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Katerji N., van Hoorn J.W., Mastrorilli M., Hamdy A.

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CROP SENSITIVITY TO SALINITY

N. Katerji*; J.W. van Hoorn; M. Mastrorilli*** and A. Hamdy******
* INRA, Station de Bioclimatologie, 78850 Thiverval-Grignon, France
** Department of Water Resources, Agricultural University, Wageningen, Netherlands
*** Istituto Sperimentale Agronomico, 70125 Bari, Italia
**** Director of Research, CIHEAM – Istituto Agronomico Mediterraneo di Bari,
9 Via Ceglie, 70010 Valenzano (BA), Italy. E-mail: hamdy@iamb.it

ABSTRACT – In this paper, we shortly review the latest studies that, by combining agronomic and eco-physiological survey techniques into a multi-disciplinary approach, have allowed interpreting the relationships between salinity, plant growth and yield directly in the field. Among the different stress indicators, maximum leaf water potential of the day (measured ad pre-dawn) is the most reliable one. Clearer indications were provided by the Water Stress Day Index (the average of the differences of pre-dawn water potential measured during the growth cycle on two identical crops, but irrigated with water of different salinity). The relationship between WSDI and relative yield was proposed as criteria to classify the cultivated species. Using this method, only two groups of crops are classified: tolerant species (durum wheat, sugar beet, maize, …) and sensitive species (tomato, soy bean, broad bean,…). This classification of crop sensitivity to salinity is based on different observations independent of each other.

Key words: salt tolerance, Mediterranean crops, durum wheat, sugar beet, maize, sunflower, tomato, soy bean, broad bean, chick pea, lentil and potato

INTRODUCTION

Faced with scarce good quality water resources, over these last years, most of the agronomic research activity for Mediterranean environments has focused on the optimisation of water use for irrigation and on the use of alternative sources of waters.

On the long run, the use of waste and brackish waters increases salinity along the soil profile. The crop response to salinity has been investigated in the last few decades (Fig. 1); empirical observations highlight that the increase in soil salinity (ECe) reduces relative yield (Y_{rel}). By relating the increase in salinity with yield decrease, the sensitivity of most of the crops to salinity was established (Maas and Hoffman, 1977; Ayers and Westcot, 1985). This method was used to classify, at any latitude and in any pedo-climatic condition, the salt tolerant and salt sensitive species (Shalhevet, 1994).

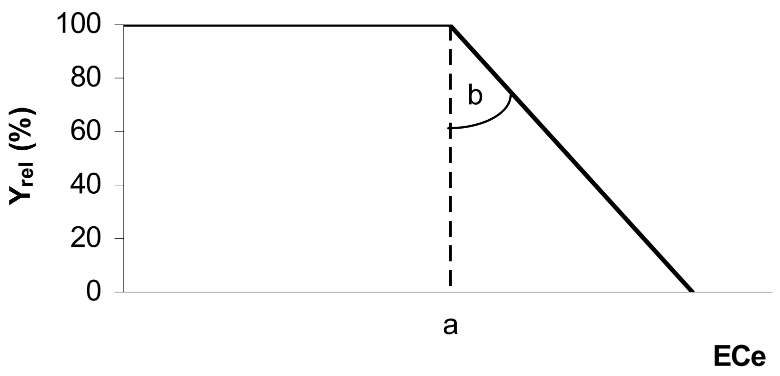


Figure 1. General relationship of relative yield Y_{rel} (%) to salinity, according to Maas and Hoffman equation (1977):

$$Y_{rel} = 100 – b (ECe – a).$$

Where:

a = salinity tolerance threshold, corresponding to the salinity value of the soil saturation extract (ECe), beyond which a reduction in yield starts appearing with respect to non-saline conditions;

b = rate of decrease in Y_{rel} by unit increase of ECe.

Though operationally sound, this classification method seems to be quite simplistic in the light of the present scientific knowledge. In fact, the direct relationship between yield and salinity cannot account for the different behaviour of the crops grown under saline conditions or why sensitivity is different. A similar approach completely ignores the function of the plants in field conditions: it remains a “black box”.

In this paper, through the studies performed on typical Mediterranean crops, we summarise the latest results that provided the key to open the “black box” and analyse its content.

MATERIALS AND METHODS

By combining the techniques for the agronomic surveys and the echo-physiological methodologies into a multidisciplinary approach, the relationships between salinity, plant growth and yield were directly interpreted in the field.

The experiments have been accurately described in a previous paper (Katerji *et al*., 2004).

The set-up consisted of 30 lysimeters of reinforced fibreglass with a diameter of 1.20 m and a depth of 1.20 m. A layer of 0.10 m thick coarse sand and gravel was overlain by a repacked soil profile of 1 m. At the bottom of the lysimeter, a pipe serving as a drainage outlet connected the lysimeter to a drainage reservoir. The set-up was sheltered at a height of 4 m by a sheet of transparent plastic to protect it against precipitation.

One series of 15 tanks was filled with loam and a second series of 15 tanks with clay from 1989 to 1999. In summer 1998, the tanks were emptied and refilled with clay. Table 1 presents some proprieties of the soils after filling the lysimeters.

Table 1. Soil properties

Soil	Particle size in percentage of mineral parts			$CaCO_3$ (%)	%Water (v/v)		Bulk density (Kg/dm^3)
	< 2µm	2-50µm	>50µm		pF2.0	pF4.2	
Loam	19	49	32	25	36.2	20.4	1.45
Clay	47	37	16	5	42	24	1.45
Clay	49	22	29	11.4	38.5	21.9	1.41

The tanks were irrigated with water of 3 different salinity levels: the control treatment with fresh water containing 3.7 meq Cl/1 and an electrical conductivity (EC) of 0.9 dS/m, and two saline treatments containing 15 and 30 meq Cl/1 and an EC of 2.3 and 3.6 dS/m, obtained by adding equivalent amounts of NaCl and $CaCl_2$ to fresh water.

During the second year, wheat was irrigated with waters containing 10 and 20 meq Cl/l; during the third year, potatoes were irrigated with waters containing 15 and 30 meq Cl/1 on loam and 15 and 20meq Cl/l on clay; from the fourth year onwards the saline waters contained 15 and 30 meq Cl/l and an EC of 2.3 and 3.6 dS/m. Table 2 presents the chemical composition of the irrigation waters. Just before sowing, 10 litres of fresh water were applied to all treatments to obtain adequate emergence.

Table 2. Composition of irrigation water (meq/l)

Treatment	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	HCO_3^{-}	SO_4^{2-}	EC(dS/m)	SAR
Fresh	6.2	3.1	2.3	0.4	3.7	7.3	0.6	1.0	1.1
15 meq Cl/l	10.8	3.2	8.7	0.4	15	6.6	0.8	2.3	3.3
30 meq Cl/l	16.7	3.4	16.2	0.4	30	6.5	0.7	3.6	5.1

Upon each irrigation event, surplus water was added to provide a leaching fraction of about 0.2. Irrigation water was applied when the evaporation from the class A pan had attained about 80 mm. The evapotranspiration of the irrigation interval was calculated as the difference between the amounts of irrigation and drainage water.

For determining soil salinity, the average chloride concentration of soil water was calculated from the balance of irrigation and drainage water and converted into EC of soil water by the equation $\ln EC = 0.824 \ln [Cl] - 1.42$, established for this type of irrigation water and soil (Van Hoorn *et al*., 1993). Moreover, soil water samplers were installed in every lysimiter at four successive depths (17.5, 42.5, 67.5 and 92.5 cm) for determining the EC and the chemical composition of soil water.

Ten species widely cultivated in the Mediterranean climate (wheat, maize, potato, sugar beet, sunflower, tomato, soy bean, broad bean, chick pea, lentil) (Tab. 3) were grown and irrigated with waters of different salinity, as described by Katerji *et al*. (2002). For each type of irrigation water, the considered parameters were: soil electrical conductivity, yield and growth, plant water status (expressed as leaf water potential measured at pre-dawn and as stomatal conductance).

Table 3. Crop, variety, growth period and literature reference

Crop	Variety	Growth period	Reference
Broadbean *(Vicia faba)*	Superaguadulce	8/12/1989-28/5/1990	Katerji *et al*. (1992)
Durum wheat *(Triticum durum)*	ISA	22/11/1990-26/6/1991	Van Hoorn *et al*. (1993)
Potato *(Solanum tuberosum)*	Spunta	3/2/1992-7/6/1992	Van Hoorn *et al*. (1993)
Maize *(Zea mays)*	Hybride Asgrow 88	27/7/1993-2/11/1993	Katerji *et al*. (1996)
Sunflower *(Helianthus annuus)*	Hybride ISA	22/4/1994-2/9/1994	Katerji *et al*. (1996)
Sugar beet *(Beta vulgaris)*	Suprema	25/11/1994-2/6/1995	Katerji *et al*. (1997)
Soybean *(Glycine max)*	Talon	18/7/1995-16/9/1995	Katerji *et al*. (1998a)
Tomato *(Lycopersicon esculentum)*	Elkol90	28/6/1996-10/9/1996	Katerji *et al*. (1998b)
Broadbean *(Vicia faba)*	Superaguadulce	25/11/1997-20/5/1998	
Lentil *(Lens culinaris)*	Idlib I ICARDA 6796	29/12/1998-13/6/1999	Katerji *et al*. (200la)
Chickpea	ILC 3279 Filip 87-59C	23/12/1999-24/6/2000	Katerji *et al*. (2001b)

RESULTS

Through irrigation, salts are inevitably supplied to the soil, even more so when using low quality waters. Through acting on the water osmotic potential, salts limit water absorption by roots. In practice, when irrigating with saline water, though adding water to the soil, such water is not fully available to feed the plant, i.e, by increasing the salt concentration in the soil, the total water potential decreases and, at the same time, water availability to plants decreases as well. This results in water stress that affects stomatal conductance, photosynthesis, leaf development and yield.

Among the different water stress indicators, maximum leaf water potential of the day (measured at pre-dawn, Ψ) is the most reliable. Even under soil salinity conditions, this indicator expresses the plant water status and perfectly synchronizes with the day-time and seasonal variations of stomatal conductance (Fig. 2).

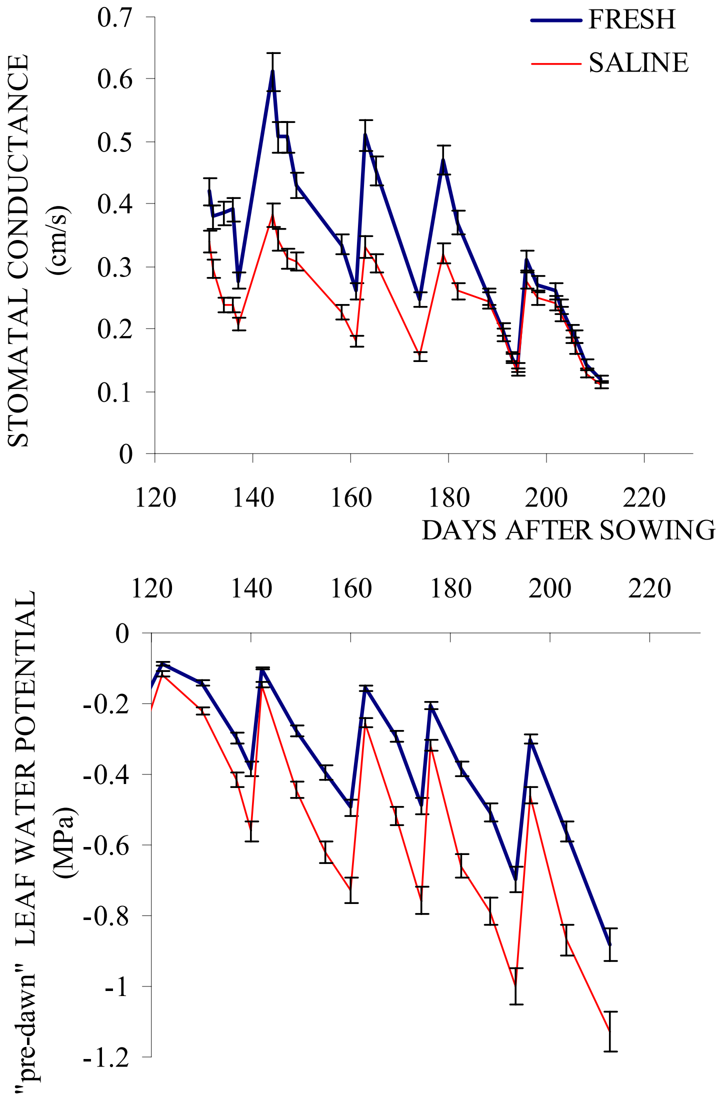


Figure 2. Maximum daily values of leaf water potential (at pre-dawn) and of stomatal conductance (at solar noon) measured during the growth cycle of sugar beet (Katerji *et al.*, 1997) supplied with two irrigation waters: fresh and saline

Clearer indications drawn from the Water Stress Day Index (WSDI, Katerji *et al.*, 2000):

$$\text{WSDI} = \sum_{1}^{n} \frac{\psi_f - \psi_s}{n}$$

Where Ψ_f the daily value of the pre-dawn leaf water potential of the un-stressed control treatment irrigated with fresh water from the start of leaf growth until the start of senescence, Ψ_s the equivalent of the stressed treatment irrigated with saline water, n the number of days from the start of leaf growth until the start of senescence.

The relationship between WSDI and relative yield (yield of the crop irrigated with saline water as compared with yield obtained with fresh water) was proposed as criteria to classify the cultivated species. Using this classification method (Fig. 3), only two groups of crops are identified: tolerant species (durum wheat, sugar beet, maize, sunflower and potato) and sensitive species (tomato, soy bean, broad bean, chick pea, lentil).

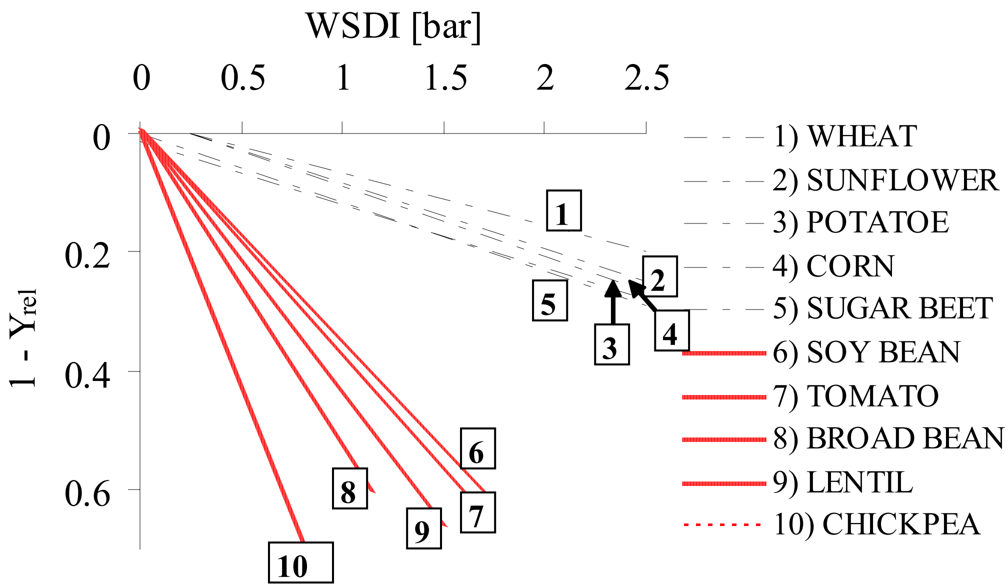
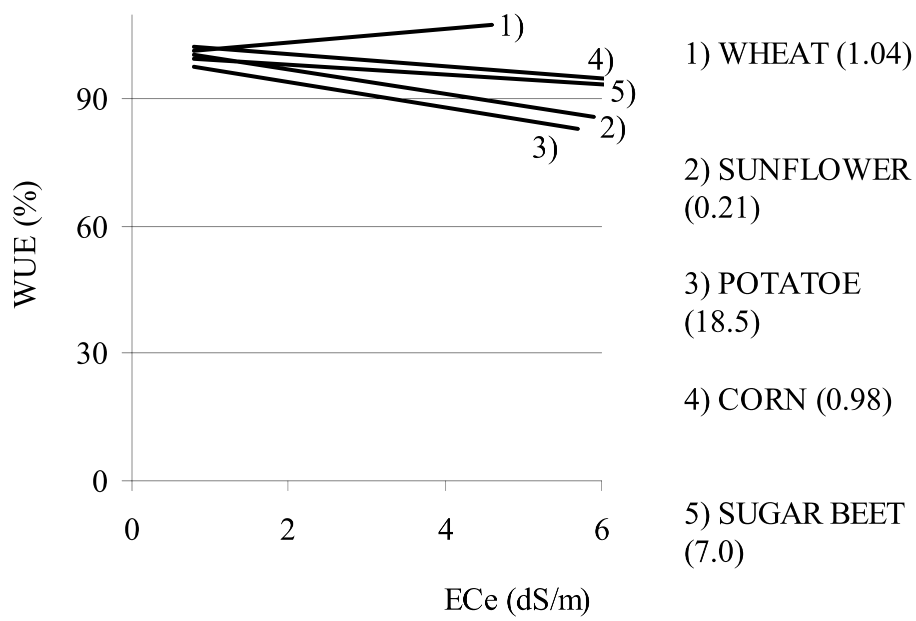


Figure 3. Decrease in relative yield ($1-Y_{rel}$) versus the WSDI (Katerji *et al.*, 2000)

The subdivision into two sensitivity groups is accounted for by the following:

1. tolerant species show relatively constant water use efficiency values (WUE = yield with respect to seasonal water use) with the increase in salinity (Fig. 4).



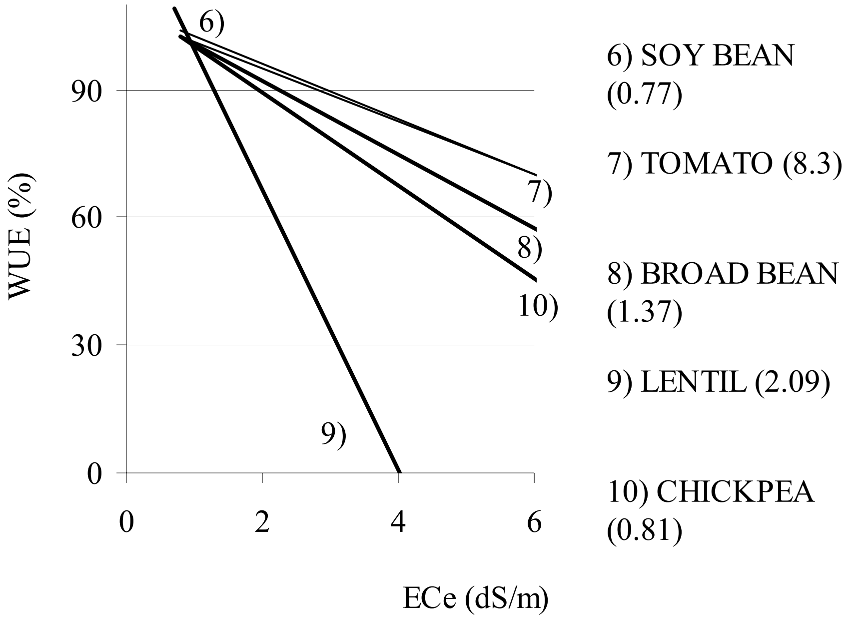


Figure 4. Water use efficiency versus soil salinity. The WUE values obtained in saline treatments are expressed as % with respect to the control irrigated with good quality water. In parentheses, the WUE values (kg m^{-3}) of the control (Katerji *et al.*, 2003)

2. the loss in relative yield ($1\text{-}Y_{rel}$) versus the relative decrease in evapotranspiration (1-ETa/ETm) is greater in the sensitive species than in tolerant species (Fig. 5). The slope of the linear regressions ($1\text{-}Y_{rel}$ *vs* 1-ETa/ETm) is 1.2 for tolerant species, whereas it doubles (2.46) for sensitive species.
3. the WSDI-based criterion recognizes as sensitive species all those of indeterminate flowering. Since effects on final yield are more severe if water stress occurs at flowering, it is likely that the longer the flowering stage, the greater the species sensitivity.

The soil salinity-based traditional method to classify crop species (Fig. 6) subdivides the species classified as tolerant by the WSDI-based method, into two groups: wheat and sugar beet as tolerant, whereas maize, sunflower and potato are reported as moderately tolerant (Ayers and Westcot, l.c.). Quite probably, such difference in tolerance depends on the fact that the two groups of crops complete their growth cycle in two different seasons: the tolerant species are autumn-winter crops, the moderately tolerant ones are spring-summer crops. Such subdivision seems to be directly determined by the climatic demand rather than by soil salinity. In fact, the greater the evaporative demand, the greater the seasonal irrigation volume. Consequently, when using brackish waters, spring-summer crops are more exposed to soil salinity.

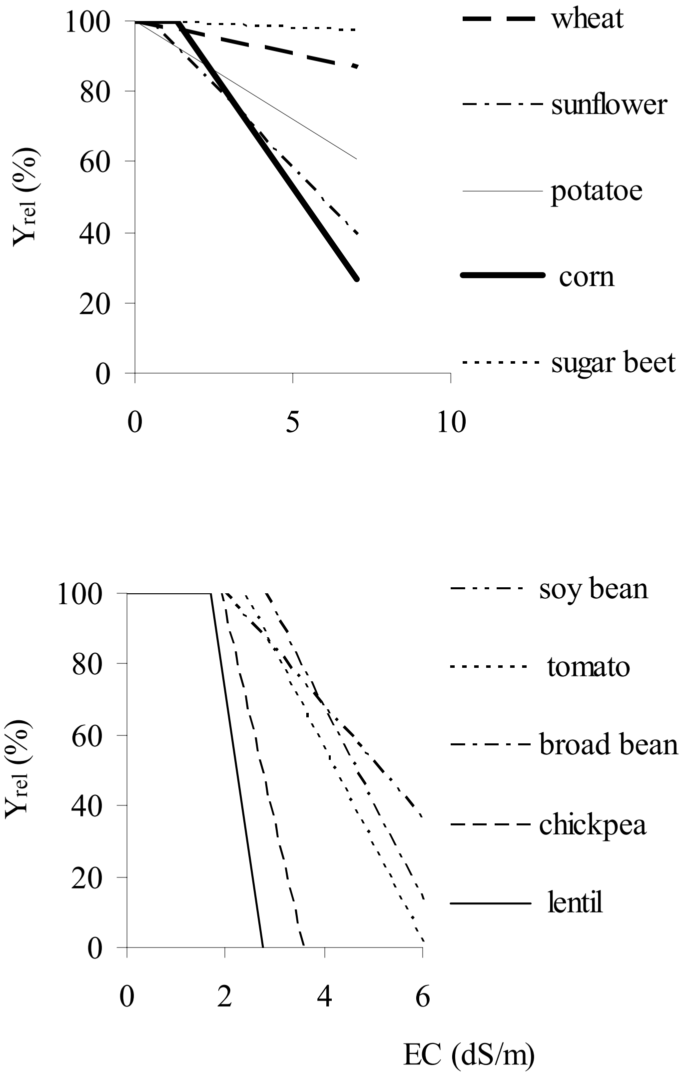


Figure 5. Decrease in relative yield (Y_{rel} = yield obtained in saline soil as compared with maximum yield of the crop irrigated with good quality water) versus the decrease in relative evapotranspiration (ET_{rel} = ETa of the crop irrigated with saline water with respect to ETm of the same crop irrigated with fresh water)

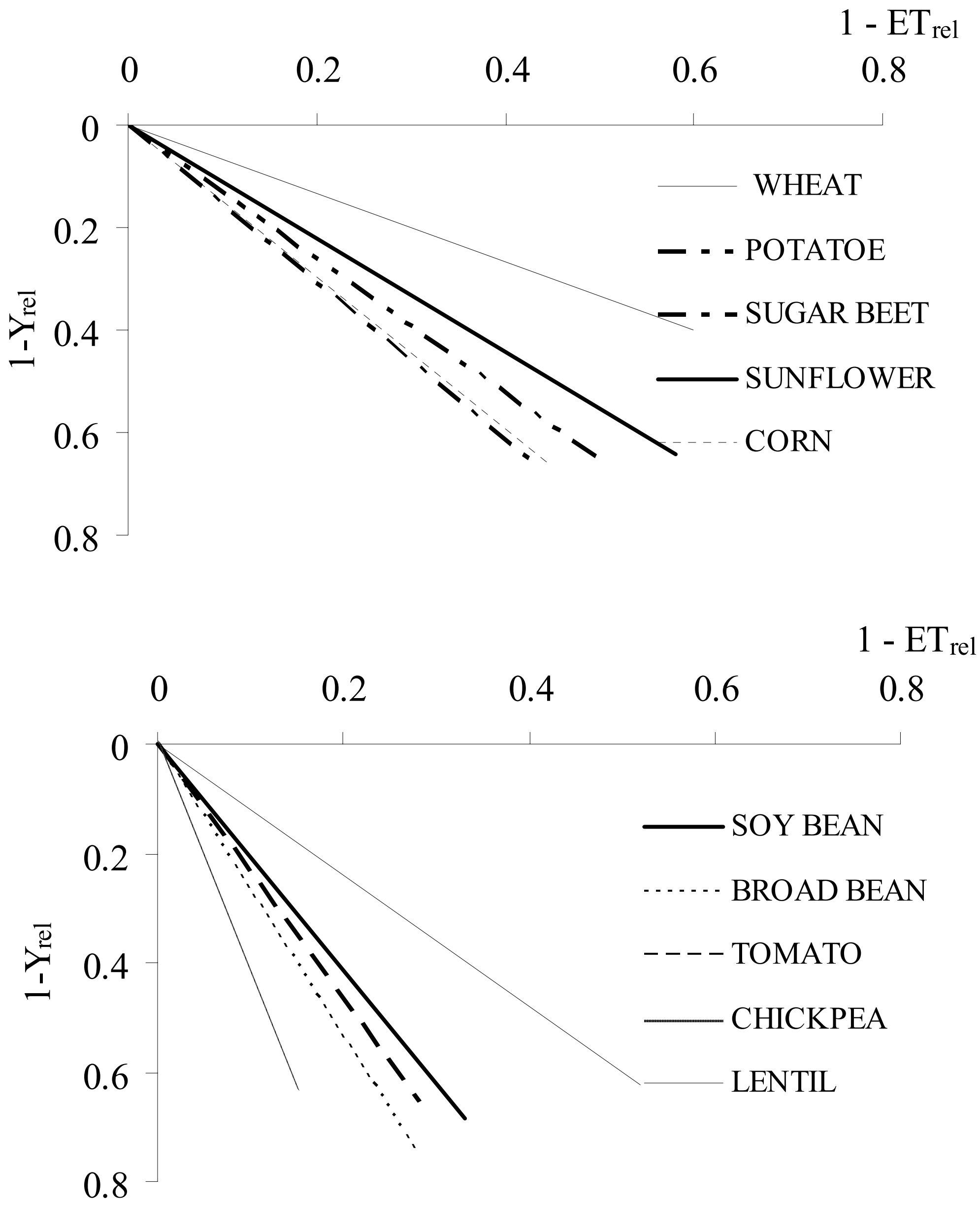


Figure 6. Relative yield (Y_{rel} = yield obtained in a saline soil as compared with maximum yield) versus relative evapotranspiration (ET_{rel} = ETa of the crop irrigated with saline water as compared with ETm of the same crop irrigated with fresh water)

The species considered to be sensitive according to the WSDI-based criteria, according to the traditional classification, in turn, are subdivided into: moderately sensitive (tomato, soy bean, broad bean) and sensitive (chickpea and lentil). Quite probably, such further grouping could be attributed to the effect of salinity on the microbial activity involved in the cycle of nitrogen of the soil. In the case of chickpea and lentil, the symbiosis between rhizobium and grain legumes is particularly sensitive to the presence of salts in the soil.

CONCLUSIONS

This paper summarises the latest studies relative to the sensitivity of the crops irrigated with low quality waters. The adoption of a multidisciplinary approach allowed a critical evaluation of the traditional crop classification method based on the loss of productivity with the increase in soil salinity. In particular, the WSDI-based criterion that directly considers the water status of the crops irrigated with saline waters proposes a new classification of the sensitivity of the crops exposed to salinity and, in particular, allows interpreting some adaptation mechanisms of the plant to saline environments.

However, even this new classification of crop sensitivity to salinity, is constrained by its being static. Indeed, in field conditions, the crop response to salinity is dynamic. In addition to water quality, plants interfere with environment-related parameters (soil texture, physical and chemical fertility of the soil, air temperature and relative humidity, ET, other stresses) and cropping conditions (irrigation techniques, sowing time, type of tillage).

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