QUANTIFYING WATER PRODUCTIVITY in RAINFED CROPPING SYSTEMS in LIMPOPO PROVINCE, RSA

John Dimes *[a] and Phonnie du Toit[b]
[a] ICRISAT – Bulawayo, Zimbabwe, j.dimes@cgiar.org
[b] Grain Crops Institute, Potchefstroom, RSA

Abstract

This paper reports results of on-farm experimentation to quantify water productivity of maize, groundnut and cowpea crops in the 2007/2008 cropping season in Limpopo Province RSA. The observed crop yield and soil water and nutrient data are used to evaluate the APSIM model's performance in simulating water productivity and soil water balance for maize and legume crops.

There was very close agreement between observed and predicted biomass, grain yield and changes in the soil water contents. The model provided outputs to fill measurement gaps in water balance components of the field experimentation, thereby allowing more detailed and appropriate calculations for comparing the WP of the different crops.

Media grab
The APSIM model performed remarkably well in predicting the crop yields and water balance of major crops in The Limpopo Province, making it a key analytical tool for CPWF applications.

Introduction

Maize production dominates the smallholder farming system in Limpopo Province of South Africa, although crop yields in these systems translate into very poor water productivity - in the order of 1-2 kg grain per mm rainfall per ha. Crop simulation analysis, supported with results from on-farm trials, suggests that water productivity (WP) could be increased by 50 to 100% if smallholder maize farmers used small doses of topdress N fertiliser and improved agronomy (Dimes and Carberry, 2008). However, with the price of fertiliser having increased more than 100% in recent times, a stronger case for expanding legume production as a means of increasing N inputs into these cropping systems is emerging. A comparison of water productivity for different crop choice and fertility management will help guide public and private sector investment aimed at improving agricultural output of smallholder farmers in the Province.

This paper reports results of on-farm experimentation to quantify water productivity of maize, groundnut and cowpea crops in the 2007/2008 cropping season. The observed crop yield and soil water and nutrient data are used to evaluate APSIM performance in simulating water productivity and soil water balance for maize and legume crops in the Limpopo Province.

Materials and Methods

Field Experimentation
Field experiments were conducted at Tafelkop, a smallholder farming village located on the Nebo Tableland in Sekukhune District of Limpopo Province, RSA. The soils are shallow (up to 1.0 m rooting depth) loamy sands to sandy loams. The rainfall season is unimodal (October/November to March/April) with an average total of 500 mm.

The Grain Crops Institute and the smallholder farmer association at Tafelkop established varietal trials of groundnut and bambara nut in the 2007/08 cropping season. Separate trials were established for each legume species, with 6 cultivars and 3 replicates laid out in a RCBD design. Demonstration plots of maize (PAN6479) and cowpea (Betch White) were established with the farmer association in adjoining plots to the legume varietal trials. Replicated treatment plots of Nyanda groundnut and SB7-1 Bambara were sampled (9.1 m^{-2}) at crop maturity for stover, in addition to grain yield. Bulk samples were also taken from the maize (stover, 72 m^{-2}, grain, 109 m^{-2}) and cowpea (36 m^{-2}) demonstration plots to determine stover and grain yield. Groundnut and maize crops were sown on November 14th, whilst bambara and cowpea crops were sown on December 5th. Maize received 15 kg N ha^{-1} as starter fertiliser at planting and a topdress application of 14 kg N ha^{-1} on January 14th, 2008. Maize was harvested on April 29th, groundnut on March 26th, and cowpea on March 18th.

ICRISAT monitored the trial plots for changes in soil water content during crop growth using gravimetric methods. Initial soil samples were collected on December 12th 2007 in the groundnut and bambara trials. Subsequent samplings took place on February 22nd (all 4 crop areas), March 29th (groundnut, maize and cowpea), and May 5th (Bambara), 2008. Sampling depth intervals were 0-0.1m, 0.1-0.3m, 0.3-0.6m and 0.6-0.9m. Three soil cores were taken at each sampling, either across treatments replicates or within the final harvest area of the maize and groundnut. Gravimetric water contents were converted to volumetric using a bulk density of 1.5g/cm^{-3} in all soil layers. Soils collected on Dec 12th were analysed for soil pH and %OC. The farm owner of the trial field recorded daily rainfall at the site.

Model analysis
Plant biomass, grain yield, and soil water balance of the maize, groundnut, and cowpea crops were

simulated using the APSIM cropping systems model (Keating et al. 2002, Version 6.0), and model outputs compared to observed data. Model input parameters for the maize (Pan6479) and groundnut (Nyanda) cultivars have been previously estimated (Dimes and Carberry 2008, Ncube et al. 2008). Growth and yield of Betch White cowpea was found to be adequately simulated using the short duration 'Banjo' cultivar description in APSIM. (As yet, there is no Bambara module in APSIM.) Dates of crop sowing and N fertiliser applications in the model were specified according to experimentation (see above). Plant populations were specified in the model as follows: maize - 2.3 plants m^{-2}, groundnut – 11.7 plants m^{-2}, cowpea - 8.8 plants m^{-2}.

Soil parameters for simulation of the soil water and N balances in the nominated rooting depth of the soil (0.9m) were specified as shown in Table 1. The crop lower limit of plant extractable water (LL) and the soil drained upper limit (DUL) were derived using the measured soil water contents as a guide. The plant available water capacity (PAWC) of the soil layers to the nominated rooting depth is 90mm. The Runoff Curve Number and soil evaporation coefficients were chosen based on previous simulation studies in these environments (eg Ncube et al, 2008)

Table 1. APSIM input parameters used in simulation of Tafelkop experiments.

Layer Number	1	2	3	4
SoilWat parameters				
Layer thickness (mm)	100	200	300	300
Bulk density (g cm^{-3})	1.50	1.50	1.40	1.40
SAT	0.250	0.270	0.300	0.320
DUL	0.140	0.155	0.176	0.185
LL15	0.052	0.064	0.070	0.081
Airdry	0.045	0.052	0.070	0.081
Swcon	0.5	0.5	0.4	0.4
CN2_bare	85			
U	3			
Cona	4			
SoilN parameters				
Organic C (%)	0.51	0.46	0.32	0.22
Finert	0.40	0.50	0.80	0.90
Fbiom	0.04	0.020	0.01	0.01
Nitrate-N (mg kg^{-1})	3.79	1.52	0.76	0.38
Ammonium-N (mg kg^{-1})	0.98	0.49	0.25	0.25
Soil C:N	12			
Crop parameters				
LL (maize, groundnut and cowpea)	0.052	0.064	0.070	0.081
Kl	0.08	0.08	0.08	0.08
Xf	1.0	1.0	1.0	1.0

Soil water and N conditions at sowing of crops were not measured. The start date of simulations was therefore chosen as October 1st with the initial soil water content of layers specified at LL and starting mineral N in the profile set to 15g NO3-N ha^{-1} and 5 kg NH4-N ha^{-1}.

Only daily rainfall data was collected at the site. Daily radiation data from a nearby climate station (Marble Hall, 29º 37' E, 25º 03' S, altitude 878 m) and daily temperature data from a site of similar altitude to Tafelkop (Polokwane, altitude 1153m), were used as climate inputs to the model, in conjunction with the measured rainfall. However, the rainfall record collected by the farmer indicated incidences of periodic totals as daily amounts. These were re-allocated or adjusted based on the rainfall distribution recorded at Marble Hall and rainfall amounts recorded at a site close by.

Results

There was very close agreement between observed and predicted total biomass and grain yield ($RMSD_{grain}$ = 257 kg ha^{-1}, $RMSD_{tbm}$ = 436 kg ha^{-1}) of the three experimental crops grown at Tafelkop (Figure 1). There was closer agreement for predicted maize yields compared to the two legume crops, for which both grain and biomass yields were slightly under-predicted. However, in general, the observed differences in plant growth and yield due to species and crop duration and the interaction of these effects and planting dates with rainfall distributions (e.g., wet Dec and Jan, dry February) were very well captured by the APSIM modelling platform used in this analysis.

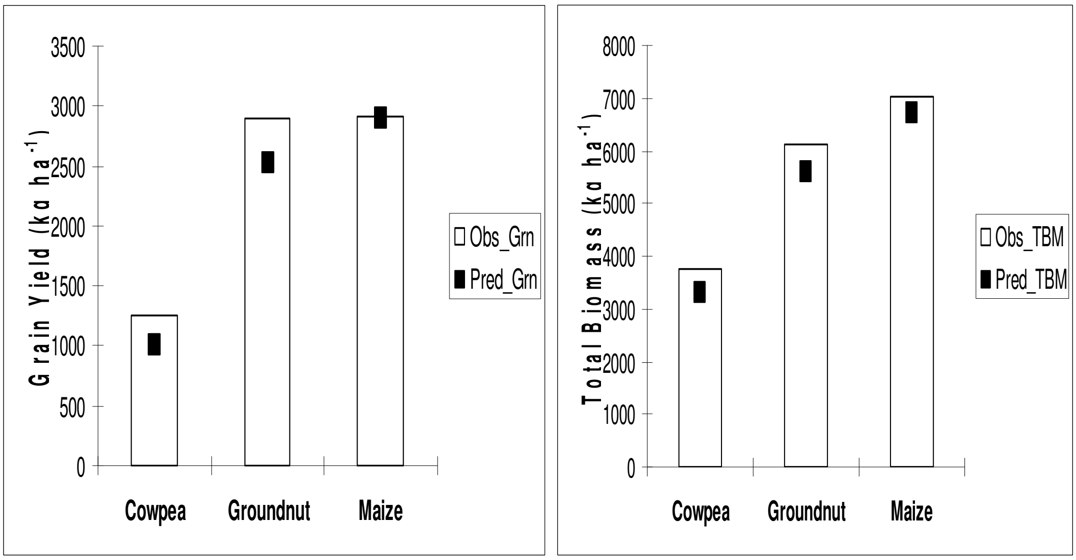

Figure 1. Observed and predicted grain yield and total biomass of cowpea, groundnut and maize crops grown at Tafelkop in 2007/08 cropping season.

The observed and predicted soil water contents at sampling dates in maize, groundnut and cowpea plots are shown in Figure 2. There is close agreement between the predicted and observed soil water contents ($rmsd_{tsw}$ = 7mm) and their distributions in the sampled rooting layers, for all three crops on December 12th. Similarly, the crop water use by maize and cowpea up to February 22nd is well predicted by the model. This was not the case for groundnut, for which simulated soil water use by the crop below 0.3m was noticeably over-predicted on this date.

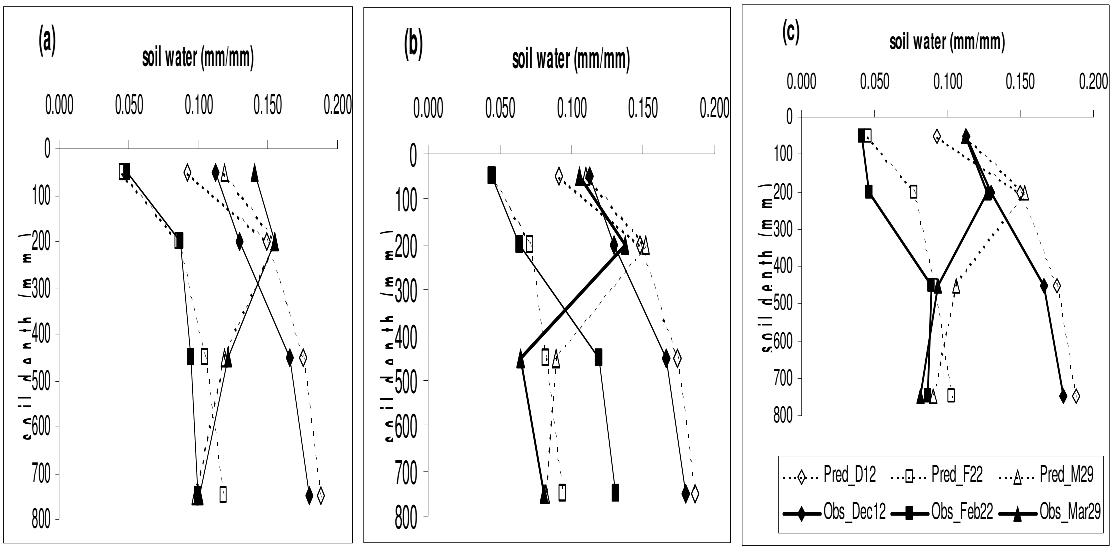

Figure 2. Observed and predicted water contents of soil layers on December 12 2007, February 22, and March 29th 2008 under (a) maize, (b) groundnut and (c) cowpea.

An important test of the model's performance in simulating the water balance was how well the model predicted the water content and distribution of the soil layers as measured on March 29th, following the late rainfall in March. As seen in Figure 2, the observed re-filling and distribution of soil water on March 29th under each crop is well predicted by the model. Overall, the performance of APSIM in predicting changes in soil water under the maize crop was most reliable ($rmsd_{tsw}$ = 7mm), followed by cowpea ($rmsd_{tsw}$ = 10mm) and groundnut ($rmsd_{tsw}$ = 14mm).

The simulated in-crop water balance (i.e. sowing to crop maturity) of the maize and cowpea grown at Tafelkop in the 2007/08 season shows runoff and soil evaporation higher than crop transpiration (Table 2). For groundnut, simulated crop transpiration comprises the largest portion of the water balance, but there is some uncertainty with this estimate given the over-prediction of crop water uptake implicit in the predicted soil water contents on Feb 22nd, as seen in Figure 2b. Using in-crop rainfall in Table 2 as the reference water for assessing crop productivity in conjunction with measured grain yields (Figure 1), the calculated WP (kg grain per mm of water input ha^{-1}) of the three crops is maize = 6.0 kg mm^{-1} ha^{-1}; groundnut = 6.0 kg mm^{-1} ha^{-1}, and cowpea = 3.8 kg mm^{-1} ha^{-1}. Including crop water use of pre-sowing water storage, (i.e., delta_sw and Water Use terms in Table 2), reduces

the WP estimates and separates the maize and groundnut as follows: maize = 5.6, groundnut = 5.4, and cowpea = 3 kg mm^{-1} ha^{-1}. A notable aspect of this analysis is the very low WP of the short duration cowpea relative to the longer duration maize and groundnut. However, for this above average rainfall season and with a distribution favouring the longer duration crops, this result can be considered to be highly season-specific.

Table 2. Simulated components of the soil water balance of maize, groundnut and cowpea crops grown at Tafelkop in 2007/08.

Crop	In_Crop rainfall (mm)	Ep (mm)	Runoff (mm)	Drain (mm)	Es (mm)	Delta_sw (mm)	Water use (mm)
Maize	485	115	170	78	158	-35	520
Gnut	485	209	119	65	145	-53	538
Cowpea	311	101	123	86	112	-86	417
		% of Water Use as:					
		Ep	Runoff	Drain	Es		
Maize		22	33	15	30		
Gnut		39	22	12	27		
Cowpea		24	29	21	27		

In-crop rainfall – sowing to crop maturity;
Ep – crop transpiration; Es – soil evaporation; Drain – drainage below 0.9m
Water use = rainfall - delta_sw
Delta_sw = Soil water storage at crop maturity - soil water stored at sowing

Discussion

APSIM's good performance in simulating the observed crop growth and yield of the three crops and the associated observed changes in soil water contents in the rooting zones are encouraging with regard to its application to quantify WP of crops in the Limpopo Province.

Firstly, reliable prediction of total biomass is a prerequisite to simulation of the soil water balance. This is because simulated crop water uptake and canopy cover estimates by the crop have important feedback mechanisms on simulation of soil water balance processes such as partitioning of rainfall into runoff and infiltration, and soil evaporation. Secondly, reliable partitioning of biomass to grain yield across the species is essential in determining estimates of WP that can be used with confidence in comparing the different cropping options, from a biological yield perspective or, more particularly, on a economic basis (eg. to take account of the high value of legume grain relative to cereal grain). Thirdly, while the only component of the soil water balance measured in the experimentation were changes in soil water storage, the good agreements achieved in predicting the different soil water distribution profiles observed over the course of the crops provide indirect evidence for having confidence in the simulated output for the other component of the water balance, namely crop water use, runoff, drainage and soil evaporation. As a consequence, the model offers a cost-effective tool to provide reliable estimates of the water balance in these rainfed cropping systems.

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