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Comparison of corn yield response to plant water stress caused by salinity and by drought

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Abstract

The effect of water stress on corn yield was studied in a salinity experiment and in a drought experiment. The plant water status was determined by measuring the pre-dawn leaf water potential regularly during the whole growing season and expressed by the water stress day index (WSDI). The yield response of corn did not differ under salinity and drought conditions. The WSDI is a useful indicator for determining crop-response to salinity and drought.

Keywords: Corn; Salinity; Drought

1. Introduction

Salinity and drought affect the plant in a similar way (Bernstein and Hayward, 1958). With increasing salinity or drought soil water availability decreases, changing the plant water status, which in turn affects on short term the gaseous exchanges and on long term the carbon balance (Robelin, 1983; Katerji et al., 2003). From the similarity of the effects of salinity and drought the question has arisen whether the same change in the plant water status caused either by salinity or by drought leads to the same yield reduction.

Stewart et al. (1977) were the first to answer this question, showing the relationship between corn yield and evapotranspiration being the same in case of salinity and drought.

Katerji et al. (1998) verified the hypothesis of Stewart et al. for four crops (corn, sunflower, potato, soybean) by comparing the measured yield under saline conditions with the yield predicted from the relationship between yield deficit and evapotranspiration deficit

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established under drought conditions. The agreement was satisfactory for corn, sunflower and potato, but not for soybean. In case of soybean salinity has a stronger effect than drought, whereas for the other three crops the hypothesis of Stewart et al. is confirmed.

Shalhevet and Hsiao (1986) studied the effects of salinity and drought on cotton and pepper. Plants grown under saline conditions showed at the same soil water potential a better growth and biomass than under drought. Apparently, the yield response to plant water status due to salinity or to drought is still a controversial subject.

In the studies mentioned above, the water stress was not measured directly on the plant, but evaluated through the evapotranspiration deficit or the soil water potential, indirect and, as such, imperfect parameters for measuring the plant water status (Hiler and Howell, 1983). According to climate and growth of aerial biomass and roots, the indirect parameters indicate more or less the plant water status in case of drought (Denmead and Shaw, 1962; Katerji et al., 1991) or in case of salinity (Shalhevet, 1994). The inaccuracy of the methods used to characterise the plant water status weakens the conclusions and is probably the cause of the controversy in literature.

This paper focus on the response of corn yield during 3 years to differences in plant water status under conditions of drought and salinity. The plant water status is determined by measuring the pre-dawn leaf water potential and expressed by the water stress day index (WSDI), proposed by Katerji et al. (2000).

2. Experimental

2.1. Salinity experiment

2.1.1. Set-up

The salinity experiment was carried out during the summer of 1993 on the lysimeter set-up of the Istituto Agronomico Mediterraneo at Bari, southern Italy.

The set-up consisted of 30 tanks of reinforced fibre glass with a diameter of 1.20 m and a depth of 1.20 m. A layer of coarse sand and gravel, 0.10 m thick, was overlain by a re-packed soil profile of 1 m. At the bottom of the tank, a pipe serving as a drainage outlet connected the tank to a drainage reservoir. The set-up was covered at a height of 4 m by a sheet of transparent plastic to protect the assembly against precipitation.

One series of 15 tanks was filled with loam and a second series of 15 tanks with clay. The tanks were irrigated with water of three different qualities: the control treatment with fresh water containing 3.7 meq Cl l^{-1} and EC of 0.9 dS m^{-1}, and two saline treatments containing 15 and 30 meq Cl l^{-1} and with EC 2.3 and 3.6 dS m^{-1}, obtained by adding equivalent amounts of NaCl and $CaCl_2$ to fresh water. For each water quality, five tanks were available.

At each irrigation, surplus water was added to provide a leaching fraction of about 0.2. As an earlier experiment had shown that under such leaching the moisture content after irrigation corresponded to field capacity, the evapotranspiration of the irrigation interval was calculated as the difference between the amounts of irrigation and drainage water.

To determine soil salinity, the chloride concentration of soil water was calculated from the salt balance of irrigation and drainage water and converted into EC of soil water by the equation $\ln EC = 0.824 \ln Cl–1.42$, the value of which was divided by 2 for the conversion to EC_e (Van Hoorn et al., 1993). Owing to differences in water application, evapotranspiration and drainage, differences in soil salinity may appear between both soils.

2.1.2. Crop

Maize (*Zea mays*, variety hybrid Asgrow 88) was sown at the end of July at a density of 21 grains per tank. This was reduced to 12 plants at the six-leaf stage, and finally to five plants per tank at harvest time because of the successive samplings to determine the growth parameters. Fertilising was done three times: at the start of vegetative growth, 3 weeks later, and at the start of flowering, a total equivalent to 120 kg N ha^{-1} and 120 kg P_2O_5 ha^{-1}. The period from sowing till harvest lasted 98 days for this early variety.

2.1.3. Water stress of the plant

The water stress was determined by measuring the pre-dawn leaf water potential on five leaves, taken from the upper part of the canopy (one leaf per tank, five leaves per treatment), with a pressure chamber (Scholander et al., 1965).

2.1.4. Yield

At harvest, the dry matter of leaf and stem and the grain yield of the remaining five plants were determined for each lysimeter. The following yield components were determined: the number of ears per plant, the number of grains per ear and the weight of 1000 grains.

2.2. Drought experiment

2.2.1. Site and climate

The drought experiments were carried out at the experimental station of the Istituto Sperimentale Agronomico at Rutigliano, 10 km southwest of Bari during the summers of 1996 and 1997.

The Rutigliano climate is characterised by warm dry summers, with maximum air temperature sometimes higher than 40 °C, and minimum relative air humidity often less than 20%. Mean annual rainfall is 600 mm, almost exclusively concentrated in spring and autumn. The year 1997 was sunnier and warmer than 1996, especially early in the crop season. For both years the central period of growth was characterised by an extended drought (except for a short rain in 1997). Precipitation was more frequent and heavier at the end of the 1996 crop season.

The soil is silty clay loam, a well-drained red earth or 'Alfic Xerarent Mixed Thermic Fine' (USDA Soil Taxanomy). The soil profile is shallow (up to 0.6 m in depth), and consequently water availability is low (about 110 mm, calculated between field capacity and wilting point), so irrigation is necessary during the maize crop season.

2.2.2. Crop management and yield analysis

Crops (variety Maltas) were sown at the end of May in rows 60 cm apart and at a rate of 10 seeds m^{-2}. The final density was 5.5 plants m^{-2}. Fertilising consisted of 120 kg P_2O_5 ha^{-1} applied before sowing and 100 kg N ha^{-1} as ammonium nitrate (26% N) applied in two slit applications, the first one early in the crop season and the second one at the jointing stage.

The experimental design was a randomised block replicated three times (nine plots in total). Each plot was 9 m long and 9.6 m wide. The period from sowing till harvest lasted 125 days in 1996 and 118 days in 1997 for this late variety. At harvest the straw and grain yield included all the plants of each plot.

2.2.3. Irrigation scheduling and experimental design

Irrigation scheduling tried to produce three different soil water conditions. The adopted methodology is based on plant water relationships. It was observed that in maize, stomatal conductance does not limit gas exchange when the pre-dawn leaf water potential (ψ) is higher than −0.3 MPa, but if ψ becomes more negative than this threshold value, maize stomata tend to close (Katerji and Bethenod, 1997). Moreover, if ψ decreases to −1.5 MPa, stomatal conductance values do not change. Therefore, −0.3 MPa represents a threshold value for separating no water stress from stress conditions.

During each trial year, plants were well-watered until leaf area index (LAI) was just higher than 1. Thereafter, three water treatments were imposed: full irrigation (Irr), moderate water stress (Str1) and severe stress (Str2). Irrigation was scheduled using a low-pressure system (drip irrigation) whenever ψ, measured daily, equalled −0.3 MPa (Irr), −0.6 MPa (Str1) and −1.2 MPa (Str2), respectively. The pre-dawn leaf water potential (ψ) was measured on the last developed leaves before sunrise. Five leaves per plot were harvested from the three treatments and the water potential was measured with a pressure chamber.

2.3. Water stress day index

The relationship between relative yield and water stress observed in case of salinity and drought is expressed in the following way (Katerji et al., 2000):

$$Y = a - b \times \mathrm{WSDI} \tag{1}$$

with

$$\mathrm{WSDI} = \sum_{i}^{n} \frac{\psi_{\mathrm{c}} - \psi_{\mathrm{s}}}{n} \tag{2}$$

in which ψ_{c} is the daily value of the pre-dawn leaf water potential of the control treatment, from the start of leaf growth until the start of senescence; ψ_{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 loss in % per unit decrease of WSDI; a the value of the ordinate, which should be around 100. Because Ψ is negative, WSDI is positive.

3. Results and discussion

3.1. Water stress and yield

Fig. 1 presents the pre-dawn leaf water potential of the salinity experiment on loam and clay for the control and two saline treatments. The pre-dawn leaf water potential shows

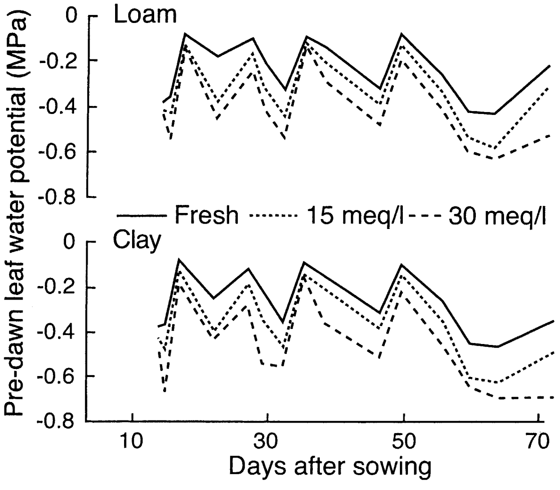

Fig. 1. Pre-dawn leaf water potential vs. days after sowing (salinity experiment).

an increase after irrigation, followed by a decrease during the irrigation interval, with a significant difference due to salinity, the largest difference always occurring just before irrigation. Soil texture also affects the pre-dawn leaf water potential, clay always showing lower values then loam.

The pre-dawn leaf water potential of the control treatments varied between −0.08 and −0.3 MPa, excepted during the last growth stage coinciding with the start of senescence, the average values being −0.22 MPa on loam and −0.26 MPa on clay. The most saline treatments (EC_e 3–4 dS m^{-1}) showed a fluctuation between −0.15 and −0.68 MPa.

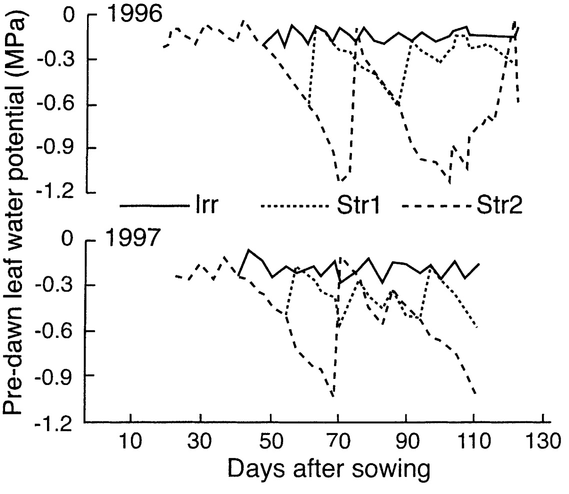

Fig. 2. Pre-dawn leaf water potential vs. days after sowing (drought experiment).

Table 1
Yield of corn in g m^{-2} and g per plant

Salinity experiment			Drought experiment		
	g m^{-2}	g per plant		g m^{-2}	g per plant
Loam			1996		
Fresh	678	153	Irr	918	167
15 meq l^{-1}	674	152	Str1	684	124
30 meq l^{-1}	533	121	Str2	503	91
Clay			1997		
Fresh	548	124	Irr	868	158
15 meq l^{-1}	486	110	Str1	721	131
30 meq l^{-1}	414	94	Str2	518	94

Fig. 2 presents the pre-dawn leaf water potential of the drought experiment. The control treatments show a slight fluctuation between −0.1 and −0.3 MPa during the growing season with averages of −0.15 MPa in 1996 and −0.2 MPa in 1997, slightly higher than those of the salinity experiment. The stressed treatments show much stronger fluctuations, between −0.2 and −0.6 MPa for Str1 and between −0.2 and −1.1 MPa for Str2. As the pre-dawn leaf water potential was used for irrigation scheduling the treatments were usually not irrigated on the same day.

The grain yields in Table 1 are expressed in g m^{-2} and then in gram per plant to take into account that the plant density was not the same in both experiments, 5.5 plant m^{-2} in the drought experiment and 4.42 plant m^{-2} in the salinity experiment. The average control yield of the salinity trial was about 15% lower that of the drought trial, which can be attributed to the difference in the length of the growing period between the varieties, 98 days against an average of 122 days.

The average yield reduction of the most stressed treatment of the drought experiment was 45% against 23% for the most stressed treatment of the salinity experiment. This corresponds with the lower pre-dawn leaf water potential observed during the drought experiment.

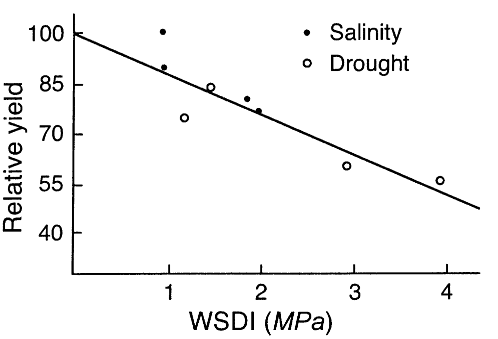

Fig. 3. Relative yield vs. WSDI.

3.2. Relative yield response to WSDI

Fig. 3 shows for the salinity and drought experiments together the relationship between relative yield and WSDI: a straight line with a slope of 0.123 and a correlation coefficient of 0.95. The slopes calculated separately for salinity (0.119) and drought (0.128) do not differ significantly. The nature of the stress, salinity or drought, does not affect the relationship between relative yield and WSDI.

4. Conclusion

The yield response of corn to water stress does not differ according to the cause whether it is salinity or drought. This confirms the hypothesis of Stewart et al. (1977) by using a different method. The WSDI takes into account the plant water status during the whole growing season by measuring regularly the pre-dawn leaf water potential. The determination of the pre-dawn leaf water potential is simpler and more accurate than the determination of the relative evapotranspiration or the soil water potential. The WSDI can be used for determining yield response under salinity or drought conditions.

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