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Salt tolerance of crops according to three classification methods and examination of some hypothesis about salt tolerance

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Abstract

This publication is a complement to a previous publication on salt tolerance classification, using the observations of a long-term experiment on the use of saline water. Three classification methods were compared, based, respectively, on the electrical conductivity of the saturated paste extract, the relative evapotranspiration deficit and the water stress day index. Among the eight crops grown during the experiment, broadbean, soybean and tomato were clearly distinguished by the methods based on the relative evapotranspiration deficit and the water stress day index as more sensitive then durum wheat, maize, potato, sugar beet and sunflower. Their greater sensitivity may be explained by the salt sensitivity of rhizobium bacteria affecting the nitrogen supply, by the degree of osmotic adjustment or by the prolongation of the flowering period.

Keywords: Crop salt tolerance; Soil salinity; Water stress day index; Broadbean; Durum wheat; Maize; Potato; Soybean; Sugar beet; Sunflower; Tomato

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I. Introduction

Several simple models have been proposed in literature to describe the effect of water stress caused by drought (De Wit, 1958; Hanks, 1974;

Feddes, 1985) or by salinity (Shalhevet and Bernstein, 1967; Childs and Hanks, 1975; Meiri, 1984) on crop yield. The model mostly used is the one proposed by Stewart et al. (1977), which links relative yield decrease with relative evapotranspiration deficit by the following equation:

$$1-\frac{Ya}{Ym}=b\left(1-\frac{ETa}{ETm}\right) \tag{1}$$

where Y_a is the actual crop yield, Y_m the maximum crop yield, ET_a the actual evapotranspiration, ET_m the maximum evapotranspiration, and *b* the yield response factor or slope coefficient, determined from field experiments.

According to Eq. (1), the higher the slope coefficient, the stronger the relative yield decrease at equal relative evapotranspiration deficit. Doornenbos and Kassam (1979) calculated the slope coefficients for 26 crops and classified the crops into four groups from drought tolerant to drought sensitive. This classification is widely used, but it was also criticised for several reasons:

- The slope coefficient shows, for the same crop, a dispersion owing to experimental shortcomings (Doomenbos and Kassam, 1979) and to soil evaporation.
- The slope coefficient is sensitive to climatic conditions. Stegman (1985) mentioned that it ranged for maize from 1.25 to 1.67 with decreasing air humidity.
- The slope coefficient is sensitive to the leaf area index (Katerji et al., 1991). At the same relative evapotranspiration deficit water stress and yield decrease are higher for plants with a higher leaf area index. Since Eq. (1) does not take the leaf area index into account, it may lead to classification errors.

Several authors (Hiler and Howell, 1983; Katerji et al., 1991), therefore, proposed classification methods based on the direct measurement of the water stress of the plant. The method proposed recently by Katerji et al. (2000) is based on the hypothesis that crop tolerance to water deficit caused by drought or salinity is experimentally determined as yield decrease resulting from internal water deficit imposed on a crop during its growing season. The relationship between relative yield decrease and water stress is expressed by the following equation:

$$1-\frac{Ya}{Ym}=a+b\,\text{WSDI} \qquad (1)$$

with

$$\frac{\text{WSDI}=\sum^{n}\left(\psi_c-\psi_s\right)}{N}$$

where WSDI is the water stress day index, c the daily value of the pre-dawn leaf water potential of the non-stressed control treatment from the start of leaf growth until the start of senescence, s the equivalent of the stressed treatment, n the number of days from the start of leaf growth until the start of senescence, b the yield response factor or slope coefficient, a the value of the ordinate which should be around 0 (Katerji et al., 2000).

This method has been used in a previous publication (Katerji et al., 2000) for the classification of eight crops grown under water stress caused by salinity. The classification was compared with the classification according to the electrical conductivity of the saturated paste extract (EC_e). Differences in classification were ascribed to the sensitivity of the latter method to the growing season: wheat and sugar beet are grown during a cooler season (winter and spring) when the evaporative demand is lower than during summer when maize and sunflower are grown.

In this publication, we propose to extend and complete the previous study, using the same experimental data with the aim to answer the following three questions:

- How are the crops classified according to the concept of the relative evapotranspiration deficit in comparison with the classification according to the WSDI and the EC_e?
- Which crops are classified with each of the three methods as more sensitive to water stress?
- Which hypothesis could explain the sensitivity of these crops?

2. Experimental procedure

For the experimental procedure, we refer to the previous publication (Katerji et al., 2000), which presents a description of the set-up and a table mentioning the crops, variety, growth period and reference publication in Agricultural Water Management.

3. Results and discussion

Table 1 presents the yield and the corresponding evapotranspiration of the crops grown during the lysimeter experiment. The three columns for each soil texture refer to three levels of increasing salinity, which varied from year to year with water application and leaching. The salinity levels were specified in Table 3 of the previous publication (Katerji et al., 2000). The statistical analysis always showed a significant (p<0.05) effect of salinity on yield and evapotranspiration.

The result of the linear regression analysis of the relationship between relative yield decrease and relative evapotranspiration deficit is presented in Fig. 1. Three groups with a different slope coefficient can be distinguished.

- Durum wheat (slope 0.57);
- Maize, potato, sugar beet, sunflower (average slope 1.36);
- Broadbean, soybean, tomato (average slope 2.28).

The slope coefficient of crops of the same group do not differ significantly, but show a significant (p<0.05) difference with the slope coefficients of the other crops.

Fig. 2 presents the relationship between relative yield decrease and water stress day index. In this case, two groups can be distinguished with different slope coefficients:

- Durum wheat, maize, potato, sugar beet, sunflower;
- Broadbean, soybean, tomato.

Both classifications give the same results for the three most sensitive crops. The other five crops belong to one single group, if the slope is calculated using Eq. (2), or to two groups, if the slope is calculated using Eq. (1). Probably, the classification according to the relative evapotranspiration deficit indicates the relative evapotranspiration deficit indicates the sensitivity of the slope coefficient to climate conditions (Stegman, 1985) and crop growth (Katerji et al., 1991). By choosing the pre-dawn leaf water potential as indication for water stress, the slope coefficient becomes less sensitive to climate conditions and crop growth.

Table 1

Yìeld (kg/m2) and evapotranspiration (mm) of the crops grown during the lysimeter experiment

	Loam			Clay		
Durum wheat, 1991						
Yield, grain	0.9	0.8	0.8	0.7	0.7	0.6
ET	883	800	721	733	648	563
Potato, 1992						
Yield, tuber	8.6	6.5	5.4	5.8	5.0	4.8
ET	415	382	328	363	327	304
Maize, 1993						
Yield, grain	0.6	0.6	0.5	0.5	0.4	0.4
ET	607	578	494	644	552	505
Sunflower, 1994						
Yield, grain	0.3	0.2	0.2	0.2	0.1	0.1
ET	1450	1310	1157	1215	1040	994
Sugar beet, 1995						
Yield, beet	6.5	5.8	5.5	4.4	3.5	3.6
ET	836	753	734	731	642	657
Soybean, 1995						
Yield, grain	0.3	0.2	0.1	0.3	0.2	0.1
ET	410	376	306	430	361	300
Tomato, 1996						
Yield, fruit	6.1	4.4	2.4	5.3	3.8	2.2
ET	708	631	540	667	628	522
Broadbean, 1998						
Yield, grain	0.4	0.3	0.2	0.7	0.5	0.3
ET	409	354	322	448	398	345

The classification according to the EC_e (Katerji et al., 2000) distinguished two groups: on the one hand, durum wheat and sugar beet as more salt tolerant, on the other, the six remaining crops as more salt sensitive. Although the slope coefficients within the second group did not differ significantly, broadbean, soybean and tomato showed higher values.

The classifications using either the relative evapotranspiration deficit or the water stress day index or the EC_e always indicate broadbean, soybean and tomato as more sensitive to water stress caused by salinity. So the question arises which hypothesis could explain the higher sensitivity of these crops.

Broadbean is a winter crop; soybean and tomato are summer crops. Their sensitivity does not seem to be linked with the season of the year.

Broadbean and soybean are legumes. In a previous publication (Katerji et al., 1998a), it was already shown that the measured grain yield of soybean deviated strongly from the yield estimated according to the model of Stewart et al. (1977). This was attributed to the large difference in soybean variety or to the salt sensitivity of the rhizobium bacteria. The nitrogen balance of broadbean and soybean showed a difference between the nitrogen uptake of the plant and the nitrogen supply from fertilizer, soil water and irrigation minus drainage, the uptake decreasing with increasing salinity. This decrease in nitrogen uptake may be caused by the direct effect of salinity on plant growth and by the salinity effect on rhizobium which, in turn, affects the nitrogen supply of the plant. According to Bernstein and Ogata (1966), the dry weight of nodules in the case of soybean decreased due to a decrease of the dry weight percentage, and at EC_e,-values between 5.5 and 8 dS/m, due to a decrease of the nodule number. Inoculated soybean without fertilizer was more affected by salinity than non-inoculated soybean supplied with nitrogen. Wilson (1970) confirmed this observation for perennial soybean and also noted a decrease in the number of nodules, especially above EC_e of about 4.5 dS/m. Tu (1981) noted a decrease of rhizobium growth at increasing salinities and a decrease of the number of nodules above an EC_e of 6 dS/m, The range indicated by these authors corresponds with the salinity range in the lysimeter experiment. The salt sensitivity of the rhizobium bacteria affecting the nitrogen supply of the plant could explain, at least partly, the sensitivity of broadbean and soybean, but cannot explain the sensitivity of tomato.

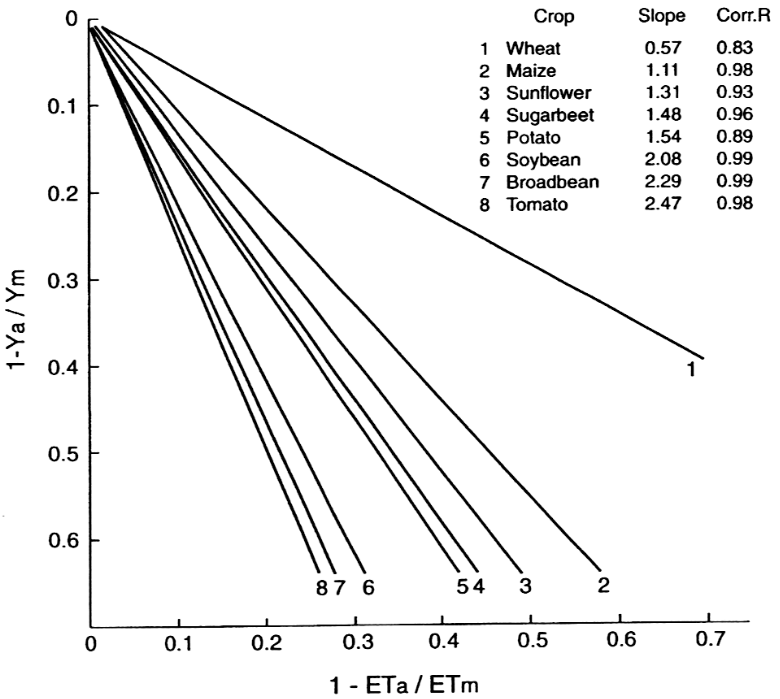

Fig. 1. *Relative yield decrease vs. relative evapotranspiratio deficit.*

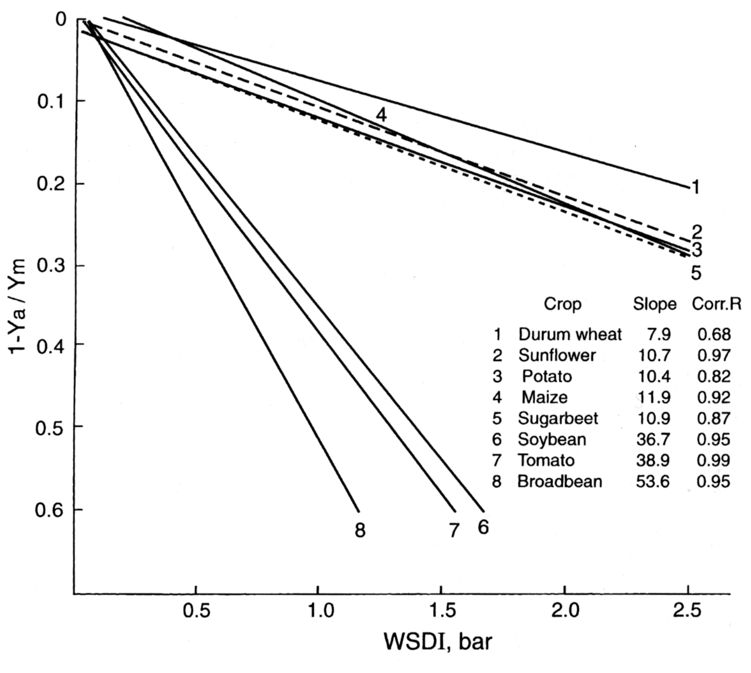

Fig. 2. *Relative yield decrease vs. water stress day index.*

It is possible, with the experimental data obtained during the lysimeter experiment, to examine the hypothesis whether crops that control the stomatal conductance more efficiently in case of water stress are more drought resistant (Ludlow, 1980) by comparing the relationship between stomatal conductance and pre-drawn leaf water potential. Fig. 3 shows that the relationship for more sensitive crops is almost the same as for more tolerant crops, e.g. soybean vs. sunflower, and tomato vs. potato. The control of the stomatal conductance in case of water stress does not appear to be of great importance for explaining the difference in crop sensitivity.

Osmotic adjustment in case of water stress caused by drought (Berg and Turner, 1976) or salinity (Shalhevet and Hsiao, 1986) could be an important mechanism for increasing crop tolerance. Two previous papers (Katerji et al., 1997, 1998b) present data on osmotic adjustment of sugar beet and tomato, grown under identical salinity conditions.

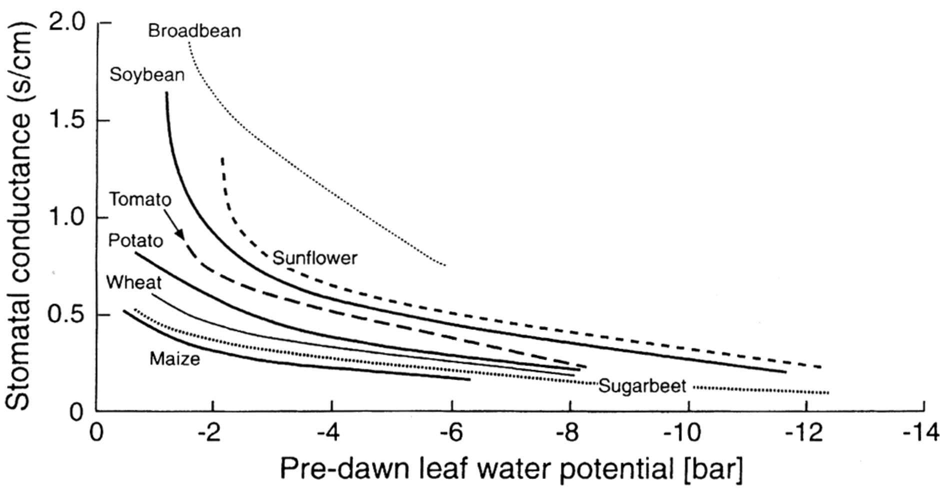

Fig. 3. *Stomatal conductance vs. pre-dawn leaf water potential.*

According to the earlier mentioned classifications, the crops belong to two groups, which differ significantly in salt tolerance. Both crops showed osmotic adjustment, but the adjustment observed for sugar beet at the end of the growing season (3.7-4 bar) was stronger than for tomato (1.5-2.7 bar), indicating that sugar beet adapts itself better to saline conditions. The time, however, during which the crop is exposed to water stress, also affects the process of osmotic adjustment. This period lasted 214 days in case of sugar beet against only 83 days in case of tomato.

Tomato is particularly sensitive to salinity in combination with a high temperature during fruit formation. This combination causes blossom end rot, a calcium deficiency, and, consequently, a decrease of the marketable yield. Late-season tomatoes are less sensitive to salinity (UNESCO, 1970). Blossom end rot, however, did not occur during the lysimeter experiment.

Broadbean, soybean and tomato are all crops of indeterminate flowering. The flowering period lasts longer in comparison with crops having a determinate flowering. Several studies (Salter and Goode, 1967; Mouhouche et al., 1998) indicate a maximum sensitivity during flowering. The effect of water stress during this period can be attributed to several causes:

- The reduction of the number of flowers, caused by a decrease of dry matter growth (Meynard and Sebillotte, 1994) or by a disturbance of the nitrogen uptake (Jeuffroy and Sebillotte, 1997), observed during water stress.
- The disturbance of pollination and fecundation. According to several authors (Sioni and Kramer, 1977; Westgate and Boyer, 1985), the fecundation is particularly affected by water stress.

So the longer flowering period, a common characteristic of the three crops, could be a cause of their greater sensitivity to water stress.

4. Conclusion

Three methods of salt tolerance classification, based, respectively, on the electrical conductivity of the saturated paste extract, the relative evapotranspiration deficit and the water stress day index, lead to different results. The two latter methods clearly indicate broadbean, soybean and tomato as more sensitive than the other crops. Their greater sensitivity may find its explanation in the salt sensitivity of rhizobium bacteria affecting the nitrogen supply, in the degree of osmoting adjustment or in the prolongation of the flowering period.

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