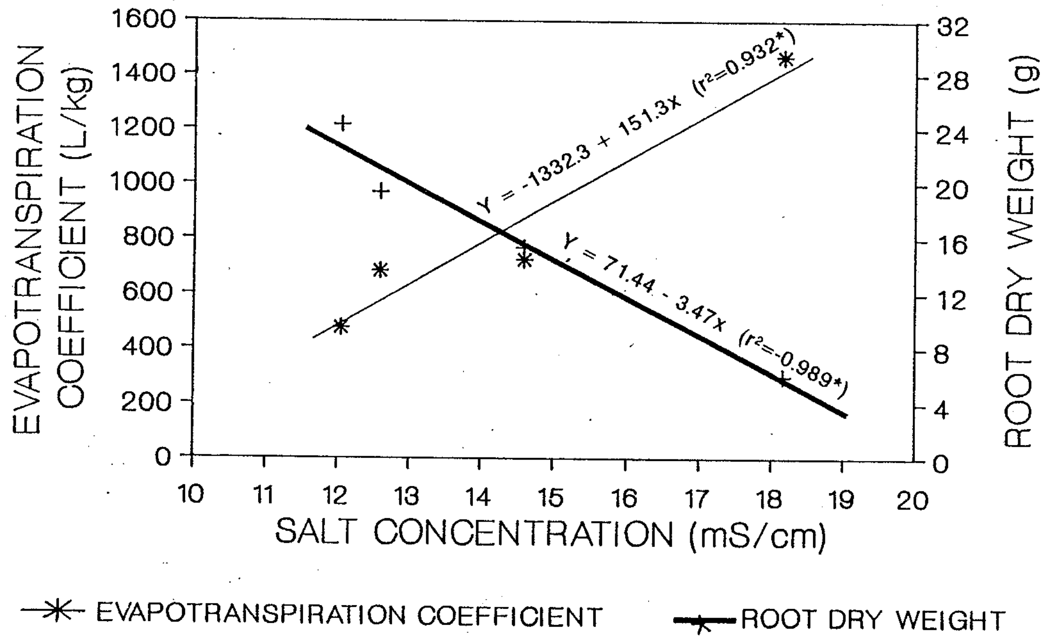

Figure 1 - Evapotranspiration coefficients and storage root dry weight production of carrots as affected by soil salinity and low soil fertility.

3.2. Water use as affected by low or adequate nutrient level under low to moderate soil salinity

Two different treatments were compared in this experiment. One series of soil columns with groundwater depths of 50, 100 and 150 cm was thoroughly desalted and poorly supplied with nutrients.

A second series of soil columns with a constant groundwater depth of 100 cm was well supplied with nutrients. In the second treatment the soils were salt free in 0-30 cm depth and the initial salt concentration in the subsoil averaged 6 mS cm^{-1}.

As in the first experiment, a positive correlation between evapotranspiration and storage root dry weight production was observed. The regression equation determined for both subtreatments was: RDW = -125.3 + 2.49 * ET ($r2=0.772^{*}$). By restricting the regression analysis to the first subtreatment only a very close relationship between evapotranspiration and storage root dry weight production was found: RDW = -22.207 + 1.082 * ET ($r^2=0.995^{*}$).

In contrast to the first experiment, a higher storage root dry weight production and lower evapotranspiration coefficients were observed with increasing salt concentrations (figure 2). With a favourable nutrient supply and under moderate salinity, the evapotranspiration coefficients averaged 356 L kg^{-1} RDW. This value increased to 597 L kg^{-1} RDW under nutrient deficient, initially non-saline conditions.

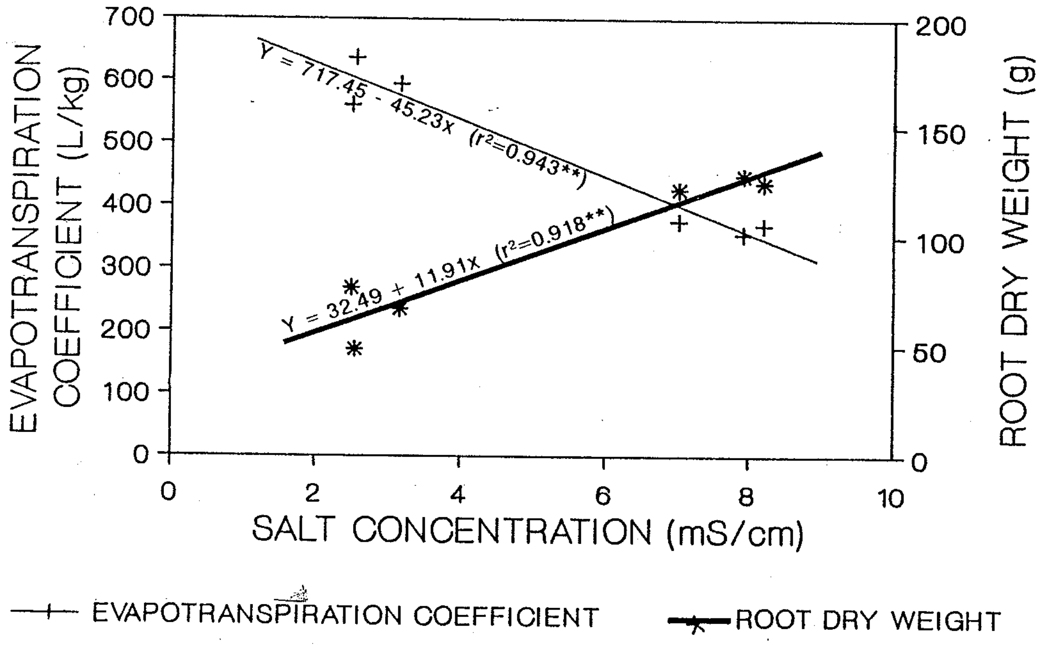

Figure 2 - Evapotranspiration coefficients and storage root dry weight production of carrots as affected by soil fertility and moderate soil salinity.

The measured NO_3 concentrations in the moderately salinized and the non-saline treatment were 7.4 and 1.0 meq L^{-1}, respectively at the beginning of the experiment. Differences with respect to other nutrients were small between the two treatments. Whereas NO_3 was almost completely depleted in the non-saline treatment, initial and final NO_3 concentrations did not differ appreciably in the moderately saline treatment. Therefore, the higher biomass production and more efficient water use, as demonstrated by plants growing in the moderately saline treatment, are probably due to the higher nitrate level in the soil as compared to the non-saline treatment.

3.3. Water use as affected by increasing salinity levels and optimum nutrient levels

The influence of increasing salinity levels on water use was investigated in soils well supplied with nutrients in a growth chamber experiment. Various salinity levels were obtained by leaching the subsoil with an one strength Hoagland nutrient solution containing appropriate amounts of NaCl. Prior to this treatment, the top thirty centimeters of the soil were removed and percolated with the same nutrient solution and thereafter refilled in the soil columns.

Storage root dry weight production showed very significant increases with increasing evapotranspiration (figure 3) and decreased with increasing salt concentration (figure 4). At optimum nutrient supply evapotranspiration coefficients were not affected by salt concentrations as low as 16 mS cm^{-1} (figure 4). At higher salt concentrations, the evapotranspiration coefficients increased from 400 to 630 L kg^{-1} root dry weight.

Extremely high evapotranspiration rates were observed under the investigated conditions. The highest measured value was 3 cm per day. Soil suction then increased to 366 cm in 20 cm depth. This shows that, with regard to water supply, non-limiting conditions existed in the investigated soil.

3.4. Influence of soil aeration on water use

The influence of increasing groundwater depth on water use efficiency was investigated in a growth chamber and field experiment. In both cases the soils were poorly supplied with nutrients. A non-saline soil was used in the growth chamber experiment and a moderately salinized soil in the field experiment.

Storage root dry weight production and evapotranspiration increased considerably by lowering the groundwater depth from 50 to 150 cm (figure 5). The evapotranspiration coefficient decreased slightly but highly significant with increasing groundwater depth (GD): $ETC = 507.6 - 0.327\ GD$ ($r^2=0.999^{**}$).

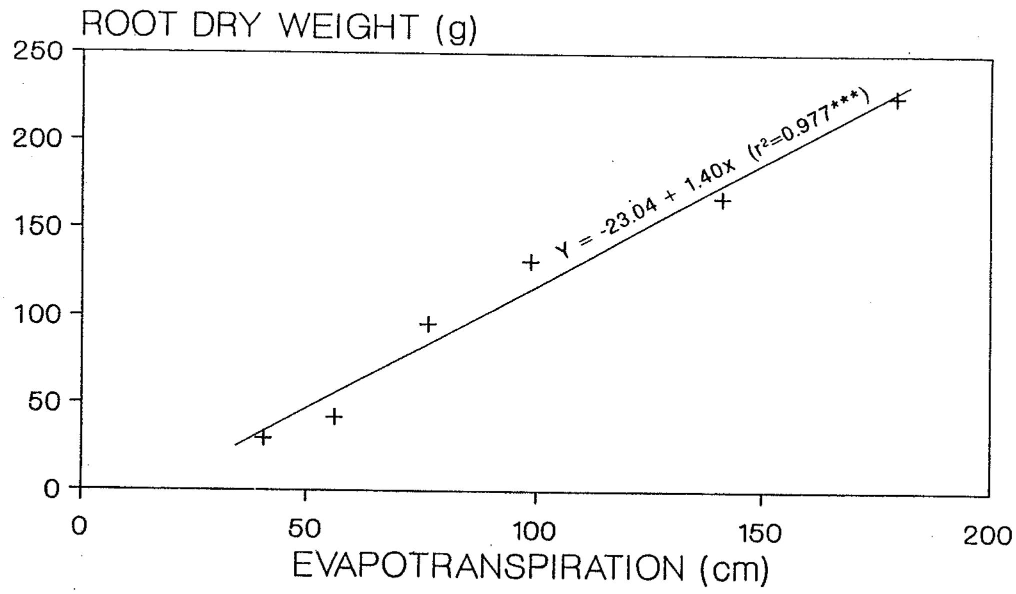

Figure 3 - Relationship between storage root dry weight production and evapotranspiration under optimum nutrient supply.

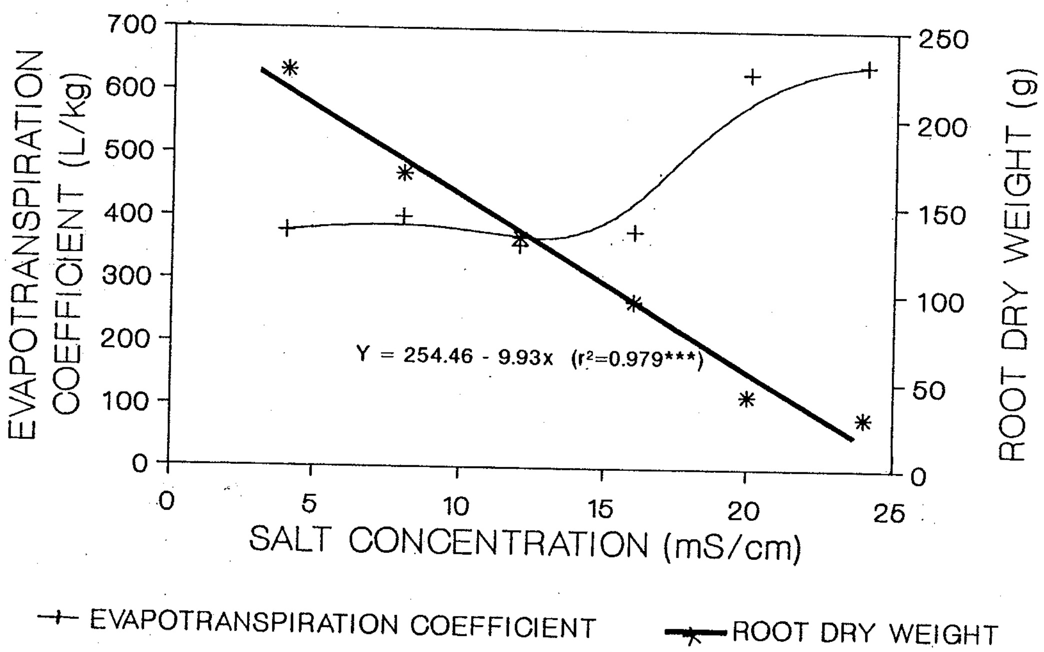

Figure 4 - Influence of salt concentration on evapotranspiration coefficients and storage root dry weight production of carrots.

The remaining air-filled pore volumes in 5 cm depth were 2.5, 4.5 and 5.9 % for the treatments with groundwater depths at 50, 100 and 150 cm, respectively. No correlation was found between groundwater depth and soil salt concentration. Therefore, differences in water use and evapotranspiration efficiency are attributed to impeded aeration which increased with lower groundwater depths and negatively influenced plant production.

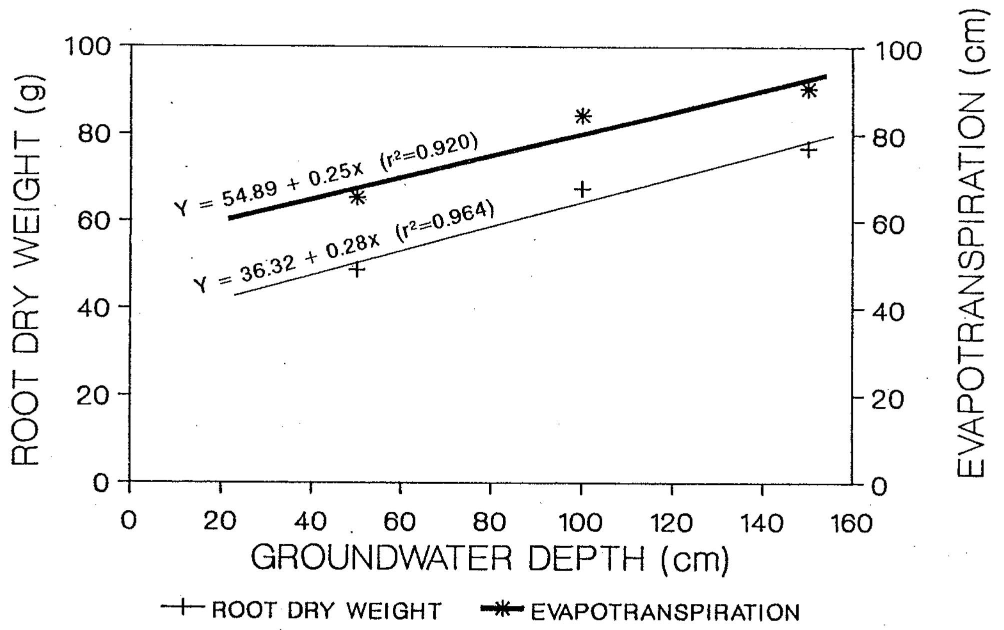

Figure 5 - Influence of groundwater depth on storage root dry weight production and cumulative evapotranspiration of carrots under growth chamber conditions.

The negative effect of decreasing groundwater depths was even more pronounced in the field experiment. Rainfall contributed to a deterioration in the soil conditions as evidenced by a decreased root growth. Silty soils are very much prone to surface sealing and crusting caused by supplemental irrigation or heavy rainfalls.

Storage root dry weight production was positively correlated with the groundwater depth (r^2=0.967). Evapotranspiration increased slightly with increasing groundwater depth (ET = 59.08 + 0.05 GD, r^2=0.375), whereas evapotranspiration coefficients decreased strongly with increasing groundwater depth (figure 6).

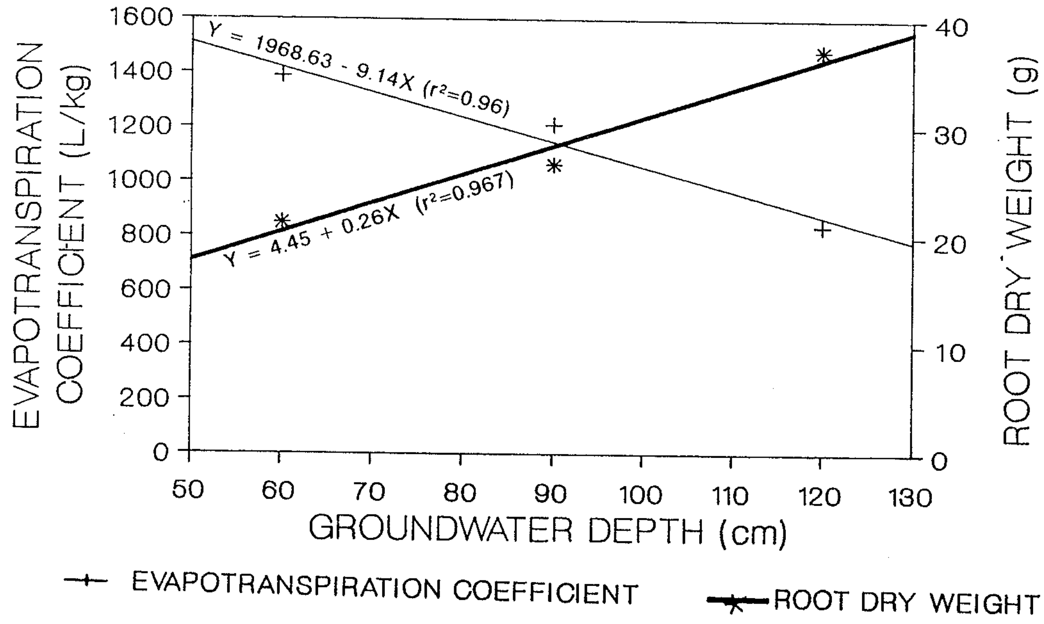

Figure 6 - Influence of groundwater depth on evapotranspiration coefficients and storage root dry weight production of carrots under field conditions.

4. Discussion

The water use by plants is regulated primarily by the evaporative potential of the atmosphere, the amount of available water, certain plant characteristics, mainly leaf area index and leaf area duration. The evapotranspiration efficiency is mainly influenced by the soil fertility status, the soil salinity and oxygen level, the leaf area index and climatic factors (vapour pressure deficit, advective energy).

Under optimum conditions and favourable nutrient supply, evapotranspiration coefficients (ETC) amounted to 300-400 L kg^{-1} storage root dry weight (RDW). Low nutrient levels increased ETC to values significantly higher than 1000 L kg^{-1} RDW. An extremely low water use efficiency resulted from poor nutrient supply associated with a salt stress or impeded aeration.

Viets (1962) pointed out that evapotranspiration efficiency is essentially constant at high yield levels. This was confirmed by the results obtained in this study.

Water use is markedly affected by soil fertility status which greatly influences leaf area and leaf area duration (Campbell et al., 1977). De Wit (1958) stated that reduced transpiration due to a lower leaf area index is the main mechanism in reducing evapotranspiration efficiency in plants having an inadequate supply of nutrients. Evapotranspiration efficiency improves in general as the availability of plant nutrients increases. Carlson et al. (1959) and Power (1983) showed that evapotranspiration efficiency was greatly improved by increased rates of N fertilizers. In this study, a more efficient water use was demonstrated by plants growing in soils with higher nitrate concentrations.

The evapotranspiration coefficients remained unchanged up to salt concentrations of 16 mS cm^{-1} in the soil solution. Evapotranspiration and storage root dry weight production were linearly decreased in the same salinity range. At higher salt concentrations the evapotranspiration coefficients increased to 600-700 L H2O kg^{-1} RDW. Evapotranspiration efficiency seems not to be affected by increasing salinity levels as long as no toxic effects or nutrient imbalances occur.

Raising the groundwater level from 150 to 50 cm caused an increase in the evapotranspiration coefficients from 560 to 636 L H2O kg^{-1} RDW in the growth chamber experiment, whereas in the field experiment, a change in the groundwater level from 120 to 60 cm caused an increase of 840 to 1390 L kg^{-1} RDW. At shallower groundwater depths root growth was restricted by impeded aeration resulting from low air-filled pore volumes.

Storage root dry weight production was more negatively influenced than evapotranspiration efficiency by low soil nutrient levels, salinity or poor soil aeration.

The nutrient level of the soil was the main determining factor of evapotranspiration efficiency. Soil salinity and soil aeration proved to be of less importance.

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