Simulation of millet response to combined application of cattle manure, millet residue and chemical fertilizer in the Sahel using APSIM

P. B. Irenikatche Akponikpe[1, 2], Charles L. Bielders[1], Bruno G?rard[2] and Karlheinz Michels[2, 3]

[1]The Faculty of Bio-engineering, Agronomy and Environment, Universit? catholique de Louvain, Croix du Sud 2, boite 2, B-1348 Louvain-la-Neuve, Belgium, http://www.geru.ucl.ac.be Email akponikpe@yahoo.com
[2]International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) BP 12404, Niamey, Niger
[3]Present address: Traut?ckerstr. 25, 70593 Stuttgart, Germany

Abstract

Soil fertility and climate risks are hampering crop production in the Sahelian region. Because the high spatial and temporal variability of these two factors restricts the widespread applicability of research findings derived from experiments, crop growth simulation models, could suitably complement experimental research to support decision making regarding soil fertility and water management. This paper reports on the testing of the millet (*Pennisetum glaucum L.*) module of the Agricultural Production Systems Simulator (APSIM) on a rainfed randomized complete block experiment combining, at three levels each, application of cattle manure (300, 900 and 2700 kg/ha), millet residue (300, 900 and 2700 kg/ha) and chemical fertilizer (no fertilizer, 15 kg N/ha + 4.4 kg P/ha and 45 kg N/ha + 13.1 kg P/ha) at ICRISAT Sahelian center, Niger during the 1994 and 1995 cropping seasons. Parameters describing leaf area expansion, phenology, radiation interception, biomass accumulation and partitioning, water dynamics, and nitrogen accumulation were obtained from the literature or on-site experiments. APSIM simulations were in satisfactory agreement with the observed crop growth but above ground biomass was overpredicted for the highest application rate of chemical fertilizer. Leaf area index was well predicted before it reached its maximum but tended to be underpredicted afterwards, mainly for high chemical fertilizer inputs. For biomass yield at harvest, the model performance was relatively good in 1994 but treatment results were slightly overpredicted in 1995 (R? > 0.50 and RMSE < 1600 kg/ha). In terms of grain yield the APSIM model performed also fairly well (R? > 0.50 and RMSE < 200 kg/ha) but no model response to N was simulated above a certain level of N input. As phosphorus is the most limiting soil factor for millet production in the Niger Sahelian region, adding P response in APSIM for millet crop could help improve the results.

Key Words

APSIM simulation, pearl millet, Sahel, fertilizer, manure, residue

Introduction

Small-holder farmers in Sahelian Niger are facing difficult times as a result of low agricultural production levels. Yield of millet, the staple crop, under traditional management rarely exceeds 500 kg/ha (De Rouw, 2004). It has been recognized that rainfed crop productivity is most strongly dependent on, and constrained by the low native soil fertility rather than rainfall. Much research has been undertaken during the last 30 years in the area with interesting and sometimes contradictory results between years and places because of the high spatial and temporal variability of soil fertility and rainfall. As a result research findings fail to be well spread and adopted by farmers and the main constraints cited above are still impeding agricultural system development. Crop growth simulation models could suitably complement experimental research to support decision making regarding soil fertility and water management. The aim of this work was to evaluate the ability of the Agricultural Production Systems Simulator APSIM (Keating *et al.*, 2003) to reproduce the response of millet to the three main fertility management strategies in the Nigerien Sahel: cattle manure, millet residue and chemical fertilizer. Another reason for modeling the response of millet to manure, millet residue and chemical fertilizer application is that the nutrients release kinetics differ greatly among the three amendments (Esse *et al.*, 2001; Dougbedji, 2002). In addition field research has shown the benefits of combining various sources of nutrients in view of preventing soil acidification by chemical fertilizer alone, reducing potential N immobilization by residue application, increasing soil microbial activity and P mobility by residue and manure application (Bationo & Mokwunye, 1991; Harris, 2002). APSIM has recently been complemented with a specific tillering millet growth module (Van Oosterom *et al.*, 2001a; Van Oosterom *et al.*, 2001b; Van Oosterom *et al.*, 2002). Hence APSIM appears to be the sole available model capable of recognizing tillers as functional entities and dealing with water and N (mineral and organic) in millet cropping systems. So far, however, none of these components have been tested for Sahelian conditions.

Materials and methods

APSIM model and parameterization

APSIM is a modular modeling framework that has been developed by the Agricultural Production Systems Research Unit in Australia (Keating *et al.*, 2003). Five modules: a specific crop module (APSIM-millet), a soil water module (SOILWAT2), a soil nitrogen module (SOILN2), a residue module (RESIDUE2), and manure module (MANURE), were linked within APSIM 3.6 to simulate the cases described in this paper. The soil and nitrogen modules were parameterized after Fetcher (1991), residue and manure modules were parameterized using data from the testing experiment below and from the literature (Esse *et al.*, 2001; Dougbedji, 2002). The parameterization of the millet CIVT cultivar was done independently and based on a separate experiment, not reported here. No calibration was performed on any other model parameter.

Experiment for model testing

The experiment was conducted during the 1994 and 1995 rainy seasons at Sador?, Niger (13?15'N, 2?17'E and 240 m of altitude) on the experimental farm of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Sahelian Centre, located 45 km south of Niamey the capital city of Niger. The objective was to evaluate the effect of combined application of cattle manure, crop residues and chemical fertilizer on pearl millet production in the Sahel. There were 3 factors with 3 levels each: (1) uniform millet residue application (300, 900 and 2700 kg/ha, noted as R1, R2 and R3 respectively), (2) uniform cattle manure application (300, 900 and 2700 kg/ha, noted as M1, M2 and M3 respectively), and (3) broadcast chemical nitrogen (Calcium ammonium nitrate) and phosphorus (Single super phosphate) fertilizer application (0 N + 0 P, 15 N + 4.4 P and 45 kg/ha N + 13.1 kg/ha P, noted as F1, F2 and F3 respectively). The millet cultivar CIVT (Composite Inter-varietal de Tarna, early maturing, 95 days) was sown in hills without prior tillage after the first rainfall event more than 20 mm in each year, at a density of 25000 (1994) or 30000 (1995) plants/ha. Millet was sown on 6 June 1994 and 20 June 1995 and harvested from 20-23 September 1994 and 26-27 September 1995. Recorded data were periodical above ground biomass, leaf area index (LAI), soil water content (1994) used to compute drainage (Klaij & Vachaud, 1992) and final biomass and grain yield (1994 and 1995).

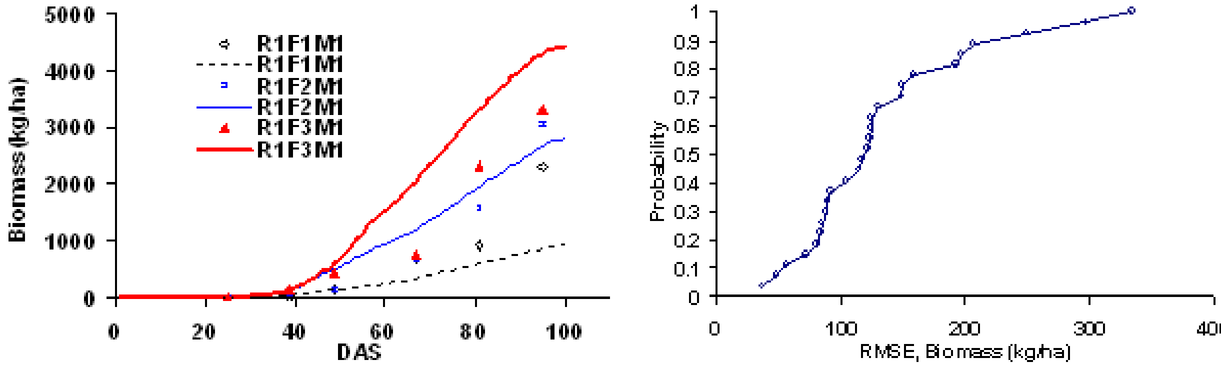
Model evaluation

The statistical criteria used are based on the analysis of residual errors, i.e., the difference between observed and simulated values. We computed the root mean square error RMSE and R^2 (Loague & Green, 1991).

Results

Millet growth

Millet growth was evaluated as total above ground biomass versus time in 1994. RMSE of all the treatments (27) ranged from 37 to 335 kg/ha. 70 % of RMSE values were below 150 kg/ha (Figure 1). APSIM simulation were in satisfactory agreement with the observed biomass over time but biomass at high level of chemical fertilizer (45N13P) inputs were over predicted.

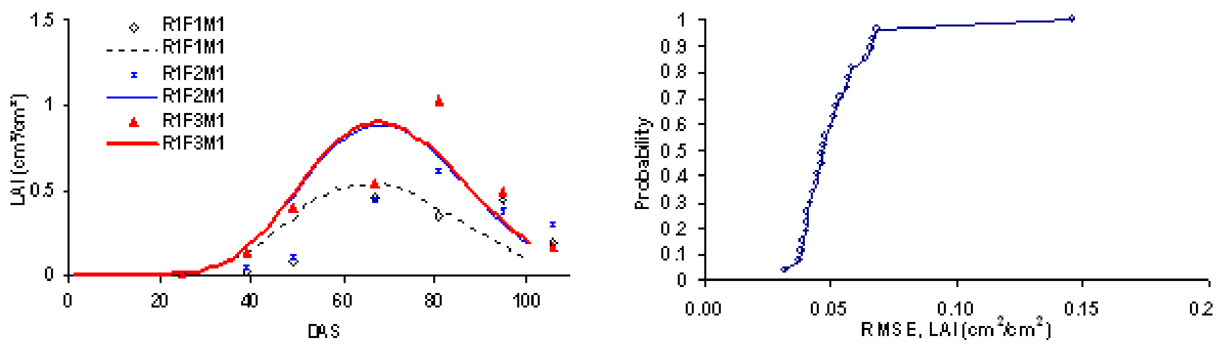


(a) (b)

Figure 1: Measured (dots) and simulated (lines) change in millet biomass over time for three selected treatments (a) and model performance RMSE of all treatments (n=27) (b) as affected by combined cattle manure, crop residue and chemical fertilizer in 1994 at Sador?, Niger.

Leaf area index

RMSE ranged from 0.03 to 0.15 cm?/cm? over the 27 treatments in 1994. 80 % of RMSE values of the 27 treatments were below 0.06 cm?/cm? (Figure 2). This demonstrates a global satisfactory response of the APSIM simulation model with regard to LAI. But it tended to well predict LAI before the maximum (left hand of the bell shape curve) but decreased rapidly underpredicting LAI afterwards, mainly for high input of chemical fertilizer.

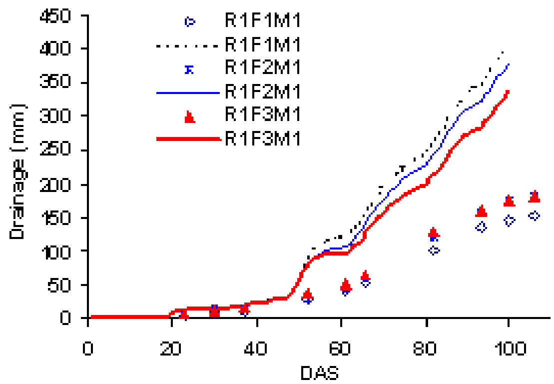


(a) (b)

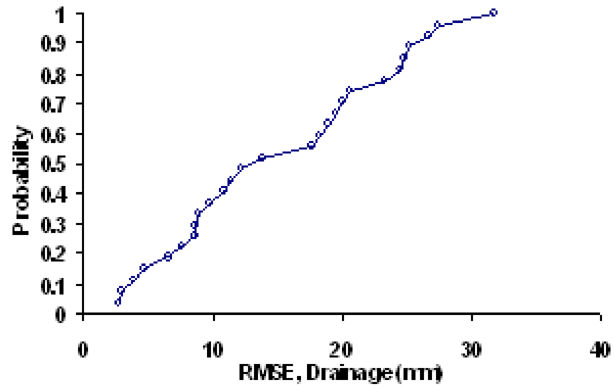
Figure 2: Measured (dots) and simulated (lines) change in millet LAI over time of three selected treatments (a) and model performance RMSE of all treatments (n=27) (b) as affected by combined cattle manure, crop residue and chemical fertilizer in 1994 at Sador?, Niger.

Drainage

RMSE ranged from 3 to 32 mm in 1994 with values of all treatments (n = 27) almost regularly distributed (Figure 3). The APSIM model tended to overestimate drainage below root zone.



(a)



(b)

Figure 3: Measured (dots) and simulated (lines) change in drainage-below-roots over time of three selected treatments (a) and model performance RMSE of all treatments (n=27) (b) as affected by combined cattle manure, crop residue and chemical fertilizer in 1994 at Sador?, Niger.

Biomass yield

Model performance varied among years of experiment. RMSE was 1006, 1673 and 1380 kg/ha respectively in 1994, 1995 and grouped data for 1994-1995. R? was 0.50, 0.54 and 0.43 for the same periods, respectively (Table 1). APSIM model performance was relatively good in 1994 but treatment results were slightly overpredicted in 1995 (Figure 4a).

Table 1: Values of statistical model validation criteria for APSIM simulation of millet biomass and grain yield as affected by combined cattle manure, crop residue and chemical fertilizer in 1994 and 1995 at Sador?, Niger

	Biomass yield			**Grain yield**		
?	1994	1995	1994-1995	1994	1995	1994-1995
RMSE (kg/ha)	1006	1673	1380	162	211	188
R?	0.50	0.54	0.43	0.50	0.45	0.51

Grain yield

The APSIM model performed better in terms of grain yield response to fertilizer, manure and crop residue application than in biomass (Figure 4b). Model performance varied among years of experiment. RMSE was 162, 211 and 188 kg/ha respectively in 1994, 1995 and grouped data for 1994-1995. R? was 0.50, 0.45 and 0.51 for the same period, respectively. No model response to N was simulated above a certain level of N input, which resulted in a limitation in grain yield.

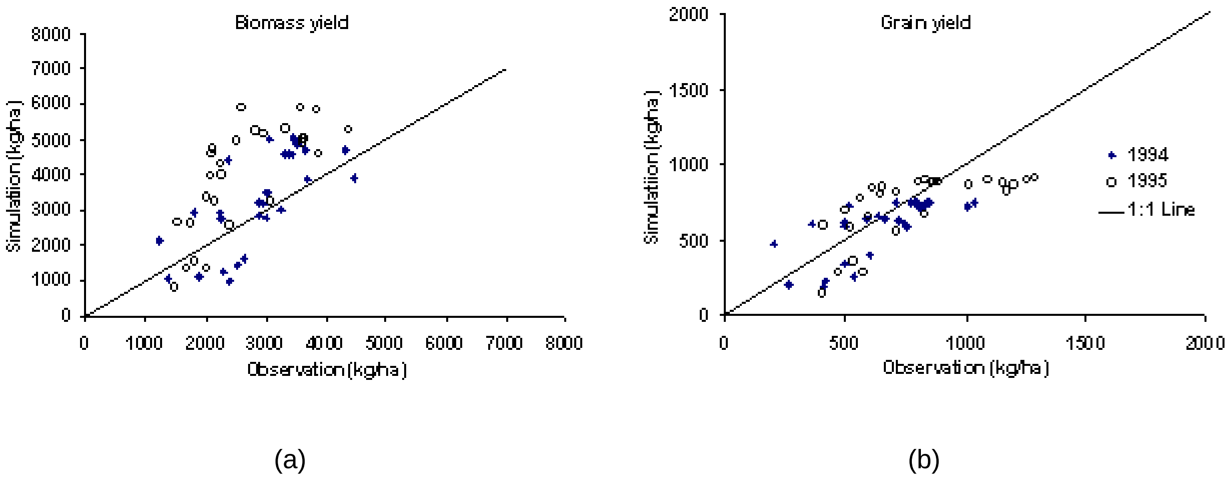


Figure 4: Comparison between observed and APSIM simulated millet biomass and grain yield as affected by combined cattle manure, crop residue and chemical fertilizer in 1994 and 1995 at Sador?, Niger (n= 27 treatments)

Discussion and conclusions

Response to increased levels of fertilizer was fairly well reproduced by the model in a linear pattern but the amplitude is higher than observed. Simulated response to manure and residue application were not so clearly perceptible whereas it was significant in 1995 according to the experimental results. This tended the model to predict the same response (LAI, biomass and grain yield) regardless of levels of application of manure and residue. Moreover, experimental results indicated a higher millet response (four fold) to P than to N but at present the APSIM-millet module is not P sensitive. The APSIM model performance was fairly good in predicting millet response to combined fertility management practices for a Sahelian millet genotype and Sahelian environmental condition. As phosphorus is the most limiting soil factor for millet production in the Niger Sahelian region, adding P response in APSIM for millet crop could help improve the results.

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