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COMPARATIVE INVESTIGATIONS OF THE EFFECTS OF SALINITY AND MOISTURE STRESS ON GERMINATION AND SEEDLING GROWTH OF CARROTS

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Abstract

Water stress and salt stress can greatly affect germination and early seedling growth. In this study, we examined the effects of saline and non-saline moisture stress on germination and seedling growth of carrots. Germination and seedling growth were differently affected at comparable levels of matric and osmotic moisture stress.

Germination and seedling growth were not affected by osmotic potentials as low as -0.5 MPa. Germination and seedling shoot and root growth decreased markedly at matric potentials higher than -0.01 MPa. Matric potentials lower than -0.2 MPa decreased germination percentage and delayed germination rate. A moderate water stress caused a gradual decrease of shoot fresh weight and a marked increase in root growth.

Therefore, germination and seedling growth have to be rather related to the individual soil water potential components than to the total soil water potential.

1. Introduction

The Rhone valley in the southwestern part of Switzerland is one of the most productive agricultural region in the country. Favourable conditions for crop growth enable an intensive agricultural production. Due to increased salt concentrations in the alluvial soils, decreases in yield and losses of vegetable crops are frequently observed. During summer crops lack a sufficient supply of water. This deficit is supplemented partly by capillary rise from the groundwater and partly by irrigation. The salt concentration of the groundwater is high. The plants are stressed on the fine-textured alluvial soils not only because of increased salt concentrations in the groundwater and irrigation water but also because of insufficient soil aeration.

Poor crop stand is frequently observed with vegetable production in this area. Germination and seedling establishment are influenced by factors such as crusting, moisture, temperature, salinity, cultivar, and interactions of these factors (Sexton and Gerard, 1982). The soil microenvironment in which a seed is expected to germinate and become established as a seedling is likely to have a higher salt concentration than the bulk of the soil because of evaporation and capillary rise of saline water (Pasternak et al., 1979). Soluble salts accumulate at the top of the crop bed where seed is planted.

To identify the processes leading to poor crop stand we investigated the effects of saline and non-saline moisture stress on germination and seedling growth of carrots.

2. Material and methods

Germination and seedling growth of carrots (*Daucus carota* L., var. Nandor) were investigated in two different soils. The experiments were run for 25 days in germinators kept at a constant temperature of 25 °C. Fluorescent lighting was provided for 12 hours daily at a proton flux intensity of 95 μmol m^{-2} s^{-1}.

Various matric and osmotic potentials in soil were created by adding different amounts of salt solutions to the same mass of air dried soil. The relationship between gravimetric water content and soil water suction was based on a previously determined soil water retention curve. The salt solutions consisted of 3/4 strength Hoagland nutrient solution containing different amounts of equal parts by weight of $CaCl_2$ and NaCl. The soil was thoroughly mixed with these solutions and then placed in tightly closed plastic boxes and left two weeks for further equilibration. Thereafter the soil was sieved to 3 mm, filled in 2.5 cm high plastic rings to a density of 1 g cm^{-3}, sown with fifty seeds and incubated in transparent boxes (9 cm diameter, 5 cm high). The experimental soil consisted of 31 % sand, 60 % silt and 9 % clay.

In a second experiment, the silty soil was mixed with 36 % of weight of sand with grain diameters of 1.5-2.2 mm. The influence of a series of numerically equivalent total soil water potentials with different or numerically equivalent matric and osmotic potential components on germination and seedling growth was investigated in three different treatments.

3. Results

At high soil moisture potentials germination decreased significantly in the silty soil (figure 1). Lower matric potentials in the investigated range did not influence germination percentage. The same was found with osmotic stress at all investigated soil water potentials.

Seedling growth did not quantitatively correlate with germination. Seedling growth showed a much higher sensitivity to changes in matric potential, but was not affected by osmotic soil water potentials ranging from -0.1 MPa to -0.5 MPa (figure 2). Shoot growth was markedly decreased at matric soil water potentials higher than -0.01 MPa and gradually at matric potentials lower than -0.2 MPa. Root growth reacted most sensitively to moisture stress. High matric potentials severely inhibited root growth, whereas a moderate drought stress lead to a substantial increase in root growth (figure 2).

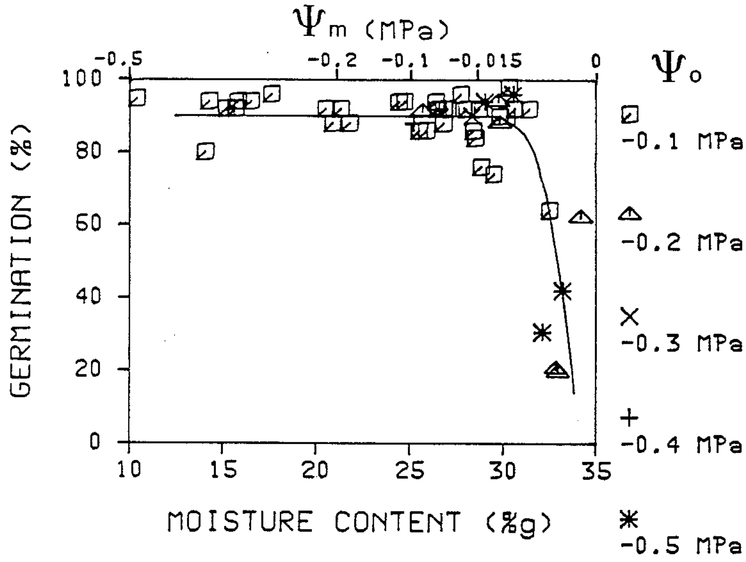

Figure 1 - Germination of carrots in a silty soil as influenced by the matric and osmotic soil water potential.

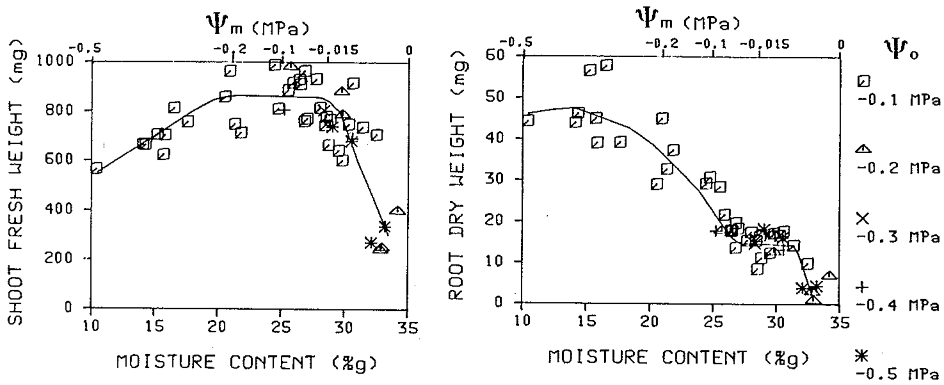

Figure 2 - Shoot fresh weight and root dry weight production of carrot seedlings in a silty soil as influenced by the matric and osmotic soil water potential.

Comparable results were found in the silty soil which contained 36 % of added sand. Osmotic soil water potentials between -0.1 MPa and -0.5 MPa did not influence germination, whereas matric soil water potentials lower than -0.3 MPa strongly decreased and reduced germination (figure 3). In the third treatment, where numerically equivalent matric and osmotic potentials had been created in the soil, germination showed a decrease only at a total soil water potential of -0.55 MPa.

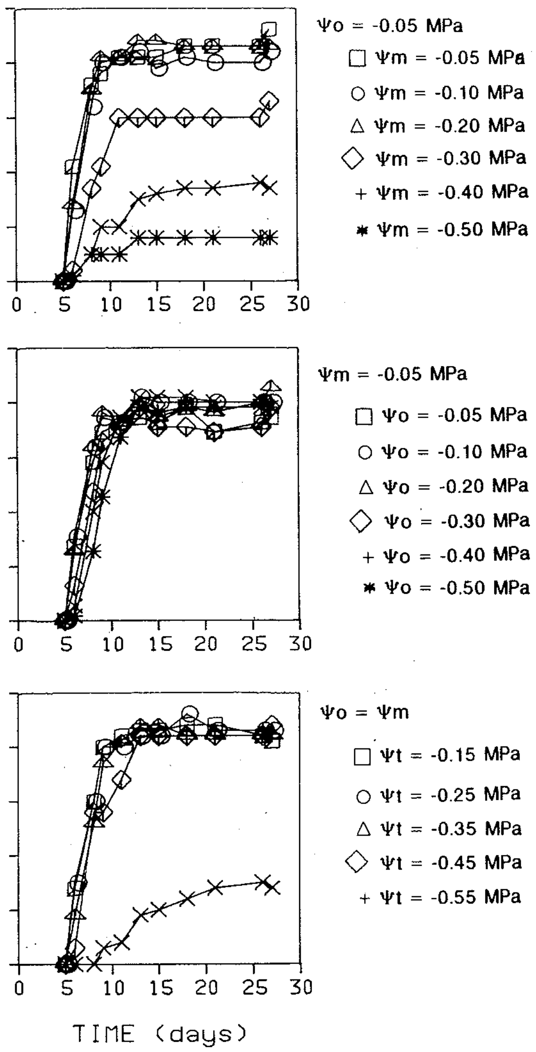

Figure 3. - Influence of osmotic (Ψ_o) and matric (Ψ_m) soil water potential components on germination of carrots in a silty soil. Ψ_t represents soil water potential.

Seedling growth was not affected by osmotic soil water potentials as low as -0.5 MPa (figure 4). Shoot growth was optimum at matric potentials of -0.05 MPa, whereas lower matric soil water potentials strongly decreased growth. Shoot fresh weight was more markedly affected than shoot dry weight by decreasing matric potentials. A moderate water stress caused a significant increase in root growth.

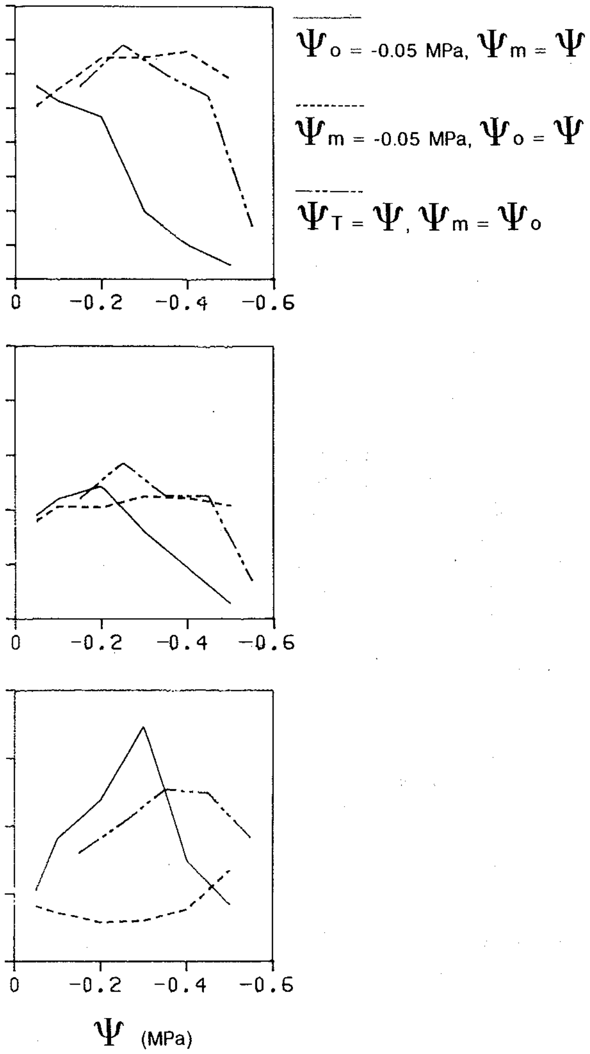

Figure 4 - Influence of osmotic (Ψ_o) and matric (Ψ_m) soil water potential components on biomass production of carrot seedlings in a silty soil. Ψ_T denotes the matric potential component, osmotic potential component and the total soil water potential as specified in the legend.

Soil water potentials composed of numerically equivalent matric and osmotic potential components showed intermediate effects on seedling growth as compared to equivalent water potentials consisting mainly of either matric or osmotic potentials (figure 4). The negative effects were due primarily to the matric potential component.

4. Discussion

Seedling growth revealed to be a better indicator of adverse soil conditions than germination. Seed germination tests as conducted frequently have only limited value for predicting seedling emergence.

When the soil becomes excessively wet, the lack of porosity soon interferes in soil aeration and plant vegetative growth (Drew, 1983). Under these conditions gas exchange between soil and atmosphere is virtually eliminated because of the very small diffusivity in water. Limited oxygen availability was found to be one of the main factors leading to poor emergence in the investigated soil. The importance of an adequate oxygen supply during the early stages of germination has been shown by Orphanos and Heydecker (1960). Root growth is greatly restricted under limited oxygen supply (Kennedy et al., 1980).

The total potential of soil water consists of three main components, the matric potential, the osmotic potential and the gravitational potential. In the case of biological organisms absorbing water from a site in a soil system, the gravitational potential term can be assumed to be zero (Collis-George and Sands, 1962).

Wadleigh and Ayers (1945) and Richards and Wadleigh (1952) suggested that the effects of matric and osmotic potential on growth are additive, regardless of which component or combination of components contributes to the total potential.

This experiment was designed to compare the respective effects of matric and osmotic potential on germination and seedling behaviour. Matric and osmotic potentials affected plant growth to differing degrees. The matric potential delayed seed germination and seedling shoot growth much more than the numerically equivalent osmotic potential.

Plants may react to the external decrease in soil water potentials by an internal decrease in osmotic potential. It is tempting to hypothesize that osmotic adjustment to matric stress is more difficult to obtain than adjustment to osmotic stress. Osmotica used for adjustment to decreasing water potentials may originate from external uptake of solutes or from internal production or translocation of existing solutes.

Osmotic adjustment in a saline medium is favoured generally by the presence of solutes, whereas, in the case of drought stress the plant is much more dependent on internally generated osmotica.

The metabolic energy required for osmoregulation is probably higher in water-stressed plants. A more efficient osmoregulation under salt stress than water stress was found by Sepaskhah and Boersma (1979) and Schmidhalter (unpublished data).

Root growth continued during periods of water stress. This was probably accomplished by osmotic adjustment and thus maintenance of turgor. The better growth of roots as compared to shoots is probably due to their greater capability to adjust osmotically.

Assimilate accumulations in the roots of stressed plants had resulted from declines in assimilate utilization for shoot growth.

Roots seem to be better adapted to water stress than shoots. Shoot growth was most likely limited by insufficient osmotic adjustment. A more efficient osmotic adjustment in roots than shoots has been reported by Sharp and Davies (1979), Taylor et al. (1982) and Schmidhalter et al. (1988).

Recent results suggest that roots do not behave as perfect osmometers (Steudle, 1987). Reflection coefficients much lower than unity were found for several solutes. This would mean that osmotic potentials components are not as effective in reducing water uptake as are matric potential components.

The results of this study suggest that matric and osmotic potentials affect plant growth differently under low and moderate stress conditions.

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