Australian Journal of Experimental Agriculture, 1996, **36**, 1037–48

Simulation of a legume ley farming system in northern Australia using the Agricultural Production Systems Simulator

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Summary. An innovative ley farming system, involving cereal crops grown in rotation with pasture legumes, has been tentatively adopted by farmers in the semi-arid tropics of northern Australia. Yet, after more than a decade of experimental research, the long-term potential of this system remains uncertain. The approach used to address this question has been to use the APSIM (Agricultural Production Systems Simulator) model in conjunction with historical climate records to simulate system performance. Thus, the objectives of this paper were to describe APSIM, to test its performance against data from cropping systems experiments, and to use it in assessing the long-term consequences of alternative farming practice in this region of northern Australia.

APSIM is able to simulate the soil carbon, water and nitrogen balances arising from interactions between different crops and pastures grown in rotation. In this paper, APSIM was configured to simulate either conventional rotations of sorghum or maize crops, or crops grown in rotation with *Stylosanthes hamata* (Verano) ley pastures. In the latter case, APSIM simulates the establishment of a Verano pasture sward, its growth and death, and its effects on subsequent cereal crops. The crop is either kept free of weeds or, alternatively, an understorey of volunteer legume can establish to form an intercrop where the crop and pasture compete for resources. Simulation of crop and pasture residues can encompass either their retention on the soil surface and decomposition over time, or their complete removal from the system (as hay).

In comparisons of simulations against limited experimental data, APSIM was able to reproduce the measured yields from sorghum, maize and Verano grown either as sole crops, as intercrops, or in rotations of several years. Likewise, a simulation analysis using APSIM of several cropping options for Katherine, Northern Territory, resulted in the preferred outcome reflecting current farming practices in the region. This preferred option, a combination of legume hay and sorghum grain production, was shown to be superior in terms of both gross margin returns and long-term soil fertility status.

It was concluded that APSIM now provides a useful tool with which farming systems in northern Australia can be further explored.

Additional keywords: legume ley, farming system, rotation, intercrop, simulation model, APSIM.

Introduction

The establishment of successful primary industries in the semi-arid tropics of northern Australia has been the goal of Governments, research institutions and entrepreneurial farmers for at least the past 5 decades (Chapman *et al.* 1996). Despite considerable expenditure on agricultural research and development over this period, until recently, the region's achievements have been modest. However, in recent years, primary producers in the Northern Territory have been successfully producing dryland crops and livestock (Price *et al.* 1996). They have achieved this success using innovative systems based on conservation tillage and ley farming that have emerged from research undertaken in the 'Top End' over the past 15 years.

A major focus of the research to enhance the feasibility of dryland farming systems has been on the use of conservation tillage technology and the integration of livestock with pasture legumes as leys (McCown *et al.* 1985; Chapman *et al.* 1996). In these systems, grain crops are grown during the wet season and are sown directly into a mulch of chemically-killed pasture which provides both protection from high soil surface temperature and a source of mineralisable nitrogen (N). The legume pasture re-establishes from hard seed during and after the grain crop. Cattle graze native grass or improved pastures in the wet season and crop residues and legume pasture during the dry season.

Research on conservation tillage and ley farming systems in northern Australia over the past 15 years has ranged from large farming systems trials to intensive physiological studies on crop development and growth. The purpose of this paper is to describe an approach where much of this information has been integrated into a dynamic simulation capacity of this farming system. This capacity, in the form of the APSIM model (McCown *et al.* 1995), provides the opportunity for exploring not only today's issues of agronomic management but also the longer-term prospects for sustaining agricultural production in this climatic zone of Australia.

The specific objectives of this paper are to: (i) describe APSIM as configured for a ley farming system, (ii) test the model's performance against cropping systems experimental data, and (iii) demonstrate the utility of the model through an assessment of the long- term consequences of alternative farming practices in northern Australia.

APSIM cropping systems model

General description

The APSIM (Agricultural Production Systems Simulator) model has been developed as a flexible software system for simulating agricultural production systems. A detailed description of APSIM, including its capabilities, design features, structure, user interface and the derivation of its main biological and environmental modules is provided by McCown *et al.* (1995).

In providing the capability to simulate system performance, APSIM has the soil as its central unit. It is through the soil that the cumulative effects of climate, crops, pastures and agricultural management affect productivity (McCown *et al.* 1995). This concept was achieved by separating system processes into distinct modules which can all interact with a common set of soil process modules. This interaction between modules occurs only via a communications 'engine' and a standard interface. Thus, APSIM contains an extensive library of modules describing different soil, biological and managerial processes, the combination of which, at the time of APSIM configuration, defines the system simulation capability. Selection of module combination is user-defined and so may differ between users and applications.

The combination of APSIM modules used to simulate a ley pasture system in northern Australia is described in the following sections. APSIM V1.0 engine and protocol were used to interface each module.

Sorghum, maize and Stylosanthes hamata *modules*

Many of the biological modules within APSIM have been derived from existing stand-alone models that simulate crop, pasture or soil processes in Australia and elsewhere (McCown *et al.* 1995). This is the case with the sorghum, maize and *Stylosanthes* modules used in this study. The 2 crop modules resulted from redesigning and re-engineering the AUSIM (AUStralian SIMulator) models described by Carberry and Abrecht (1991), which themselves were derivatives of the CERES-Maize model (Jones and Kiniry 1986). The *Stylosanthes hamata* (cv. Verano) module resulted from re-engineering an existing model described by Carberry *et al.* (1992, 1993).

Whereas the re-engineered sorghum module, APSIM-CSSAT V0.1, largely remains true to the process descriptions used in its parent model, the new generation maize module, APSIM-Maize V1.0, was developed from a generic APSIM crop template (McCown *et al.* 1995). The resulting difference in process description is chiefly in how soil water is extracted by the crop, with APSIM-Maize V1.0 using the approach where the rate of soil water extraction is defined for each soil layer (Passioura 1983; Meinke *et al.* 1993). Likewise, APSIM-Stylo V1.0, being based on the crop template, resembles its parent in all but the water extraction routines.

Soil water, nitrogen, temperature and residue breakdown modules

The soil water (APSIM-SoilWat V1.0), soil N (APSIM-SoilN V1.0), and surface residue breakdown (APSIM-Residue V1.0) modules used in this study have been described in some detail by Probert *et al.* (1996). Their applicability to the soils of northern Australia is underlined by the fact that the validation datasets used by Probert *et al.* (1996) to test APSIM included data from Katherine, Northern Territory.

The soil surface temperature (APSIM-SoilT V0.1) module in APSIM consists of a 'patched-in' version of the TC1MAX model of Ross *et al.* (1985). This module predicts daily maximum soil surface temperature for different levels of surface cover. The original model was validated for soils at Katherine by Carberry and Abrecht (1991) and this validation has been confirmed for APSIM-SoilT V0.1 (data not shown).

Arbitrator (intercropping) module

APSIM permits any number of biological modules to be 'grown' together as mixtures or intercrops, each of which compete for light, water and N resources. APSIM allocates resources using rules defined in the arbitrator (APSIM-Arbit V1.0) module. Carberry *et al.* (1996) have described this capability in detail.

Manager, fertiliser, irrigation and report modules

In this study, APSIM was configured with APSIM V1.0 utility modules that permitted implementation of management options (rules for sowing, harvest, irrigation, fertilisation etc.) and the reporting of simulation outputs.

Simulation of ley cropping systems

APSIM is able to simulate quite complex agricultural systems by making available modules for the key components of the system, providing the means to link these modules (via the APSIM engine) and, most importantly, providing a user-defined, flexible and rule-based management system that permits the simulation to realistically mimic both natural and interventionist actions. These rules are specified in the APSIM-Manager V1.0 module.

For this study, APSIM was configured to enable simulation of either sole sorghum or maize crops sown every year, or crops grown in rotation with *Stylosanthes hamata* (Verano) ley pastures of different durations. In the latter case, APSIM simulated the establishment of a Verano pasture sward on 'build-up' rains at the start of the wet season. This established pasture was either allowed to grow for the duration of the wet season until terminating from drought at the start of the dry season the following year or killed on a specified date to form a surface mulch at the time of crop planting. Sowing (no-tillage) of a cereal crop was simulated with user-specified sowing criteria. During its growth, the crop was either kept free of (Verano) weeds or, alternatively, an understorey of volunteer legume established (from hard seed) and the growth of the crop and legume pasture intercrop were simulated under conditions where they competed for light, water and N until crop maturity, after which the pasture continued growth while excess resources were available. Simulations assumed that grain was harvested at crop maturity and removed from the system. The management of crop and pasture residues ranged from them being retained on the soil surface to complete removal as hay.

Materials and methods

Experimental data sets

Over 1978–90, an experimental program was conducted at Katherine Research Station, Northern Territory (14°30'S, 132°20'E, elevation 108 m) with the objective of exploring the prospects for dryland cropping in this climatic zone. Many of the experiments were conducted to research a zero-tillage, ley farming system, or used such a system as part of their experimental methods. Consequently, a sizeable database of experimental data was accessible in the development and testing of a simulation model of a ley farming system. The key experiments employed in this task are described briefly below.

Sorghum and maize experiments. The majority of the single season, sole crop data used in developing and testing models for sorghum and maize was compiled from the comprehensive experimental program described in detail by Muchow (1988, 1989, 1990*a*, 1990*b*). These experiments included variations in cultivar, sowing date, plant population, water regime and nitrogen fertility. Data from other locations in semi-arid northern Australia (A. L. Cogle, P. S. Carberry and R. L. McCown unpublished data) were also utilised in model testing.

*Maize–*Stylosanthes *intercropping experiment.* In the 1986–87 wet season at Katherine, sole maize was compared with an intercrop of maize and *Stylosanthes hamata* (cv. Verano) under variable water supply. A pure Verano sward was also included in the experiment. A split, split-plot design with 2 replicates was sown on 6 January 1987 with water regime as main plots, row direction as subplots and cropping system by maize population as sub-subplots. The 2 water regimes were a fully irrigated treatment, in which the soil water profile was restored after 4 rain-free days, and a dryland treatment in which irrigation ceased 21 days after sowing (DAS). Due to the incidence of rainfall, identical water regimes were maintained in the 2 treatments until 57 DAS, whereafter the dryland regime received no further precipitation. Maize was sown in 75-cm rows oriented either north-south or east-west. Maize populations in the sole maize and the maize–Verano intercrop treatments were thinned to either 35 000 or 67 000 plants/ha at 13 DAS. Verano seed was broadcast in the sole Verano and maize–Verano intercrop at 30 kg/ha at the time of maize sowing and at a further 15 kg/ha at 13 DAS. Nitrogen was broadcast to all treatments at 137 kg N/ha as urea 5 days before sowing, as well as 93 kg potassium chloride/ha, 10 kg zinc/ha, 10 kg copper/ha and 0.2 kg molybdenum/ha. A further 40 kg N/ha as 'Nitram' was banded at 44 DAS.

Intensive growth measurements were made with destructive harvests of 4 m^2 taken at 21, 35, 48 and 63 DAS and of 8 m^2 at maturity. For maize, dry weights of stover and grain for 5 representative plants, and leaf areas for 3 plants, were recorded at each harvest. Verano dry weight and leaf area were recorded from quadrats of 4 m^2. Light interception was calculated from whole-day integrations taken from tube solarimeters (Type TSL, Delta-T Devices), and soil water was monitored at regular intervals using a neutron moisture meter.

Maize grain yield was significantly less ($P<0.05$) under dryland than under irrigated conditions, and at the lower population densities. The presence of the understorey Verano had no significant effect on maize yields, nor did the orientation of the maize rows. Maize population density and its interaction with water regime and the presence or absence of maize were the only factors that had a significant effect on Verano dry weight.

Data from the irrigated pure Verano swards were used in developing the parameters for the *Stylosanthes* model (Carberry *et al.* 1992, 1993). Data from the dryland pure

Verano and sole maize plots were used to quantify the water extraction rate of both species and to determine the lower limits of soil water extraction. Data from the maize–Verano intercrop treatments were not used in model development.

*Sorghum–*Stylosanthes *rotational experiment.* Over 4 wet seasons in 1986–90 at Katherine, sorghum was grown in rotation with 12-month leys of *Stylosanthes hamata* (cv. Verano) under different tillage systems and N fertiliser regimes. The experimental objectives, design and results are described in detail by Dalgliesh and McCown (1996). The tillage treatment of interest for this paper is where sorghum was sown under zero tillage into legume mulch. The pasture ley was established by broadcasting Verano seed at 15 kg/ha. In the following year, a regenerating legume sward was allowed to grow from the onset of the wet season until a week before the anticipated sowing date. At this time, the pasture was chemically killed and sorghum was sown at the first opportunity using a no-tillage planter at a row spacing of 50 cm and a depth of 5 cm. Established sorghum populations ranged from 125 to 200 000 plants/ha. The experiment contained 2 replicates.

Crop growth, Verano biomass, soil water and soil N were measured each year in the first crop phase after each legume ley. For sorghum, harvests were conducted at floral initiation, 50% anthesis, soft dough and physiological maturity. Quadrat estimates of above-ground Verano biomass (green plus dead material) were taken periodically throughout the experiment. A neutron moisture meter was used to monitor soil water in the sorghum plots on a weekly basis for the duration of each wet season. Soil nitrate was measured before sowing and after harvest.

Due to the high background level of soil nitrate, sorghum crops showed no N fertiliser response in any year (Dalgliesh and McCown 1996). Thus, this paper presents results from the zero fertiliser treatment only. Data from the 1989–90 sorghum crop were used to define the lower limits of soil water extraction in each soil layer for sorghum. Data from 3 Verano–sorghum rotations in 1986–90 were used to test model performance.

Site characterisation

The ability to simulate multi-year cropping systems is highly dependent on reliable site (particularly climate and soil) characterisation. At Katherine, daily rainfall records were available from 1888 (103 years), daily radiation from 1960 (31 years), and daily maximum and minimum temperatures from 1947 (44 years). Where existing records were absent, data were generated using the approach of McCaskill (1990) to create a complete record for the period 1888–1990.

Williams *et al.* (1985) provided comprehensive data on the morphological, physical and chemical characteristics of the major soil types of north-west Australia, including the cropping soils at Katherine Research Station. The major soil of interest in this study is the loamy red earth (Tippera) soil (Williams *et al.* 1985). To supplement this information, specific measurements of moist bulk density (BD) and the volumetric soil water content at saturation (SAT) and drained upper limit (DUL) were determined from ponding experiments, where about 10 m^2 of soil was saturated, covered with black plastic and allowed to drain in the manner described by Ritchie *et al.* (1986). Likewise, volumetric soil water content at the lower limit (LL) of extractable water for a crop was determined from terminal drying points of crops that were well developed at flowering.

Information required to characterise the inherent N fertility of the soil was taken either from Probert *et al.* (1996), Jones *et al.* (1996) or Dimes and McCown (1992).

Long-term model runs

To assess the profitability and sustainability of cropping at Katherine, APSIM was used to simulate the outcome of alternative management options using the available climatic record from 1888 to 1990. Management options included: (i) continuous sorghum with no applied N fertiliser; (ii) continuous sorghum with 40 kg N/ha fertiliser; (iii) continuous sorghum with 80 kg N/ha fertiliser; (iv) continuous Verano pasture, cut for hay; and (v) sorghum grown in rotation with a Verano ley, with the Verano allowed to re-establish as a volunteer weed under the sorghum crop and no applied fertiliser. The simulated sorghum crops were sown each year within a window from 1 December to 31 January, using the rule that sowing occurred after accumulated rainfall over a 5-day period exceeded 25 mm. Crops were simulated at a density of 20 plants/m^2 with fertiliser applied at sowing. Verano was assumed to regenerate when 25 mm rainfall in a 5-day period first occurred between 1 November and 1 March each year. In simulating a sorghum–Verano rotation, Verano was allowed to establish on early rains every year, but was terminated (assuming a herbicide application) every alternate year at the time of sorghum sowing (selected with the above sowing criterion for sorghum). Verano was then simulated to re-establish at the same time as the sorghum was sown to form an understorey weed. On 20 July every year, the continuous Verano and Verano–sorghum simulations assumed that 80% of above-ground dry matter (including the mix of Verano and sorghum stubble in some years) was cut for hay and removed from the system.

Management options were compared by calculating gross margins (GM) each year for each production system and accumulating them over the 100 years of simulation. GMs were calculated using prices and costs specified for cropping in the Northern Territory by

Kirby *et al.* (1996). Briefly, the import parity price for sorghum of \$A235/t represented a cost equivalent to importing sorghum from elsewhere in Australia. High and low demand for hay by livestock industries were represented by Verano hay prices of \$135 and \$100/t, respectively. Variable costs for sorghum production totalled \$174/ha plus \$1/kg for N fertiliser and \$30/t for haulage. Variable costs for hay production totalled \$212/ha plus \$10/t for bale wrapping.

The consequence of the alternative management options for long term soil fertility was assessed by predicting changes in the total soil N content of the top 0.15 m of soil over the simulation period. Total soil nitrogen included the N contained in the soil humic pool, the soil microbial biomass, and the fresh organic matter residues.

Results

Site characterisation

The limits defining the plant available water content used by APSIM for sorghum, maize and Verano are shown in Figure 1*a*. The values for DUL were determined from the mean of 3 soil water profiles, from 2 separate ponding experiments and a third profile after a prolonged wet period in the maize–Verano experiment (the coefficient of variation was ≤3% for any soil layer across the 3 profiles). Values for LL were determined from the driest soil profiles for each species. In the top 0.5 m, all 3 species can potentially extract similar amounts of soil water, although soil evaporation can dry the surface layers much further. Below 0.5 m, sorghum can extract considerably more water than either maize or Verano, resulting in a potential plant available soil water capacity (PAWC) of 193 mm for a soil profile depth of 1.8 m. Maize and Verano have potential PAWCs of 148 and 154 mm, respectively, indicating Verano's slight advantage in available water in the 0.5–1.0 m depths.

The change in volumetric water content in a soil layer under a crop experiencing a continuous drying cycle can be described as

$$\delta(\theta_t - \theta_l)/\delta t = -kl(\theta_t - \theta_l) \quad \text{if} \quad \theta_t \geq \theta_l$$

where θ_t is the layer's volumetric water content at time t, θ_l is the layer's volumetric water content at the crop's lower limit, and kl is the rate of soil water extraction (Passioura 1983; Meinke *et al.* 1993). The APSIM maize and *Stylosanthes* modules require estimates of kl for each soil layer, which change with soil type and depth. Figure 1*b* presents values of kl estimated from soil moisture measurements under sole maize and Verano crops and the values used in the APSIM modules. The data indicate that values of kl for maize are higher than Verano in the top 0.6 m but are similar in the deeper soil layers. Values for both species decline significantly with depth, reflecting a probable decline in root length density.

Model testing

Overall yield predictions. Predicted grain yields of maize and sorghum, and biomass yield of Verano are

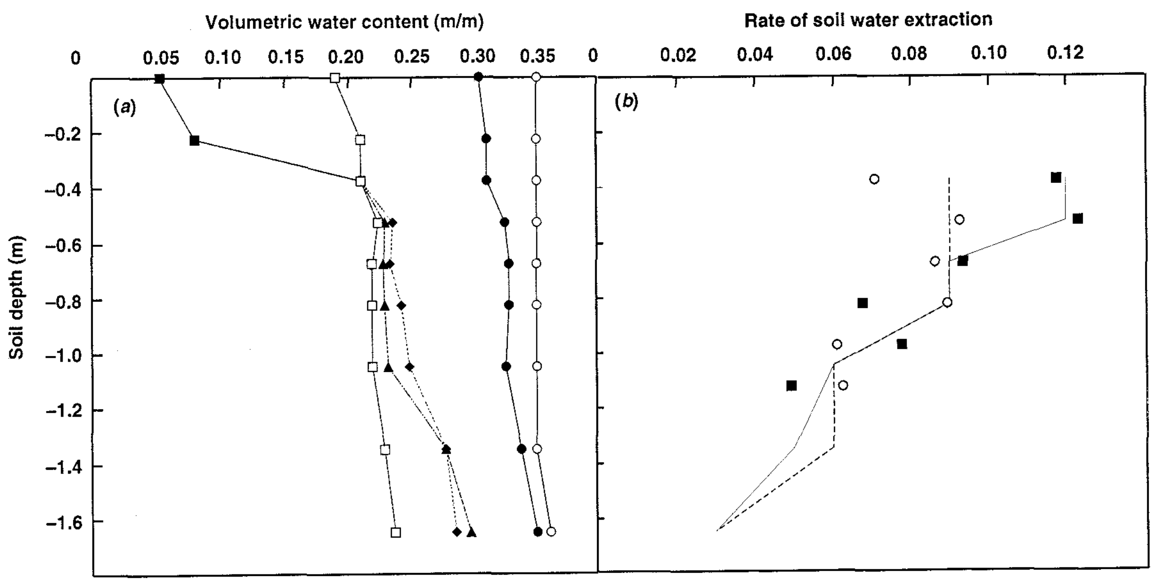

Figure 1. (*a*) Volumetric water content (VWC, m/m) describing soil saturation (○), drained upper limit (●), air dry (■), and the lower limits of water extraction for sorghum (□), maize (◆) and Verano (▲). (*b*) Rate of soil water extraction (kl) measured for maize (■) and Verano (○) and the values used in APSIM modules for maize (——) and Verano (- - -). Error bars represent ± s.e.

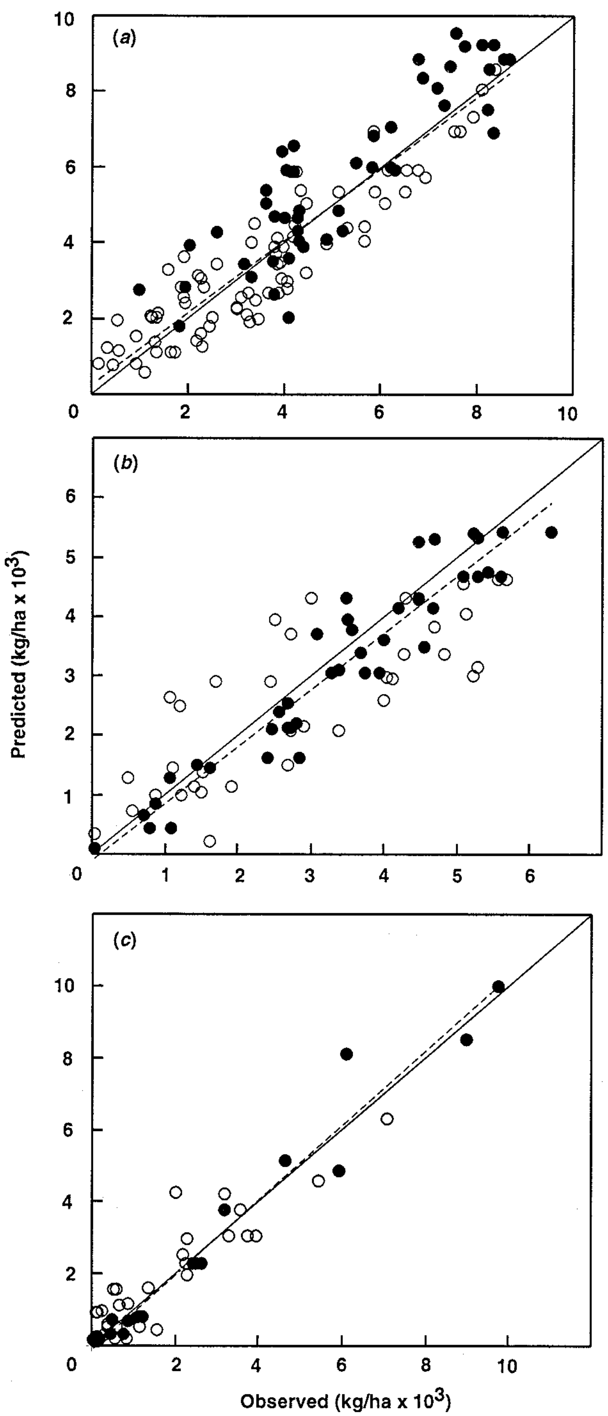

Figure 2. Simulated versus observed (*a*) grain yield of maize either at maturity (●) or during grain filling (○), (*b*) grain yields of sorghum either at maturity (●) or during grain filling (○), and (*c*) biomass yield of sole (●) and intercropped (○) Verano.

compared with measured values in Figure 2. In most experiments, APSIM configured for the 3 crop modules satisfactorily simulated grain yield and other plant components (Table 1). Predictions were generally consistent with the accuracy demonstrated previously for models simulating these data (Carberry and Abrecht 1991; Carberry *et al.* 1993, 1995).

Maize–Stylosanthes *intercropping.* The ability of APSIM to simulate competition between a crop and competing (legume) weed is demonstrated in Figure 3. Except for some underprediction in total maize biomass at final harvest, predictions closely followed measured data from crops grown at different densities and under different water regimes. The simulated response of the understorey Verano to changes in its environment closely matched the measured response. The model simulated the early suppression of Verano growth under high maize density and its subsequent accelerated growth as maize leaf area senesced during grain filling. The simulation accurately calculated the continuation of this late flush of Verano growth under irrigated conditions and its cessation under terminal water deficit (Fig. 3). These results help confirm that APSIM has the capability to adequately simulate the growth of crops and legume pastures grown as intercrops.

Sorghum–Stylosanthes *rotations.* Figure 4 shows simulated and observed data for sorghum grown in rotation with Verano in 3 different rotations over 4 years (1987–90) at Katherine. The simulation was for a zero-tillage system, where crop and pasture residues were left on the soil surface and their decomposition simulated in response to climate conditions. The only removal of biomass from the system was the grain yield of sorghum. Thus, amounts of residue remained unchanged over the long dry season each year, with simulated decomposition commencing with the first rain at the start of the following wet season. Also noticeable in the simulations is the growth of volunteer Verano weeds before the sowing of each sorghum crop (this Verano growth was terminated on the dates specified within the experiment).

Overall, APSIM closely simulates the observed growth of sorghum and Verano in rotation, and the changes in surface residues over time. Simulated sorghum grain and biomass yields were generally close to measured data for a number of crops. Unfortunately, regular measurements of Verano biomass were not available, but comparison with the few measures of surface residue (green and dead Verano plus sorghum stubble) suggested that the simulations were reasonable. Neither the measured data nor the simulations showed large differences in sorghum growth when grown after either a Verano ley or a sorghum crop (Fig. 4). A small yield advantage was simulated in the 1988–89 season (Fig. 4*a* v. 4*b*).

Table 1. Validations for selected parameters predicted by the three APSIM modules

Parameter	n	Data range	Predicted v. observed regression			
			Slope	Intercept	R^2	RMSD[A]
		Maize				
Grain yield (kg/ha)	148	150–8650	0.98	294.0*	0.83	1012.0
Grain number (no./plant)	62	139–581	0.85	75.5*	0.62	69.4
Biomass (kg/ha)	68	1879–28 179	0.68*	4691.0*	0.78	2606.0
N uptake (kg/ha)	26	43–206	0.96	22.8*	0.89	25.3
		Sorghum				
Grain yield (kg/ha)	79	87–6281	0.80	326.5	0.78	689.0
Grain number (no./plant)	47	734–2443	0.83	599.0*	0.54	481.0
Biomass (kg/ha)	33	3217–16438	0.75*	4291.0*	0.79	2466.0
N uptake (kg/ha)	36	33–187	0.52*	75.5	0.63	38.0
		Stylosanthes				
Biomass (kg/ha)	54	39–9750	0.95*	170.6*	0.93	646.7

[A] The root mean square deviation between predicted and observed values. * $P = 0.05$.

Long-term model runs

Gross margins accumulated over 1888–1990 are presented for a number of alternative management options in Figure 5. At a legume hay price of $A135/t (Fig. 5*a*), the most profitable farming option at Katherine is clearly hay production from pure legume pastures (GM averaged $867/ha.year over 102 seasons). Alternating pure legume pasture with sorghum crops reduced the average GM to $668/ha.year. Continuous sorghum production was less profitable than either of the options which incorporated hay production. Nitrogen fertiliser application was essential for higher returns: GMs averaged –$5, $293 and $501/ha.year for sorghum fertilised with 0, 40 and 80 kg N/ha, respectively.

The long-term trend in sorghum returns with no applied fertiliser showed a small profit in the initial years, with declining returns in subsequent years (Fig. 5). Similarly, lower rates of return are evident after several decades of cropping, even when 80 kg N/ha was applied to sorghum crops every year. The simulated decline in sorghum returns corresponded closely with the simulated decline in soil fertility over the years of cropping (Fig. 6). In contrast, management options that incorporated legume pastures resulted in relatively stable soil fertility levels over the 102 seasons simulated in this analysis.

A fall in legume hay price to $A100/t resulted in similar returns between continuous Verano and continuous sorghum grown with 80 kg N/ha over the first 20 years of simulation (Fig. 5*b*). However, returns from sorghum production could not be maintained at this level (due to the changes in soil fertility) and a differential developed between the 2 strategies.

Discussion

In a region of Australia where cropping experience is limited, the climate is highly variable, and the potential for soil degradation is high, experimental research on innovative farming systems is difficult, expensive and time-consuming. One solution to this research dilemma is to partially substitute simulation experiments for field experiments with the obvious advantages in the amount and scope of the system that can be explored (McCown 1989, 1991). However, system simulation requires, firstly, a model with the capacity to deal with the key components of the system of interest and, secondly, confidence in model predictions. The objectives of this paper have been to meet these requirements by detailing how APSIM simulates system performance and by testing predictions against measured data from ley farming experiments conducted in northern Australia. The evidence as presented suggests that these objectives have been satisfactorily fulfilled.

The research program on ley farming systems for semi-arid tropical Australia proposed by McCown *et al.* (1985) led to experimental research on key components of the system, including the effect of ley pastures on subsequent crops (Dalgliesh and McCown 1996; Jones *et al.* 1996), soil N dynamics in ley pastures (Dimes and McCown 1992; Dimes *et al.* 1996), crop establishment into pasture mulches (Abrecht 1989, 1996; Abrecht and Bristow 1990; Gould *et al.* 1996; Thiagalingam *et al.* 1996), crop response to harsh environments (Carberry and Abrecht 1991; Abrecht and Carberry 1993), crop–pasture competition (Carberry *et al.* 1992, 1993), and animal production from ley farming systems (Winter *et al.* 1996). While many of these component processes have been well researched, quantified and modelled, it is only now that these processes have been integrated within a systems simulation capability. With the current exception of animal production, APSIM can deal with each of these key system components. In fact, the information generated from the experimental

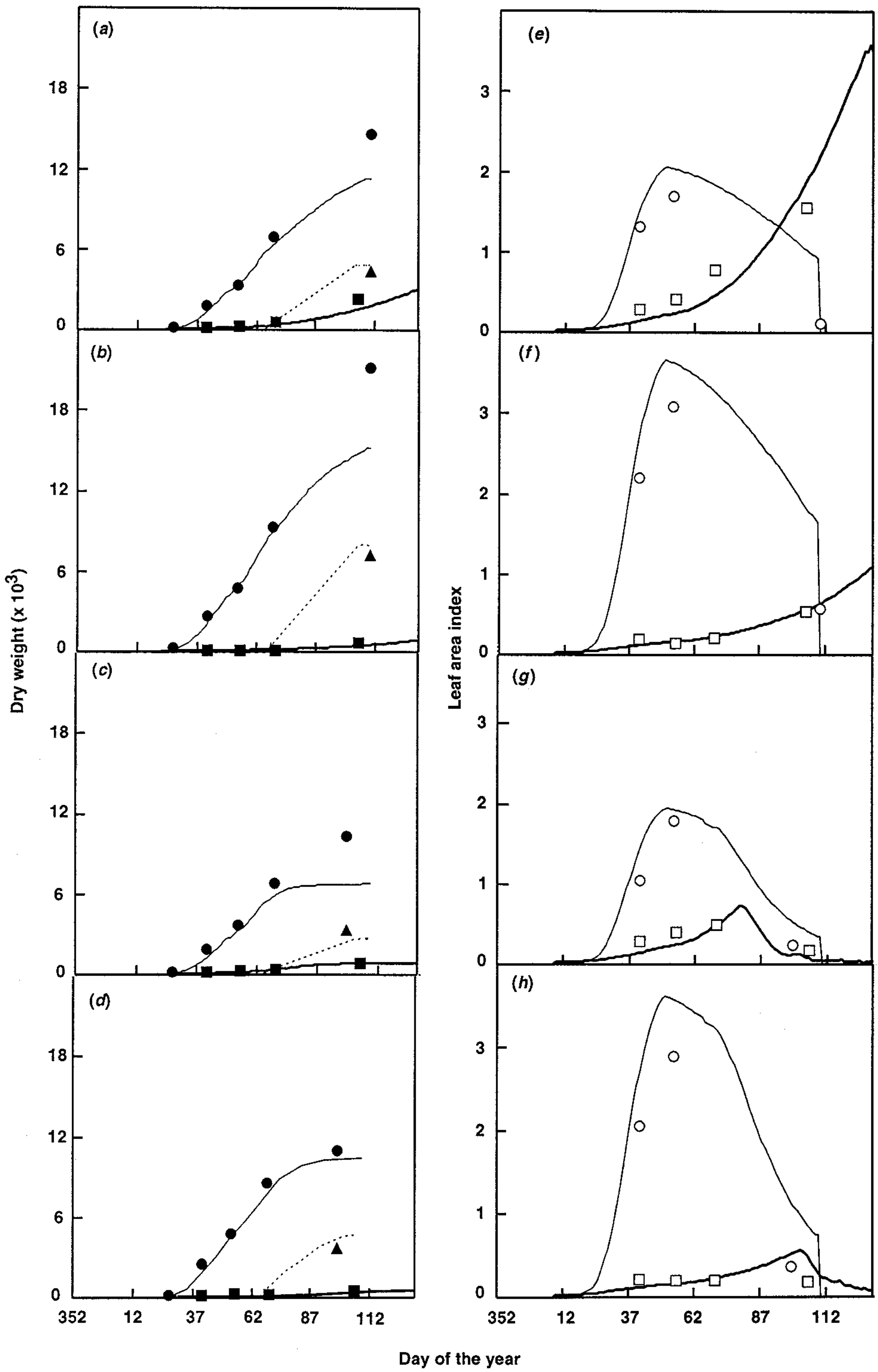

Figure 3. Simulated (lines) versus observed total biomass (●), grain yield (▲) and leaf area index (LAI) (○) of maize (thin lines), and total biomass (■) and LAI (□) of Verano (thick lines) intercrops for water regime x maize population density treatments: (*a* and *e*) wet, 3 plants/m^2; (*b* and *f*) wet, 6 plants/m^2; (*c* and *g*) dry, 3 plants/m^2; and (*d* and *h*) dry, 6 plants/m^2.

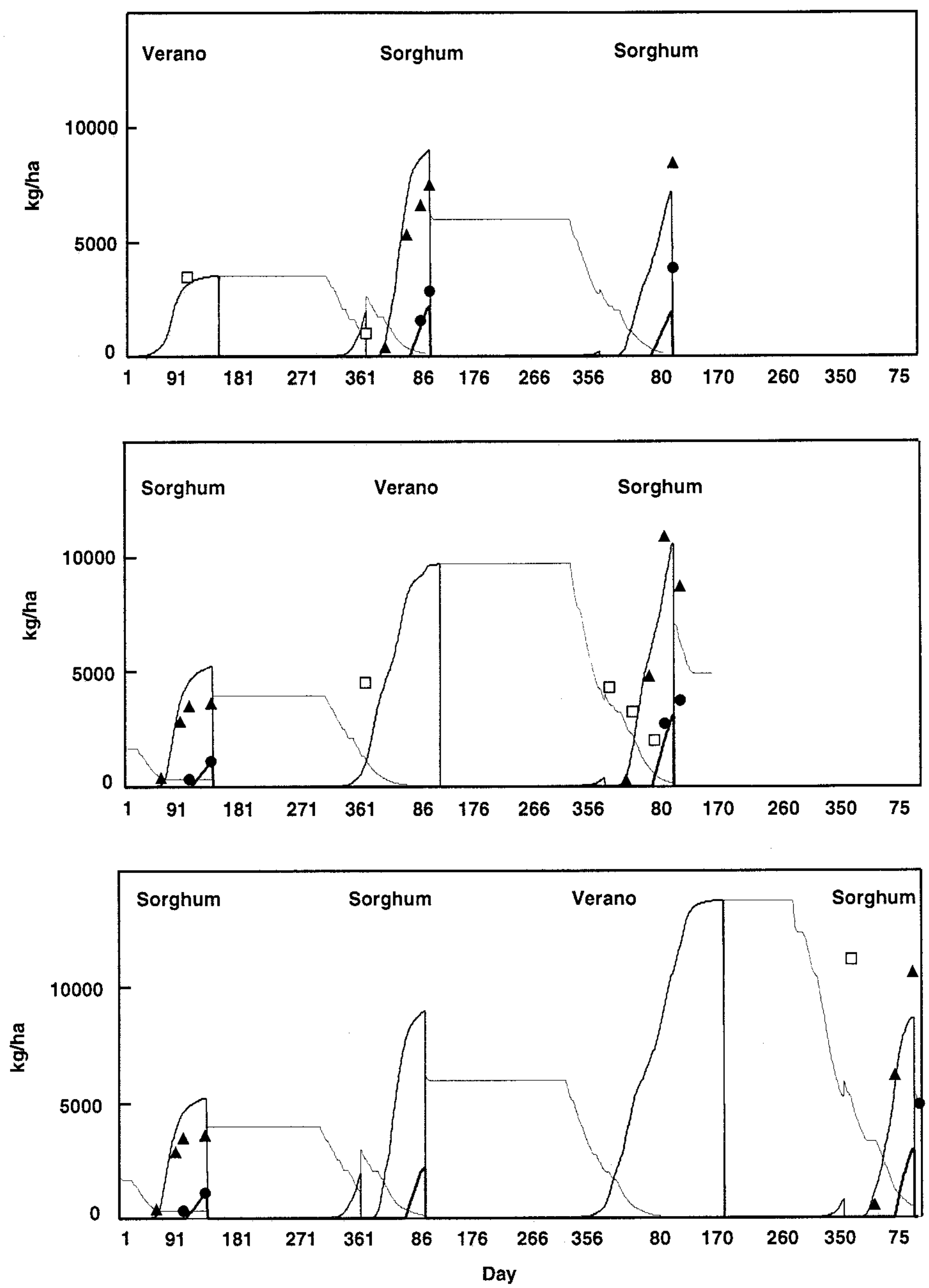

Figure 4. Simulated (lines) versus observed total biomass (▲) and grain yield (●) of sorghum and dry weight of live and dead Verano (□) grown in three different rotations over four years.

research conducted on this ley farming system contributed significantly to the initial design and implementation of APSIM (McCown *et al.* 1995).

The task of demonstrating credible model performance for a complex agricultural system, where system variables are many and consequences of actions have repercussions beyond a single season, is so difficult that few attempts have been published to date. The maxim that the availability (and suitability) of measured data will always be less than desirable will not be disputed here. Nevertheless, the tests of APSIM presented in this paper (Figs 3 and 4), and by others

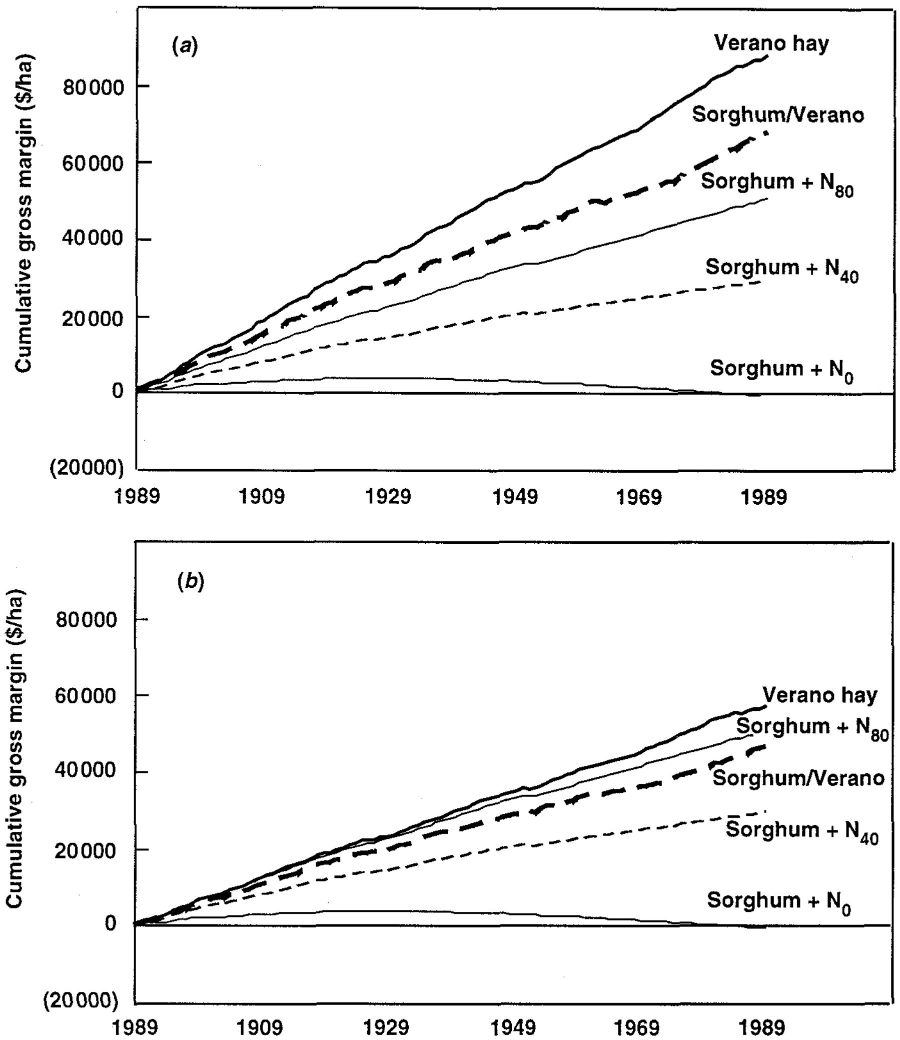

Figure 5. Gross margins accumulated over 1889–1990 for a number of alternative management options with a Verano hay price of (*a*) \$A135/t and (*b*) \$A100/t.

(Jones *et al.* 1996), have demonstrated simulations that have captured much of the measured results from a limited set of ley farming experiments conducted in northern Australia. However, this result cannot be regarded as a final confirmation of the model, but as the initial test in an on-going process.

The final objective of this paper was to illustrate the use of APSIM in exploring the long-term consequences of alternative farming practices in northern Australia. The outcome showed a clear advantage, assessed in terms of both profitability and sustainability, for continuous legume hay production over sorghum grain production under the prevailing economic conditions in the Katherine region (Figs 5 and 6). Continuous pure legume production is, however, unrealistic due to the invasion of grass weeds within 1–2 years of a sown legume pasture (Martin 1996). The ley farming system, where a cereal crop is planted after a period of pure legume ley, assists in the control of grass weeds through the use of herbicides in the cropping season (McCown *et al.* 1985). Considering this requirement for weed control along with the options in the simulation analysis, a rotation of sorghum and Verano would seem the preferred management strategy for maintaining profitability (Fig. 5*a*) and soil fertility (Fig. 6). This simulated outcome, in fact, roughly reflects current farming preference in the region (Price *et al.* 1996).

The scenario analysis raised 2 important points to be

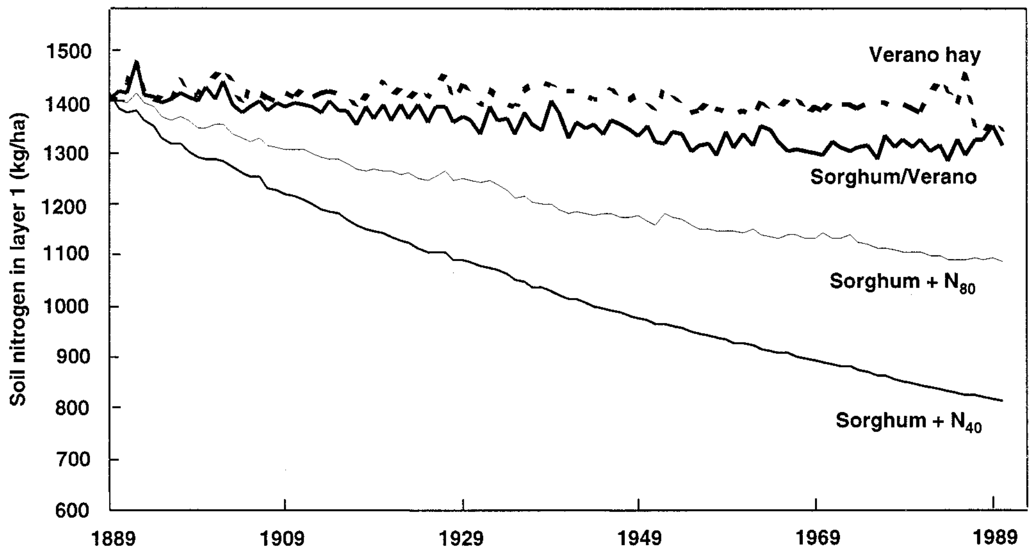

Figure 6. Simulated changes in the total soil nitrogen content of the top 0.15 m of soil over 1889–1990 for a number of alternative management options.

remembered in utilising APSIM in simulation experiments. Firstly, APSIM does not deal with every issue relevant to farming in semi-arid northern Australia, such that outcomes should be tempered by the agronomic practicalities and socio-economic circumstances faced by farmers in this region. The use of APSIM can be viewed in much the same way as traditional field experimentation, but where the number of treatment years can be expanded to utilise the historical climate records for a region. The second point is that APSIM provides the opportunity to explore the farming system not only for the current system of interest but also for new or different permutations to this system (e.g. Fig. 5*b*).

In conclusion, this paper has succeeded in applying APSIM to the ley farming system as proposed by McCown *et al.* (1985). The challenge now is to utilise fully the potential offered by APSIM in further enhancing the prospects for farming in this climatic zone.

Acknowledgments

The authors acknowledge the team of people who have worked on the ley farming project from its inception until today. They have all contributed to making this paper possible.

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Received 22 August 1995, accepted 4 April 1996