Modelling soil water, carbon and nitrogen dynamics in wheat/chickpea rotations: parameterisation and evaluation of APSIM in a Mediterranean environment

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Abstract

Accurate predictions of multi-seasonal soil N, C and water dynamics are essential for assessing rotational effects and system sustainability. The cropping systems model APSIM was evaluated for its ability to simulate wheat and chickpea systems at a site in northwest Syria. Simulated soil water dynamics suggested that the two-stage soil evaporation model used in APSIM's cascading water balance module does not sufficiently explain actual discharge of the soil profile following crop maturity at the study site. A more appropriate representation of soil water dynamics was achieved by resetting the soil water content in the upper profile layers (0-30 cm) to 'air dry' between cycles of the rotation. APSIM captured the trends in soil organic matter dynamics, although it overpredicted the likely increase in soil microbial biomass carbon under wheat-chickpea. By increasing the amount of N in chickpea roots through a different set of parameters for chickpea root N concentration limits, simulated wheat yields improved. With this parameterisation, APSIM was capable of simulating the observed dynamics of N and C and crop yields in wheat/chickpea rotations conducted at the study site.

Media summary

The capability of APSIM to simulate soil water, carbon, and nitrogen dynamics of wheat/chickpea rotations in northwest Syria is documented.

Key Words

Crop rotation, simulation, , Mediterranean climate

Introduction

In the semi-arid environments of the southern and eastern Mediterranean region, contemporary developmental and demographic pressures necessitate changes in agricultural practices and resource use to meet increasing demand for agricultural products. The potential for productivity increases is yet unknown, and reported degradation of agriculturally productive land and water resources indicate that current management practices are often suboptimal. The development of resilient cropping systems requires a well-tested, quantitative systems analytical framework suitable to investigate the complex soil, crop, climate and management interactions. The Agricultural Production Systems Simulator (APSIM) is a cropping systems model that describes the dynamics of crop growth, soil water, soil nitrogen and carbon, and plant residues as a function of climate, cropping history and soil/crop management. Through the linking of crop growth with soil processes, APSIM is particularly suited for the evaluation of likely impacts of alternative management practices on the soil resource and crop productivity. The model has been used successfully in the search for strategies for more efficient production, improved risk management, and sustainable production (Keating et al. 2003). However, climate, soil and cultivars in the present study are different from those where APSIM was developed and is most widely used. Hence, APSIM was parameterised with data obtained from experiments conducted during two seasons in northwest Syria. Subsequently, APSIM was evaluated for its ability to simulate experimental results from an independent rotation experiment conducted at the study site.

Methods and material

Site description

All experiments were conducted at the International Center for Agricultural Research in the Dry Areas (ICARDA) at Tel Hadya, northwest Syria (N 36?01, E 36?56). The site has Mediterranean-type climate with an average annual precipitation of 340 mm and a temperature of 17.6 ?C. Soils are calcareous, silty-loamy clays and have been classified as *Calcixerollic Xerochrepts* (Ryan et al. 1997). Typically, they swell when wet and develop deep wide cracks when dry. Soil organic matter content is ≤ 1% in 0-20 cm depth.

Data sources

Experiments with durum wheat (*Triticum turgidum* ssp. *durum*, cv. Cham3) and kabuli chickpea (*Cicer arietinum*, cv. Ghab2) were conducted during the 1998/99 and 1999/00 seasons to obtain a data set suitable to initialise and parameterise APSIM as well as evaluate aspects of model performance. In the experiments, crops were grown under different nitrogen and/or water supply. Field observations included crop growth and development (phenology, above ground biomass, crop N content, leaf area, yield), soil water (neutron probe measurements) and mineral N. Soil organic carbon was measured before sowing.

For model evaluation, APSIM was tested against independent data from a rotation experiment (Productivity of Cropping Systems Trial, PCS-trial, Harris 1990), which was established in 1983/84 at Tel Hadya. Four treatments of the PCS-trial were simulated: wheat-chickpea with 0, 30 and 90 kg N/ha, and wheat-fallow with 30 kg N/ha applied at wheat sowing (WN0-CP, WN30-CP, WN90-CP, WN30-F). Simulations were run for a period starting 1-Sep 1983 and ending 31-Aug 1999, on a 150 cm deep soil with 246 mm plant extractable soil water (PESW). Published sources did not provide exact sowing dates. Hence, planting of wheat cv. Cham3 and chickpea cv. Ghab2 was triggered by PESW in the seedling layer within defined sowing windows. For simulation purposes wheat was sown on 10-26 Nov at 5 cm depth and a plant density of 300 plants m^{-2}. Chickpea was sown on 1-21 Dec at 5 cm depth and a density of 50 plants m^{-2}. After the wheat phase, 75% of straw residues were removed from the system and the remaining residues were left on the soil surface. Chickpea was directly drilled into the remaining wheat stubble. After chickpea and after wheat in the wheat-fallow system, 90% of surface residues were incorporated at 25 cm depth.

Results and discussion

Single season simulations

Under all conditions, model predictions were satisfactory for biomass and yield of wheat and chickpea grown in 1998/99 and 1999/00 at Tel Hadya (data not shown). Total crop N content was well simulated for wheat and reasonably well for chickpea. Seasonal decline in soil mineral N was overpredicted, particularly in the irrigated and unfertilised wheat treatment. Soil water dynamics were well simulated during crop growth. Discharge of the soil profile following crop maturity was underpredicted when the seasonal water supply exceeded the demand by evapotranspiration, as it was the case in irrigated wheat.

Modelling fallow water dynamics in rotations

At Tel Hadya, Harris (1994) repeatedly observed air dry moisture contents to a depth of 60 cm following wheat and chickpea crops, indicating that there was substantial water loss from deeper profile layers, possibly as evaporation (E_s) *via* ‘crack flow’ (Feddes et al. 1988). E_s from such wide cracks is not explicitly simulated by APSIM’s cascading water balance module. In the model, E_s follows Ritchie’s (1972) two-stage evaporation model and is simulated to occur from the surface layer only. From the results of single season simulations it was hypothesised that this model behaviour caused an underprediction of discharge of the upper profile layers when the seasonal water supply exceeded the demand by evapotranspiration. Based on the documented soil water dynamics and our findings, we tested whether the accuracy of predictions could be enhanced by resetting the soil water content (SW) in upper soil layers to the initial air dry moisture contents (AD) between rotational cycles (Figure 1). The reset to AD in 0-30 cm depth equalled 18 mm of water removed from the system, if soil water (SW) was at the lower limit of plant extractable water (LL15) at crop maturity. This reset was performed on 1-Jun and on 1-Jul to achieve air dry moisture contents in the upper soil layer throughout the summer fallow period and a fallow efficiency of 15-25% (Cooper et al. 1987). Results showed that when seasonal precipitation was almost entirely used as evapotranspiration (ET), as in the WN90-CP system, there is only a minor difference in SW in 0-30 cm depth with and without reset. The effect of the reset to AD was more pronounced in the unfertilised rotation (WN0-CP) and in the wheat-fallow system (WN30-F) where water use by wheat was less and significant amounts of water remained in the soil profile after wheat harvest. Without reset, SW in 0-15 cm depth during the dry summer was above LL15 in some seasons in the WN0-CP rotation, and in every fallowed year in the WN30-F system. This was due to simulated unsaturated flow and the build up of high water gradients between upper and lower profile layers. Under such conditions the upper soil layers were continuously refilled by unsaturated flow from deeper soil layers between resets on 1-Jun and 1-Jul. Our own soil moisture data revealed that lowering simulated unsaturated flow through a different parameterisation for the soil's diffusivity greatly reduced the simulation accuracy for recharge of the soil profile at the start of the rainy season. Hence, a more appropriate representation of fallow efficiency and long-term soil water dynamics was achieved by resetting the upper profile layers (0-30 cm) twice to air dryness between cycles of the rotation (Figure 1). By applying the reset, wheat yields from the wheat-fallow system were well predicted (data not shown).

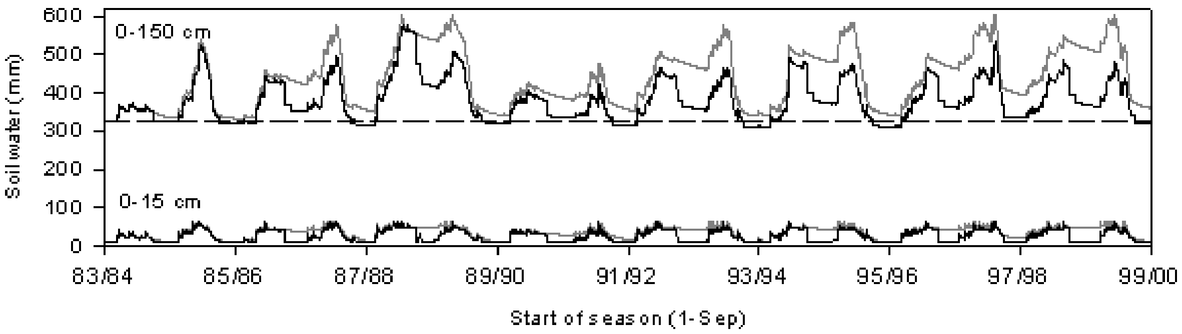

Figure 1. Simulated soil water dynamics for the entire profile (0-150 cm) and the surface layer only (0-15 cm) in a wheat-fallow system at Tel Hadya. Black curves: soil water in the upper two soil layers (0-30 cm) was reset to initial air dry moisture contents on 1-Jun and on 1-Jul. Grey curves: soil water dynamics without reset. Dashed line: lower limit of plant extractable soil water for the profile.

Soil organic matter and mineral N dynamics

Simulations indicated that WN30-F would reduce while WN30-CP would enhance soil fertility (as measured by soil organic matter, SOM, %) in the long-term. Ryan (1997) and Jenkinson et al. (1999) reported similar trends for the PCS-trial, suggesting that the predictions were sensible. While microbial biomass pool C was well predicted for the WN30-F system, the likely increase in microbial C was overpredicted for the WN30-CP system. The reason for this could not be established. The model underpredicted background levels of NH_4-N, which are generally 20-50% of total mineral N in soils at Tel Hadya (e.g. experimental data from the 1998/99 and 1999/00 season, Ryan et al. 1997). Nitrification was simulated as a rapid and unrestricted process so that virtually no NH_4-N was present throughout the simulated time frame except shortly after the application of urea N and at model initialisation. At the study site, soils are smectite rich and have a high cation exchange capacity. Such properties influence the NH_4-N dynamics through adsorption and desorption of NH_4-N on and from clay particles. Successive release of adsorbed NH_4-N is not treated by APSIM but may *in situ* alter the time course of N supply to the crop and N turnover processes.

N benefits from chickpea

In the PCS-trial, cropping of chickpea in rotation with unfertilised wheat increased wheat biomass on average by 1.2 t/ha compared to an unfertilised wheat-wheat rotation (Ryan 1997). While soil water use is similar for chickpea and wheat grown at Tel Hadya (Harris 1994), increased wheat biomass could be related to N benefits from chickpea and its effect as a break crop. With the original parameterisation, wheat yields for the unfertilised wheat-chickpea rotation where largely underpredicted suggesting that the simulated N benefits from chickpea may have been too low. A sensitivity analysis showed that higher wheat yields, i.e. closer to those measured in the PCS-trial, can be obtained by including root N concentration limits of chickpea as part of the model's parameterisation (Figure 2, Table 1).

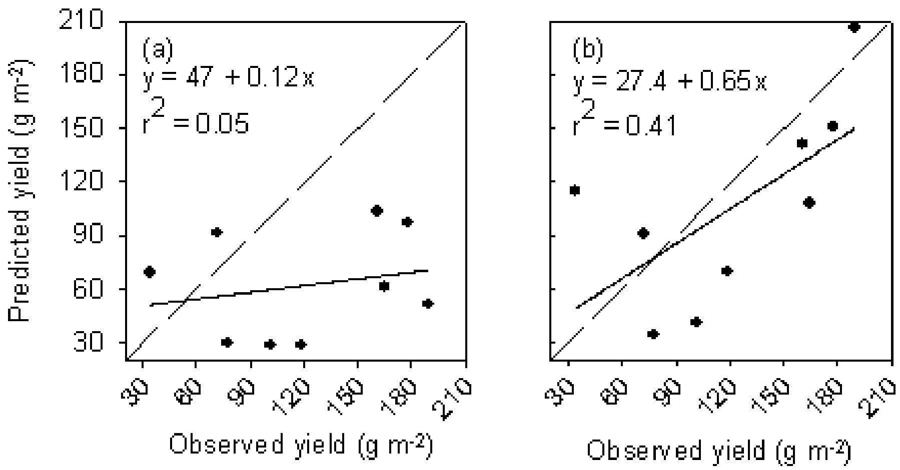

Figure 2. Observed vs. simulated wheat yields from an unfertilised wheat-chickpea rotation at Tel Hadya using two sets of parameters for chickpea root N concentration limits. (a) default, (b) adjusted optimum root N concentration limits. Perfect fit is indicated by the dashed line.

Table 1. Two sets of parameters for optimum root N concentration limits of chickpea used in simulations of wheat-chickpea systems at Tel Hadya.

APSIM crop growth stages				
Emergence	Juvenile	Flowering	Start grainfilling	Maturity
Default optimum root N concentrations				
1.5	1.5	1.5	1.5	1.5
Adjusted optimum root N concentrations				
3.5	3.2	2.5	2.0	1.5

Yield predictions

Overall, the model captured the dynamics of yield responses to water and nitrogen supply and was capable of simulating yield variability (Figure 3). Results suggested that the above outlined assumptions on fallow water dynamics and the N contribution of chickpea root residues were sensible.

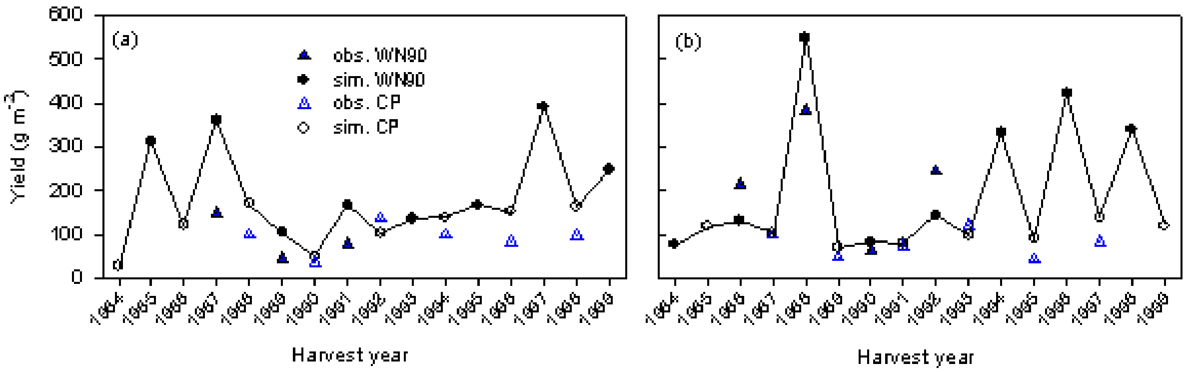

Figure 3. Simulated (circles) and observed (triangles) wheat (closed symbols) and chickpea (open symbols) yields from a wheat-chickpea rotation with 90 kg N/ha applied to wheat at Tel Hadya, Syria. (a) CP-W, (b) W-CP.

Conclusion

APSIM was evaluated for its ability to simulate wheat and chickpea yields, and consequent water, nitrogen and carbon dynamics of a rotation experiment conducted in northwest Syria. With the described parameterisation, the overall performance of the model was sensible, providing sufficient confidence in the simulation capabilities for subsequent scenario analysis.

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