EIP-AGRI Focus Group

Soil salinisation

MINIPAPER: Crop productivity under saline conditions

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1 Introduction

Yield and abiotic stressors are inversely related, that's the case of crops growing under salt or drought conditions. Drought is a meteorological (and environmental) event systematically present in the southern European countries during the summer period and sometimes also during the other seasons. Salinity originates with the practice of irrigation used to fight drought. Poor irrigation management and the use of non-conventional water favour the appearance of salinity (secondary salinization).

Drought and salinity are a well-known challenge to plant growth and cause a growing threat to the development of agriculture (Golldack et al. 2014). In the Mediterranean areas, both stressors are often combined. Their combination reduces water availability for the plant more than the effect of salinity or drought alone.

Under drought soil stress, the plant water status changes and in turn it reduces leaf area, evapotranspiration and yield. These effects become more pronounced as soil salinity increases. However, for the same level of soil salinity, the species response could be different.

To estimate the productivity the traditional approach, which compares crop responses to drought and salinity separately, is no longer appropriate (Mittler 2006).

2 State of the art

Crop salt tolerance is traditionally associated to the concept of relative yield (Yr). Yr is defined as the fraction of the yield observed in the saline environment compared to the yield in the non-saline environment, assuming that the other parameters remain the same. However, it should be underlined that salinity tolerance does change with external environmental factors, particularly the evaporative demand of the atmosphere (in relation to temperature, relative humidity, and wind speed). In the hypothesis that the role of these external environmental factors is negligible, yield decrease could be evaluated as a function of soil salinity increase (Maas and Hoffman 1977):
With:

$$Yr = 100 - b\,(EC_e - a)$$

a: The salinity threshold value; b: The percentage decrease in yield per increase in salinity unit above the threshold; ECe: Soil salinity expressed as Electrical Conductivity in dS/m.

The coefficients a and b are then a convenient way to classify the salinity tolerance of the cultivated species (Table 1).

Table 1: Classification of cultivated species according their salt sensitivity

TOLERANT	**MODERATELY TOLERANT**	**MODERATELY SENSITIVE**	**SENSITIVE**
barley	durum wheat	tomato	onion
sugar beet	bred wheat	cucumber	carrot
rye	zucchini (courgette)	alfalfa	bean
asparagus	red beet	clover	apple
		corn	cherry
		melon	raspberry
		potato	strawberry

As for the tree crops, the relationship between productivity and soil salinity is dependent on the combination rootstock/variety. As an example, the citrus species could be tolerant if grafted on a Rangpur lime or sensitive if the rootstock is a citrange. As well as the grape variety "Thompson seedless" is retained moderately tolerant, while the "Cardinal" quite sensitive.

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The physiological studies underlined that drought and salt stresses affect directly the plant water relationships and the photosynthesis (limited diffusion through the stomata and the mesophyll; alterations in photosynthetic metabolism). Secondary effects are the oxidative stress which arise from the superimposition of multiple stresses. The final carbon balance of crops experiencing salt/water stress may depend on the photosynthetic recovery, as well as on the stress dynamics (stress level, duration, phenological stage). Aside the physiological and biochemical alterations, transcript-profiling studies highlight that plants subjected to drought and salinity react by quickly altering the gene expression. When compared with drought, salt stress affected more genes and more intensely, possibly reflecting the combined effects of dehydration and osmotic stress in salt-stressed plants.

Usually physiological observations should be joined on field studies. The agronomical approach emphasized that in the croplands, the accumulation of salt is at the origin of the secondary salinization, if salinity in the soil layer colonized by the root system causes damage to the growing crops. Generally, the salt translocation in the plant tissues would affect crop growth by reducing the root and leaves expansion and, in turn, the dry matter accumulation in the above ground biomass and its partitioning. The main cause of the growth inhibition is due to a decrease in soil water potential and, as a consequence, in plant water status. Moreover the salt excess in the soils affects unbalance in nutritional elements (Galmés et al. 2011) and provokes accumulation of toxic ions. Finally the changes in pH and in salinity level affect the symbiotic organisms, in the case of a leguminous species, and the whole soil microbiological activity.
The list of harmful salts is varying. In general, the toxic ions added to the soil trough irrigation water are chloride, sodium and boron. Visual symptoms of Cl- and Na+ ion toxicity are recognizable by burns on the edges and tips of the leaves, chlorotic spots between the veins (yellowish or reddish) and leaf drop (Figure 1).

Figure 1: Sodium and Chloride toxicity symptoms in Grape.

Most boron-related toxicity symptoms concern first of all the ends and edges of the old leaves.

What is promising, and could bring potential innovations, consists in pooling up the physiological and the agronomical approaches. Both information allow to describe and model the production behaviour of crops in saline soils. Model outputs are of great importance for farmers and planners in order to design the cropping systems more suitable for the saline environments.

5 Knowledge gaps, potential innovations and sustainability of innovations (problems and opportunities)

Operatively the estimation of crop productivity should be based exclusively on two parameters: the soil water availability and leaf area index.

Rather than the soil water content, the plant growth depends on the energy they have to spend to uptake water from the soil. The soil matric potential (Ψ) represents the force by which water is held by the soil.

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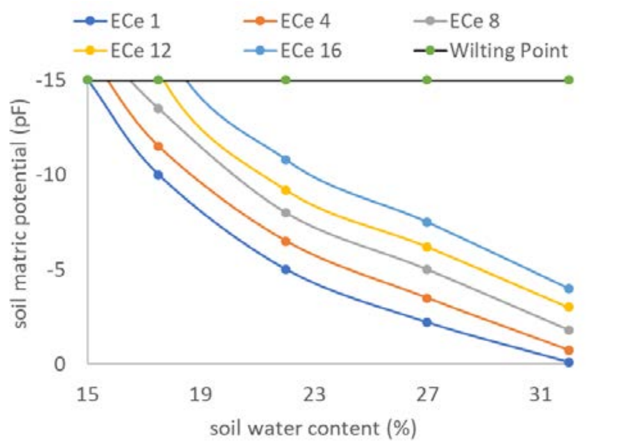

Figure 2: The effect of soil salinity (5 levels of soil electrical conductivity, ECe) on the relationship between soil potential (Ψ) and soil water content

Under dry soil conditions, if the soil contains only fresh water (and ECe is low, <1), the decrease in Ψ is mainly caused by a decrease in the matric potential. When in a soil dryness is combined with the presence of salts, the decrease in water availability will be much greater, because in addition to the decrease in matric potential, there is an extra decrease due to the osmotic component. As a consequence, more energy is required by crops to uptake water (Figure 2).

The final effect is a significant reduction in soil water availability as the salinity increases. It results in a change in the water status of the plant (Figure 3). Also in saline soils, the pre-dawn leaf-water potential represents the link between soil and plant water status (Katerji et al 2004).

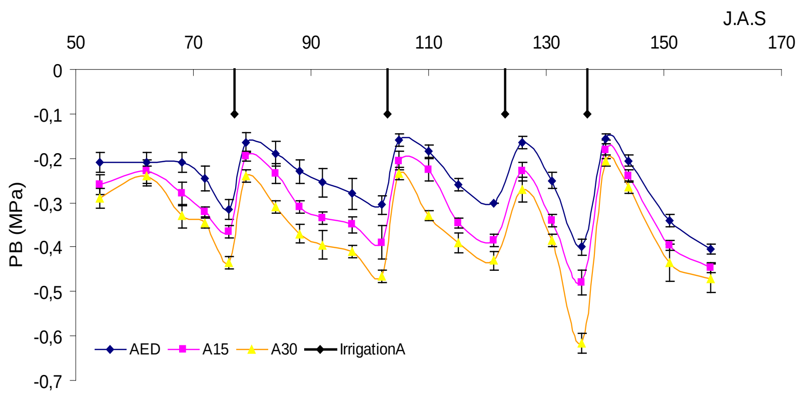

Figure 3: Time evolution (days after sowing J.A.S.) of pre-dawn leaf-water potential (PB in MPa) observed in corn supplied (arrows stand for irrigation times) with fresh (AED) or saline irrigation waters (having 15, A15, or 30 meq of Cl⁻, A30)

By surveying the plant water status, the effects of the salinity on the plant water relationships can be modelled as well as the crop evapotranspiration (ETc). A series of models estimates the crop productivity from the determination of ETc. Such models are based on the same hypothesis of the traditional approach, i.e. final yield and cumulative evapotranspiration decrease as soil salinity increases.

More accurately crop productivity can be modelled by the medium and long-term observations on development of the phenological stages and leaf canopy expansion. Salinity can alter the course of phenology in some species. If combined with drought, in all species the duration of phenological stages does change. At the canopy scale, the higher the salinity of the soil, the lower the LAI (leaf area index) values are, and also lower is the intercepted solar radiation. The time evolution of LAI is retained in several models to estimate productivity since it is a sound criterion for actual crop development which as well as takes into account the site-specific agro-environmental conditions. LAI values allow to determine dry matter accumulation and consequently the final yield.

The other sound alternative is represented by the deterministic models. As an example, the “transient state” models allow for the quantification of the salinity build-up in the root zone (Figure 4). These types of models let to simulate irrigation-induced salinity processes, the upward movement of salts from saline ground water-table, and sodification processes. Most models are based on the numerical solution of the Richards equation for variably-saturated water flow, and on analytical or numerical solutions of the Fickian-based convection–dispersion equation for solute transport. A sink term is usually included in both equations to account for water uptake by plant roots, and further to consider the impact of water and salinity stress on crop transpiration and yields. As for the case of the salinity stress, several equations are available including the Maas and Hoffman (1977) formulation given earlier.

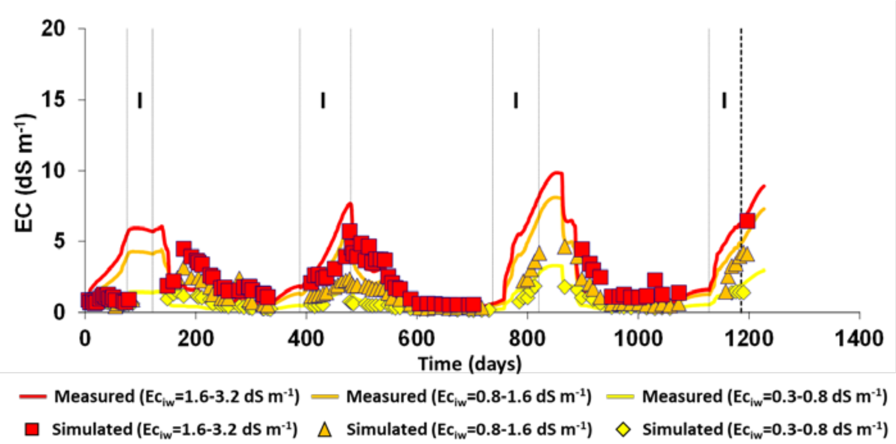

Figure 4: Electrical conductivity of the soil solution (EC) in soil lysimeters irrigated with different water qualities (EC_{iw}, electrical conductivity of the irrigation water; I, irrigation season) (Adapted from Gonçalves et al., 2006).

These type of models require detailed data on soil, crop, and climate to simulate the crop growing conditions under saline environments. For example, in terms of soil characterization, these models require a complete description of soil hydraulic functions (the soil water retention and soil hydraulic conductivity curves, in the range between saturation and dryness), which are fundamental for solving the non-linear partial differential equations used to compute soil water and salt dynamics. These parameters can be directly determined in the field or in the laboratory on undisturbed soil samples of different sizes collected in different horizon/layers of the soil profile. Alternatively, these parameters can be estimated from basic soil data (e.g., soil texture, dry bulk density, organic matter content) using soil pedotransfer functions. Finally, due to their complexity, transient-state deterministic models are mostly used in research. Examples of applications can be found in Gonçalves et al. (2006) or Ramos et al. (2011, 2012, 2019).

Between the empirical approaches and the research findings, a series of operative models merit to be considered since, moving from the research, they can represent predictive tools easy to use. In the following two examples are reported.

1. An attempt to ameliorate the traditional approach for estimating the productivity yield reduction on saline soils is suggested by van Genuchten and Hoffman (1984). They proposed the following non-linear model as a better alternative to predict the crop behaviour in saline soils:

$$Yr = 100 / (1 + (ECe/ECe50)^p$$

   Where: ECe50 is the ECe value at which the yield is reduced by 50% in dS/m; p: empirical parameter

2. A second model moves from the correct determination of ETc in saline conditions, as indicated in the FAO56 handbook[1]. This approach computes ETc as the product of the crop coefficient (Kc), specific of the crop and of its stage of development, and the reference evapotranspiration (ETo), that is solely a function of the local climate. A stress coefficient (Ks) is then introduced for the effect of water and salinity stress on crop ET.

$$ETc = Ks\ Kc\ ETo$$

$$Ks,i = [(TAW – Dr,i) / (TAW – RAW)]\ [1 – b/(Ky\ 100)\ (ECe – a)]$$

[1] FAO56, http://www.fao.org/3/X0490E/X0490E00.htm

where: TAW is the total available water in mm; RAW is Readily available water in mm; Dr is soil water depletion in mm; Ky is yield response factor describing the relationship between the relative yield decrease with the relative evapotranspiration deficit (-).

3.- Finally, yield reduction can be computed with the following equation:

$$(1 - Ya/Ym) = Ky\,(1 - ETa / ETc)$$

with: Ya is the actual yield in kg/ha; Ym is maximum yield in kg/ha; ETa is actual crop evapotranspiration in mm.

This approach offers a simple solution to model the general impacts of soil salinity on crop ET and yields over extended time periods. It is embedded in several modelling tools aimed at quantifying the effect of saline waters on crop yields and has been tested worldwide for different crop, soil and environmental conditions. One of its first applications was reported by Pereira et al. (2007), who analysed various water saving and salinity control practices for wheat and maize in the upper Yellow River Basin, China, using the ISAREG model. Also, Domínguez et al. (2011) predicted onion (Allium cepa L.) and potato (Solanum tuberosum L.) response to salinity in Spain and Lebanon, respectively, using the MOPECO model, evaluating the need for the leaching fraction during irrigation when rainfall was not sufficient to washout the soluble salts accumulated in the root zone. Another example is suggested by Reca et al. (2018), who implemented a decision support system (DSS) for optimizing the combined use of saline (2.5 to 4.0 dS m^{-1}) and desalinated seawater for greenhouse watermelon (Citrullus spp.) irrigation while providing maximum economic profit.

If the dual Kc approach (FAO56) is considered, those effects can be assessed directly on crop transpiration, allowing a more accurate estimate of crop water dynamics at the plot scale. This was shown in southern Portugal, where the evapo-transpiration rates of irrigated maize grown were estimated under saline conditions (Rosa et al., 2016). As a result, the trend of actual crop coefficients (Kcb act) differs from the potential crop coefficient (Kcb) along the crop growing season due to irrigation by using saline waters (Figure 5). Likewise, the evaporation coefficient (Ke) has a tendency to increase due to the effect of salinity on reducing the plant development. A smaller canopy does expose more soil surface to the solar energy and more water is lost as soil evaporation.

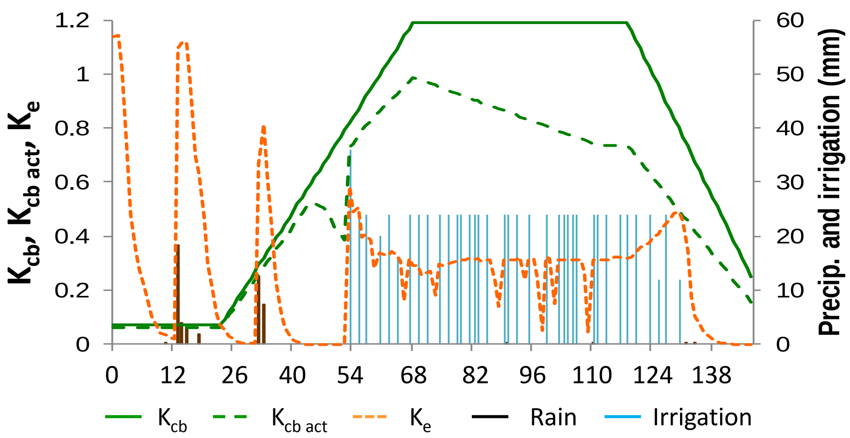

Figure 5: Evolution of the basal crop coefficient (Kcb), actual basal crop coefficient (Kcb act), and evaporation coefficient (Ke) in irrigated maize grown under saline conditions in southern Portugal (modified from Rosa et al., 2016).

These two examples clearly indicate where the limits are that prevent these operational models from being directly used in practice by farmers or agricultural extension services. These models requires a series of parameters which are not sufficiently known. In other words, they are reported in literature however such "tabulated" parameters can't be generalized in any field condition.

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3 Research needs from practice

The determination of model parameters is a prerequisite for the simulating tools to become operational innovations in the agricultural sector. It is essential that these determinations are carried out in real cropping systems. There is a need for specific field researches that collects data from environments subject to salinity. Even better would be to create a series of Long Term Experiments (LTEs) in a double transept from North to South Europe and from East to West from which to obtain the crop and soil data necessary to formalize the modelling parameters. Since they are not generally available, these values represent the real limit that currently prevents the speeding up of the use of models in the agricultural practice.

These parameters are currently affected by great uncertainty and empiricism. The real challenge is to transfer these values from research laboratories to agricultural practice, indeed it is essential to study them in tune with farmers who work every day in saline environments. This would have the double advantage: 1) to measure the parameters necessary for modelling in conditions of actual cultivation; 2) to be able to validate the models directly by means of field observations.

A further advantage that derives from the proximity of the modelers to the LTEs and to the farmers is the adaptation of the models so that they become friendly tools that can be easily used by the end-users to predict the crop productivity in saline soils.

4 Ideas for innovative projects/Operational Groups

A number of operational groups could benefit from the simulations provided by the modelling approaches foreseeing the crop or soil behaviour. Operational groups focusing on the production chain or on environmental issues both deal with modelling solutions. In particular, models could predict the consequences of salinity on production levels and *viceversa* the consequences on the sustainability (in terms of soil fertility) of contrasting agronomic practices.

Below are some examples of OGs where the estimates of crop productivity, and salinity accumulation in soil (and salt dynamics), accelerate the generalisation of on-farm observations or the "good practices" that may be of interest in other rural areas.

- Agronomic profiling of salt tolerance and product quality traits in European crops exposed to soil salinization
- Diversifying and promoting cropping systems
- Surveillance of soil salinity in areas changing from dryland to irrigated
- Adaptation of crops and farming practices in a coastal area with salinity problems derived from sea water intrusion

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