Field and laboratory studies towards better use of saline irrigation water in NW China

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Field and laboratory studies towards better use of saline irrigation water in NW China

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Abstract. The Shiyang River basin is located in the northwest China and suffers from water scarcity, drought and salinity. The objective of this paper is to evaluate the impact of saline water on crop yield and on the soil water retention capacity under different irrigation treatments and climate conditions. A soil water and solute flow model was calibrated at low salinity level (Tds= 0.8 g l^{-1} identified as C_{08}) and at a moderate salinity level (Tds =5 g l^{-1} identified as C_5). Numerical experiments were carried out on a dry and wet year

The water retention capacity (WRC) was larger for the C_5 treatment for all depths: 121.09 mm for the C_{08} and 249.53 mm for the C_5 , both for the 0 – 100 cm soil layer. The lower WRC for the C_{08} treatment can be explained by higher percentage of macropores and by a partial redistribution for the C_5 treatment of the porosity in smaller and more retentive micropores. Model calibration gave RMSE = 0.06 $cm^3\ cm^{-3}$ for the C_{08} and 0.045 $cm^3\ cm^{-3}$ for the C_5 For the C_{08} treatment available soil water, AW, in the 0 - 60 cm root zone was lower than WRC for 84 days in 2005 (dry year) and 71 in 2002 (wet year). For the C_5 treatment, instead, AW < WRC for the entire irrigation season of 93 days in all years. The numerical experiments gave higher WUE on the C_{08} treatment than the C_5 treatment for all years considered.

Keywords. Soil salinity – Model simulation – Saline water management.

Etudes de laboratoire et sur le terrain pour une irrigation par eau saline dans la Chine du nord-ouest

Résumé. *Le fleuve Shiyang du Nord-Ouest de la Chine présente une pénurie d'eau ; il est souvent à sec et ses eaux sont salines. Le but de cette étude est d'évaluer l'impact de l'eau saline sur le rendement des cultures et la capacité du sol de retenir l'eau dans de différentes conditions climatiques et stratégies d'irrigation. Un modèle de flux d'eau et d'un soluté a été calibré à un faible niveau de salinité (Tds= 0.8 g l^{-1} identifié par C_{08}) et à un niveau modéré de salinité (Tds =5 g l^{-1} identifié par C_5). Des expérimentations numériques ont été exécutées au cours d'une année sèche et d'une année pluvieuse.*

La capacité du sol de retenir l'eau (WRC) s'est démontrée plus grande sous le traitement C_5 à toutes les profondeurs : 121.09 mm pour le C_{08} et 249.53 mm pour le C_5, toutes les deux pour une couche de 0 – 100 cm. Les valeurs plus basses de WRC pour le traitement C_{08} peuvent être expliquées par un pourcentage plus élevé de macropores et pour le traitement C_5 par une redistribution partiele de la porosité dans des micropores plus petits et plus rétenteurs. La calibration du modèle a donné RMSE = 0.06 $cm^3\ cm^{-3}$ pour le C_{08} et 0.045 $cm^3\ cm^{-3}$ pour le C_5. Pour le traitement C_{08} l'eau disponible dans le sol, AW, dans la zone racinaire 0 - 60 cm était plus basse que la WRC pour 84 jours en 2005 (année sèche) et 71 en 2002 (année pluvieuse). Pour le traitement C_5, par contre, AW < WRC pour toute la saison d'irrigation de 93 jours dans toutes les années. Dans toutes les années étudiées, les expérimentations numériques ont montré que WUE est plus élevé pour le traitement C_{08} que pour le C_5.

Mots-clés. *Salinité du sol – Modèle de simulation – Gestion de l'eau saline.*

I – Introduction

Human water consumption effectively exacerbates the impact of drought. A combination of drought and human activity (such as overcultivation, overgrazing, deforestation and salinity) may lead to desertification of vulnerable areas, causing soil and bioproductive resources to become degraded. In this situation drought and salinity can be considered as related phenomena and represent two of the most important environmental stresses influencing the productivity of agricultural systems around the world.

Salinity increases in extensive portions of irrigated lands and the area becomes degraded by salinization and waterlogging resulting from over-irrigation and other forms of poor agricultural management (Ghassemi, *et al*., 1995). Saline and sodic water is used in different parts of the world, especially in arid and semi-arid regions. In these areas, scarce water often is of poor quality. Appropriate management of saline-sodic soils in arid and semi-arid regions is one of the key factors to maintain or improve their agricultural productivity and/or avoid soil and environmental degradation.

The inner drainage basins of Northwest of China, such as the Shiyang River basin, are progressively becoming salt affected, mainly because of irrigation with saline groundwater.

The irrigation with saline waters can lead to negative effects on the soil related to the relationship between the concentration of sodium ion, calcium and magnesium ions. The saturation level of sodium and the saline concentration of the soil solution have adverse effects on the physical state of the soil rather than directly on toxicity conditions for crops or interference with the absorption of other ions. They affect the dispersion of clay particles, the soil hydraulic conductivity (Shainberg and Letey, 1983) and aggregate stability in water and the formation of crusts on the soil's surface (Varallyay, 1977a, b; Postiglione et al, 1995).This may led to clogging of soil pores, so that a considerable reduction in soil permeability, soil porosity and soil hydraulic conductivity occurs (Felhendler *et al.*, 1974; Frenkel *et al.*, 1978; Pupisky and Shainberg, 1979; Shainberg *et al.*, 1981a,b; Shainberg and Levy, 1992; Amézketa, 1999). Somani (1991) found that these changes were clearly reflected by changes in a water retention curve (see also Tedeschi *et al.*, 2007). The curve indicated a close relationship between the degree of Na saturation and the water retention of the soil, especially in the pF 2.0-3.0 range. A similar tendency was also observed even when swelling was limited. Water retention increased over the entire range of soil water content. By contrast macropore space decreased. The same author found that the available moisture content increased with ESP, which conflicts with the classical explanation of the water supply of plants in alkali soils and confirmed the findings of Varallyay (1977).

Under saline condition, a reduction in growth is a consequence of several physiological responses, including modifications of ion balance, water status, mineral nutrition, stomatal behaviour, photosynthetic efficiency, and carbon allocation and utilization (Greenway and Munns 1980; Mass, 1986). Photosynthesis is generally reduced in plants growing in saline condition.

Notwithstanding the known negative effects described above, the reduction of good quality water for agricultural use has determined in the Northwest of China an increase in the use of water with high salt concentration. Such waters are traditionally rated as unsuitable for irrigation due to the negative effects on the soil physical and chemical characteristics.

In the NW of China the salinization of the groundwater in the last 20 years has increased with consequences on the crop production and on the soil physical characteristics.

The objective of this paper is to evaluate the impact of the saline water on crop yield and soil properties under different irrigation treatments. The work described includes model calibration, followed by numerical experiments to evaluate irrigation schedules for two different soil conditions, at low salinity level (Tds= 0.8 g l^{-1} identified as C_{08}) and at a moderate salinity level (Tds =5 g l^{-1}

idefitied as C_5). SWAP model has been used. The research was carried out on a silt-loam soil; a melon crop was furrow irrigated with water at concentration of 0.8, and 5 g l^{-1}.

The observed differences in soil hydrological properties for the low respectively moderate salinity conditions may have a significant impact on the temporal variability of soil water content, e.g. on the frequency and duration of soil water content lower than a pre-defined critical threshold. To this end the soil water balance calculations will be performed for a range of different meteorological conditions, in particular when a dry, wet and normal climatic year occurs. The water balance calculations will be used to evaluate the water storage in the profile through the year.

II – Description of the experimental areas

The Shiyang River basin is located in the Hexi Corridor, central-west Gansu province, northwest China. Two sub-basins can be distinguished in the Shiyang River, namely the Wu Wei basin in the south and the Min Qin basin in the north. The Min Qin basin where the research was carried out, borders WuWei basin to the south, Tegger desert to the east and north. The Shiyang River basin has features of arid to semiarid areas, and is a typical region of arid continental inland climate, characterized by low and irregular rainfall, high evaporation and severe drought periods. In fact in the Min Qin Basin, the mean annual precipitation is less than 150mm, but the mean annual evaporation can reach 2650 mm. Since 1940s, the rapid increase of population in Shi Yang River led to an increase of irrigation farmlands, and much grassland has been reclaimed and became farmlands. In the Min Qin Basin, 50% water supply comes mainly from groundwater. Along the Min Qin basin the groundwater salinity is between 2 g l^{-1} and 12 g l^{-1}. In the Min Qin basin two plots with groundwater at two different saline concentrations were selected, i.e. 0.8 g l^{-1} (C_{08}); and 5 g l^{-1} (C_5), to evaluate the effects that the saline water had on soil properties and on crop production. The irrigation system is furrow irrigation and usually the farmers apply an irrigation before sowing to leach the salt from the soil profile using canal water that has a TDS value of 0.8 g l^{-1}. This high quality resource is very scarce and lower quality groundwater must be used throughout the season. The crops grown in the area are horticultural crops, wheat and crops typical for the Chinese habits. Irrigation water gifts are determined by local practice and it was not possible to determine any objective estimation procedure. The irrigation volume is neither calculated on the ET0 basis nor to restore the soil root zone to field capacity.

III – Materials and methods

At the Minqin experimental farm (province of Gansu) in a arid environment an experiment on a melon crop was carried out in 2007. The soil characteristics of the two soils are reported in Table 1. The ions composition of groundwater was for C_{08} : Cl 120 (mg l^{-1}); SO_4 225 (mg l^{-1}); HCO_3 196 (mg l^{-1}); CO_3 absent; Ca 87 (mg l^{-1}); Mg 44 (mg l^{-1}); K 5 (mg l^{-1}); Na 52 (mg l^{-1}); pH 8 and ECw (dS m^{-1}) 1.0. For C_5 the groundwater composition was: Cl 781(mg l^{-1}); SO_4 1334(mg l^{-1}); HCO_3 346 (mg l^{-1}); CO_3 5(mg l^{-1}); Ca 205 (mg l^{-1}); Mg 136 (mg l^{-1}); K 34 (mg l^{-1}); Na 704 (mg l^{-1}); pH 7.5 and ECw (dS m^{-1}) 7.03.

Two local melon varieties were used, they were irrigated by furrow irrigation with a frequency of around 15 days. Local regulations aim at limiting water use, particularly groundwater, by prescribing rather long irrigation intervals. Farmers may determine irrigation water gifts, albeit within limits. Table 2 reports the water volume applied on melon in the 2007.

Table 1. Soil properties for the C_{08} and C_5 soil.

Soil site	Organic matter	Bulk density	Silt	Clay	Sand
	%	g cm^{-3}	%	%	%
C_{08} (0-40 cm)	0.45	1.56	43.08	11.02	45.90
C_{08} (40-60 cm)	0.44	1.52	64.14	17.98	17.89
C_{08} (60-100 cm)	0.39	1.54	54.10	15.19	30.71
C_5 (0-40 cm)	0.70	1.55	53.86	15.81	30.32
C_5 (40-60 cm)	0.54	1.46	69.63	16.72	13.65
C_5 (60-100 cm)	0.46	1.48	58.00	21.47	20.53

An ex-post comparison of water gifts with ET0 (see Table 2) shows that the ratio of irrigation water gift to ET0 changed throughout the season, leading to a variable water stress. This is confirmed by the comparison of water gifts with the actual soil water deficit, evaluated by measuring the soil water content the day before the irrigation and by calculating the water needed to restore a soil layer of 60 cm to field capacity. Table 3 shows that the irrigation water gifts were different from actual soil water deficit.

Undisturbed soil samples were taken to determine the hydrological properties of two soils that have been irrigated by saline water for a long time .

The undisturbed soil samples were taken at 0-20; 45-60 and 80-100 cm depth, in two repetitions to determine the h(θ) and K(h) characteristics in the laboratory according to the procedure suggested by Tamari *et al.*, (1993). The soil water retention characteristics have been parameterized using the relationship proposed by van Genuchten (1980) and by the one proposed by Ross & Smettem (1993). The parameters of the retention functions were obtained by a least squares optimization technique and were used to calculate available water retention capacity at prescribed pressure head values.

Additional disturbed soil samples were taken at 0-20; 20-40; 40-60; 60-80 and 80-100 cm depth to determine the texture, and the organic matter, moreover undisturbed soil samples were taken to determine the bulk density, as reported in Table 1. Moreover on these disturbed soil samples at the depths indicated, the aggregates stability indexes (IASW and IC) were determined on aggregates with diameter between 1 and 2 mm. The results were expressed as reported in Pagliai, 1997.

Table 2. Water volume applied throughout the season. Water volume calculated to recover a layer of 0-60 cm at field capacity by the water content measurements taken throughout the irrigation season.

Treatment								
	θ field measurements (cm^3 cm^{-3}) at 0-60 cm		Irrigation volume calculated to restore root zone to field capacity m^3 ha^{-1}		Irrigation water applied		ET0 Penman Monteith	Ratio of irrigation to ET0
Doy	C_{08}	C_5	C_{08}	C_5	Doy	m^{3}ha^{-1}	m^3 ha^{-1}	%
164	0.265	0.223	177	245	165	510	1068.4	48
179	0.117	0.221	1063	297	180	390	534.3	73
191	0.220	0.221	445	295	192	390	635.2	61
208	0.200	0.203	567	401	209	337.5	805.1	42
225	0.160	0.186	797	507	226	337.5	625.1	54

The Van Genuchten parameters were estimated by using the Hypres pedotransfer procedure (Wösten *et al.*, 1998) implemented in the SWAP model.

After each irrigation disturbed soil samples from the treatments C_{08} and C_5 were taken at depth 0-20; 20-40; 40-60; 60-80 and 80-100 cm to determine the ECe . Before and after each irrigation the soil water content by gravimetric methods was determined at depth 0-20; 20-40; 40-60; 60-80 and 80-100 cm.

The meteorological station gave daily observations of precipitation, temperature relative humidity, net radiation an wind speed. Every two weeks values of leaf area index (LAI) were measured as well as the root depth.

- Model simulations.

The SWAP Model (van Dam *et al.*, 1997) was used. Soil water actual transport extended (SWAP) is a one-dimensional, deterministic model based on the Richard's equation. It was developed by Feddes *et al.* (1978) and later modified by Belmans *et al.* (1983).

To solve the differential equation describing water and solute flow, either boundary conditions at both the top and bottom of the system or one initial condition (e.g. water content) and one boundary condition (e.g. at the bottom) have to be specified. Therefore from the available data at beginning of the crop season, the initial soil conditions were described. We assumed that the soil profile was at saturation after the first irrigation applied on the 27/4/2007 by 1500 m^3 (150mm), such quantity was programmed to leach the salt from the soil profile, therefore the assumption that was at saturation was not so far from the reality. At the bottom of the domain a free drainage boundary condition was prescribed. On both C_{08} and C_5 the crop was melon, sown on 1/5/2007 and harvested on 20/8/2007. Though the irrigation calendar, frequency, quantity and salt concentration of each irrigation, it was possible to reproduce the experimental conditions in the model simulation.

Code	Year	h(θ), K(h)
207_C_{08}	2007	C_{08}
207_C_5	2007	C_5
205_ C_{08}	2005	C_{08}
205_ C_5	2005	C_5
202_ C_{08}	2002	C_{08}
202_ C_5	2002	C_5

After the calibration, numerical experiments were performed. The analysis was conducted for a dry and a wet year, selected on the basis of the value of ET0 between March and September (irrigation season) and the annual rainfall R. The highest value of (ET0-R) identifies the dry year, the lowest value of (ET0-R) the wet year. During the period 2000 – 2007 the wet year was 2002 and the dry year was 2005. For easy reference the numerical experiments described in this paper were coded as above reported in the table.

IV – Results

1. Effects of sodic water on soil physical properties

The data in Table 1 were used to estimate the h(θ) using the Hypres pedotransfer procedure implemented in SWAP (Fig. 1). The same soil properties were also determined in the laboratory on undisturbed soil samples (Fig. 2).

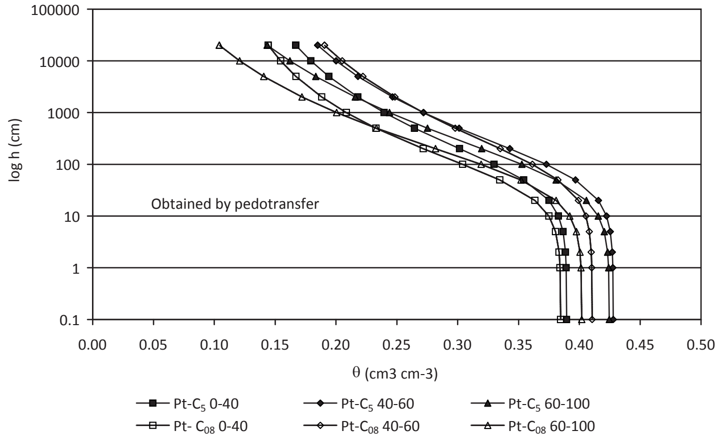

Figure 1. h(θ) for the 2 soil type and different depths estimated by the Hypres pedotransfer implemented in SWAP

Fig 1 shows curves with a very similar trend for the C_{08} and C_5 cases, although the θ value at 100 cm of pressure head is always higher for the C_5 treatment than the C_{08} at each depth. Different is the case of the laboratory analyses (Fig. 2).

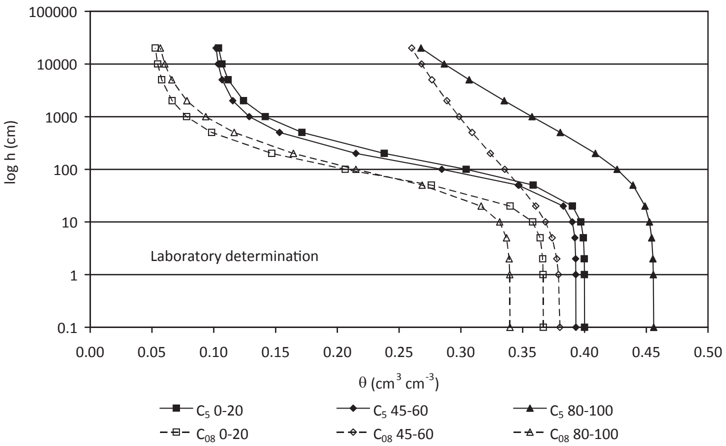

Figure 2. h(θ) for the 2 soil type and different depths estimated by the laboratory analysis on undisturbed soil samples.

Except the depth 45-60 cm of C_{08}, the C_5 has higher value of θ at the pressure head of 100 cm than the C_{08}. The different behaviour of the C_{08} at depth 45-60 cm could depend by a compaction of the layer due to the depth of ploughing, that usually it is around 45-50 cm. Moreover the total porosity for the C_5 is always higher at any layer considered, even for the layer 45-60 cm, that is (0.39) in the case of C_5 and (0.38) for the C_{08}. To evaluate if a change in soil structure, in particular compaction occurred on both soils, at the same depth at which the hydrological parameters were determined, disturbed soil samples were taken through the soil profile to determine the index of aggregates stability in water (IASW %) (Tedeschi *et al.*, 2005) as well as the IC index. The latter differs from IASW because of a correction factor that considers the sand fraction. Figure 3 shows the aggregates stability index (IASW and IC). Both IASW and IC are significantly lower for C_5 at all depths, while at the depth 45-60 cm both IC and IASW are lower for the C_{08}.

This depth it is the same at which the C_{08} h(θ) curve has an anomalous behaviour, with a consequence on the available water in the soil profile. This effect can only be captured by using the laboratory experiments on undisturbed soil cores. The observed differences in the h(θ) curves agree with the results of Somani (1991) and Tedeschi *et al.*, (2007), although smaller because of the lower clay content in the Minqin soil. Quirk and Schofield (1955) suggested: that swelling of clay particles, which increase in clay sodicity, could result in blocking or partial blocking of the conducting pores.

To evaluate the impact of differences in the h(θ), the water retention capacity, WRC, defined as [θ(h=100 cm) - θ(h=10000 cm)] and calculated for a 100 cm deep soil layer and for the C_{08} and C_5 cases. The WRC was larger for the C_5 treatment for all the depths considered, except the 80-100 cm. Overall WRC was 121.09 mm for the C_{08} and 249.53 mm for the C_5 case. The lower WRC for the C_{08} treatment can be explained by higher percentage of macropores and by a partial redistribution for the C_5 treatment of porosity in smaller and more retentive micropores. For the layer 45-60 cm WRC is even lower and it depends on a strong reduction in porosity due to the plough layer, as confirmed by the IASW values.

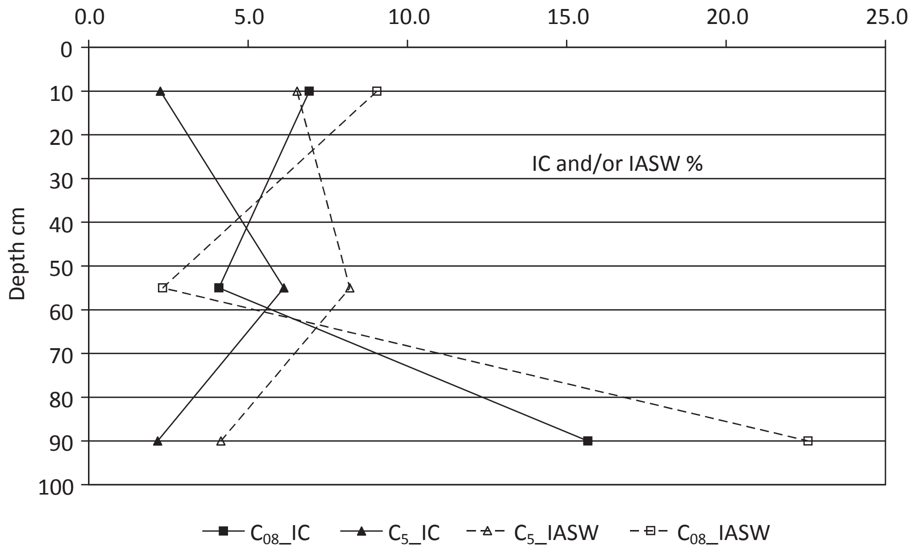

Figure 3. Aggregate stability index expressed as IC (%) and IASW (%) for the soil C_{08} and C_5 at different depth

2. Numerical experiments

A. Model calibration

SWAP calibration was performed on the 2007 experiment. The van Genuchten parameters determined by both the pedotransfer approach and the laboratory experiments were used in different runs to evaluate which one better describes the soil profile and leads to higher accuracy of numerical simulations. The calibration was done by comparing the soil water content measured throughout the crop growth season at different depths and the soil water content calculated with SWAP. The comparison between the results obtained by the simulation and the measured data was done by computing the RMSE (root mean square error). Both the results obtained by the pedotransfer or the laboratory were rather good. The absolute RMSE for the soil profile (100 cm) of the C_{08} treatment shows a value of 0.0586 cm^3 cm^{-3} obtained with the pedotransfer against the 0.0603 cm^3 cm^{-3}obtained with the laboratory experiments for the same C_{08} treatment. The C_5 treatment gave a value of absolute RMSE of 0.0425cm^3 cm^{-3} with the pedotransfer and 0.0454$cm^3 cm^{-3}$ with the laboratory experiments.

Overall, the agreement is good, moreover the difference between the use of Van Genuchten parameters estimated by pedotransfer or determined in laboratory are very small. We decide to use the laboratory parameters because are based on real measurements and were able to detect the discontinuity present in the soil profile that the pedotransfer of course cannot due, since it is based on soil texture only.

B. Model application

SWAP can be applied to analyze the effect of saline water by relating crop yield to the ratio of actual to potential transpiration, T_{act} / T_{pot}. This ratio is often used as a measure of moisture availability. Hanks (1974) stated the reduction in crop yield Yact/Ypot , when moisture is the only limiting factor can be estimated as : Yact/Ypot=Tact/Tpot. This concept was based on De Wit (1958), who found a linear relationship between total dry matter and seasonal transpiration for a number of field experiments.

Table 3. Estimation of the potential and actual yield for several scenarios and the water use efficiency for each (kg m^{-3}) moreover the water productivity is reported (lt Kg^{-1})

Scenarios	Yr* (swap output)	Yact = Ypot *Yr Dry matter (kg ha^{-1})	Tact m^3	WUE (kg m^{-3})	Water productivity lt kg^{-1}
207_C_{08}	0.76	3158	1892	1.67	599
207_C_5	0.51	2119	1382	1.53	652
205_C_{08}	0.47	1953	1996	0.98	1022
205_C_5	0.28	1163	1397	0.83	1200
202_C_{08}	0.62	2576	2100	1.23	815
202_C_5	0.40	1662	1513	1.10	910

This relationship will be used to evaluate the water use efficiency (WUE) for all treatments included in our study. In fact SWAP directly gives the results of the following relationship Yr* = Yact/Ypot. To estimate the unknown Y_{pot} for our crop, soil and environmental conditions we assumed that the value of T_{act} / T_{pot} is correct and used the observed actual yield for the non-saline, fully irrigated treatment $C_{08,}$ i.e. 3158 (kg ha^{-1}) for the year 2007. This gives Y_{pot} = 3158 kg ha^{-1} / 0.76 = 4155 kg ha^{-1}. Given the ratio T_{act} / T_{pot} and the value of T_{act} obtained with SWAP for each treatment and case we can then estimate WUE = Y_{act} / T_{act} (Tab. 3).

The model estimate can be compared with observed actual yield for the scenario 207_C_5, i.e 1962 kg ha^{-1}., in good agreement with the *calculated* Y_{act} = 2119.

We have also evaluated the impact of climate conditions (Table 3) using meteorological data collected between 2001 and 2006. The driest and wettest year were selected on the basis of the difference between yearly reference ET and rainfall: the largest the difference, the drier the year. The driest year in this period was 2005 and the wettest 2002. Crop yield was 2576 kg ha^{-1}

respectively 1662 kg ha^{-1} for the C_{08} respectively the C_5 treatment in 2002. In 2005 it was 1953 kg ha^{-1} for C_{08} , respectively 1163 kg ha^{-1} for the C_5. It should be noted that yield in 2007, the reference year for model calibration, was higher than 2002, since 2007 was wetter than 2002.

The Water Use Efficiency (WUE) was calculated for each case considered in Table 3. The C_{08} treatment had a higher WUE than the C_5 treatment in all cases. The WUE for the C_{08} treatment was higher in the wet year than in the dry year (e.g. 1.23 against 0.98; and 1.1 against 0.83).

In 2007 and for the C_{08} treatment the WUE calculated with field data was 1.32 kg m^{-3} against the 1.67 kg m^{-3} obtained with model values, while for the C_5 treatment was 1.0 kg m^{-3} with field data against 1.53 kg m^{-3}. Such results show that model simulations, due to the estimated Y_{pot}, overestimate WUE, but provide useful informations about differences in irrigation treatments and climate conditions and, as such, have significant value for comparative analyses. All results taken together indicate that yield was either water or salt-limited or both under all conditions, since both higher water deficit and salinity of irrigation water led to lower yield and lower WUE.

To evaluate the adequacy of applied irrigation gifts to replenish actual soil water deficit, we have estimated the soil water content of the layer 0-60 cm on the day before the irrigation and then calculated the irrigation volume required to restore the root zone to field capacity (Table 4). For the C_{08} treatment, irrigation water gifts were excessive for the first two irrigations and much lower than needed for the last irrigations. For the C_5 treatment, irrigation water gifts were insufficient throughout the crop growth season.

As regards: 1) the local irrigation management, 2) the water volume to recover the ET0 and 3) an irrigation volume to restore root zone to field capacity; we can conclude that for our study area:

- due to water scarcity resource the full recovery of ET0 is not feasible because it would lead to excessive water use;
- the local farmer management is suitable for the local situation but stress the plant in, a particular and important phenological stage.
- An intermediate irrigation strategy between local farmer management and restoration of the root zone to field capacity, coupled with shorter irrigation intervals, could improve yield and reduce the duration of water stress spells

Table 4. Water volume applied throughout the season. Water volume calculated to recover a layer of 0-60 cm at field capacity by the water content obtained by the SWAP output throughout the irrigation season.

	Treatment							
	θ SWAP (cm^3 cm^{-3}) 0-60 cm		Irrigation volume calculated to restore root zone to field capacity m^3 ha^{-1}		Irrigation water applied		Difference between applied and estimated. m^3 ha^{-1}	
Doy	$C_{0.8}$	C_5	$C_{0.8}$	C_5	Doy	m^3 ha^{-1}	$C_{0.8}$	C_5
164	0.23	0.18	370.30	537.20	165	510	+140	-27.2
179	0.24	0.19	300.30	483.35	180	390	+89.70	-93.35
191	0.23	0.18	403.25	536.70	192	390	-13.25	-146.7
208	0.19	0.15	632.15	703.95	209	337.5	-294.65	-313.95
225	0.18	0.14	702.70	765.20	226	337.5	-365.20	-375.2

C. Occurrence and severity of soil water deficits

The numerical experiments for the dry and wet years were carried out to evaluate the impact of observed differences in soil hydrological properties.

The accumulated duration of soil water deficit, i.e. the number of days with AW < WRC in the root zone (0 to 60 cm), was calculated for all numerical experiments.

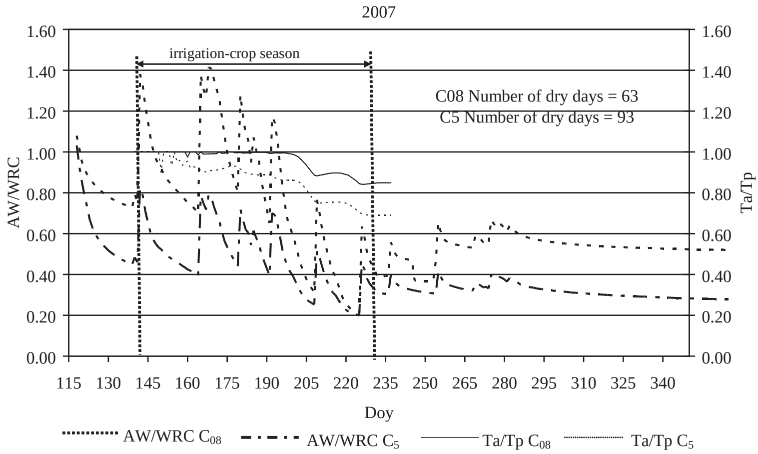

Figure 4. Relation of AW on WRC and the relation Ta/Tp for the 2007, for C_{08} and C_5 treatments, the number of dry days is reported.

For the C_{08} treatment AW < WRC for 84 days in 2005 (dry year) and 71 in 2002 (wet year). For the C_5 treatment, instead, AW < WRC for the entire irrigation season of 93 days in all years. Very evident is the impact of soil water content on actual transpiration, T_a, in response to applied irrigation water. For the C_{08} treatment the applied irrigation water is in excess of actual water deficit and gives T_a close to potential transpiration, T_p, up to the fourth water gift. Conversely, for the C_5 treatment T_a drops below T_p right past the first irrigation already. On the other hand the significant water deficit (AW < WRC) for the C_5 treatment during the entire irrigation season does not lead to extremely large differences in T_a between the C_{08} and C_5 treatments.

V – Conclusion

The results of the laboratory analyses showed higher value of θ at the pressure head of 100 cm for the C_5 treatment than the C_{08}. The different behaviour of the C_{08} soil at depth 45-60 cm could depend by a compaction of the layer due to the depth of the ploughing, that usually it is around 45-50 cm .

The compaction effect on the soil structure was detected also by the IASW index. IASW was significantly lower for C_5 at all depths, while at the depth 45-60 cm IASW was lower for the C_{08}. This depth it is the same at which the C_{08} h(θ) curve has an anomalous behaviour, with a consequence on WRC, which was larger for the C_5 treatment for all depths considered, except the 80-100 cm layer. Overall WRC was 121.09 mm for the C_{08} and 249.53 mm for the C_5 , both for the 0 – 100 cm soil layer. The lower WRC for the C_{08} treatment can be explained by higher percentage of macropores and by a partial redistribution for the C_5 treatment of the porosity in smaller and more retentive micropores. For the layer 45-60 cm WRC is even lower and it depends on a strong reduction in porosity, as above confirmed by IASW.

The model calibration on the 2007 was rather good as showed by the RMSE for the soil profile (100cm) that gave a value of 0.06 $cm^3\ cm^{-3}$ for the C_{08} and 0.045 $cm^3\ cm^{-3}$ for the C_5 both by using soil hydrological properties determined in the laboratory on undisturbed soil cores.

In 2007, estimated Y_{act} = 2119 kg ha^{-1} for the C_5 treatment was in good agreement with the observed Y_{act}.= 1962 kg ha^{-1} The results on the estimation of the WUE from the simulation data show higher WUE on the C_{08} treatment than the C_5 treatment for all the years considered. In 2007 and for the C_{08} treatment the WUE calculated with field data was 1.32 kg m^{-3} against the 1.67 kg m^{-3} obtained with model values, while for the C_5 treatment was 1.0 kg m^{-3} with field data against 1.53 kg m^{-3}. Such results show that model simulations, due to the estimated Y_{pot}, overestimate WUE, but provide useful informations about differences in irrigation treatments and climate conditions and, as such, have significant value for comparative analyses. All results taken together indicate that yield was either water or salt-limited or both under all conditions, since both higher water deficit and salinity of irrigation water led to lower yield and lower WUE.

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