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THE EFFECT OF SALINE IRRIGATION WATER ON THE YIELD OF PEPPER: EXPERIMENTAL AND MODELLING STUDY†

PONNAMBALAM RAMESHWARAN[1*], AKIN TEPE[2], ATTILA YAZAR[3] AND RAGAB RAGAB[1]

[1]*Centre for Ecology & Hydrology, Crowmarsh Gifford, Wallingford, Oxfordshire, United Kingdom*
[2]*West Mediterranean Agricultural Research Institute, Antalya, Turkey*
[3]*Department of Irrigation and Agricultural Structures, Faculty of Agriculture, Cukurova University, Adana, Turkey*

ABSTRACT

The present study investigates the impact of using saline water on pepper crop yield and the application of a numerical model in predication of soil moisture and relative yield under saline irrigation conditions. In the greenhouse experimental study, that has been conducted in Antalya, Turkey, the effects of different irrigation regimes with salinity treatments using a drip irrigation system were investigated for two pepper varieties. The irrigation regimes consisted of four irrigation treatments with four salinity levels in two cropping seasons - spring 2011 and autumn 2011. The numerical model SALTMED was used and calibrated using measured soil moisture of a control experiment run during spring 2011. After the calibration, the model was validated using other experimental treatments during the spring 2011 and all the experimental treatments in autumn 2011, with appropriate salinity stress parameter π_{50} values which are calibrated versus the highest salinity treatments in the spring 2011 and autumn 2011 experiments. The predicted results show the ability of the model to reproduce the measured soil moisture at three soil layers 0-20 cm, 20-40 cm and 40-60 cm. The predicted relative yield results are in good agreement with measured data. Although the numerical model SALTMED has been used in several studies in the past, this is the first study that illustrates the potential capacity of the model for use in managing greenhouse productions.

† L'effet de la Saline eau d'irrigation sur le rendement de Pepper: Etude expérimentale et modélisation

* Correspondence to: Dr Ponnambalam Rameshwaran, Centre for Ecology & Hydrology, Crowmarsh Gifford, Wallingford, Oxfordshire, OX10 8BB, United Kingdom. E-mail: ponr@ceh.ac.uk

KEY WORDS: drip irrigation; greenhouse; numerical model; pepper; salinity; soil moisture

RÉSUMÉ

La présente étude examine l' impact de l'utilisation de l'eau salée sur le poivre rendement des cultures et de l'application d'un modèle numérique de la prédication de l'humidité du sol et le rendement relatif dans des conditions d'irrigation salines. Dans l'étude expérimentale à effet de serre, qui a été menée à Antalya, en Turquie, les effets de différents régimes d'irrigation avec des traitements de salinité à l'aide d'un système d'irrigation goutte à goutte ont été étudiés pour deux variétés de piments. Les régimes d'irrigation étaient composés de quatre traitements d'irrigation avec quatre niveaux de salinité dans deux saisons de culture - printemps 2011 et l'automne 2011 Le modèle numérique SALTMED a été utilisé et calibrés à l'aide mesurée humidité d'une expérience de contrôle de fonctionner au cours du printemps 2011 du sol Après la calibration, le modèle a été validée en utilisant d'autres traitements expérimentaux au cours du printemps 2011 et tous les traitements expérimentaux à l'automne 2011, avec des valeurs paramètre de contrainte de salinité de π_{50} appropriées qui sont calibrés par rapport aux traitements de salinité plus élevés au printemps 2011 et l'automne 2011 expériences. Les résultats prédits indiquent la capacité du modèle à reproduire l'humidité du sol mesurée à trois couches de sol 0-20 cm, 20-40 cm et de 40 à 60 cm. Les résultats de rendement par rapport prédites sont en bon accord avec les données mesurées. Bien que le modèle numérique SALTMED a été utilisé dans plusieurs études dans le passé, cette étude est la première qui illustre la capacité potentielle du modèle destiné à être utilisé dans la gestion de la production en serre.

MOTS CLÉS: irrigation localisée; effet de serre; modèle numérique; poivre; salinité; l'humidité du sol

INTRODUCTION

In many areas in the world, farmers encounter soil salinity due to saline ground water or irrigation with available local saline water. In such areas drip irrigation has advantages over other irrigation systems, such as sprinkle or furrow, because it only wets area around the emitters which mostly leach out salts and causes no foliar damage due to salts added during irrigation. With drip irrigation, it is also possible to maintain a relative high soil moisture and low soil salinity level over time with the frequent irrigation where emitters are placed reasonably well within the plant rows (Malash *et al*., 2008).

Pepper (*Capsicum annuum L.*) is a high value crop cultivated in warm countries. It is one of the major vegetable crops produced in Turkey. Antalya, located on the Mediterranean coast of Turkey, is the main location for pepper production in greenhouses (Sevik, 2011). It is an important part of the local economy and pepper production depends almost entirely on water management. In the Mediterranean coast, vegetable crops are often irrigated with available saline water which can cause damage to the plant and soil and cause a reduction in yield if poorly managed. For that reason, drip irrigation can be an appropriate water management system in greenhouses on the Mediterranean coast.

In many crop production areas, use of low quality water for irrigation and application of excess amounts of mineral fertilizer are the major reasons for increased salinity problem in cultivated soils. Due to very rapid accumulation of salts in soil under greenhouse conditions, salinity problem is also a critical constraint to vegetable production (Shannon and Grieve, 1999). Pepper (*Capsicum annuum L.*) plants are sensitive to drought stress and moderately sensitive to salt stress (Rhoades *et al.*, 1992; Lee, 2006). In greenhouse conditions, pepper plants grown under water deficit with excess fertilizers accumulate large amounts of sodium (Na), potassium (K), phosphorus (P), and chloride (Cl) (Gunes *et al*., 1996). This leads to an excess ion uptake and an imbalance of various mineral elements. Plants exposed to high salinity exhibit membrane destabilization and inhibition of exposed photosynthetic capacity (Munns and Termaat, 1986). Salt-affected pepper shows severe decreases in growth and disturbances in membrane permeability, water channel activity, stomatal conductance, photosynthesis and ion balance (Shannon and Grieve, 1999; Navarro *et al.*, 2003; Cabanero *et al.*, 2004; Aktas *et al.*, 2006). Reduced water uptake is the common response of plants subjected to water and/or salt stress (Munns, 2002).

In recent years, the numerical model SALTMED has increasingly been used in several field studies with different crops and different irrigation regimes in order to calibrate and validate model (e.g. Hirich *et al.*, 2012, 2013; Pulvento *et al.*, 2013; Silva *et al,* 2013). SALTMED model, however, has not yet been tested in a greenhouse environment. Therefore, the main objective of this paper is to investigate the impact of irrigation with saline water on pepper yield grown in greenhouse environment and to calibrate and validate the numerical model SALTMED using the results of the experiments.

MATERIALS AND METHODS

The greenhouse study site was located on the Mediterranean coast at Antalya, Turkey. Figure 1 shows the greenhouse layout. In the study site, soil is sandy clay loam and the soil properties of the experimental site before planting of pepper in spring 2011 are given in Table I. The soil is slightly alkaline pH and affected slightly by salinity. Soil parameters - saturated moisture content, field capacity, wilting point, bubbling pressure and saturated hydraulic conductivity - were measured. Soil moisture at three soil layers 0-20 cm, 20-40 cm and 40-60 cm were measured periodically during the spring 2011 and autumn 2011 growing seasons at a middle point between two plants along the plant row. Climate parameters such as temperature, sunshine hours, relative humidity and net radiation were measured within the greenhouse.

Four irrigation treatments were studied using Class A pan evaporation data multiplied by pan coefficient (Epkc) of 0.50, 0.75, 1.00 and 1.25. In each irrigation treatment, plants were subjected to four salinity levels treatments with electrical conductivities (EC_w) of 1.0, 2.5, 3.5 and 6.0 dS m^{-1} as listed in Table II. A drip irrigation system with dripper spacing of 0.2 m and 2 l hr^{-1} discharge rate was utilised. The drippers were placed about 5 cm away from the plant row. The Class A Pan Evaporation was used for measurement of water evaporation within greenhouse. Fertilizers were applied as 60% NO_3 and 40% NH_4 during irrigation. The irrigation duration, the salinity level and the amount of fertilizer applied were recorded for all 16 experimental trials listed in Table II for both cropping seasons.

Experiments were performed for the spring 2011 and autumn 2011 cropping seasons with two varieties of pepper ONUR F1 and ADA F1. The experiment was laid out using split plot design of 16 subplots with size of 8.0 m long and 2.1 m wide. In each subplot, the pepper plants were transplanted in rows at 0.7 m row spacing and 0.4 m apart with the top 4.0 m lengths with ONUR F1 variety and the rest 4.0 m with ADA F1 variety. In other words, each subplot contained two varieties with three replications. During the spring 2011, transplanting from the seed bed was carried out on 25th of March 2011 and harvest ended in 12th July 2011 (Growth length of 110 days from transplanting). In autumn 2011, transplanting from the seed bed was carried out 26th September 2011 and harvest ended in 22nd February 2012 (Growth length of 150 days from transplanting). Plant parameters - crop height and leaf area index - were measured for each growth stage (initial, mid and late stages) and also the total fresh pepper yields were measured. Fresh yields are standardised and expressed in term of relative basis in order to compare with model results. Relative yield is defined as:

$$Y_r = Y/Y_{max} \quad (1)$$

where Y_r is the relative yield, Y is the absolute yield and Y_{max} is the maximum yield where salinity has very minimum or no effect on yield.

SALTMED MODEL

SALTMED model is a physically based model using water and solute transport, evapotranspiration and water uptake equations (Ragab, 2002, 2010). It was developed to predict soil moisture profiles and soil salinity, dry matter and yield, salinity leaching requirements and soil nitrogen dynamics and nitrate leaching, soil temperature, water uptake, and evapotranspiration. In this paper, SALTMED model was used to predict the soil moisture profiles and relative yield where the experiment measurements were available for calibration and validation.

In drip irrigation system, the water and solute transport can be viewed as two-dimensional flow. Hence, in this study, a 'plane flow' model involving the Cartesian coordinates x and z is used to simulate the water and solute transport where a set of dripper sources at equal distance (0.2 m) and close enough to each other so that their wetting fronts overlap after a short time from the start of the irrigation.

The model is a free download at the website of the International Commission on Irrigation and Drainage, ICID at: http://www.icid.org/res_tools.html and the EU funded project Water4crops at: http://www.water4crops.org/saltmed-2013-integrated-management-tool-water-crop-soil-n-fertilizers/

Soil moisture

The soil moisture calculation in SALTMED model is based on the well-known Richard's equation, developed from two soil physical principles: Darcy's law and mass continuity. The details of the model equations and approach are given in Ragab (2002).

Relative yield

In the model, the relative yield Y_r is expressed in following relationship (van Genuchten, 1987):

$$Y_r = S/S_{max} = 1 / \{1 + [(ah + \pi) / \pi_{50}]^3\} \quad (2)$$

where S is plant water uptake and S_{max} is the maximum potential plant water uptake (under no water and salinity stress conditions), h is the soil water pressure, a is a weighing coefficient that accounts for the differential response of a crop to matric and osmatic pressure, π is osmotic pressure, π_{50} is the osmotic pressure at which yield reduced by 50 percent and h_{50} is the matric pressure at which S_{max} is reduced to 50 percent. Further detail of the equation (2) can be found in van Genuchten and Gupta (1993) and Cardon and Letey (1992).

MODEL CALIBRATION AND VALIDATION

The model is first calibrated using the first control experiment case 1 in Table II (1.0 dS m^{-1} and Epkc = 0.50) of spring 2011 for soil moisture and then on the last highest salinity experiment case 16 in Table II (6.0 dS m^{-1} and Epkc = 1.25) of spring 2011 and autumn 2011 on ONUR F1 variety for salinity stress parameter π_{50}. It is carried out using experimentally measured crop and soil parameters along with crop coefficients K_c and K_{cb} values from FAO-56 (Allen *et al*., 1998). The soil parameter pore size distribution index (lambda) was fine tuned in order to obtain a good calibration. The model validation is performed on all other experimental cases.

RESULTS AND DISCUSSION

Experimental study

The measured relative and fresh pepper yields for four irrigation treatments with four salinity levels in two cropping seasons (spring 2011 and autumn 2011) are shown in Figures 2a and 2b, respectively. Figure 2a shows that the rate of decrease in yield with salinity in the spring 2011 measurements is higher than the autumn 2011 measurements. In other words, the pepper cultivated in the spring season is slightly more sensitivity to salinity than the pepper cultivated in the autumn season. In terms of actual productivity, Figure 2b shows that the pepper cultivated during spring, with salinity level less than 3.5 dS m^{-1}, had a much higher fresh yield than the autumn 2011 pepper; while for the salinity level of 6.0 dS m^{-1} the fresh yield was similar for both seasons. Figure 2 also shows that both varieties ONUR F1 and ADA F1 performed in a similar manner during both spring and autumn seasons.

Modelling study

Figure 3 shows the comparison of soil moisture data against predicted values for all three soil layers 0-20 cm, 20-40 cm and 40-60 cm for the first control experiment case 1 of spring 2011 along with the 1:1 agreement line and linear regression line fitted by least squares. The correlation coefficients are listed in Table III. The degree of scatter is indicated by the coefficient of determination (R^2), while the slope (m) and intercept (c) indicate any bias in the comparison. Table III shows that both the slope and intercept of the regression lines tend towards 1 and 0, respectively (i.e. there is no significant bias revealed in the slope and intercept) with a correlation value of 0.88. Figure 4 shows that the predicted soil moisture results from the calibration are in good agreement with the measured data over the cropping season of spring 2011.

The calibrated osmotic pressure (i.e. salinity stress parameter) π_{50} for initial, mid and late growth stages are given in Table IV. It can be seen from the Table IV that the calibrated salinity stress parameters, π_{50}, for the spring 2011 experiments are lower than the autumn 2011 experiments. This behaviour is clearly reflected in the measured relative pepper yield data plotted in Figure 2a. Therefore, the calibrated salinity stress parameters, π_{50}, in Table IV reflect the seasonal variation on the pepper production.

Using the above calibration, the model predictions were performed for all other experimental cases of the spring 2011 and autumn 2011 cropping seasons. Figure 5 shows the correlation between the measured and predicted soil moisture for all 16 experiments of spring 2011 and autumn 2011. The coefficients for the linear regression lines fitted by least squares are also listed in Table III. The slope of the regression lines of spring 2011 and autumn 2011 and the intercept of the regression line of spring 2011 are significantly different ($p<0.001$) from 1 and 0, respectively. Detailed inspection of the data and prediction revealed that the discrepancies are mainly due to errors in the three layer measurements (on some dates where there are no clear profile differences in the measured values as model predicted) or the imperfect prediction of the model in some instance during cropping seasons. This can be clearly seen from Figures 6 and 7 which show the measured and predicted soil moisture for the three layers 0-20 cm, 20-40 cm and 40-60 cm for experimental cases 6, 7, 10 and 11 of spring 2011 and autumn 2011, respectively. Overall, Figures 6 and 7 show a reasonably good agreement in all layers between predicted and measured soil moisture over the cropping season.

Figure 8 shows the measured and predicted relative yield for spring 2011 and autumn 2011 experiments for pepper varieties ONUR F1 and ADA F1 along with the 1:1 agreement line and linear regression line fitted by least squares. The root mean square errors, RMSE and coefficients of residual mass, CRM, (Hosaini *et al.*, 2009) along with correlation coefficients of the regression line are listed in Table **V**. Figure 8 shows that the predicted results match the measured data reasonably well, with good correlation. Table **V** also shows that there is no significant bias revealed in the slope and intercept of regression lines. The RMSE values show that the overall model predictions are within 6% of error for all four cases while the CRM values show that the model tends to overestimate the yield by the tiniest margin. These results show the ability of the model to capture the relative yield of greenhouse pepper and, thus, illustrate its potential capacity for its use in a greenhouse environment. The early version of the model was successfully tested against field experiments of tomato irrigated with saline water using surface (furrow) and drip irrigation in Egypt and Syria (Ragab *et al.*, 2005a & b). The model has also been applied successfully on a field experiment of maize irrigated with saline water in Syria (Najib *et al.*, 2007), a sugar cane field experiment in Iran (Golabi *et al.*, 2009), a cotton plantation in Greece (Kalfountzos *et al*., 2009) and on several field crops in the north east of Brazil (Montenegro *et al.*, 2010). More recently the SALTMED model has been calibrated and validated under dry and wet year conditions using chickpea field data from Southern Portugal by Silva *et al*. (2013); using saline irrigation water on quinoa (*Chenopodium quinoa Willd*) in Denmark (Razzaghi *et al*., 2011) and in Italy (Pulvento *et al*., 2013); and in applying deficit irrigation (including Partial Drying Method, PRD) on quinoa, sweet corn and chickpea in Morocco (Hirich *et al*., 2012, 2013). In all of these experiments, dry matter, crop yield, soil moisture profiles and soil salinity profiles were predicted reasonably well by the model as is the case with the present study.

CONCLUSION

In this study, the numerical model SALTMED is calibrated and applied to greenhouse pepper experiments conducted at Antalya, Turkey for two seasons - spring 2011 and autumn 2011. In the experimental study, the effects of different irrigation regimes with salinity treatments using drip irrigation system were investigated. Two variety of pepper ONUR F1 and ADA F1 were used with four irrigation treatments subjected to four salinity levels.

The study shows that there are considerable variations in productivity between the two seasons and that the productivity decreases with the increase in irrigation water salinity level. In both seasons, both varieties largely tend to perform in a similar manner with reduced yield and less tolerance to salinity in autumn season compared to spring season. The results show that the model is capable to reproduce the measured soil moisture for different irrigation regimes with different salinity levels using drip irrigation system. The predicted relative yield results were in good agreement with the measured data, similar to the results achieved in field applications of the model already cited in the literature. While there is now a need for good quality data for other crops with different irrigation regimes to test the SALTMED model more rigorously in greenhouse environment, this first study has shown that the SALTMED performs well and provides a practical modelling solution for greenhouse environment for pepper crop.

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Table I. Soil properties of the experimental site before planting of pepper in spring 2011.

Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture	pH	EC_e (dS m^{-1})
0 – 20	60	15	22	Sandy clay loam	7.8	0.42
20 – 40	62	16	23	Sandy clay loam	7.6	0.38
40 – 60	62	16	25	Sandy clay loam	7.8	0.36
60 – 80	59	15	25	Sandy clay loam	7.7	0.33

Table II. Irrigation and salinity treatments.

Salinity (dS m^{-1})	Epkc = 0.50	Epkc = 0.75	Epkc = 1.00	Epkc = 1.25
1.0	Case 1	Case 2	Case 3	Case 4
2.5	Case 5	Case 6	Case 7	Case 8
3.5	Case 9	Case 10	Case 11	Case 12
6.0	Case 13	Case 14	Case 15	Case 16

Table III. Comparison of regression lines of measured and predicted soil moisture.

Experimental case	No. of data points	R^2	Regression	
			Slope (m)	Intercept (c)
Case 1 spring 2011 data	30	0.88	1.1500±0.1673	-0.0243±0.0319
Cases 1 to 16 spring 2011 data	480	0.79	1.2075±0.0585	-0.0360±0.0126
Cases 1 to 16 autumn 2011 data	624	0.67	1.0626±0.0608	-0.0066±0.0128

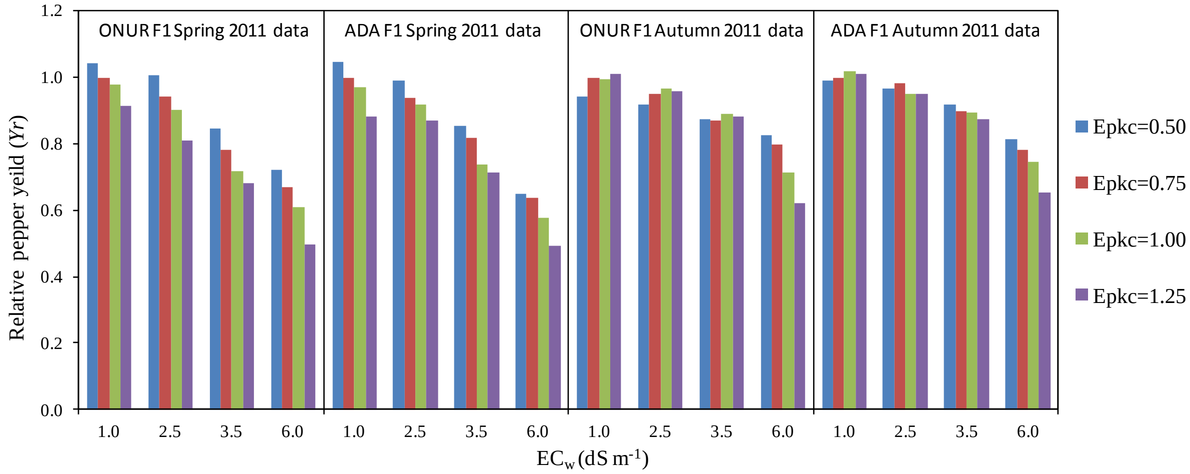
Table IV. The calibrated π_{50} values for growth stages from SALTMED model.

Crop	Initial π_{50}	Mid π_{50}	Late π_{50}
Spring 2011 data	7.5	9.5	11.5
Autumn 2011 data	9.5	11.5	13.5

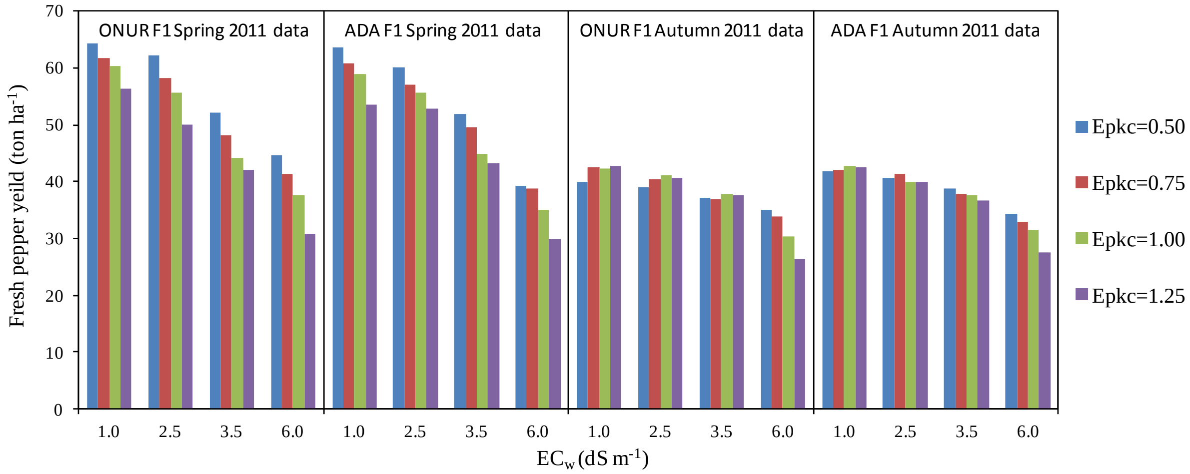
Table V. Comparison of regression lines of measured and predicted relative yield.

Experimental case	No. of data points	RMSE (%)	CRM	R^2	Regression	
					Slope (m)	Intercept (c)
ONUR F1 spring 2011 data	16	5.24	-0.02	0.91	1.0398±0.1750	-0.0165±0.1459
ADA F1 spring 2011 data	16	4.70	-0.02	0.93	1.0110±0.1482	0.0085±0.1236
ONUR F1 autumn 2011 data	16	5.91	-0.03	0.81	1.0202±0.2676	0.0125±0.2393
ADA F1 autumn 2011 data	16	4.58	-0.02	0.87	1.0635±0.2265	-0.0413±0.2058

Figure 1. The greenhouse layout.



(a) Relative pepper yield (Y_r)



(a) Fresh pepper yield (ton ha^{-1})

Figure 2. Measured yield (a) relative pepper yield (Y_r), (b) Fresh pepper yield (ton ha^{-1})

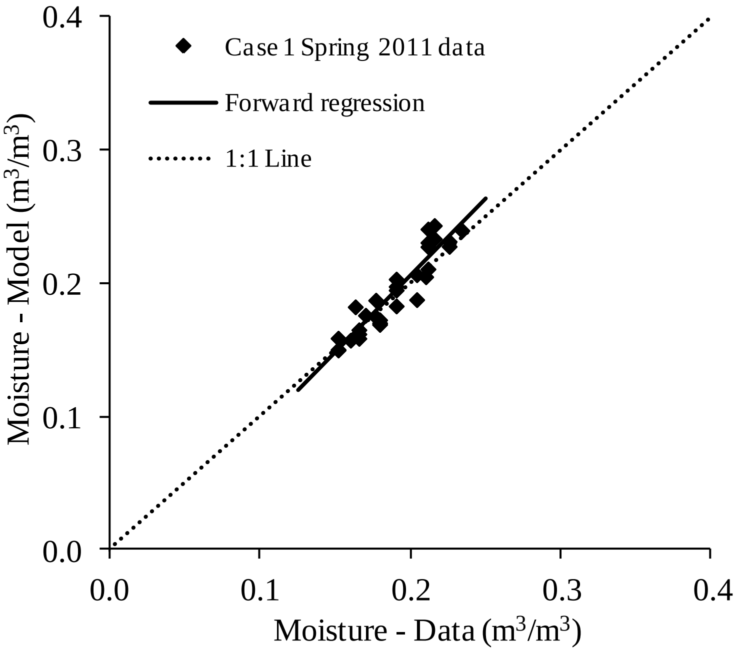


Figure 3. Correlation between measured and predicted soil moisture for case 1 spring 2011 experiment.

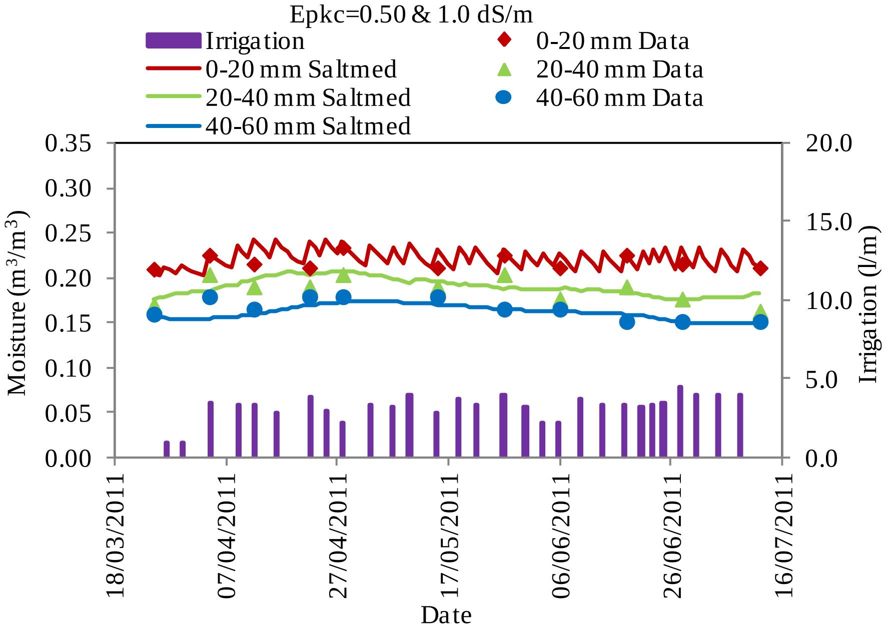
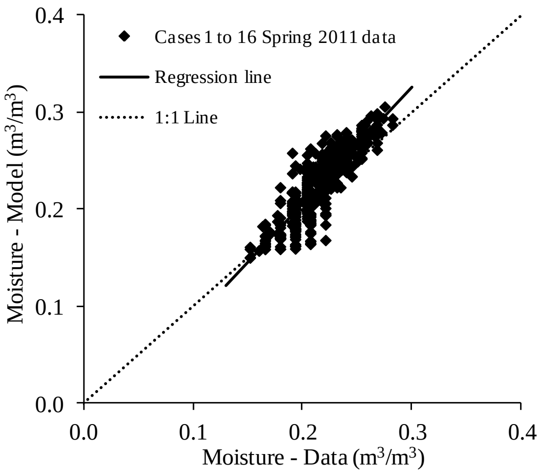
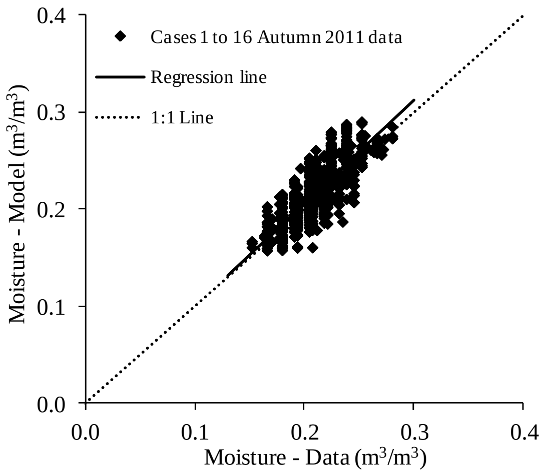


Figure 4. Measured and predicted soil moisture for case 1 spring 2011 experiment.

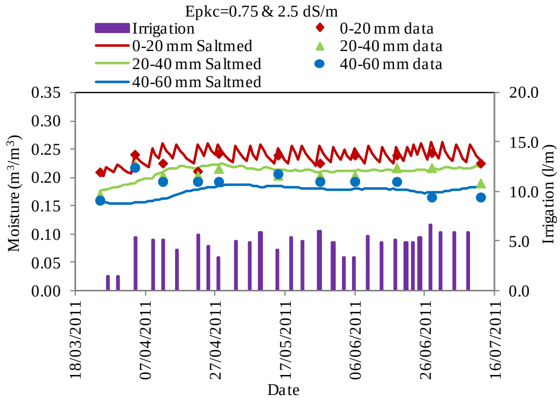


(a) Cases 1 to 16 spring 2011 data

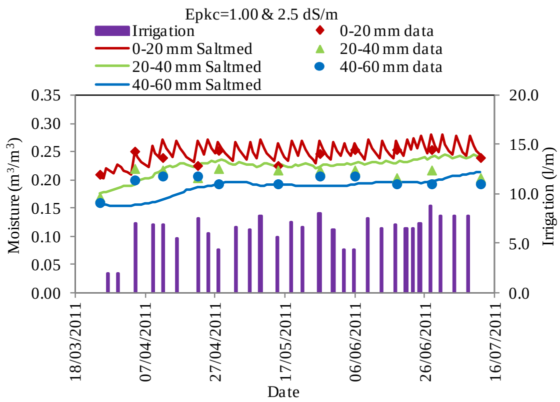


(b) Cases 1 to 16 autumn 2011 data

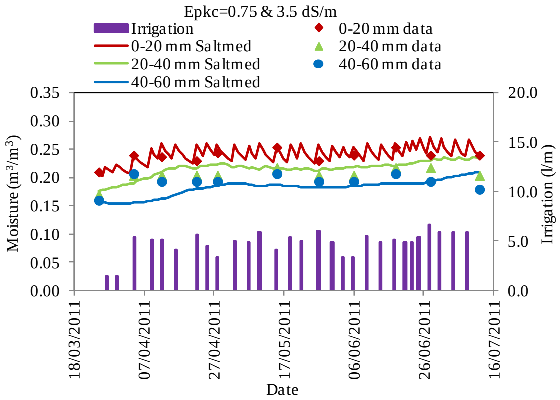
Figure 5. Correlation between measured and predicted soil moisture for all spring and autumn 2011 experiments.



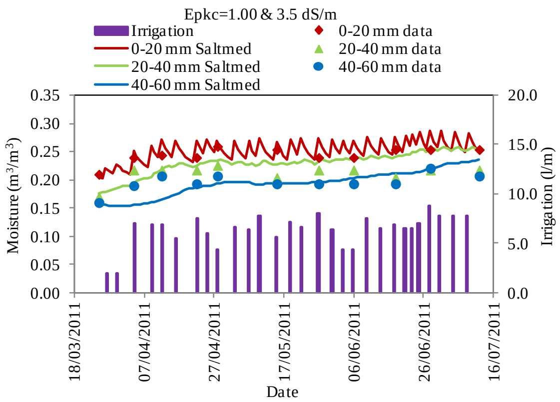
(a) Case 6 (Spring 2011)



(b) Case 7 (Spring 2011)

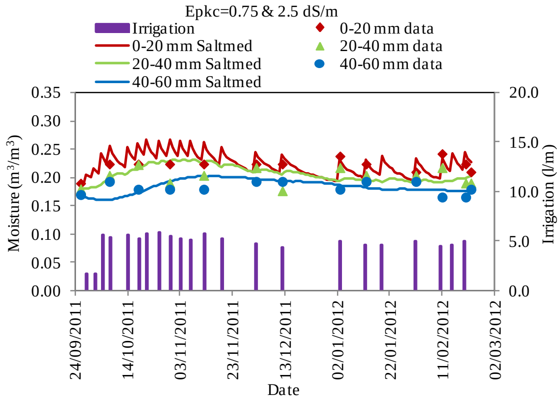


(c) Case 10 (Spring 2011)

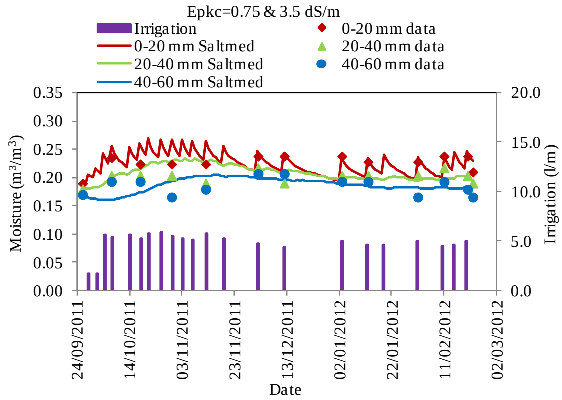


(d) Case 11 (Spring 2011)

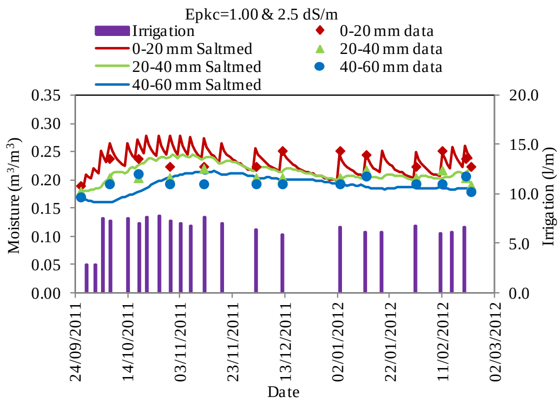
Figure 6. Measured and predicted soil moisture for experimental cases 6, 7, 10 and 11 (Spring 2011).



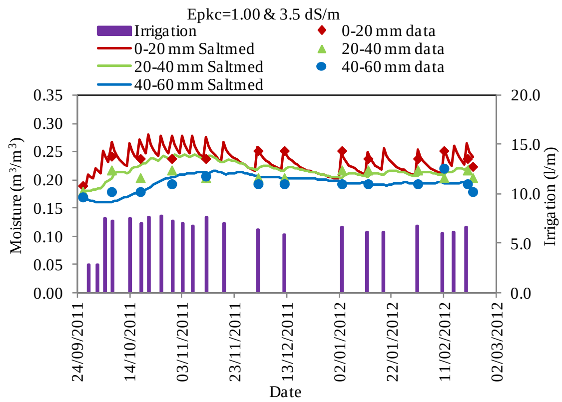
(a) Case 6 (Autumn 2011)



(c) Case 10 (Autumn 2011)

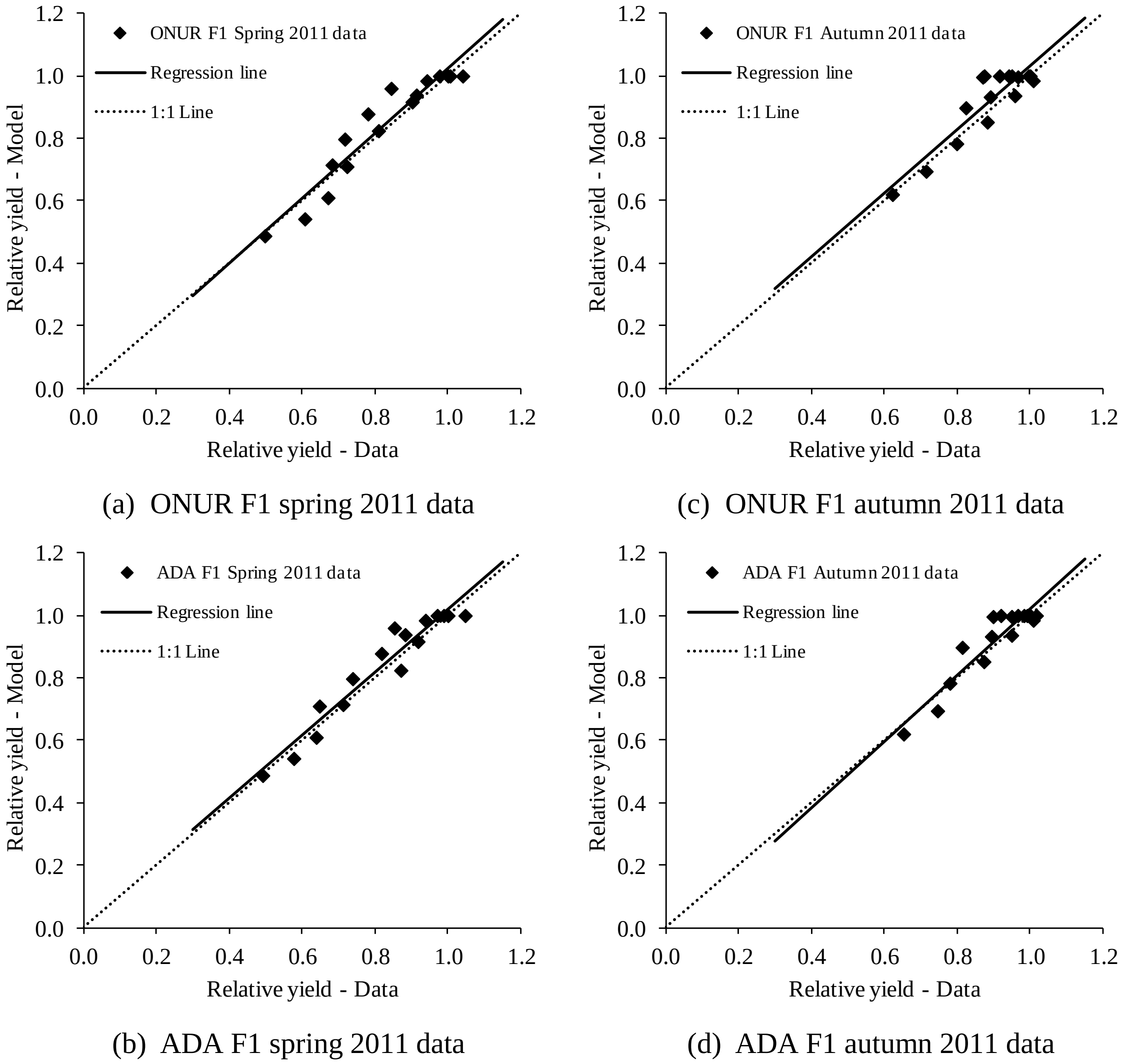


(b) Case 7 (Autumn 2011)



(d) Case 11 (Autumn 2011)

Figure 7. Measured and predicted soil moisture for experimental cases 6, 7, 10 and 11 (Autumn 2011).



(a) ONUR F1 spring 2011 data

(c) ONUR F1 autumn 2011 data

(b) ADA F1 spring 2011 data

(d) ADA F1 autumn 2011 data

Figure 8. Correlation between measured and predicted relative yield.