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Mechanistic Approach to Understand Salt Tolerance of Irrigated Crops

Key words: salt tolerance, soil salinity, precision brackish water irrigation

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Introduction

Every minute 3 ha of fertile land are lost due to increasing soil salinity, mainly in the dry areas of the world. Over 20% of the worlds agricultural soils are salt-affected. In the US annual production losses due to salinity are worth over 12 billion USD. These few data point to the big economic potential associated to research activities in the field of crop salt tolerance improvement.

Definitions of the Term ‘Salt Tolerance’

A clear definition of the term Plant/Crop Salt Tolerance is needed in order to avoid confusion. As shown in Table 1 there are different definitions in use according to discipline. The definition used in biology and physiology refers to effect on plant tissue only and is part of the generic term ‘Salt Resistance’.

In irrigated agriculture the term ‘Crop Salt Tolerance’ concerns the impact of soil salinity on crop yield resp. crop growth. The crop specific yield loss based on the ECe (electrical conductivity of the soil saturation extract) is the key parameter. In my presentation the focus is on the agronomic definition.

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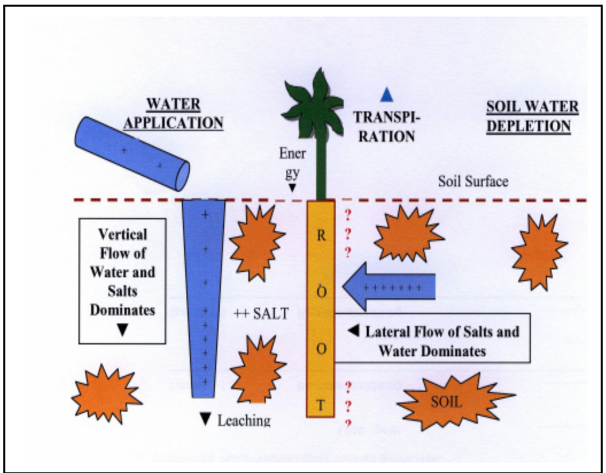
Table 1: Definitions

Definitions of SALT TOLERANCE	
Irrigated Agriculture (Crop Salt Tolerance)	**Biology/Ecology/ Plant Physiology**
Y = 100 - b (ECe - a) **Y** = relat.Yield/Crop Growth in % **a** = ECe (dS/m), where Yield Loss Starts **b** = Yield Loss in %, expected by an ECe increase of 1 dS/m **ECe** = Recent **Soil Salinity** in dS/m	Salt**RESISTENCE** = Salt**TOLERANCE** + Salt**REGULATION** **TOLERANCE**: Ion Pumps, Compatible Solutes, Photosynthesis, Protoplasmatic Components (Ion Relations, Membrans etc. **REGULATION**: Salt Exclusion, Filtration, Selectivity (root), Desalination (Hairs, Glands), Leaf Dropping, Succulence, Compartimentalization etc.

Principles on Water and Salt Movement under Brackish Irrigation

The sketch shown in Fig.1 introduces into the basic flows of water and salts happening during a water application (left hand side of the sketch) and between two succeeding applications (right hand side), when (evapo)transpiration dominates. It is shown on the left that after a water application the vertical flow of water and salts dominates, which under controlled irrigation results in a salinity gradient increasing downwards the rooted soil at a specific leaching fraction. Present crop salt tolerance rating after USDA and FAO

Fig.1: Basic Water and Salt Flow in Soils under Brackish Irrigation



is based on the establishment of vertical soil salinity profiles by irrigation management including salt leaching.
On the right water and salt flow between two succeeding water applications is shown, when the impact of the transpiration driven, lateral flow of water and salts dominates. Since decades it is well-known that most salts transported to the roots are excluded from root uptake and hence accumulate in the soil fraction close to roots, the rhizospheric soil. Thus it is basically accepted that there develop lateral salinity gradients between water applications. However little has been done on the impact of rhizospheric salt build-up on root water uptake and consequently crop salt tolerance. I assume that there is a big potential for improvement of crop salt tolerance with respect to plant breeding and precision brackish irrigation, when understanding processes happening between bulk and rhizospheric soil, where plant meets soil. I propose to focus future research on crop salt tolerance on soil based impacts, which are closer to field-grown conditions and have been neglected in the past at national as well at international level, mainly because of conceptual and experimental shortcomings.

Root Morphology of Selected Plants as Related to their Salt Tolerance

In this context the rhizospheric soil is defined as part of the rooted soil volume directly altered by roots as compared to the bulk soil, which is not directly altered. Root morphological traits affect the volume of the rhizospheric soil. As shown in Table 2 plant roots differ significantly in their ability to form a rhizospheric soil volume. The most salt sensitive crop (leek, onion) form a very small volume/g root dry matter (DM), while the more salt tolerant rape and Russian thistle form a much larger volume, which is related to their longer and thinner roots, and longer root hairs (0,04 mm, 0,43 mm, 0,60 mm for onion, rape and R. thistle).

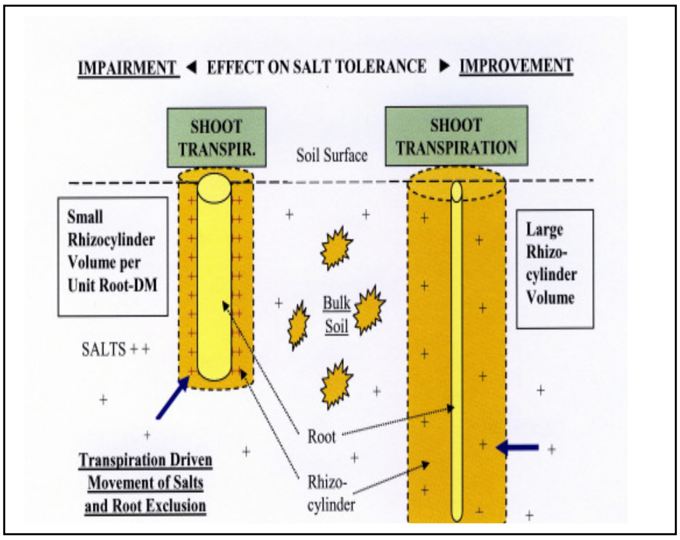
Table 2: Morphological Traits of Roots
(Values in brackets: estimated or calculated)

CROP	Root Length (m/g DM)	Root-Radius (mm)	R of Rhiz-cyl. (mm)	Rhiz-cyl. (cm^3/ g root)	Salinity Class
Onion/ Leek	30	0,225	0,36	12	sensi-tive
Rape	200	-	1,38	1200	moder toler
Russian Thistle (Salsola Kali)	(550)	0,056		(7000)	Halo-phyte

Impact of Soil-Root Interactions on Crop Salt Tolerance

Principally it is well known that salts dissolved in (soil) water reduce root water uptake due to decreasing osmotic water potential. However little is known on effective water potentials (osmotic, matric and total) roots are directly exposed to in rhizospheric irrigated soils, especially during periods of soil water depletion, following a water application.

Fig.2: Impact of Soil-Root Interactions on Crop Salt Tolerance

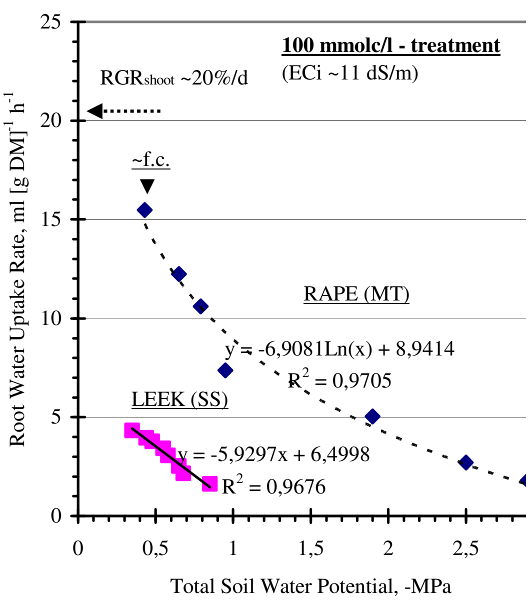


The sketch presented in Fig.2 shows the principle impact of the transpiration driven salt transport into the rhizospheric soil volume, when the volumes differ due their root morphology. Based on the same water uptake, increase of soil water salinity is expected to be much stronger in case of the small rhizocylinder volume as compared to the larger volume. This is because the same amount of salts are transported into and dissolved in a smaller rhizospheric soil volume. Consequently I conclude that the volume of the rhizospheric soil plays an important role for the build-up of rhizospheric soil water potential, root water uptake and thus crop salt tolerance.

Water Uptake from a Saline Soil by Roots of Different Morphology

Experimental results using rape and leek as model plants proved the assumption that roots forming a large rhizo-volume (rape) are significantly more efficient in water uptake from saline soils as compared to roots forming a small rhizo-volume (leek). As shown in Fig.3, water uptake rate by roots of rape was about 500% higher as compared to leek roots, when the soil was salinized with an ECi-water of ~11 dS/m to achieve a total soil water potential (ψ_T) of ~-0,3 MPa (3 at) at 'field capacity' (f.c.) from the start of the water depletion phase. Rape depleted the soil water down to ~-2,5 MPa, while water uptake by leek roots finished already near -0,8 MPa (wilting of shoot).

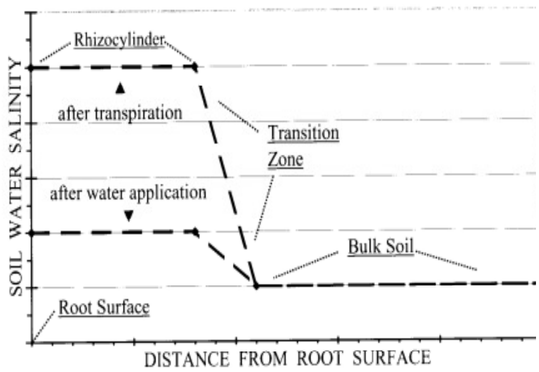
Fig.3: Water Uptake by Rape and Leek Roots from a Saline Soil
(SS=Salt Sensitive; MT=ModeratelyTolerant)



Lateral Salt Distribution as Affected by Watering and Transpiration

As shown in Fig. 4 I distinguish between the three soil fractions: the rhizospheric soil volume (rhizocylinder) close to the root surface and penetrated by root hairs, the bulk soil fraction not directly root affected, and a transition zone between both, where balancing processes occur.

Fig.4: Principles of Lateral Salt Distribution around Irrigated Roots



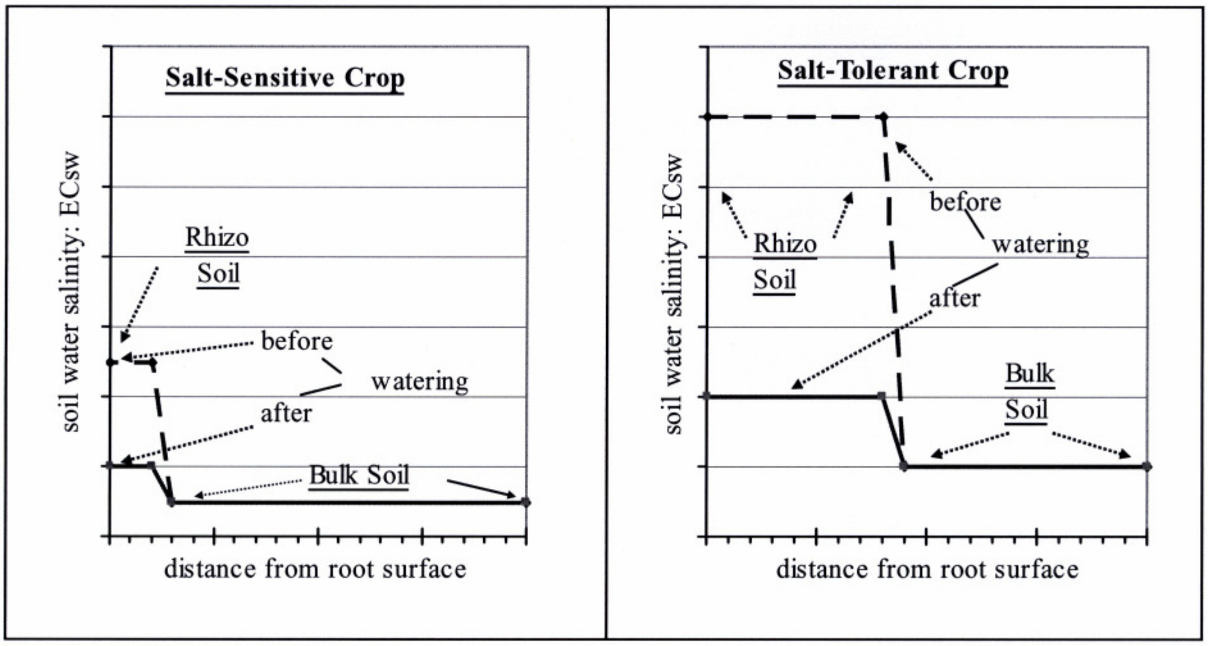
The lowest soil water salinity in the rhizocylinder is expected immediate after a water application due to dilution and leaching. Most probably it is still higher than the salinity of the bulk soil water, at least under controlled irrigation. Transpiration effects a continuous increase of rhizospheric soil water salinity, at most up to a crop specific maximum salt concentration. Bulk soil water salinity probably is affected at longer irrigation intervals only.

Impact of Rhizospheric Soil Water Salinity for Crop Salt Tolerance

Supposing the principles of this concept, I consider the following two topics as key factors affecting the salt tolerance (Fig. 5). The one factor is the concentration of rhizospheric soil water salinity that severely reduces root water uptake or even blocks it and which is shoot determined. Root water uptake of sensitive crops is blocked by lower salt concentrations, of tolerant crops only at higher concentrations.

The second factor that is crucial for crop salt tolerance is the diameter of the rhizocylinder respectively the volume of rhizocylinder formed by root mass. When roots form a small rhizocylinder volume salt build-up happens in a small soil water volume affecting a strong increase of soil water salinity (per unit root water uptake). The crop will be salt sensitive.

Fig. 5: Lateral Distribution of Soil Water Salinity under Brackish Irrigation of a Salt-Sensitive and a Salt-Tolerant Crop



In case of a larger volume of the rhizocylinder salt build-up will occur in a larger soil water volume and salt increase will be lower, which is expected to improve salt tolerance. Differences in both factors are expected to be larger between different species of plants, but smaller between varieties.

Conclusion

The presented soil-based approach to detect crop salt tolerance is definitely more complex as compared to hydroponic based approaches. Fortunately it is not too complicated and will provide promising results that are most useful for application on field grown crops. It is proposed to include the impacts of root morphology and interactions happening between root and soil into breeding activities for more salt tolerant crops and optimization of brackish irrigation.

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