Simulation of Crop Growth and Soil Water for Different Cropping Systems in the Gansu Loess Plateau, China using APSIM

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Abstract

The objective of this paper is to evaluate the performance of the APSIM model in simulating crop growth and soil water for different cropping systems in China. The APSIM was parameterised and tested using data collected from two dryland field experiments being conducted on the well-fertilized Heilu soil of the Gansu Loess Plateau. In bare fallow and continuous lucerne treatments, soil water and lucerne biomass were well simulated. In a maize-wheat-soybean (M-W-S) rotation with crop stubble either being removed or retained, crop biomass and grain yield were well simulated. Soil water was generally well simulated in the M-W-S rotation without stubble retention except for the periods near harvest of the maize and wheat crops; where stubble was retained, the over-prediction continued through the soybean phase. Simulated water balance components suggest that water use efficiency could be improved if lucerne, summer and early maturity crops were integrated with winter wheat cropping.

APSIM shows promise for simulating soil water balance, crop growth and grain yield for different cropping systems in Gansu, China. By using long-term climatic data, the model offers opportunities for evaluating climatic risk associated with changing from ‘current’ to ‘new’ cropping systems.

Media summary

APSIM shows promise in simulating soil water balance, crop growth and grain yield measured in field experiments for different cropping systems in the Loess Plateau of Gansu, China.

Key words

Loess Plateau of China, soil water erosion, crop rotation, simulation

0Introduction

The Loess Plateau (34-40?N and 101-113?E) of China is the one of the world’s worst examples of soil erosion with 0.28 million km^2 of severely eroded land. In this region, annual rainfall is highly variable with 60% of the annual rainfall occurring in the 3 months between July and September, often in the form of intense thunderstorms. Predominant winter wheat cropping together with summer fallow after the wheat harvest between July and September and poor land management, leads to the severe soil erosion, which is the major threat to sustainable crop production.

Cropping systems with increased soil cover and high water use are the key to reduce soil erosion and sustain crop yields in this region. Recent research in this region (Li et al. 2002) suggests that rotation systems that integrate summer crops (eg maize) or lucerne with winter wheat and replace fallow with early maturity crops (eg soybean) are effective ways to improve precipitation use efficiency and reduce soil erosion. However, issues such as the impact of rainfall variability on crop yield and climatic risk associated with changing from winter wheat dominant cropping systems to more diversified cropping systems that include summer crops, ‘fallow’ crops and lucerne are not well addressed quantitatively in the region, and will affect adoption of ‘new’ cropping systems by farmers. These issues can be addressed with the aid of a simulation modelling approach. The central objective of this paper is to investigate the performance of the APSIM model in simulating crop growth and soil water for different cropping systems in Gansu, China.

1Methods

0APSIM

The Agricultural Production Systems Simulator (APSIM) software system has been developed in Australia to facilitate analysis of complex production and sustainability issues of agricultural systems (McCown et al. 1996; Keating et al. 2003). APSIM simulates cropping systems at the point-scale, accounting for soil chemical, physical and crop physiological growth processes on a daily time step. The model has been developed using a modular software structure so that different modules can be easily linked to adapt to different applications. In this study, crop (wheat, maize, soybean and lucerne), soil water (SOILWAT2), soil N (SOILN2) and crop residue (RESIDUE2) modules have been linked within the APSIM framework. The simulations were carried out with APSIM version 2.1.

1Data source

Data on soil water, crop biomass and grain yield from two field experiments were used to validate the APSIM model. The two experiments have been conducted at the Qingyang Research Station, Gansu, China (35?40'N, 107?5'E; 1298m above sea level) on the well-fertilized Heilu soil (a sandy loam of loess deposits; FAO soil classification: Los-Orthic Entisols). Average temperature for the station varies from 21?C in the warmest month of July to –6?C in the coldest month of January, and annual rainfall is 480-660mm. The first experiment was designed to study the impact of time of lucerne removal (May or August) on winter wheat production (wheat sown in September) in a lucerne-wheat rotation. The second experiment was designed to evaluate the impact of different tillage and stubble management systems on soil water dynamics and crop production in a maize-wheat-soybean rotation. Seeding and fertilization rates for each of the 3 crops were based on local recommendations (Shen et al. unpublished).

2APSIM parameterisation

Soil parameterisation of the model was based on site-specific measurements of soil bulk density, organic carbon and pH. The maximum effective rooting depth of different crops was based on neutron moisture meter observations from the two field experiments (Table 1). Plant available water was estimated to be 330, 315, 255 and 245mm for lucerne, winter wheat, maize and soybean, respectively. In the water balance module of APSIM, simulation of soil evaporation is based on the concept of first and second stage evaporation (Probert et al. 1998). The evaporation parameters of *U* and *cona* were set to 5 and 4.5. Runoff was simulated using the USDA curve number of 75. Standard values were chosen for the model constants in SoilN2 and Residue2 (Probert et al. 1998). Parameterisation of lucerne phenology and growth in this cold temperate climate was based on the previous work of Chen et al. (2003). The simulations were initialised for soil water and nitrogen based on the field experimental observations at the beginning of each experiment, and no resetting was done after the model initialisation.

Table 1. Summary of soil and crop parameters used in the APSIM simulation

Layer (cm)	BD (g cm^{-3})	LL15 (mm/mm)	Crop ll (lucerne)	Crop ll (wheat)	Crop ll (maize)	Crop ll (soybean)	DUL (mm/mm)
0-10	1.3	0.11	0.11	0.11	0.11	0.11	0.27
10-30	1.2	0.12	0.12	0.12	0.12	0.12	0.27

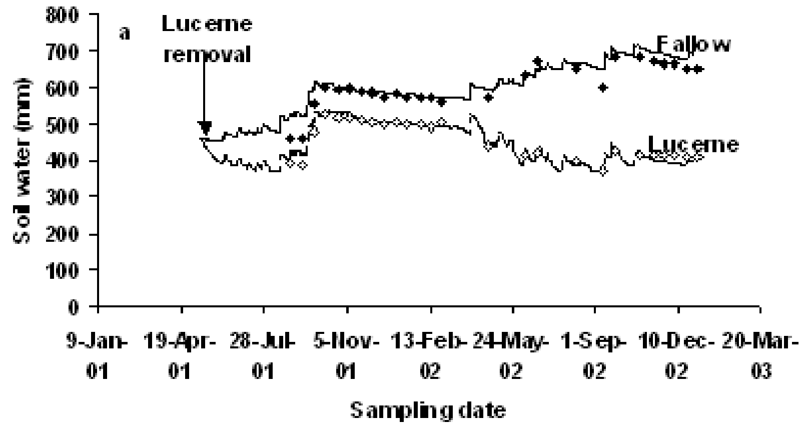
30-60	1.4	0.13	0.13	0.13	0.13	0.13	0.27
60-90	1.3	0.14	0.14	0.14	0.14	0.14	0.27
90-120	1.2	0.14	0.14	0.14	0.14	0.14	0.27
120-150	1.3	0.14	0.14	0.14	0.14	0.14	0.27
150-200	1.3	0.13	0.13	0.14	0.16	0.18	0.24
200-250	1.3	0.13	0.13	0.14	0.19	0.19	0.20
250-300	1.3	0.13	0.13	0.14	0.19	0.19	0.20

BD=bulk density, LL15=lower limit, DUL=drained upper limit, Crop ll=crop lower limit.

2Results

0Soil water and lucerne under continuous lucerne and after removal of lucerne

In general, there was a close agreement between simulated and observed data on soil water and lucerne biomass production in the fallow and continuous lucerne systems (Fig. 1). Soil water recharge (through rainfall in the fallow) and drying (by lucerne in the continuous lucerne) processes were well simulated. Lucerne biomass production of the four harvests over the two growing seasons was also well simulated.



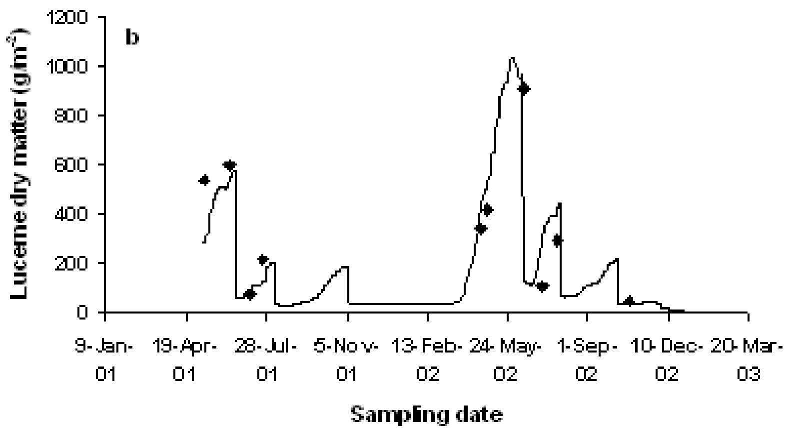
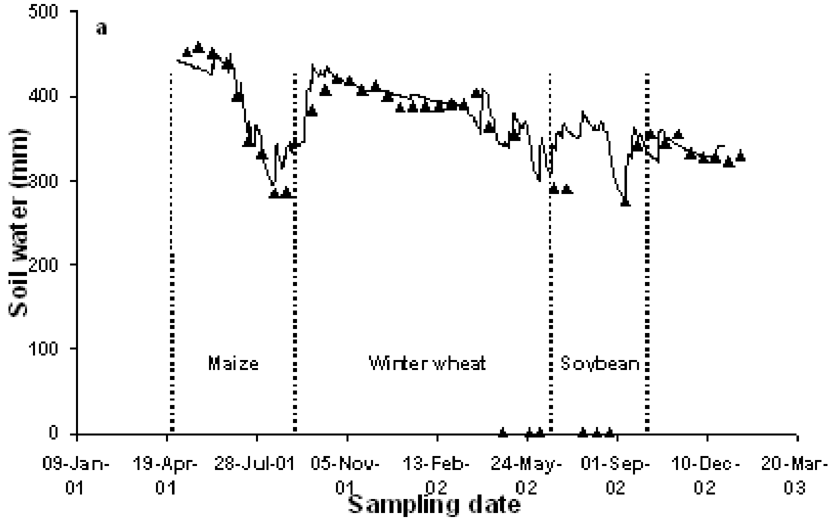


Fig 1. Observed (points) and simulated (lines) soil water content down to 3m (a) and lucerne biomass (b) in the fallow and continuous lucerne. In the fallow treatment, lucerne stand was terminated on 13th May 2001 and left as bare fallow since. In the continuous lucerne treatment, lucerne was cut to ground level twice in 2001 and three times in 2002.

1Soil water and crop growth in maize-wheat/soybean rotation

Crop biomass accumulation and grain yield were well simulated in M-W-S rotations when crop stubble was either being removed or retained (Fig. 2 and 3). In the M-W-S rotation with stubble removed, soil water was generally well simulated; except, at the end of maize and wheat cropping phases of the rotation, when APSIM tended to over-predict soil water content (Fig. 2). Where stubble was retained, the over-prediction continued through the soybean phase of the rotation (Fig. 3).



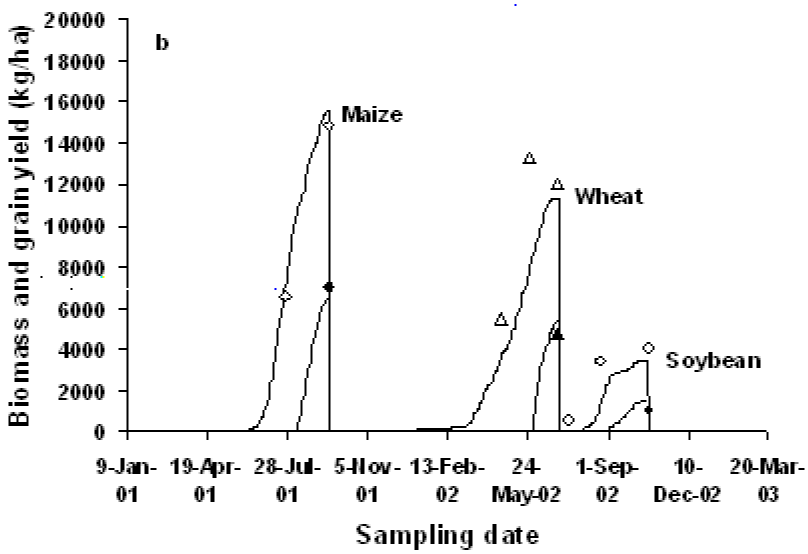


Fig 2. Observed (points) and simulated (lines) soil water content down to 2m (a), crop biomass and grain yield (b) in the maize-winter wheat/soybean rotation with crop stubble being removed at each harvest.

2Simulated components of the water balance for different cropping systems

Simulated components of the water balance for different cropping systems are summarized in Table 2. In the bare fallow treatment, 221mm water was recharged over the experimental period so that soil water content (681mm) was approaching DUL. In contrast to this, in the continuous lucerne treatment, a total of 540mm of water was used by lucerne for biomass production through transpiration thereby maintaining soil water (397mm) close to crop lower limit. Having lucerne in the system significantly reduced water losses through runoff and soil evaporation compared with fallow treatment (Table 2).

Simulated water balance components were only summarized for the M-W-S rotation with stubble removed, as there was no observed consistent difference in soil water content and crop productivity when stubble either being removed or retained. The overall water balance in M-W-S was similar to continuous lucerne treatment except that more runoff occurred in M-W-S compared with continuous lucerne treatment, thus more stored soil water was used for crop production (Table 2).

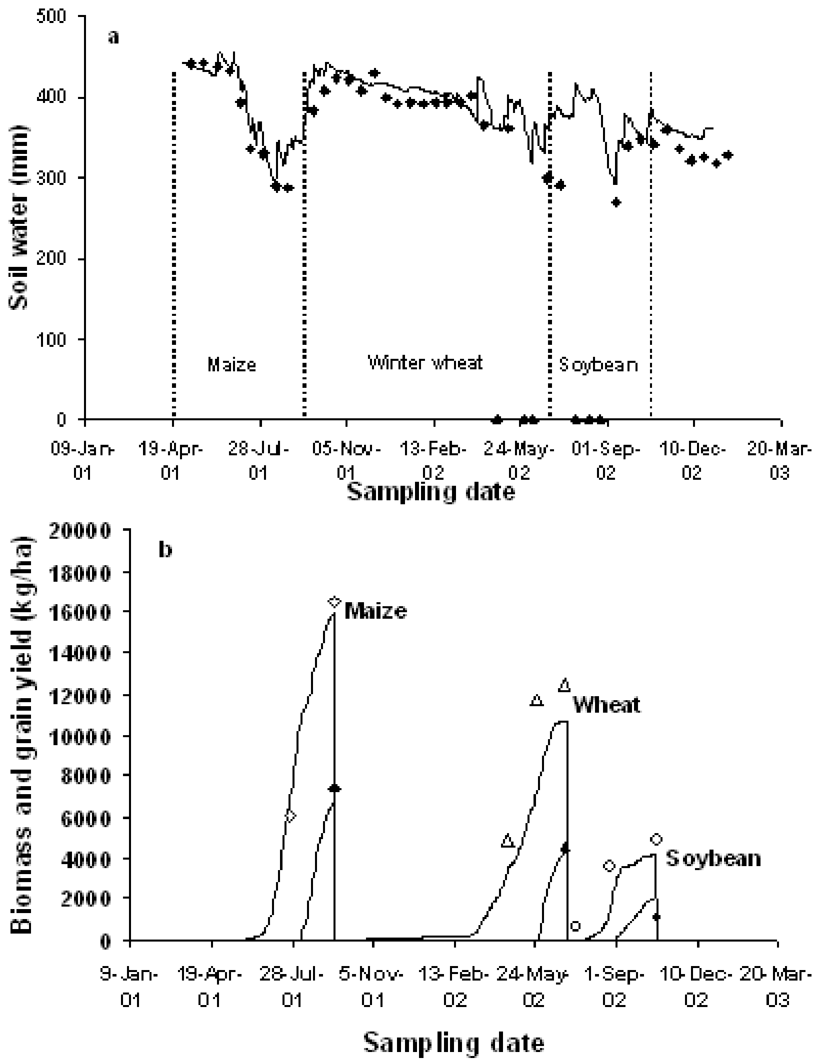


Fig 3. Observed (points) and simulated (lines) soil water content down to 2m (a), crop biomass and grain yield (b) in the maize-winter wheat/soybean rotation with crop stubble being retained at each harvest.

Table 2. Summary of simulated water balance (mm) components for different cropping systems in Gansu, China

Cropping system	Rain	Runoff	Soil evaporation	Drainage	Transpiration	Δ SW[1]
Fallow[2]	1086	133	733	0	0	221
Lucerne[2]	1086	34	575	0	542	-64

M-W-S[3]	1086	63	584	0	550	-111

[1]soil water change, [2]In fallow and continuous lucerne treatments, the simulated water balance components were calculated over 13th May 2001 to 31 December 2002 period. [3] In maize-wheat-soybean rotation without stubble retention, the calculation was made over 1 May 2001 to 31 December 2002 period.

3Conclusion

APSIM shows promise for simulating soil water balance and crop growth and grain yield for different cropping systems in Gansu, China. Some aspects of the model performance, particularly the water balance, need further improvement. Detailed data collection towards understanding surface soil water dynamics under different land management systems (stubble retention, zero-tillage etc.) with the aid of a rainfall simulator are currently in progress. These new data together with the on-going data collection from the field rotation experiments will be used to further refine the model performance to capture the observed soil water dynamics in different land management systems. The validated model that is capable of predicting the system behaviour will be used with long-term climatic data to evaluate climatic risks associated with alternative cropping systems for the region.

4Acknowledgements

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5References

Chen, W, Bellotti, WD, Roberston, MJ, Nan, ZB, and Shen, Y (2003). Performance of APSIM_Lucerne in Gansu, north-west China. In Proceedings of the 11th Australian Agronomy Conference (CD). 2-6 Feburary 2003, Deakin University, Geelong, Victoria (Australian Society of Agronomy).

Keating, BA, Carberry, PS, Hammer, GL, Probert, ME, Robertson, MJ, Holzworth, D, Huth, NI, Hargreaves, JNG, Meinke, H, McLean, G, Verburg, K, Dimes, JP, Silburn, M, Wang, E, Brown, S, Bristow, KL, Asseng, S, Chapman, S, McCown, RL, Freebairn DM, Smith, CJ (2003). An overview of APSIM, a model designed for farming systems simulation. *European Journal of Agronomy* **18**, 267-288.

Li, FR, Gao, CY, Zhao, HL, Li, XY (2002). Soil conservation effectiveness and energy efficiency of alternative rotations and continuous wheat cropping in the Loess Plateau of northwest China. *Agriculture, Ecosystems and Environment* **91**, 101-111.

McCown, RL, Hammer, GL, Hargreaves, JNG, Holzworth, DL, Freebairn, DM (1996). APSIM: A novel software system for model development, model testing, and simulation in agricultural systems research. *Agricultural Systems* **50**, 255-271.

Probert, ME, Dimes, JP, Keating, BA, Dalal, RC, Strong, WM (1998) APSIM’s water and nitrogen modules and simulation of the dynamics of water and nitrogen in fallow systems. *Agricultural Systems* **56**, 1-28.