10 - CALIBRATION OF RZWQM AND EVALUATION OF ALTERNATIVE WATER AND CROP MANAGEMENT PRACTICES

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Abstract: The search of the best combination between the available resources and crop yields can be eased by the use of system modelling. In this work the Root Zone Water Quality Model (RZWQM) was calibrated and used as a management tool. The research was conducted in an experimental field located in the Fergana Valley, Uzbekistan. The soil is a Sierozem cropped with maize (*Zea maïs*) and irrigated with saline water. The soil hydraulic and crop growth components of the model were calibrated against field data. After calibration the model was run as a management tool to predict the impact of different irrigation and fertilization practices upon crop yield. Soil moisture, soil water potential, water table depth and plant development were monitored during the 2001 growing season and used for model calibration. Results from the comparison of field and simulated data show a good calibration of the soil hydraulic and plant growth model components. Soil water was simulated for five soil layers with an average deviation from the measured values of 3.6%. Crop yield was estimated by the model with an error of 13%. The results from the simulation of various agricultural management scenarios can be used for further agro economical analysis and assessment in view of economic profitability. Nevertheless, other model components like the chemical modules must be calibrated against detailed field experiments.

Keywords: Soil hydraulic properties, Maize, Model calibration, Irrigation management, Fertilization management, Crop growth simulation.

Introduction

Located in the Aral Sea basin, the Republic of Uzbekistan suffers from an environmental desertification crisis that destabilizes sustainable development. The prevailing arid climate requires that cultivated crops be intensively irrigated.

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Farm practices require specific field and modelling approaches as dealt in this paper and by Horst *et al.* (2005) relative to surface infiltration improvements. In this area, up to 90% of the total water uses are related to irrigated agriculture. Increasing irrigation water productivity is essential to cope with the scarcity of irrigation water.

Among others, modelling is an effective tool to develop new management approaches. The Root Zone Water Quality Model (RZWQM) (Ahuja *et al.*, 1999) is an integrated physical, biological, and chemical process model simulating plant growth and movement of water, nutrients and pesticides over and through the root zone at a representative area of an agricultural cropping system. The model has been successfully used in several parts of the world (Ma *et al.*, 2001; Cameira *et al*., 2005). Cameira *et al*. (2000a) describes the use of the model in combination with field studies to characterize soil hydraulic properties of irrigated maize in a Mediterranean alluvial soil.

The model incorporates additional features needed for simulating management impacts, such as chemical transport via macropores, tile drainage, advanced soil chemistry and nutrient transformations, improved water and salt dynamics, a comprehensive plant growth model, and important water and chemical management scenarios. In can be used to simulate the influence of different agricultural management scenarios, including irrigation and fertilization management upon crop yields.

The RZWQM model allows simulation of a wide spectrum of management practices and scenarios (Cameira *et al*., 2000b). These management alternatives include evaluation of: conservation tillage and residue cover versus conventional tillage; methods and timing of fertilizer and pesticide applications; manures and alternative chemical formulations; irrigation and drainage technology, and the methods and timing of water applications; and different crop rotations. Tillage and residue management affect soil's physical and hydraulic properties, micro-topography and surface roughness, energy and water balance, and chemical transfer from soil to surface runoff- Tillage induced changes to soil hydraulic properties are slowly changed back to their original conditions as rainfall reconsolidates the tilled layers (Cameira *et al*., 2003).

The model's generic crop growth component plays a major role in effecting the state of the simulation system. Shading from the plant canopy reduces soil evaporation, while transpiration links root water and nutrient extraction from soil layers to atmospheric demand. Seasonal sloughing of leaf material and dead roots, coupled with harvest residue, provide a source of carbon and nitrogen for the soil nutrient transformations. Estimates of crop production and yield allow for a relative economic evaluation of the simulation results.

The reliability of RZWQM depends on how well each individual process is represented in the model and on the accuracy of the measured parameters needed to run the model. The model components have undergone extensive verification, evaluation and refinement in collaboration with several users in the USA. These components are water movement (Ahuja *et al.*, 1993), pesticide transport (Ahuja *et al.*, 1993, 1996), evapotranspiration (Farahani and Ahuja, 1996), subsurface tile drainage (Johnsen *et al.*, 1995), organic matter/nitrogen cycling (Ma *et al.*, 1998), and plant growth (Nokes *et al.*, 1996).

The RZWQM is a complex model that requires a large amount of input data to characterize the system to be modelled. As it was shown in previous studies (Cameira *et al.*, 2005), each time that is applied to a new region the model has to be globally calibrated.

This paper has two main objectives. The first is to present the essential aspects of RZWQM parameterisation based upon field data when applied to a different soil environment. The second is to analyse several alternative agronomic, irrigation and fertilizing practices with the scope of improving agricultural production under the perspective of environmental friendliness adapted to the conditions prevailing in Fergana Valley, Uzbekistan.

Materials and methods

Experimental conditions

Several field experiments were designed and conducted in Azizbek farm, Fergana, in Uzbekistan, for the collection of the required input data for the RZWQM. These experiments are described in detail in Stulina and Cameira (2005).

Modelling

Models like RZWQM require a detailed set of parameters. Some of these parameters cannot be easily measured or determined. Also, natural conditions of the soil-plant-atmosphere system are difficult to define for some parameters requiring a calibration for the site and crop. The user is confronted with the task of determining which parameters to calibrate and how to do it. An iterative calibration approach is needed to account for the interactions between soil water, available nitrogen and crop production. This approach will reduce the error propagation between model components. In this work two model components were calibrated: the hydraulic properties and the crop development. The evapotranspiration and the nutrient components were not studied.

The starting moisture profile and the depth of the water table gave the initial conditions for solving the water-flux Richards equation. At the soil surface, precipitation and potential evapotranspiration were given as top boundary flux conditions. A unit soil water potential gradient was used as the bottom boundary condition.

Calibration

First, the hydraulic soil properties obtained from field and laboratory experiments (Stulina and Cameira, 2005) were calibrated without the presence of root extraction using infiltration and redistribution profiles. The RZWQM was run in inverse mode to calibrate the hydraulic parameters.

Then the crop development component of RZWQM was calibrated for maize. In this component two types of parameters were calibrated. They were the duration of each growth stage and the crop-specific parameters (Table 1).

Table 1. Phenological and site-specific maize crop parameters before and after calibration of the crop development component.

Parameter	Defaults	Maize
1. Minimum time for the beginning of the germinating phase (days)	5	5
2. Minimum time for the beginning of emergence (days)	15	15
3. Minimum time for the beginning of the four leaf stage (days)	20	25
4. Minimum time for the beginning of the reproductive stage (days)	30	30
5. Maximum N uptake rate (g/plant/day)	5	1.0
6. Relation N uptake/biomass (0-1/day)	0.12	0.05
7. Specific leaf density (g/LAI)	11.5	13.5
8. Photosynthetic efficiency in the flowering phase (0-1)	0.45	0.85
9. Photosynthetic efficiency in the seed formation phase (0-1)	0.6	0.80

The latter reflect the effect of the environment over crop development for each production system. The first four values shown in Table 1 are used to adjust the duration of each crop stage. Increasing the parameter 6 results in a decrease in biomass while increasing the parameter 7 results in a decrease in total plant production. Parameters 6 and 7 can be adjusted to change the slope of the biomass growth curves. When the parameter 8 is increased yield also increases while above ground biomass is kept constant. Similar changes in parameter 9 produce the same impacts but later in the growing season. Parameters 8 and 9 can be changed to adjust the harvest index. For this particular component the model developers suggest that the simulations must be within 15% of the measured control variables, which are above ground biomass, yield and leaf area index (Hanson, 1999).

The calibration process was initiated using the default value of 5 for parameter 1. After the simulation the estimated biomass was compared with the measured. If the error was higher than 15% the parameter 6 was adjusted. Then the parameter 7 was adjusted in order to reduce the error to approximately 10%. When necessary, the harvest index was adjusted by changing parameters 8 and 9. The process was repeated as necessary.

Using the model as a management tool

After the calibration of these two components the model was used as a tool to evaluate the impact of different irrigation and fertilization practices upon crop yield. With this purpose, different simulation scenarios were created. The irrigation scheduling simulation model ISAREG (Teixeira and Pereira, 1992) was used to build the water management scenarios. This model was validated using data collected in the same Fergana farm and is used to support improved irrigation management in the area (Fortes *et al*., 2005).

Results and discussion

Soil water retention and hydraulic conductivity functions

Table 2 presents the Brooks & Corey parameters obtained after calibration of the hydraulic properties using moisture data from a bare soil infiltration and redistribution experiment. The starting point for the calibration were the parameters obtained from the field and lab data obtained as described in Stulina and Cameira (2005).

Table 2. Parameters of the modified Brooks & Corey functions of the Sierozem soil in the experimental plot.

Horizon (cm)	θs	θr ($m^3 m^{-3}$)	Ks ($cm\ h^{-1}$)	h_b (cm)	λ	N_2	C	N_1	A
0-25	0.48	0.01	1.9	-14.0	0.20	2.60	1814.2	0	0.003
25-35	0.42	0.01	1.3	-27.0	0.10	2.30	2547.3	0	0.0001
35-50	0.42	0.00	0.8	-33.0	0.10	2.30	2486.9	0	0.0001
50-62	0.42	0.00	0.8	-32.0	0.10	2.30	2317.0	0	0.0001
67-76	0.42	0.00	0.6	-35.0	0.10	2.30	2135.5	0	0.0001
76-91	0.44	0.04	0.6	-23.2	0.10	2.30	825.3	0	0.0001
91-130	0.42	0.03	0.8	-23.0	0.10	2.30	1084.0	0	0.0001

The calibration of the hydraulic properties showed the necessity to divide the soil profile into more layers than the ones originally defined, especially between 55 and 95 cm. Differences in the parameters of the $\theta(h)$ function are due to the new layering. The calibrated K(h) functions also present some differences when compared with the ones adjusted to the experimental data especially in the wet zone, corresponding to the macroporosity. In fact, the calibrated saturated conductivities are higher for the entire profile, except for the 35-55 cm layer. These differences in Ks are due to the sampling methods, which cause some compaction, especially in the ploughed layer, destroying macroporosity (Cameira *et al.,* 2000a, Cameira *et al.*, 2005).

Model testing

Soil water

The comparison of measured and simulated water contents after the calibration of soil hydraulic properties is given in Fig. 1 for all soil layers.

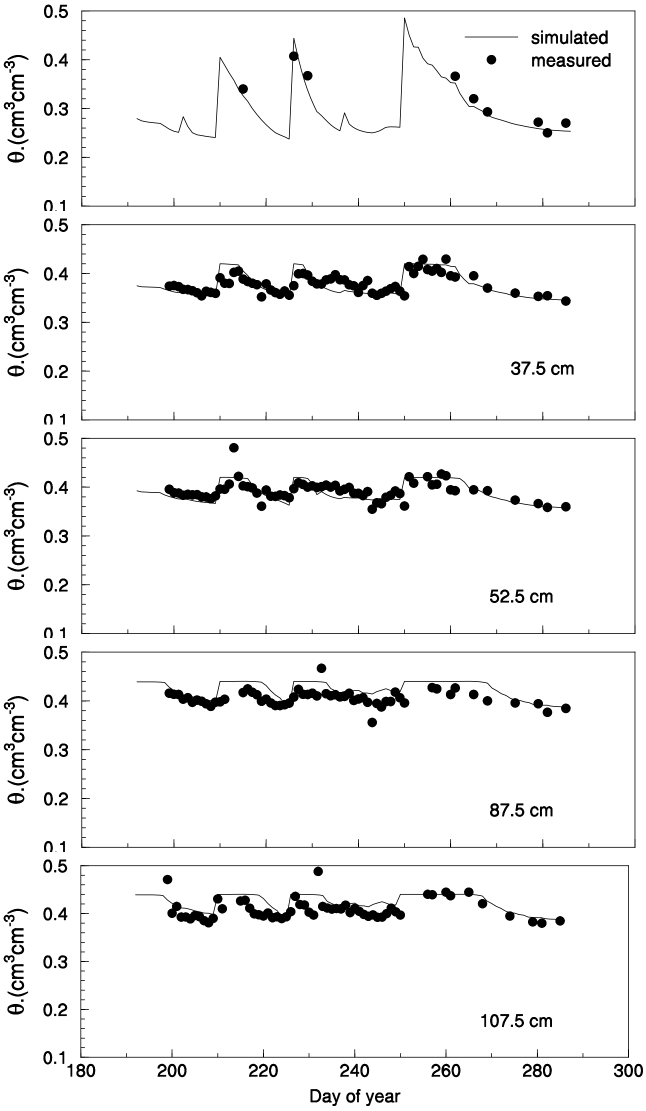

Fig. 1. Comparison of measured and simulated water contents after the calibration of soil hydraulic properties model component.

Results show a good agreement between simulated and observed data both for the upper layers, where changes are more drastic between irrigations, and the deeper layers where the variation of the soil water content was lesser. The deviation between simulated and measured values averages 3.6%, being the maximum 18%. These good fitting results indicate that model parameterisation of the soil hydraulic properties has been successfully achieved. This is reinforced by the good agreement between the measured and the simulated matric potentials for the different soil layers (Fig. 2).

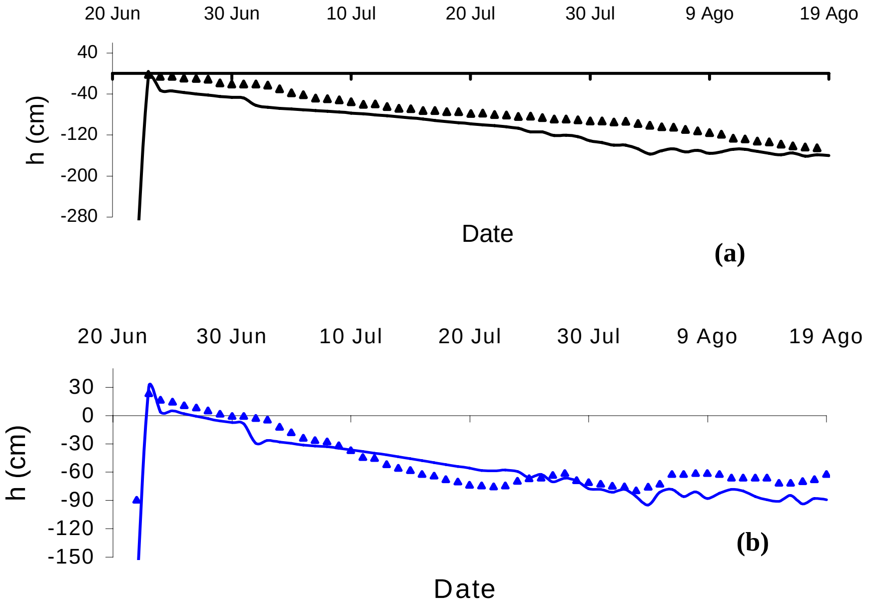

Fig. 2. Comparison of observed and simulated matrix potential (cm) at two soil depths: (a) 88 and (b) 113 cm.

The contribution of groundwater to the water balance in the root zone is considerable. During almost all the whole growing season, upward water fluxes were observed in soil profile. Thus, the up- and downward flux from/to the water table constitutes an important variable to be simulated since it determines the fluxes inside the root zone. Fig. 3 shows the simulated hydraulic fluxes during the growing period at various depths.

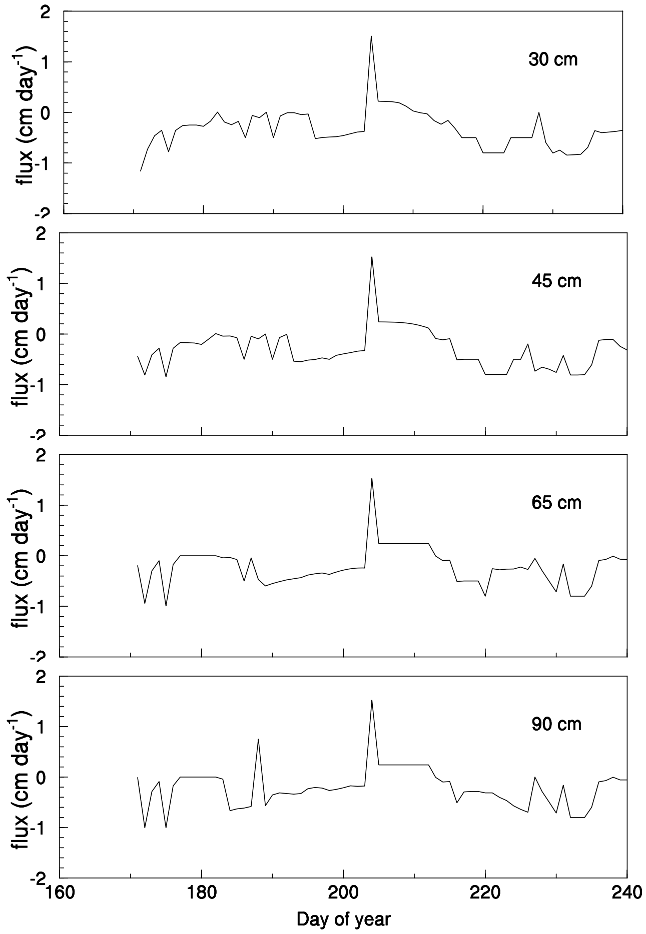

Fig. 3. Simulated hydraulic fluxes at different depths.

Crop development

After calibration of the crop development component, RZWQM estimated the yield with an error of 13% (measured yield = 15 Mg ha^{-1}; simulated yield = 13 Mg ha^{-1}). Fig. 4 shows the simulated evolution of plant height and above ground biomass during the crop cycle and the comparison with the correspondent measured values. The deviations between simulated and measured values were considered small enough, so that the crop growth component was calibrated.

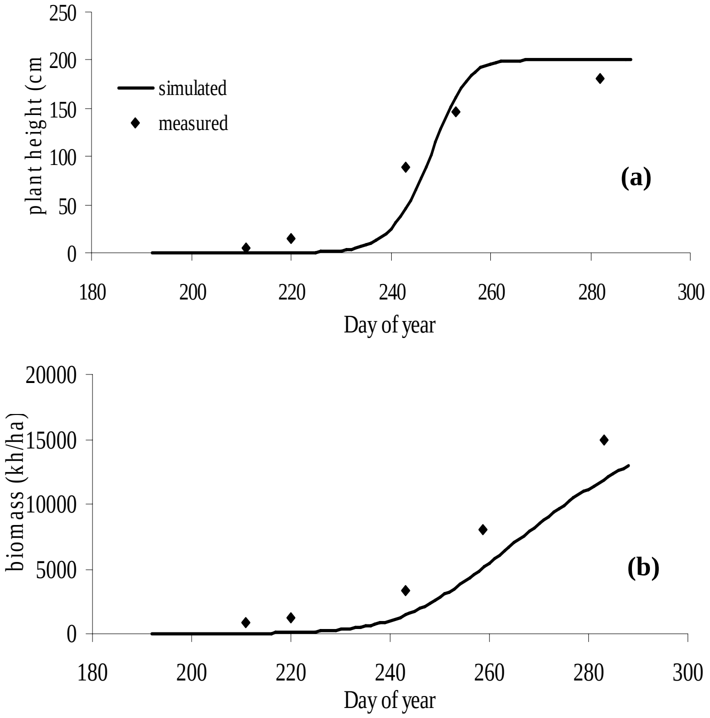

Fig. 4. Simulated and measured crop height (a) and biomass (b) for silage maize.

Scenario analysis

The model simulates a wide rage of management scenarios. This includes assessment of pesticides and fertilizer applications rates and timings of application, as well as irrigation methods, irrigation depths and frequency. These capabilities of the model were explored in order to predict impacts on crop yields caused by different management practices.

Three nitrogen fertilizer application methods were considered: Scenario A1 – incorporated broadcast, scenario A2 – surface broadcast, and scenario A3 – injection. Fig. 5 shows the simulated crop yields for each scenario. The most effective method of fertilizer application was the injection, originating a yield increase of 5% relative to surface broadcasted, which is the most common at present. Differences among methods are small, thus focusing crop management improvements in fertilizing application methods is not a priority.

Four scenarios were considered for the amount of nitrogen fertilizer: Scenario B1 – 40 kg ha^{-1}, scenario B2 – 80 kg ha^{-1}a, scenario B3 – 200 kg ha^{-1}, and scenario B4 – 400 kg ha^{-1}. The prediction of maize yields for the different scenarios is shown in Fig. 6. Increasing N application up to 200 kg ha^{-1} leads to a steady increase in yields. For higher rates the crop yield response is much smaller, with a lower fertilizing productivity, thus indicating that increasing the N fertilising above that value may not be of interest.

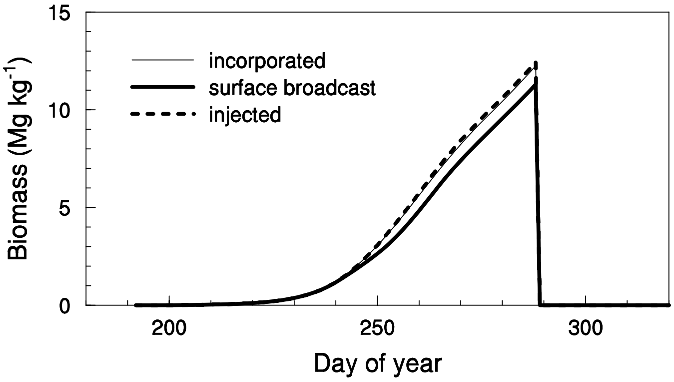

Fig. 5. Model results of maize biomass for different methods of N application.

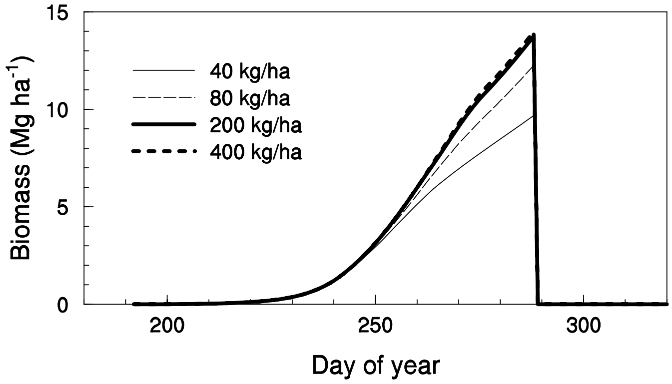

Fig. 6. Model results of maize biomass (kg/ha) for different N application rates.

Three irrigation scenarios were simulated in order to determine the impact of different irrigation amounts upon crop production. Scenario C1 corresponds to the actual irrigation performed in the field. Scenario C2 corresponds to an improved irrigation schedule aiming at maximizing ET and yield simulated with the model ISAREG (Teixeira and Pereira, 1992), which was validated with field data obtained in the same plot. Scenario C3 is a water saving scenario, also simulated with ISAREG, where the irrigation amount was decreased by 16%. Results in Fig. 7a show that an improved schedule may lead to significant increase in yields, up to 13.3 Mg ha^{-1}, i.e. near 10% relative to the common practice, and those in Fig. 7b show that the water saving practice results in the decrease of maize yield by 2.45 Mg ha^{-1}, i.e., 20% less than the control irrigation schedule. Further simulation analysis will be performed to build up best management practices for irrigated agriculture in the area. With this purpose, the calibration of RZWQM chemical and nutrient modules is being performed.

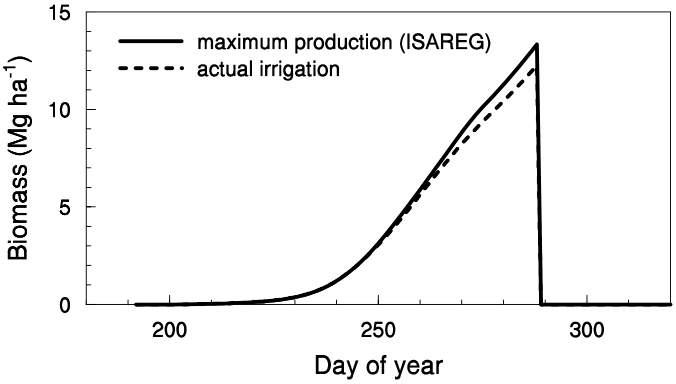

Fig. 7a. Simulated total maize biomass (kg/ha) comparing an improved irrigation schedule with the actual one.

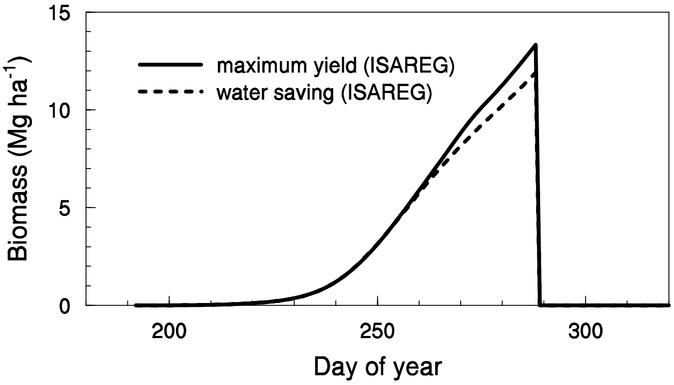

Fig. 7b. Simulated biomass (kg/ha) for the water saving irrigation scenario and the ISAREG scenario.

Conclusions

The results presented in this work show that the methodology used to parameterize the hydraulic properties and the crop development modules of RZWQM for the Fergana Valley is adequate, thus encouraging further developments for using the model in this area. However several difficulties have been found due to the gypsum presence in the soil. Overall the data collected allowed a good description of the soil hydraulic properties of the Sierozem soils.

The calibration process originated soil hydraulic parameters in some extent different from the ones obtained from the field and lab data, meaning that the conventionally measured soil hydraulic properties did not describe the porous system with enough accuracy. These conventionally measured parameters should be taken as initial values for the inverse parameter estimation procedure using simplified field trials like the infiltration and redistribution experiment in a bare soil.

In relation with soil water, the deviation between simulated and measured values averages 3.6%, being the maximum 18%. These good fitting results indicate that model parameterisation of the soil hydraulic properties was successfully achieved. After calibration of the crop development component, RZWQM estimated the yield with an error of 13% (measured yield = 15 Mg ha^{1}; simulated yield = 13 Mg ha^{-1}).

This work describes the first attempt to use the model RZWQM for Uzbek conditions. Results confirm the ability of RZWQM to predict the impacts of different agricultural practices, including irrigation and fertilization, upon the crop yields. When complemented with an agro-economic analysis methodology, it constitutes a useful tool for decision-making in the Uzbek irrigated agriculture in a medium to long run, including selecting the practices that may lead to higher land and water productivity. However further and detailed field studies need to be performed in order to adequately calibrate the model for the Fergana Valley specific conditions, particularly related to salinity, agronomic and economic features of the model, with particular focus on the chemical modules in order to consider the current salinity problems.

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