Wheat Crop Simulation in a Mediterranean Environment on Duplex Soil

S. Asseng[1], B. A. Keating[2] and I. R. P. Fillery[1]

[1]CSIRO Division of Plant Industry
[2]CSIRO Division of Tropical Crops and Pastures

A wheat module was attached to the APSIM (Agricultural Production Systems Simulator) cropping systems model to examine crop growth and water dynamics of a crop-soil system. Simulations were carried out for wheat crops grown on a soil type which is characterised by a layer of sand (ca. 35 cm deep) with low water holding capacity over deep compacted clay. Experimental data was obtained from 8 studies conducted over three seasons. Sowing date and seeding rate varied between the studies. Precipitation was predominantly in the vegetative phase of the wheat crop, and grain filling occurred in a period of increasing atmospheric evapotranspiration demand. The combination of crop and soil modules linked in APSIM were found to be sufficiently sensitive to the soil and climatic factors that constrain wheat yields in this region (range of wheat yields from 0.7 to 4.2 t ha^{-1}). Water deficits and soil constraints, particularly root growth restrictions, were identified as the major factors limiting yields. There was generally good agreement when simulated results were compared to crop biomass, LAI, yield components and the dynamics of soil water measured in the field. Shoot growth and leaf development were occasionally overestimated and this is thought to be due to the inability of the model to describe the effects of frequent waterlogging.

INTRODUCTION

Western Australia has about 5 million ha of land that is cropped each year. The major crop is wheat (ca. 3.4 million ha) with an average yield of 1.4 t ha^{-1} [Turner, 1992]. About 60% of the crop production in Western Australia occurs on yellow or yellow-grey duplex soils, comprising the Dy series of Northcote *et al.* [1975]. The soils are characterised by sandy or loamy A horizons of varying thickness, which overlie yellowish clayey subsoils. The shallow sandy layer has a low water holding capacity, the clay subsoil is compacted and poorly draining.

The climate type in the Western Australian wheatbelt is Mediterranean with precipitation predominantly in the vegetative phase of a wheat crop. Little precipitation occurs postanthesis when the evaporative demand can be high. The concentration of rainfall in the winter period on soil types that possess subsoils that impede water movement and root growth can cause major limitations to crop production [Turner, 1992]. Large variations in wheat yield, ranging from 0.7 to 4.2 t ha^{-1} have been recorded [Belford *et al.*, 1991].

APSIM [McCown *et al.*, 1995] provides a framework for simulation of cropping systems. It consists of linked modules of crop and soil processes together with input / output and management modules. The objective of the work was to test, and adapt where necessary, the model to Western Australian conditions with a view to subsequent exploration of a range of management options for wheat farming in Western Australia.

In this paper, we examine the ability of the APSIM wheat model to predict wheat growth and grain yield on a duplex soil in a Mediterranean climate. The sensitivity of the crop-soil system to root elongation rate will be discussed, and the components of the model requiring further development and testing will be highlighted.

METHODS

Model

Wheat, water and nitrogen modules were attached to the Agricultural Production Systems Simulator (APSIM) [McCown *et al.*, 1995]. The wheat module was an adaptation of CERES-Wheat version 2.0 [Ritchie *et al.*, 1988]. This module simulates crop phenology, leaf and tiller development. Photosynthesis is based on intercepted radiation and carbon is partitioned to roots, leaves, stems, ears and grain. It simulates the extension of a root system to depth and development of root length density, water and nitrogen uptake, nitrogen distribution to plant parts and retranslocation of carbon and nitrogen to grain during grain filling. Water and nitrogen deficits and unfavourable temperatures affect the key crop processes by modifying the rate of growth and assimilation.

The original CERES model structure was modified by Keating [*pers. com.* 1995] and includes the replacement of the CERES water deficit routine with a routine based on the fraction of available soil water (*fasw*) in the root zone. Photosynthesis is limited when the *fasw* falls below 0.25, leaf area development is limited when *fasw* is lower than 0.45. The crop water demand is linked to biomass production via transpiration efficiency instead of being a function of potential evaporation and leaf area index (LAI) as in the original CERES model. A further modification to the original CERES model is that the rate of root extension in any soil layer can be set to a value less than the maximum of 2.2 mm per $^{\circ}$C-day^{-1} to simulate unfavourable soil physical and chemical conditions [Keating *pers. com.* 1995].

The APSIM wheat model has been calibrated and tested for wheat (var. *Hartog*) grown in Queensland and wheat (var. *Gamenya*) grown on deep sandy soils in Western Australia by Keating [*pers. com.* 1995].

The water and nitrogen modules used are described by Probert *et al.* [1995]. They represent elaborations of earlier water and nitrogen routines in CERES-Maize [Jones and Kiniry 1986] and PERFECT [Littleboy *et al.*, 1992]. The water module, SOILWAT is a multi-layer cascading representation of the soil water balance that also redistributes solutes along with water flux between layers. The nitrogen module, SOILN, deals with soil organic matter transformations, nitrification, denitrification, and provides a total balance of carbon and nitrogen.

Field Data

Eight data sets were used to test and adapt the APSIM model to duplex soils in Western Australia. These sets include information on shoot biomass, tiller number, root biomass, root depth, root length density, soil water content and perched soil watertable, as well as phenology. Data was obtained from field experiments conducted between 1990 and 1992 [Gregory and Eastham 1995]. Wheat (var. *Kulin)* was sown early or late in each season; the early sowing date was dependent on opening rains. As a result, sowing date varied from the beginning of May to late June. Two sowing densities (112/121 and 186/205) were used in 1992 for the early and late sown treatments.. Nitrogen fertiliser (60 kg N ha^{-1} in 1990; 90 kg N ha^{-1} in 1991; and 80/90 kg N ha^{-1} in 1992) was applied as urea.

The required daily weather input data to the model (solar radiation, maximum and minimum temperature and precipitation) were obtained from the Western Australian Department of Agriculture weather station located 200 m north of the field site. Missing temperature data were calculated using a regression between on-site maximum and minimum temperatures and weather records obtained from nearby Bureau of Meteorology weather stations. Missing solar radiation data were calculated using a regression of maximum temperature and solar radiation. Missing precipitation data were calculated using on-site cumulative rain gauge data and precipitation from nearby Bureau of Meteorology weather stations.

To parameterise the model for the duplex soils and the variety *Kulin*, different literature sources were utilised. Soil water parameters came from Tennant *et al.* [1992], Gregory and Eastham [1995] and Tennant [*pers. com.* 1994] and crop parameters from Loss *et al.* [1989], Siddique [1989], Gregory and Eastham [1995], Simmons and Crookston [1979]. Soil nitrogen parameters (inorganic N in the soil profile at break of season) were obtained from measurements undertaken on lupin-wheat rotation treatments at East Beverley in 1994 [Fillery *pers. com.*].

To quantify model performance, model precision (F) and bias were calculated. Model precision is the measure of the population variance accounted by the model and is the same as the correlation coefficient of the 1:1 line with zero intercept.

RESULTS

The long-term annual rainfall at Beverley is 421 mm with 350 mm between May and November inclusive [Perry and Hillman, 1991]. The years 1990-92 experienced below average rainfall during the entire growing season, but rainfall still exceeded evapotranspiration during the vegetative phase of wheat. This excess rainfall caused water to perch above the clay subsoil, and occasionally the perched watertable reached to the surface.

Low rainfall after anthesis in 1990 and 1991 caused low grain filling rates, resulting in grain yields between 1.8 - 2.5 t ha^{-1}. Wheat largely drew on stored water during the post anthesis period in 1990 and 1991. In contrast, in 1992, 21 mm of rain fell on 19/20 September and this recharged the surface soil water content.

According to Gregory and Eastham [1995] the early sown wheat in 1992 was affected by *Septoria*. Therefore, grain yield and shoot biomass measurements after anthesis in the early sown wheat 1992 were omitted.

All 8 wheat trials were simulated with the same genetic crop coefficients and the same set of soil parameters, including initial soil-N contents. Sowing date, density, and daily weather data were specific to the season and crop growth/grain yields being simulated.

Adjustment of Soil and Root Parameters

Initial simulation runs with the APSIM model identified problems with simulation of recharge and depletion of soil water from the clay subsoil in the duplex soil. Neutron probe measurements [Gregory and Eastham 1995] showed that the water content in soil below 60 cm was relatively constant throughout the growing season. This finding suggested that water moved through preferred pathways in the subsoil during periods of drainage, and that wheat does not extract soil water below 60 cm in the soil under study. To simulate these observations we set the soil water conductivity parameter in soil layers deeper than 50 cm to 1.0 to enable excess water above the drained upper limit to leave the soil profile. It is notable that simulated drainage values corresponded to observed drainage data [Eastham *pers. com.* 1995]. Adjustments were also made to the soil hospitality factors to slow down root elongation in the whole profile in order to match observed root elongation during the season, in particular the limited root elongation below 60 cm.

Simulation results

Inclusion of a value of 1 for hydraulic conductivity in the clay layer and changes to the soil hospitality hospitality factors for root growth improved the fit of simulated compared to observed soil water data. In general the APSIM model simulated the soil water balance in a realistic manner, with a water- filled profile throughout the vegetative phase of wheat followed by rapid drying of the soil profile by crop water uptake after anthesis, in most cases down to 60 cm.

A comparison of observed wheat root elongation depth for 1990 to 1992 studies with that simulated in APSIM is shown in Figure 1.

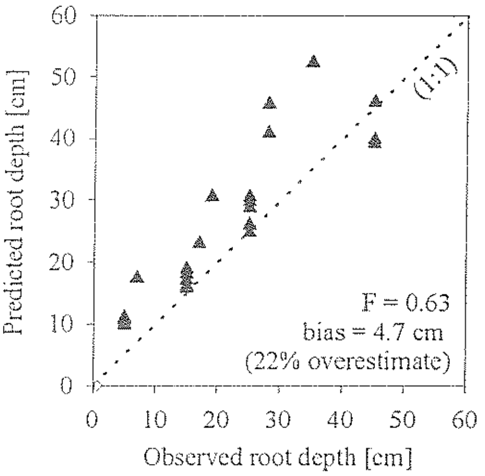

Figure 1: Comparison of observed wheat root elongation depth for 1990-1992 with that predicted by APSIM. F is model precision. Broken line is 1:1.

Simulation runs for 1990 and 1991 were initialised on 1 May, those for 1992 on 1 April. A comparison of the predicted biomass/grain yield against observed biomass/grain yield for the three seasons is shown in Figure 2. Simulation of shoot and root biomass, and grain yield were reasonable, although there was a tendency for the model to overestimate biomass production and especially LAI at times when the perched watertable came close to the soil surface.

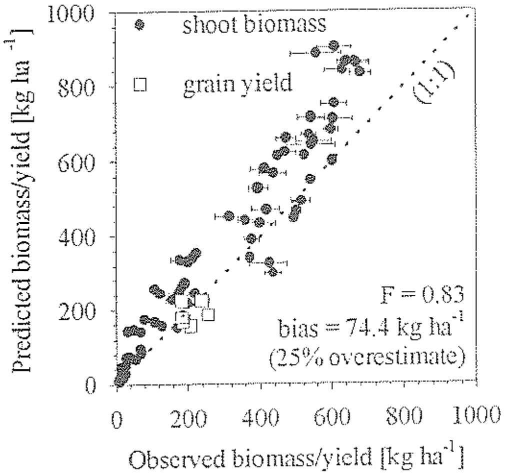

Figure 2: Comparison of observed wheat shoot biomass (•) and grain yield (□) for 1990-1992 with that predicted by APSIM. Model precision F and bias for wheat biomass, excluding grain yield. Broken line is 1:1.

Grain number per m^2 and specific grain weight were adequately simulated, while shoot numbers per m^2 were overestimated in 1990 and 1991 but simulated well in 1992 (data not shown). The predicted date of anthesis was later than that observed in 1990 and 1991. In contrast, anthesis was predicted 8 days earlier than observed for early sown, low and high density treatments in 1992.

All simulations of crop growth suggested that suboptimal N nutrition would result in reduced leaf expansion and photosynthesis during the vegetative phase. Water deficits had the major impact on photosynthesis, and leaf senescence during grain filling.

Sensitivity to Root Elongation Rate

Sensitivity analysis to root elongation rate was undertaken to evaluate the importance of root system development in duplex soils. Input parameters were for the 1991 early sown wheat except the root elongation rate in the top 30 cm of the soil was a) increased by 100%, and b), reduced by 50%. In both cases root elongation was modified by altering the soil hospitality parameter. None of the other input parameters to the model were changed.

The faster rate of root growth increased N-uptake from deeper soil layers, and reduced N-deficit. These changes lead to increased leaf expansion and photosynthesis during vegetative growth. The larger biomass resulted in a higher grain yield potential (Figure 3). However, the larger biomass and leaf area transpired more water earlier in the crop cycle resulting in reduced water availability later in crop growth and increased water deficit and reduced grain filling (Figure 4).

A reduction in the root elongation rate by 50% in the top 30 cm reduced N-uptake and, increased the N-deficit during the vegetative phase. The resulting N-deficit reduced biomass production which reduced the water deficit later in the season, even though water uptake only occurred to a depth of 30-40 cms, compared to 50 to 60 cms in the other simulations. The highest grain yield was predicted in the unmodified simulation with 1.7 t ha^{-1}, which agreed well with the recorded yield of 1.9 t ha^{-1} for this treatment [Gregory and Eastham 1995]. A theoretical increase and a reduction in root elongation resulted in lower simulated grain yields (1.4 to 1.5 t ha^{-1}) compared that recorded.

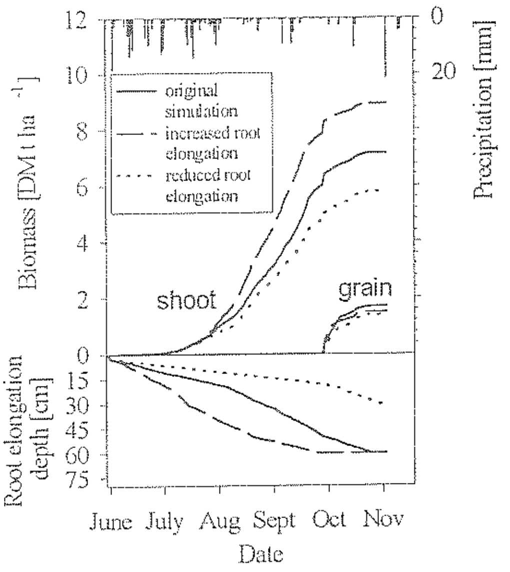

Figure 3: Effect of increasing or decreasing root elongation rate on shoot biomass and grain yield. Original simulation applies to 1991 wheat data. Vertical bars show precipitation.

DISCUSSION

It was possible to capture a large part of the observed variation in wheat growth, yield and soil water content in a duplex soil with the wheat, water and nitrogen routines linked into the APSIM cropping systems model. Perched watertables were not simulated in this model, but the data contained evidence of their impact on root growth, leaf area expansion and shoot biomass production. The soil water model adequately described the water content data in different soil layers without explicitly simulating perched watertables.

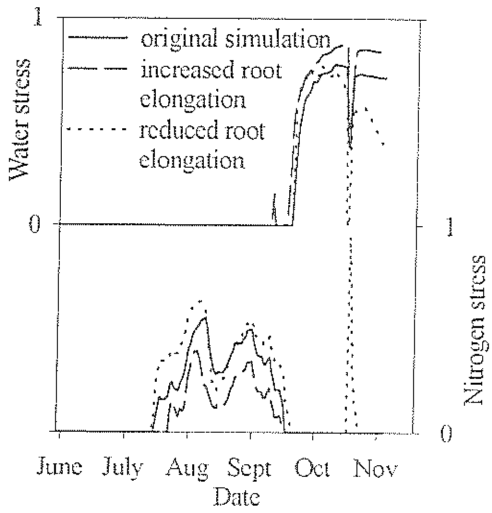

Figure 4: Effect of increasing or decreasing root elongation rate on water and nitrogen stress. Original simulation applies to 1991 wheat data.

Additional aeration-deficit factors will have to be included in the model to account for the effect of oxygen deficits on root, leaf and tiller growth. Belford *et al.* [1985] and Meyer and Barrs [1988] have described the relationships between oxygen in water filled soil pores and assimilation and growth processes in wheat. These relationships will be used to construct routines that modify wheat growth in response to oxygen deficits following waterlogging events in duplex soil. The affect of oxygen on denitrification is handled in the soil N module [Jones and Kiniry, 1986].

The sensitivity of the crop-soil system to root elongation rate highlights the importance of accurately simulating the root system in depth and time. The practical value of the APSIM model is underscored by the ability of the model to account for complex interactions between root growth, soil factors and season.

Further work is needed on the description of waterlogging effects on root growth and biomass production and grain yield before the APSIM model can be used with confidence to explore the effect of a number of management issues in wheat production on duplex soils.

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INVITED

Simulation of Pasture and Sheep Production on the Northern Tablelands of New South Wales Australia.

MALCOLM. J. MCPHEE. Elizabeth Macarthur Agricultural Institute, NSW Agriculture, Menangle, N.S.W., Australia.

Abstract.
The paper demonstrates the verification and validation of the mathematical relationships for a Northern Tablelands version of SheepO (version 4.0), a Decision Support System that simulates pasture and sheep production. The current version of SheepO (version 3.0) was primarily developed for the Winter rainfall areas of Southern Australia and fails to work in regions with a Summer rainfall pattern. Therefore, these differences in regions have led to the implementation of a water balance model, a digestibility model and the development of a shoot death model. The development of the shoot death model used production data for fine-wooled Merino wethers (4-5 year old) grazing on a Phalaris/White clover pasture obtained from an experiment conducted at CSIRO, Chiswick, Armidale (Latitude 30°, 31'S, Altitude 1070m). The verification of version 4.0 shows the calibration of pasture and sheep production at a low (9.9 sheep/ ha) stocking rate and the experimentation of making one management change to a high stocking rate (19.8 sheep/ha). Similarly, validation is shown using an independent data set from Glen Innes (Latitude 29°, 42'S, altitude 1057m) of fine wooled Merino wethers (8 months old) at low and high stocking rates, respectively 10 and 15 sheep/ha. SheepO version 4.0 will assist advisers, producers and researchers on the Northern Tablelands of New South Wales, Australia to investigate the outcome of changes to current management strategies.

1. INTRODUCTION

SheepO, a sheep management package that mimics the pasture and sheep production of a farm, addresses "what if" questions regarding different management strategies. The initial development of SheepO dates back to the early 1980's when White et al.[1983] developed a financial and biological simulation model of a breeding ewe flock. SheepO continued to evolve from these early beginnings into a microcomputer Decision Support System (DSS) (SheepO version 3.0, McLeod et al. 1992).

The primary application of SheepO's version 3.0 to date has been in the Winter rainfall areas of Victoria and Southern N.S.W. Under various test conditions it was found that version 3.0 failed to calibrate pastures in a Summer rainfall environment. Therefore, with approximately 21.6 million sheep grazing on the Northern Tablelands it was considered a high priority to develop a regional model for this environment. As Jakeman [1993] indicates, the easiest alternative to a highly complex generic environmental model is to "develop models which have, within each region, a common model structure employing the same set of processes".

SheepO, version 4.0, utilises a common model structure for pasture and sheep production along with three regional models for water balance, shoot death and digestibility of the green pasture. This paper sets out to describe, verify and validate the regional models for the Northern Tablelands version of SheepO (version 4.0).

2. MODEL DEVELOPMENT

2.1 Differences between version 3.0 and 4.0

The main difference between version 3.0 and 4.0 is that version 4.0 has a regional model for the Northern Tablelands with a summer rainfall pattern. The original program, version 3.0, was developed predominantly for the Southern area of Australia with a Winter rainfall pattern generally depicted by an Autumn break occurring between March and June and a drying off period that begins sometime between October and February. However these indicators do not exist on the Northern Tablelands.

Figures 1 and 2 show the failure (Figure 1) and success (Figure 2) of calibrating pasture and sheep production on the Northern Tablelands with and without a regional model.

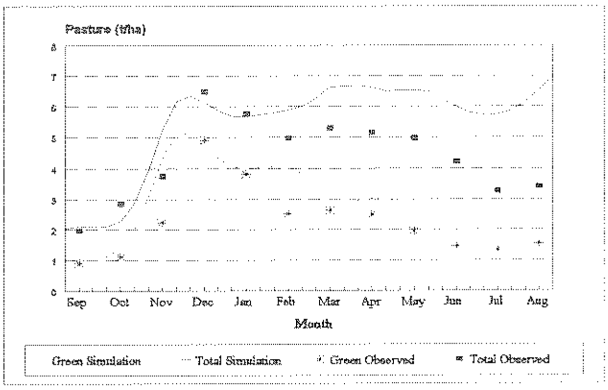

Figure 1: Simulation of Green and Total Pasture Version 3.0 at a Low Stocking Rate.