Root Ecology and its Practical Application, 3. ISRR Symp. Wien, Univ. Bodenkultur, 1991, L. Kutschera, E. Hübl, E. Lichtenegger, H. Persson, M. Sobotik (eds.) — 1992 — Verein für Wurzelforschung, A-9020 Klagenfurt.

WATER UPTAKE BY ROOTS AT SPATIALLY VARIABLE SOIL MATRIC POTENTIALS

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SUMMARY: Water uptake by roots at spatially variable soil matric potentials and the gradients in the soil-root-shoot continuum were quantified. As long as the evaporative demand can be met by roots present in zones with high matric potentials, water uptake will essentially occur there. If the water stress is not too severe, roots and shoots tend to equilibrate during the night with the wetter zones. Roots in drier zones are supplied with water from roots growing in wetter zones. If the evaporative demand exceeds the amount of water supplied by the roots, leaf and root water potentials decrease, thus enabling the roots to extract water from drier zones, provided that a sufficiently steep gradient exists from the soil to the leaves.

1 INTRODUCTION: The root zone is usually dominated by spatially variable soil matric potentials. The principles of water uptake from this "normal" situation are still not clearly understood. Therefore, water uptake by roots, under spatially variable soil matric potentials, and the gradients in the soil-root-shoot continuum were quantified.

2 MATERIALS AND METHODS: A divided root section technique was used to study water uptake by roots under spatially variable soil matric potentials. Details are given in a related paper (Schmidhalter and Oertli, 1991). An interrupted distribution of water was created in vertically separated soil compartments. Sand layers, 0.8 cm thick, separated the compartments and minimized vertical water exchange between them. Root growth was still possible. Maize was sown in PVC-tubes (38 cm in height, 10 cm in diameter) filled with soil and divided into four compartments. The tubes were placed in a growth chamber for 20 days (12 hours day/night; 20/18 °C; 50 % relative humidity; 470 μmol m^{-2} s^{-1}). After 10, 13, 18 and 20 days, the soil columns were dissected and the gravimetrically determined soil moisture content, based on a soil moisture release curve, was converted into soil matric potentials. Water uptake and root dry weight were quantified for each compartment.

The water potentials of individual roots (seminal, primary, nodal) and of the whole root were determined with a modified pressure chamber technique as described by Schmidhalter et al. (1991). Additionally, leaf and shoot water potential components were determined. The solute potentials of root and shoot sap were determined with an osmometer. All treatments were replicated four times.

3 RESULTS AND DISCUSSION: Soil matric potentials of the four soil compartments after 0, 10, 13, 18 and 20 days are given at the bottom of Fig. 1, the corresponding pre-dawn leaf water potentials at the top. At later stages of the experiment, the soil matric potentials of the upper soil compartments were considerably lower than the leaf water poten-

tials. The leaves could equilibrate during the night with the wetter bottom soil compartments. Hence, neither the average nor the lowest soil matric potential agrees with the plant pre-dawn water potential but the matric potential measured in the wettest zones. This example shows that pre-dawn leaf water potentials may be of limited use in interpreting the biomass production under a restricted soil water supply. It follows that, as long as the evaporative demand can be met by roots present in zones with high soil matric potentials, water uptake will essentially occur there. However, it can be concluded from the decreased soil matric potentials in the medium soil layers that this situation did not prevail during the experiment. A report of pre-dawn measurements of root water potentials in different layers and the diurnal variation of leaf water potentials follows.

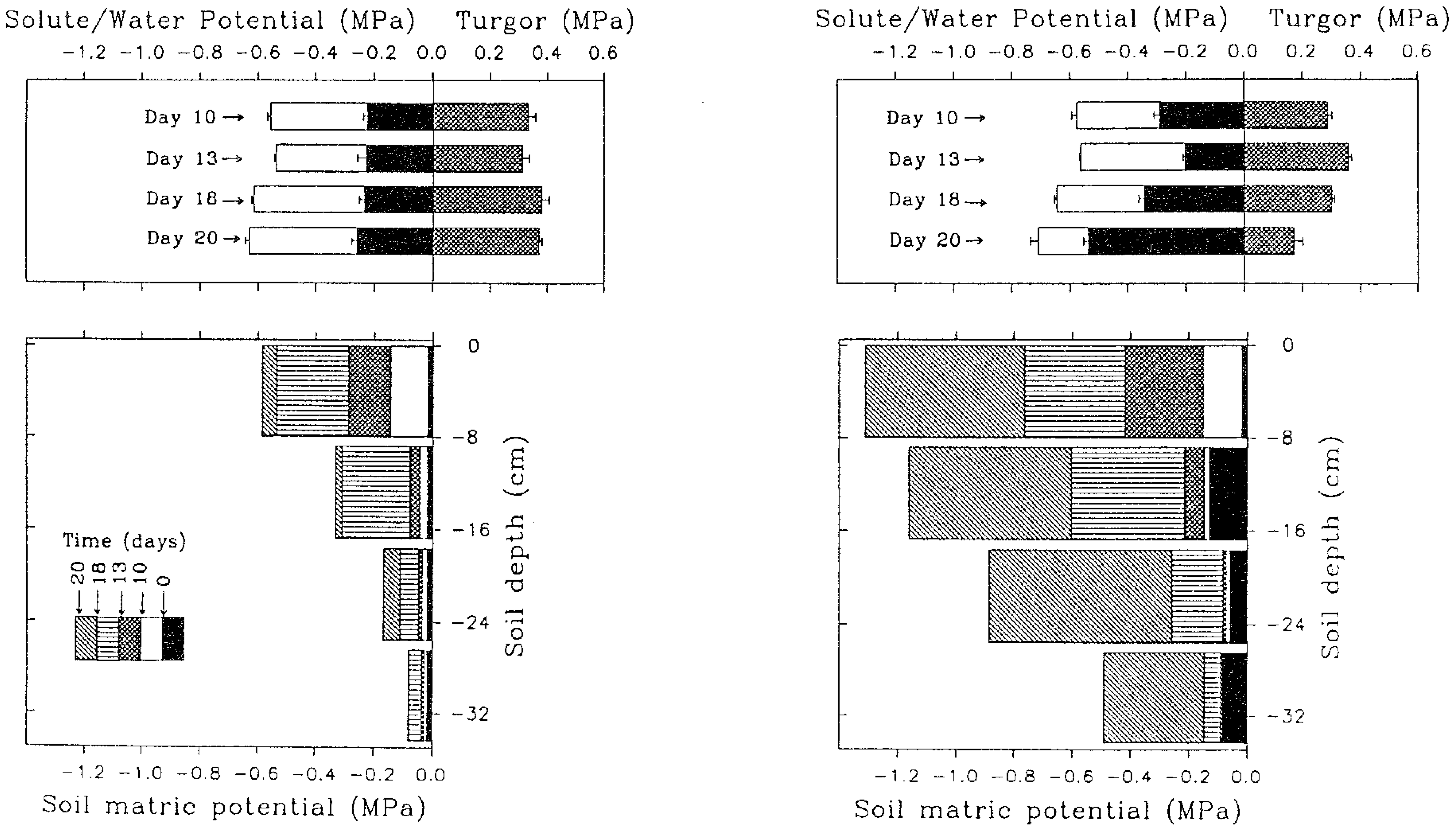

Fig. 1. Maize plants were grown for 20 days without watering in tubes filled with soil at different soil matric potentials in four vertically separated compartments. Pre-dawn leaf solute and water and turgor potentials after 10, 13, 18 and 20 days are shown for two treatments (top left and right). The corresponding soil matric potentials prevailing at different depths are given in the lower figures. Horizontal bars indicate standard errors.

Pre-dawn values of water potential components of roots grown in soil compartments with different soil matric potentials were measured after 15, 18, and 19 days (Fig. 2). Results are shown for treatments which were irrigated daily (C) or stressed (V_3). The water potentials of the stem base or "root crown" are also given. The irrigated treatment shows that a water potential gradient exists between the soil, the root and the stem base. The resistance accounting for this gradient is located in the soil-root contact zone and/or in the root. Pre-dawn values of root water potentials indicate that the roots tend to equilibrate during the night with the zones having the highest soil matric potentials. This agrees with the results obtained for leaves. Nodal roots, which extended only into the top compartment, had significantly higher water potentials than the surrounding soil. This means that roots in drier zones were supplied with water from roots growing in wetter zones. This occurs as long as the evaporative demand can be met by roots present in the more moist zones. Small amounts of water delivered to the drier top compartments were found (data not shown). The water potentials of the nodal roots and the stem bases were comparable in the stress treatment, whereas the primary roots which extended into the bottom compartments exhibited higher values.

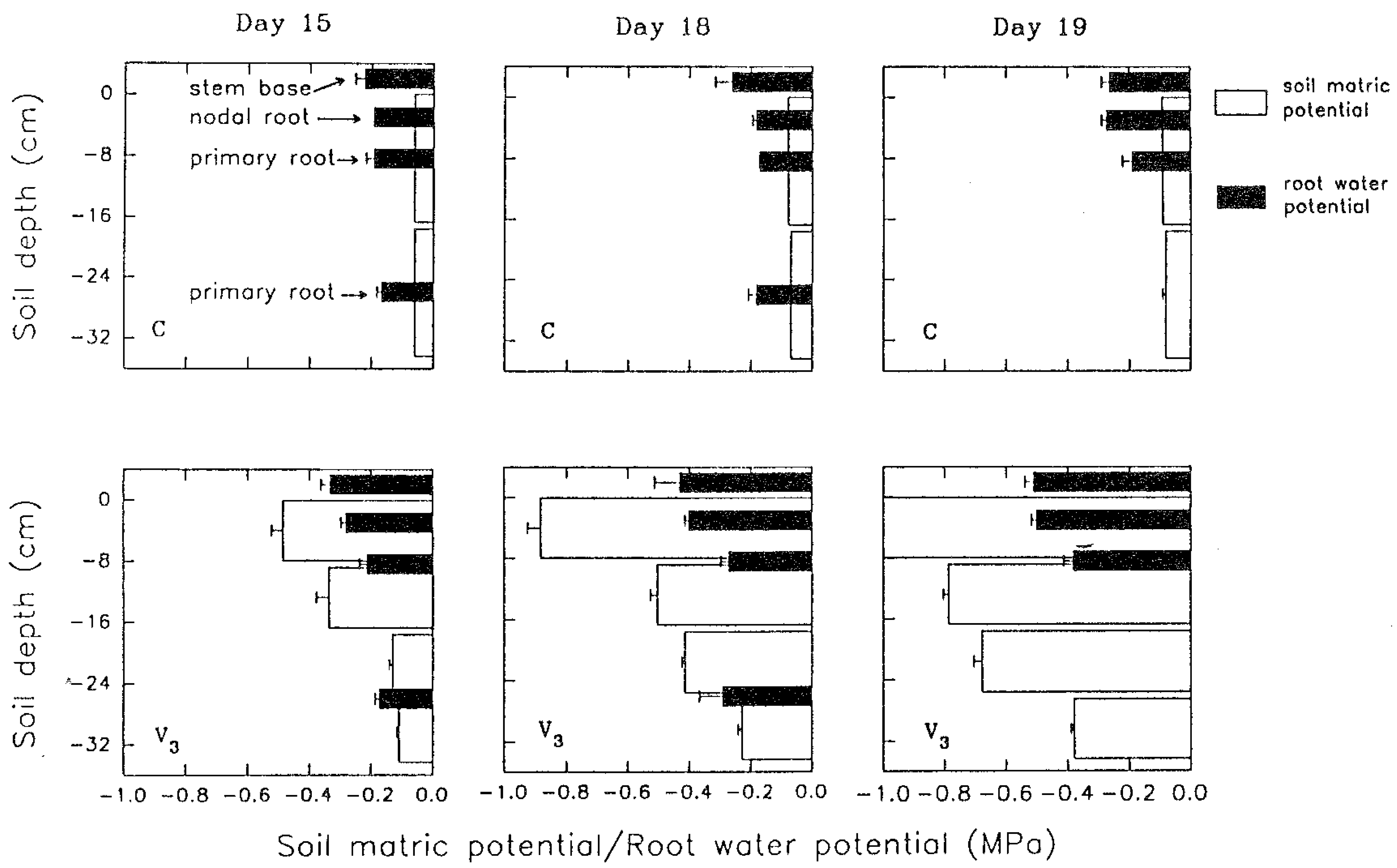

Fig. 2. Soil matric potentials and root water potentials, measured in different soil depths in treatment (C) and (V_3) 15, 18 and 19 days after the beginning of the experiment. Horizontal bars indicate standard errors.

The above findings have consequences for a postulated transfer of root signals indicating soil drying. No signals can be received from roots in drier zones in the absence of water transfer to the shoot. This however may occur if the evaporative demand exceeds the amount of water supplied by the roots. The leaf and root water potentials then decrease, enabling the roots to extract water from drier zones as well, provided that the down-hill gradient from the soil to the leaves is steep enough. Fig. 3 shows diurnal changes in the leaf solute, and in the water and turgor potentials and compares them with the soil matric potentials measured in different depths.

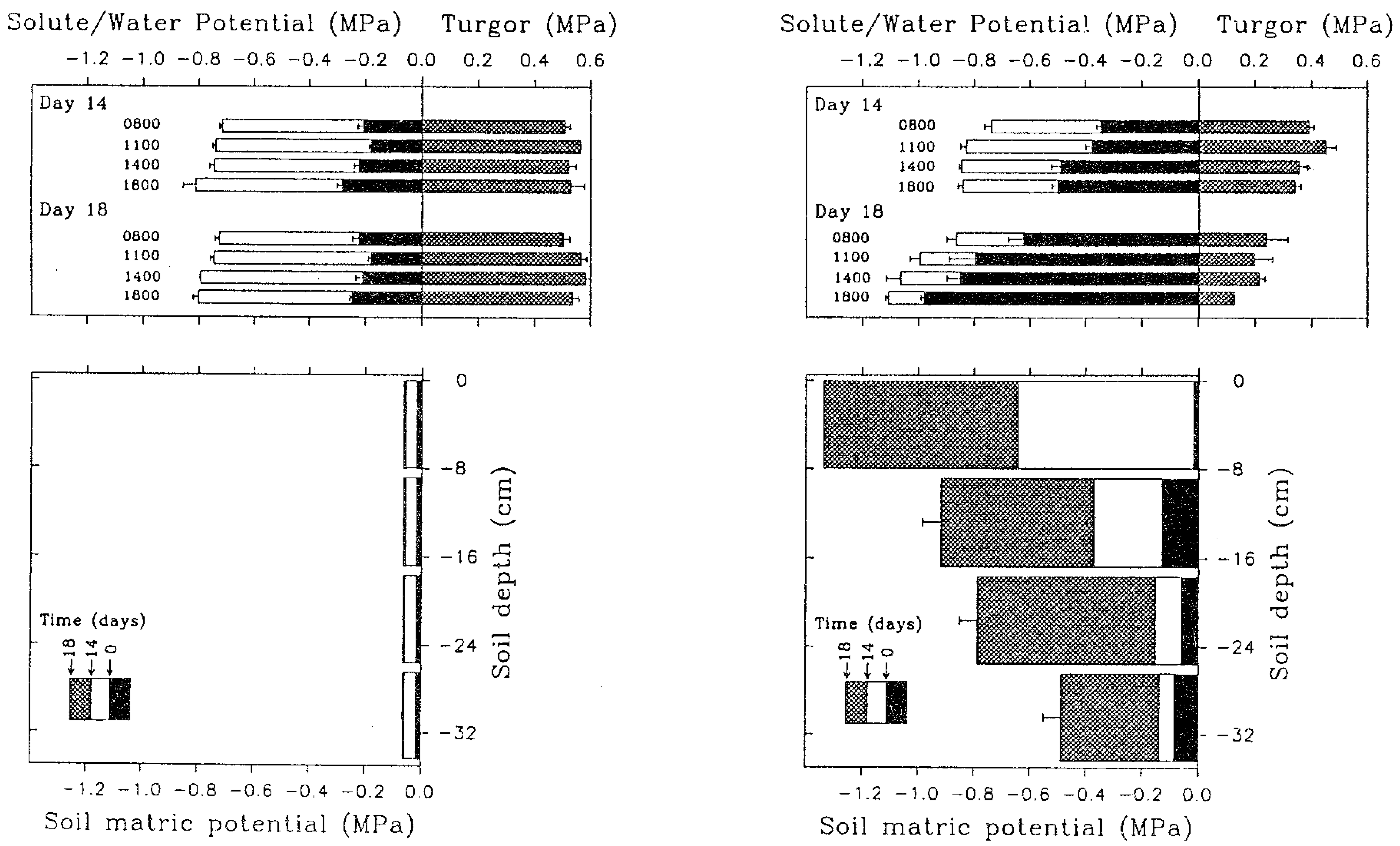

Fig. 3. Diurnal variation in the leaf water potential components of plants irrigated daily (top left) and water-stressed plants (top right), 14 and 18 days after the beginning of the experiment. The corresponding soil matric potentials prevailing at different depths are indicated in the lower figures. Horizontal bars indicate standard errors.

In this experiment, root water uptake (RWU, g water day^{-1}) at very different soil water distributions could easily be described by a simple model taking into account root dry mass (RDM, mg), a time-factor indicating its activity and the water potential gradient in the soil-plant continuum (GRA, MPa). Illustrative examples for different times are given below:

$$RWU_{day0\text{-}10} = 0.14\ RDM_{day0\text{-}10} + 42\ GRA_{day0\text{-}10} \quad (R^2=0.61^{**})$$
$$RWU_{day10\text{-}13} = 0.16\ RDM_{day10\text{-}13} + 24\ GRA_{day10\text{-}13} \quad (R^2=0.84^{**})$$
$$RWU_{day13\text{-}18} = 0.11\ RDM_{day13\text{-}18} + 96\ GRA_{day13\text{-}18} \quad (R^2=0.91^{**})$$
$$RWU_{day18\text{-}20} = 0.13\ RDM_{day18\text{-}20} + 9\ GRA_{day18\text{-}20} \quad (R^2=0.81^{**})$$

This work shows that a better knowledge of growth-limiting processes can be obtained by measuring the gradients in the soil-plant continuum.

REFERENCES: Schmidhalter U., M. Evéquoz and J.J. Oertli, 1991. Osmotic adjustment of roots and shoots (this proceedings).
Schmidhalter U. and J.J. Oertli, 1991. Divided root section techniques (this proceedings).

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