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Salinity and drought, a comparison of their effects on the relationship between yield and evapotranspiration

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Abstract

The observations of a long-term experiment on the use of saline water were used to check the hypothesis whether models developed for drought conditions are valid for yield prediction in case of salinity. The models for the relation between yield and evapotranspiration, proposed by Stewart and Hagan (1973) and Stewart et al. (1977), were used for maize, sunflower, potatoes and soybean. The yield estimation for maize and sunflower was quite accurate, for potatoes somewhat less, but unsatisfactory for soybean. The estimated yield of soybean under saline conditions was higher than the measured one. This may be attributed to the differences in salt tolerance between soybean varieties or to an additional effect of salinity on the nitrogen supply of this legume.

Keywords: Evapotranspiration; Maize; Potatoes; Salinity; Soybean; Sunflower; Yield model

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1. Introduction

The prediction of crop yield in relation to water requirement or evapotranspiration is important for irrigation project planning and evaluation (Hanks and Hill, 1980). Considerable research effort has been given to the development of simple models for predicting crop yield from evapotranspiration during the growing season (Stewart and Hagan, 1973; Doorenbos and Kassam, 1979; Feddes, 1985; Howe] and Musick, 1985).

Different conditions for evapotranspiration were obtained by applying different soil moisture regimes, but rarely (Letey and Dinar, 1986) by using saline water.

The extension of irrigation projects in several Mediterranean countries nowadays relies on the use of water of marginal quality (Hamdy et al., 1995) and the question arises whether models developed for drought conditions are able to predict crop yield for saline conditions.

Stewart et al. (1977) showed that the relation between yield and evapotranspiration of maize is the same in case of drought and salinity. Shalhevet (1994) appears to generalize this result for other crops, assuming a common relationship between yield and evapotranspiration, independent of whether changes in the two variables are caused by drought or salinity. No research has been done to check this hypothesis for other crops than maize.

This paper aims at checking the hypothesis for several crops by predicting the yield under saline conditions with models developed for drought conditions. The observations of four crops, maize, sunflower, potatoes and soybean, were obtained at the Mediterranean Agronomic Institute at Bari, southern Italy, where a long-term experiment on the use of saline water started in 1989.

2. Modelling yield response to evapotranspiration

According to the theory of de Wit (1958) crop yield (Y) is a linear function of its transpiration T:

$$Y = \frac{mT}{E_o} \quad (1)$$

in which E_0 represents the evaporation of a free water surface and *m* a crop coefficient. This relationship was the basis for several models to predict yield from evapotranspiration (Rijtema and Endrodi, 1970; Hanks, 1974). The model mostly used is the one proposed by Stewart and Hagan (1973):

$$Y = Y_m - Y_m K_y \frac{\mathrm{ETD}}{\mathrm{ET}_m} \quad (2)$$

in which: *Y* = crop yield; Y_m = maximum crop yield under the same conditions of soil texture, fertility etc.; K_y = crop coefficient; ETD = cumulated evapotranspiration deficit during the growth period, calculated as:

$$\mathrm{ETD} = \mathrm{ET_m} - \mathrm{ET_a}$$

in which: ET_m = maximum evapotranspiration; ET_a = actual evapotranspiration.

Doorenbos and Kassam (1979) determined the crop coefficient for 25 crops grown under different soil moisture regimes. The crop coefficients for maize, sunflower, potato and soybean were 1.25, 0.95, 1.1 and 0.85, respectively.

The model is simple and practical and can be used when the sensitivity to moisture stress is the same during the whole growing period. For the case that the sensitivity differs significantly among growth periods, Stewart et al. (1977) proposed a model that takes into account the effect of moisture stress during successive phenological stages according to:

$$Y = Y_m - Y_m \frac{B_\mathrm{v}\mathrm{ETD_v} + B_\mathrm{p}\mathrm{ETD_p} + B_\mathrm{m}\mathrm{ETD_m}}{\mathrm{ET_m}} \quad (3)$$

in which B_v, B_p and B_m are crop coefficients for the stages of vegetation, pollination and ripening and ETD_v, ETD_p and ETD_m the evapotranspiration deficits for the same stages. Stewart et al. (1977)

showed that the crop coefficients B_v, B_p and B_m. for maize under climatic conditions similar to the Mediterranean area are 0.8, 1.1 and 1.5, respectively.

3. Experimental procedure

3. 1. Setup

The setup consisted of 30 tanks of reinforced fiberglass 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 repacked 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 setup 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. Table 1 presents some properties of the soils.

The tanks were irrigated with water of three different qualities: the control treatment with fresh water containing 3.7 meq Cl/l and an electrical conductivity (EC) of 0.9 dS/m, and two saline treatments containing 15 and 30 meq Cl/l and an EC of 2.3 and 3.6 dS/m, obtained by adding equivalent amounts of NaCl and CaC_2 to fresh water. For each water quality, five tanks were available. Potatoes on clay were irrigated with water containing 20 meq Cl/l instead of 30 meq/l. A recent paper (Van Hoorn et al., 1997) presents detailed information on composition of irrigation water and soil salinity.

At each irrigation surplus water was added to provide a leaching fraction of about 0.2. Irrigation water was applied when the evaporation of the class A pan had attained about 80 mm. The evapotranspiration during the irrigation interval was calculated for each tank as the difference between the amounts of irrigation and drainage water. Water was applied on the same day on all treatments.

Table I

Soil properties

Soil	Particle size in % of mineral parts			CaC03 (%)	% water (v/v)		Bulk density (kg/dM3)
	$< 2\,\mu$m	$2-50\,\mu$m	$> 50\mu$m		pF2.0	pF4.2	
Loam	19	49	32	25	36.3	20.4	1.45
Clay	47	37	16	5	42.0	24.0	1.45

Table 2

Crop, variety, growth period and fertilization

Crop	Variety	Growth period	PO, (kg/ha)	N (kg/ha)
Potato	Spunta	03.02-07.06.1992	250	200
Maize	Hybrid Asgrow *88*	27.07-02.11.1993	120	120
Sunflower	Hybrid ISA	22.04-02.09.1994	35	75
Soybean	Talon	18.07-16.09.1995	250	50

3.2. Crops

Table 2 presents the variety, growth period and fertilization of the four crops. Details concerning sowing density, date of fertilizing, growth and yield of potatoes, maize and sunflower were published in previous papers (Van Hoorn et al., 1993; Katerji et al., 1996).

Soil salinity, expressed as average EC_e during the growing period, ranged between 0.8 and 6 dS/m for potatoes, between 0.8 and 4 dS/m for maize and sunflower, and between 0.8 and 7 dS/m for soybean.

Potatoes, maize and sunflower showed the same relationship between relative yield and soil salinity, corresponding with the data for maize published by Ayers and Westcot (1985). Soybean showed a relationship almost similar to the one obtained for the other three crops, but differing strongly from the data of Ayers and Westcot (Fig. 1). The four crops can be classified as moderately salt sensitive.

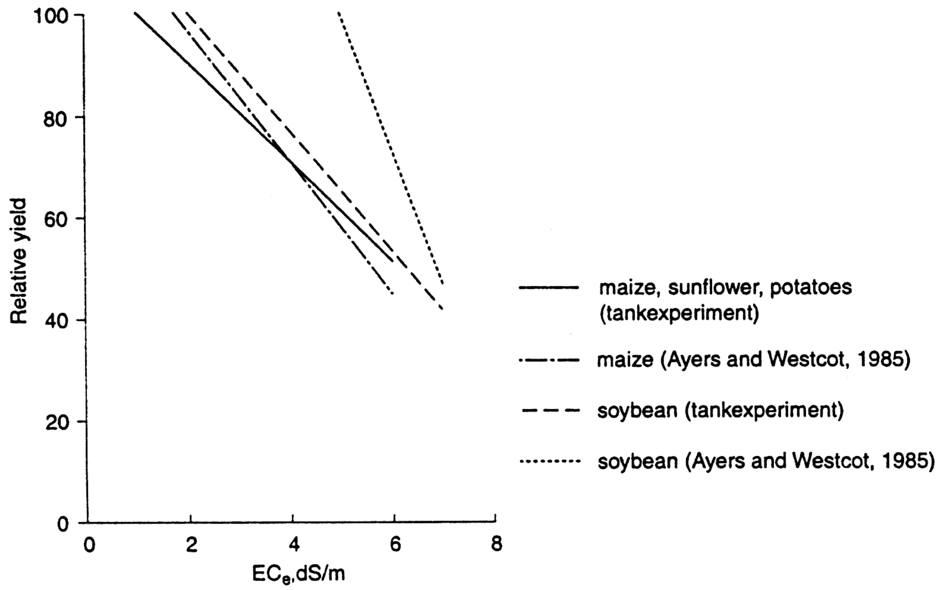

Fig. 1. *Relative yield vs. soil salinity.*

The yield was always lower on clay soil than on loam for corresponding treatments of irrigation water, but the relationship between relative yield and soil salinity was not affected.

3.3. Yield estimation

The procedure was the following.

(1) Y_m and ET_m were calculated for both soils as the average values of the five control tanks.

(2) These values Y_m and ET_m were then introduced in Eq. (2) with the values K_y published by Doorenbos and Kassam (1979). For maize we also used in Eq. (3) the values B_V, B_P, and B_m published by Stewart et al. (1977).

(3) The yield of each tank was calculated by introducing in Eq. (2) the measured evapotranspiration of the tank. For maize the evapotranspiration was split up according to the phenological stage and introduced in Eq. (3).

In this way 30 estimated yield values were obtained for each crop.

3.4. Statistical analysis

The following statistical analysis was applied to check whether the equations are adequate for yield prediction in case of salinity:

measured yield = a $\times$ estimated yield + *b*

in which *a* and *b* represent the slope and the intercept of the regression line, respectively. If *a* and *b* are not significantly different from 1 and 0, respectively, the regression line coincides with the line 1:1. Tests according to Student were carried out to check these hypotheses at the 0.01 and 0.05 probability level.

4. Results and discussion

The Fig. 2a, Fig. 2b and Figs. 3-5 present the measured and estimated yield of maize, sunflower, potatoes and soybean. The yield estimation of maize and sunflower is very good, as for both crops the slope and the intercept of the regression line are not significantly different from 1 and 0, respectively (Table 3). Eq. (3) does not give a better result for maize than Eq. (2), justifying the use of the latter.

The yield estimation of potatoes is less accurate than those of maize and sunflower, as the slope and the intercept differ significantly from 1 and 0, respectively. Eq. (2) tends to overestimate slightly, but the overestimation never exceeds 10% within the range of measured yields.

The accuracy of the yield prediction for soybean with Eq. (2) is not satisfactory. The high yield values obtained on the fresh water and 15 meq Cl/l treatments are spread along the straight line 1: 1, but the low yields obtained on the 30 meq Cl/l treatments clearly deviate from this line. Eq. (2) overestimates the yield under saline conditions, which means that for the same water stress salinity affects soybean yield more than drought does. This conclusion contradicts the results of Shalhevet and Hsiao (1986) on cotton and pepper, who observed that plants under saline conditions presented at the same soil water potential a better growth than plants under drought conditions. They attributed this difference to osmotic adjustment of plants to salinity.

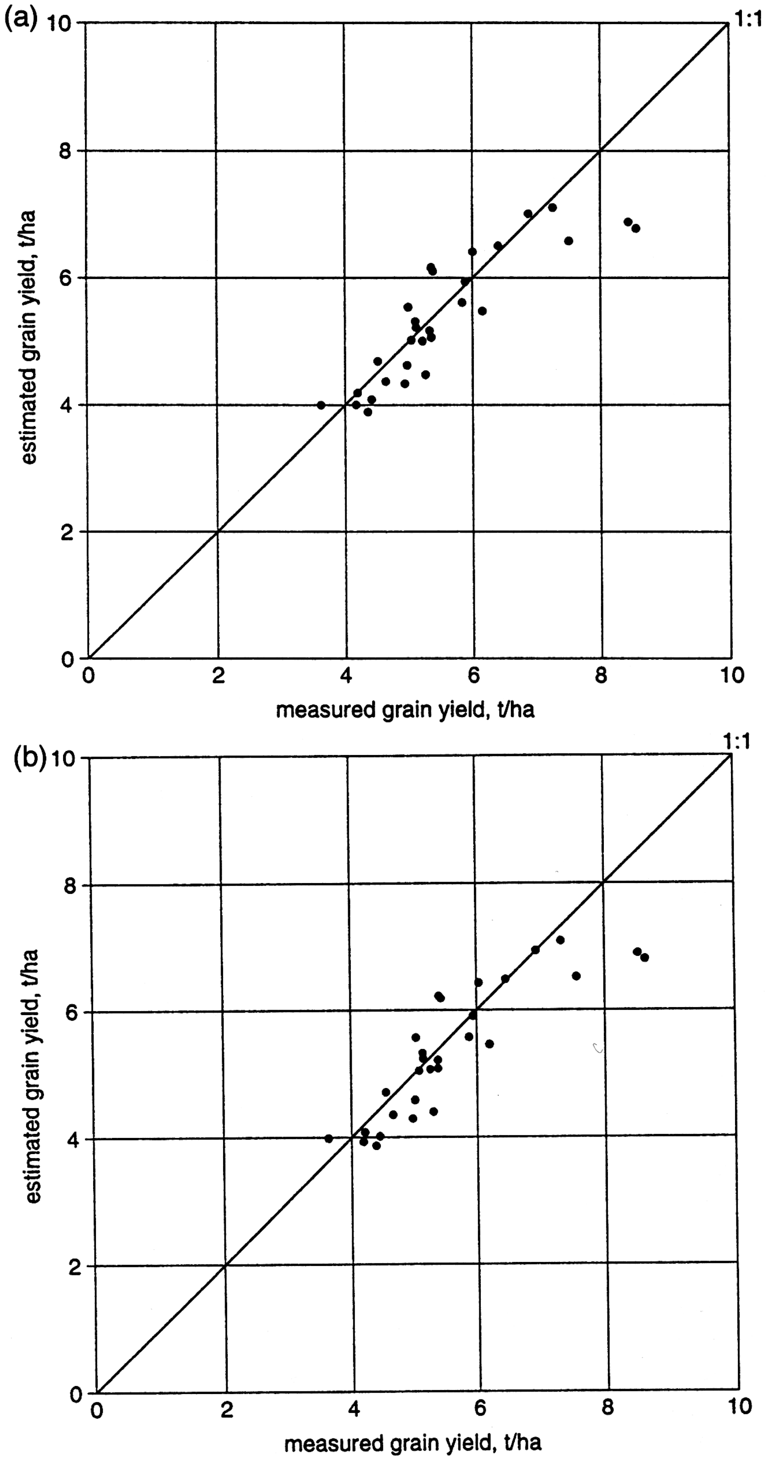

Fig. 2.*(a) Measured yield of maize vs. yield estimated with Eq. (2).*
(b) Measured yield of maize vs. yield estimated with Eq. (3).

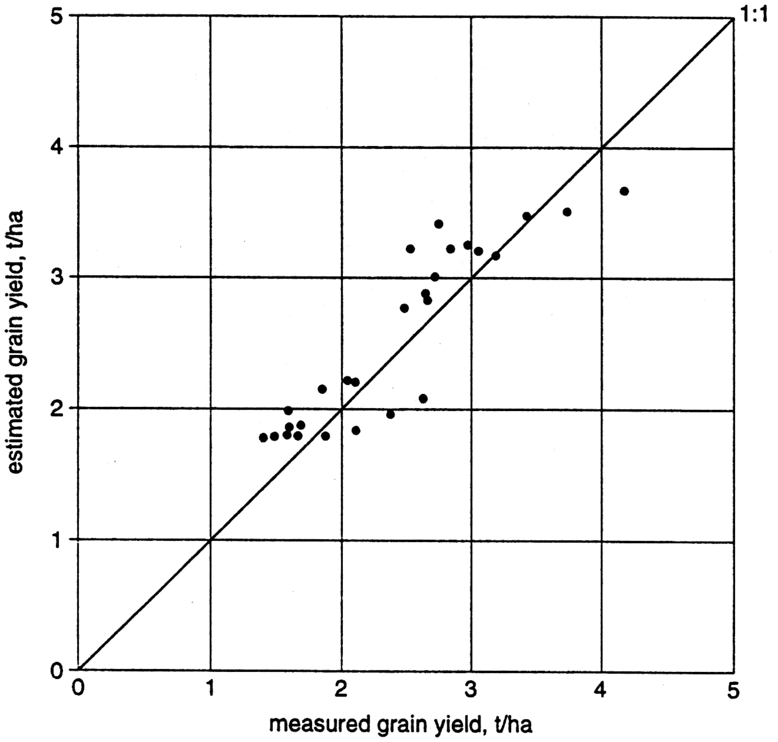

Fig. 3. *Measured yield of sunflower vs. yield estimated with Eq. (2).*

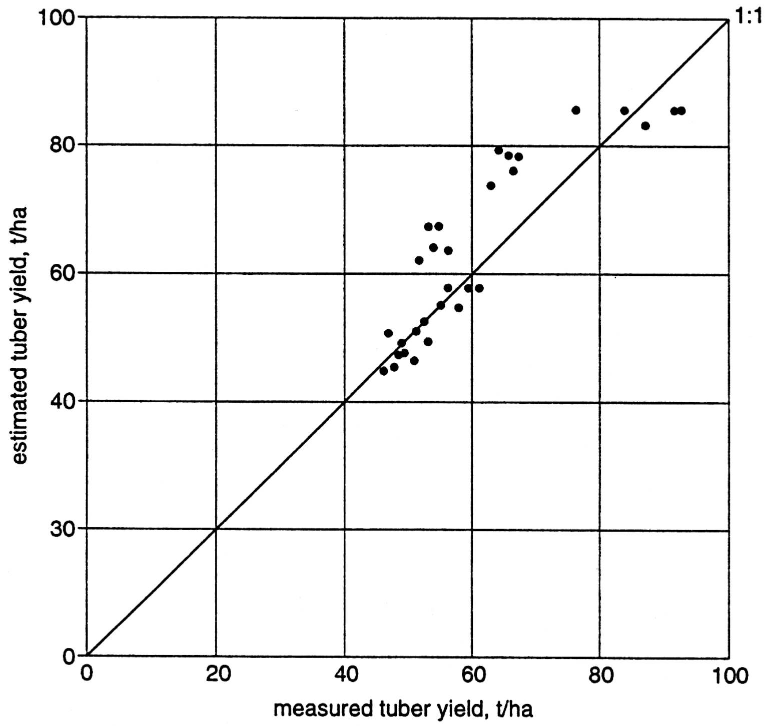

Fig. 4. *Measured yield of potatoes vs. yield estimated with Eq. (2).*

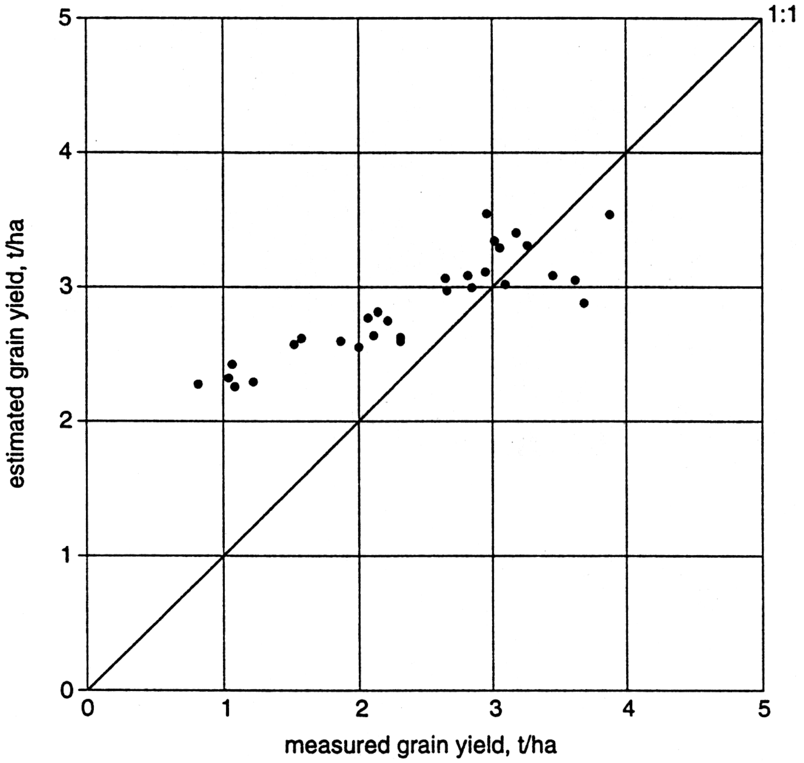

***Fig.* 5**. *Measured yield of soybean vs. yield estimated with Eq.* (2).

Two hypotheses may explain the particular behaviour of soybean under saline conditions.

(1) The large difference in salt tolerance between soybean varieties (Abel and Mackenzie, 1964; Velagaleti and Schweitzer, 1993). As already mentioned, the soybean variety grown in the tank experiment was less salt tolerant than would be expected from the data of Ayers and Westcot. So it is doubtful whether the coefficient K_y determined for drought may be used in case of salinity.

(2) Soybean is a legume receiving a large part of its nitrogen through symbiosis with rhizobium bacteria. Bernstein and Ogata (1966) noted for a rather salt tolerant variety a decrease of the dry weight of nodules, 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 strongly affected by salinity than non-inoculated soybean supplied

with nitrogen. So for soybean grown under saline conditions there may be an additional affect by the nitrogen supply.

Table 3

Result of the linear regression analysis between measured and estimated yields

Model	Crop	Slope *a*	Intercept *b*	Correlation R^2
Eq. (2)	maize	1.05 ± 0.068	-0.12 ± 3.73	0.77
Eq. (3)	maize	1.02 ± 0.020	0.03 ± 2.70	0.77
Eq. (2)	sunflower	0.97 ± 0.022	-0.04 ± 0.20	0.82
Eq. (2)	potatoes	0.82[a] ± 0.024	8.14[b] ± 0.020	0.78
Eq. (2)	soybean	1.98[a] ± 0. 12	-3.28 ± 0.68	0.77

[a]Significantly different from 1 at the 0.05 probability level.
[b]Significantly different from 0 at the 0.05 probability level.

5. Conclusion

The results of this study confirm those of Stewart et al. (1977) on maize and support their conclusion concerning a similar relationship between yield and evapotranspiration for drought and salinity. According to our results this conclusion is also valid for sunflower and, to a lesser degree, for potatoes, but does not hold true for soybean. The deviation between measured and predicted soybean yield may be attributed to the differences in salt tolerance between soybean varieties or to an additional effect of salinity on the nitrogen supply of this legume.

References

Abel, G.H., Mackenzie, A.J., 1964. Salt tolerance of soybean varieties during germination and later growth. Crop Sci. 4, 157-161.

Ayers, R.S., Westcot, D.W., 1985. Water quality for agriculture. FAO Irrigation and drainage paper 29, Rev. 1, Rome, 174 pp.

Bernstein, L., Ogata, G., 1966. Effects of salinity on nodulation, nitrogen fixation, and growth of soybeans and alfalfa. Agron. J. 58, 201-203.

de Wit, C.T., 1958. Transpiration and crop yields. Versl. Landbouwk. Onderz. 64.6, Pudoc, Wageningen, 88 PP.

Doorenbos, J., Kassam, A.H., 1979. Yield response to water. FAO Irrig. Drain. Paper No. 33, Rome, 193 pp. Feddes, R.A., 1985. Crop water use and dry matter production: state of the art. In: Perries, A., Riou, Ch. (Eds.), Crop Water Requirements, pp. 221-233.

Hamdy, A., Abu Zeid, M., Lacirignola, C., 1995. Water crisis in the Mediterranean: agricultural water demand management. Water Int. 20, 176-187.

Hanks, R.J., 1974. Model for predicting plant yield as influenced by water use. Agron. J. 66, 660-665.

Hanks, R.J., Hill, R.W., 1980. Modelling crop response to irrigation in relation to soils, climate and salinity. III C Publication No. 6, 66 pp.

Howel, T.A., Musick, J.T., 1985. Relationship of dry matter production of field crops to water consumption. In: Perrier, A., Riou, Ch. (Eds.), Crop Water Requirements, pp. 247-269.

Katerji, N., van Hoorn, J.W., Hamdy, A., Karam, F., Mastrorilli, M., 1996. Effect of salinity on water stress, growth and yield of maize and sunflower. Agric. Water Manage. 30, 237-249.

Letey, J., Dinar, A., 1986. Simulated crop-water production functions for several crops when irrigated with saline waters. Hilgardia 54.1, 32 pp.

Shalhevet, J., Hsiao, Th.C., 1986. Salinity and drought: A comparison of their effects on osmotic adjustment, assimilation, transpiration and growth. Irrig. Sci. 7, 249-264.

Shalhevet, J., (994. Using water of marginal quality for crop production: major issues. Agric. Water Manage. 25, 233-269.

Stewart, J.I., Hagan, R.M., 1973, Functions to predict effects of crop water deficits. J. Irr. Drain. Div. ASCE 99,421-439.

Stewart, J.I., Danielson, R,E., Hanks, RT, Jackson, E.B., Hagan, R.M., Pruitt, W.O., Franklin, W.T., Riley, J.P., 1977. Optimizing crop production through control of water and salinity levels in the soil. Utah Water Research Lab. PR. 151-1, Logan, Utah, 191 pp.

Rijtema, P.E., Endrodi, G., 1970. Calculation of production of potatoes. Neth. J. Agric. Sci. 18, 26-36.

Van Hoorn, J.W., Katerji, N., Hamdy, A., Mastrorilli, M., 1993. Effect of saline water on soil salinity and on water stress, growth and yield of wheat and potatoes. Agric. Water Manage. 23, 247-265.

Van Hoorn, J.W., Katerji, N., Hamdy, A., 1997. Long-term salinity development in a lysimeter experiment. Agric. Water Manage. 34, 47-55.

Velagaleti, R., Schweitzer, S.M., 1993. General effect, of salt stress on growth and symbiotic nitrogen fixation in soybean. In: Pessarakli, M. (Ed.), Plant and Crop Stress, pp. 461-471.