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Assessing soil water trajectories and WUE: A multi-year modeling approach to design resilient cereal-legume rotations in the dry areas

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1 Introduction

Cropping system simulation can address the complex and interactive nature of resilience and allows for biological (crop growth and development), physical (soil-water dynamics), chemical (soil carbon and N turnover), and management-related (e.g. crop choice, applications of nitrogen fertilizer, timing of sowing) aspects of resilience to be quantified. Soltani & Sinclair (2012) recently presented a non-calibrated, mechanistic, simple model, called Simple Simulation Model (SSM), which uses a generic approach for simulating the growth and yield of cereal and legume crops. The robustness of the legume and cereal versions of SSM has been demonstrated for a wide range of environments and various species including wheat (Soltani *et al*., 2013) and chickpea (Vadez *et al.* 2013). In cropping systems of the semi-arid Mediterranean region, variable and deficient rainfall and drought episodes are primary constraints to productivity. Under these conditions, maximizing water-use efficiency (WUE, defined as the ratio of yield per unit evapotranspiration) is critical. Hence the accurate prediction of soil-water dynamics and crop–water relations is required to identify management strategies that increase the use of scarce rainfall and its conversion into grain yield. We applied SSM to examine rotations including wheat and chickpea that are representative of rainfed environments of the southern and eastern Mediterranean.

2 Materials and Methods

Simulations were carried out for Tel Hadya, Syria. The site (36°01'N, 36°56'E; elevation 284 m) has a semi-arid Mediterranean climate. Firstly, SSM was parameterized to simulate the growth and development wheat and chickpea crops and the soil water dynamics as observed in experiments conducted in 1998/99 and 1999/2000 at Tel Hadya (Moeller *et al.* 2007). Secondly, data from a longer term two-course rotation experiment established in 1983 at Tel Hadya (Harris, 1990) were used to assess the ability of the model to simulate long-term soil water dynamics and crop productivity as observed under field conditions. In the rotation experiment, wheat (*Triticum turgidum ssp. durum*, cv. Cham3) was rotated with wheat, annual fallow, and chickpea (*Cicer arietinum,* cv. Ghab2), and crop productivity and the soil-water dynamics were quantified under different N fertilizer regimes from 1986 to 1998 (12 crop cycles). For the purpose of simulating successive rotational cycles, a new version of the model (SSM-Rotation) was designed. In SSM, the soil water status is calculated daily as the amount of transpirable soil water (ATSW) using the water balance equation for an expanding volume of soil, corresponding to the addition of the soil layer explored by roots on that given day. Finally, SSM-Rotation was applied to simulate a continuous 30-year period and compare three long-term rotations of Wheat-Fallow (used as reference), Wheat-Chickpea and Wheat-Wheat-Chickpea. Simulations were run with no nitrogen stress effect on wheat; chickpea is supposed to be self-sufficient in Nitrogen. The performance of rotations is discussed regarding yield, in-crop WUE (WUE1), and the WUE calculated over all cycles of the rotation (WUE2). For the sake of uniformity, the wheat yield equivalent (WYE) of chickpea was calculated as: WYE =Yield of Chickpea x (Price of Chickpea/Price of Wheat) (Chetty & Reddy, 1987).

3 Results - Discussion

Overall, the model was able to simulate wheat and chickpea yields, total biomass, and the soil water dynamics as reported for contrasting conditions in Moeller *et al.* (2007) (Fig.1 A-D). In addition, SSM-Rotation simulated the long-term soil-water dynamics in rotations with reasonable accuracy (Fig.1E). The predictive abilities of SSM-Rotation demonstrated here showed that the model is robust enough to be applied to explore indicators of cropping systems resilience such as WUE.

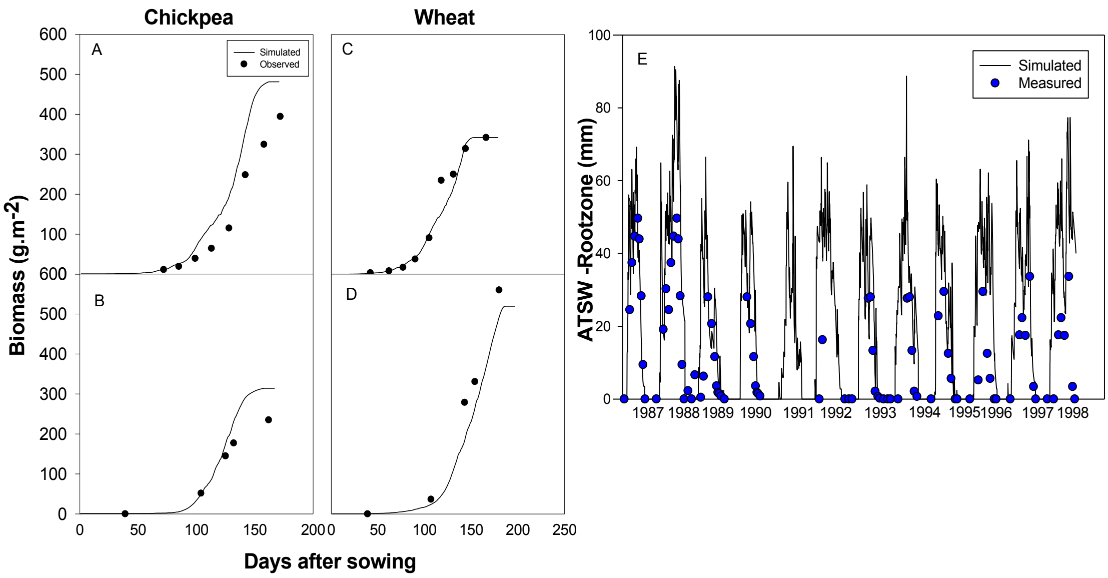

Fig. 1. (A-D) Simulated (curves) and measured (closed circles) of biomass chickpea and wheat grown at Tel Hadya: (A) rainfed chickpea, 1998-99, (B) irrigated chickpea, 1999-00, (C) rainfed wheat, 1998-99, with a nitrogen (N) fertilizer rate of 60 kg N.ha^{-1}, and (D) irrigated wheat, 1999-00, with a N fertilizer rate of 100 kg N.ha^{-1}. (E) Simulated (curves) and measured (closed blue circles) of actual transpirable soil water in the rootzone (ATSW-RZ) in a rainfed wheat–chickpea rotation without N fertilizer applications.

Although wheat WUE was increased in wheat/fallow rotation compared to diversified rotations, the total WUE of the rotation (WUE2, Table 1) was lower in the fallow rotation due to important evaporative losses during the fallow period. The 3 years wheat/wheat/chickpea rotation was the most productive and the most efficient regarding total water use (WUE2) as it combined i) a high proportion of high economic value wheat, ii) reduced evaporative losses due to ground cover every year.

Table 1. Simulated mean yield and WUE in three rotation schemes

Rotation scheme	Wheat yield (t.ha^{-1})	Chickpea yield (t.ha^{-1})	Wheat WUE	Chickpea WUE	WUE1 (in-crop)	WUE2 (over entire rotation)
Wheat/Chickpea	1.42	0.89	0.53	0.39	0.42	0.30
Wheat/Fallow	1.80	-	0.60	-	0.60	0.26
Wheat/Wheat/Chickpea	1.62	0.75	0.62	0.32	0.50	0.37

4 Conclusions

The overall performance of the model was sensible, providing sufficient confidence in the simulation capabilities of SSM-Rotation for subsequent scenario analyses. The analyses will be expanded to different crops (lentil, barley), sowing dates, N rates, and crop maturity types (short and long-season).

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