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Role of modelling in improving nutrient efficiency in cropping systems

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Abstract

The applicability of models in addressing resource management issues in agriculture has been widely promoted by the research community, yet examples of real impacts of such modelling efforts on current farming practices are rare. Nevertheless, simulation models can compliment traditional field experimentation in researching alternative management options. The first objective of this paper is, therefore, to provide four case study examples of where models were used to help research issues relating to improved nutrient efficiency in low-input cropping systems. The first two cases addressed strategies of augmenting traditional farming practices with small applications of chemical fertilizer (N and P). The latter two cases explicitly addressed the question of what plant genetic traits can be beneficial in low-nutrient farming systems. In each of these case studies, the APSIM (Agricultural Production Systems Simulator) systems model was used to simulate the impacts of alternative crop management systems.

The question of whether simulation models can assist the research community in contributing to purposeful change in farming practice is also addressed. Recent experiences in Australia are reported where simulation models have contributed to practice change by farmers. Finally, current initiatives aimed at testing whether models can also contribute to improving the nutrient efficiency of smallholder farmers in the SAT are discussed.

Introduction

McCown et al. (1992) reported on a 10 year research effort in utilizing experimental research and simulation modelling in attempting to identify a development path for subsistence agriculture in semi-arid Kenya. They have suggested that a strategy of augmenting traditional soil enrichment practices, based on manure and legumes, with modest amounts of fertilizer is economically feasible for many farmers and provides the best prospects for food security in this climatic zone. McCown et al. (1992) provided a strong argument that the use of the simulation model permitted the assessment of fertilizer use in a way that would not have been possible using traditional field experimentation alone. Subsequent research has confirmed both the apparent attractiveness of fertilizer use in Kenya and the applicability of models to address such research questions (Rötter and Van Keulen, 1997). However, both McCown et al. (1992) and Rötter and Van Keulen (1997) conclude that implementation of apparently advantageous changes to current farming practice remains an intractable problem.

In reflecting on this research program in Kenya, McCown and Cox (1994) suggested that there were six lines of endeavour that were worthy of further exploration in addressing soil fertility decline in Africa:

1. Find more efficient ways to capture, store and use manure on crops;
2. Test various FASE (Fertilizer-Augmented Soil Enrichment) strategies for combining applications of chemical fertilizer with manure and crop residues;
3. Extrapolate research results on legumes in systems;

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4. Research the economics of FASE strategies for different price-cost scenarios;
5. Contribute to national policies on commodities, food security and fertilizers;
6. Keep fertilizer on the policy agenda.

While the application of simulation models were explicitly recommended in the second and third areas, one could easily imagine modelling analyses contributing to other recommended areas of future activity, particularly as inputs into economic and policy analyses.

The McCown and Cox (1994) recommendations address both research activities to broaden our understanding of the biophysical system under study and operations research that uses our current understanding to predict likely outcomes for alternative management strategies that may be imposed on the farming system. Also included is possible intervention via policy actions. However, important questions are whether intervention directly with farmers is possible and whether simulation models can contribute beyond the research phase to assist in achieving improved farming practices. While not suggesting close analogy between developed and subsistence agriculture, it is relevant in the context of this paper to refer to recent experiences in Australia that have demonstrated how simulation models can contribute to farmer exploration and acceptance of practice change (Carberry and Bange, 1998; McCown et al., 1998).

Clearly, there has been significant past research effort into utilizing modelling in exploring management strategies in nutrient-stressed environments. The objectives of this paper are firstly to provide some case study examples of how models can contribute to research on nutrient efficiency in cropping systems and, secondly, to address the question of whether these models can assist the research community in contributing to purposeful change in farming practice.

In fulfilling our stated objectives, opportunity is taken to report on the current status of the systems model APSIM (Agricultural Production Systems Simulator), particularly in regard to current capabilities in addressing the issues raised by McCown and Cox (1994). Accordingly, applications addressing the use of manure and the incorporation of legumes in cropping systems will be explored.

APSIM

The Agricultural Production Systems Simulator (McCown et al., 1996) is a software environment that enables the biophysical simulation of farming systems. The distinguishing characteristics of APSIM are its:

1. Flexibility, achieved via a library of 'plug-in/pull-out' modules representing the biological, physical, environmental, managerial and economic components of farming systems;
2. Ability to simulate the production and resource consequences of a range of crops, pastures and trees grown in response to a variety of management practices, species mixtures and rotational sequences; and
3. Emphasis on high standards in software engineering, incorporating software coding standards, version control, maintenance and development protocols, and extensive documentation.

While the simulation capability of APSIM is continually expanding with the addition of new modules of crops (groundnut, faba bean, canola, lupins, hemp), pastures (lucerne, mucuna), trees (*Pinus radiata*, *Eucalyptus globulus*) and soil processes (phosphorus, manure, acidification), most recent progress has been in expanding the testing and application of APSIM to systems issues. Examples include the assessment of cereal-legume rotations (Probert et al., 1998), ley farming systems (Carberry et al., 1996a), intercropping systems (Carberry et al., 1996b), alley farming systems (Nelson et al., 1998), tree windbreak systems (Meinke et al., 2000), crop-weed associations (Keating et al., 1999), genetic traits within cropping systems (Robertson et al., 2000b), seasonal climate forecasting systems (Hammer et al., 2000), drought policy (Keating and Meinke, 1998), impacts on deep drainage (Asseng et al., 1998) and on-farm participatory research trials (Robertson et al., 2000a).

The above-referenced examples not only demonstrate the broad applicability of APSIM to a wide range of systems issues, but also provide evidence of APSIM applications both in the commercial agricultural systems of Australia and in the smallholder farming systems of the semi-arid tropics. APSIM is well placed, therefore, to contribute to research on improving the nutrient efficiency of low-input cropping systems.

Case studies in smallholder agriculture

Four case studies are used to demonstrate how APSIM could contribute to research on nutrient efficiency in low-input cropping systems. The first two address the

Table 1. Characteristics of the two manure sources, low quality manure (LQM) and high quality manure (HQM)

	%C	%N	Relative Composition [a]	Rates of application	
				DM (t/ha)	N (kg/ha)
LQM	10	0.6	0: 0.01: 0.99	5, 10, 20	30, 60, 120
HQM	15	1.5	0: 0.20: 0.80	2.5, 5, 10	37.5, 75, 150

[a] Proportions in three pools with decreasing rates of decomposition; for comparison, the composition of crop residues is 0.20: 0.70: 0.10.

recommendation for a FASE strategy of augmenting traditional farming practices with small applications of chemical fertilizer (McCown et al., 1992; McCown and Cox, 1994). The first case study utilizes the recently developed APSIM-Manure module to compare the application of manure of different qualities with inorganic fertilizer. The second study reports on the analyses of Keating et al. (1999) who explored why on-farm agronomic efficiencies of fertilizer nitrogen (N) (kg grain per kg N fertilizer applied) are often less than on-station efficiencies, due possibly to the impacts of low levels of weed competition.

The latter two cases explicitly address the question of whether models can assist in identifying how plants' genetic diversity may be exploited in low nutrient farming systems. Accordingly, the third case study addresses the question of the impact of different morphologies of cowpea intercropped with maize under low-input production systems. For this purpose, we reproduce the analyses reported by Robertson et al. (1999). The final case study uses the newly developed APSIM-SoilP module to explore the production and resource consequences of selecting for plants with more efficient root systems for extracting soil phosphorus (P).

Case study 1: The application of manure and N fertilizer

Manure recovered from open 'bomas' (corals) by subsistence farmers of semi-arid Africa is generally of poor quality in that it contains only low concentration of nutrients (Probert et al., 1995). Working in Zimbabwe, Tanner and Mugwira (1984) reported that manure with low concentrations of nutrients was an ineffective source of nutrients even in low-input cropping systems.

Using APSIM v1.55, the following analyses explore the response of maize to inputs of manure of two different qualities (Table 1) on a Chromic Luvisol soil in Kenya. The weather record used was for Katumani (latitude 1.5° S) extending from 1957 to 1997 (80 seasons due to the bimodal rainfall pattern). The effectiveness of manure in the APSIM-Manure module is determined by concentrations of nitrogen and carbon (C) and also by susceptibility to decomposition. This latter effect is controlled by considering the organic C and N as three fractions (carbohydrate, cellulose, lignin) with differing rates of decomposition (Probert et al., 1997).

In this simulation exercise, manure was applied and incorporated each year on 15 September (to represent the local practice of moving manure to the cropping lands prior to cultivation and before the commencement of the short rains) at the rates shown in Table 1. Maize crops were simulated in both the short-rain (sowing window 16 October–20 November) and the long-rain (15 March–1 May) seasons each year using the cultivar KCB sown at 3 plants m^{-2}. For comparison, there were treatments that received 0, 20, 40, 60 and 80 kg of fertilizer-N, as nitrate, applied to each crop at sowing. A subset of the manure treatments also received an input of 20 kg N as fertilizer at sowing.

In the first set of simulations, the model was re-initialised each year on 1 September. Thus, the simulations provide a comparison of the responses to the manure and fertilizer for the 40 years of the weather file (Figure 1). The effect of manure on the crop grown in the long rains is the residual effect from manure applied the previous September.

The material denoted HQM performed similarly to that in the experiments of Ikombo (1984) using manure collected from dairy yards. He reported that the application of 8 t ha^{-1} gave high and consistent yields, close to those obtained with the standard rate of mineral fertilizer (40 kg N ha^{-1}). Good residual effects were also found in the following long-rain season. In contrast, the specified LQM was a much less effective source of N for the short-rains crop and its residual effect was also inferior for the next long-rains crop. The poor response may help explain why seemingly very high rates of manure were being applied by some farmers (Probert et al., 1995).

The response to an extra 20 kg fertilizer-N applied at planting is shown in Table 2. The effect of manure and fertilizer in these simulations is essentially additive, with the expected decline in response as one moves up the response surface. The two manures simulated here have low C:N ratios (16.7 for LQM and 10.0 for HQM, see Table 1). When such materials decompose, there is net mineralization of N. When

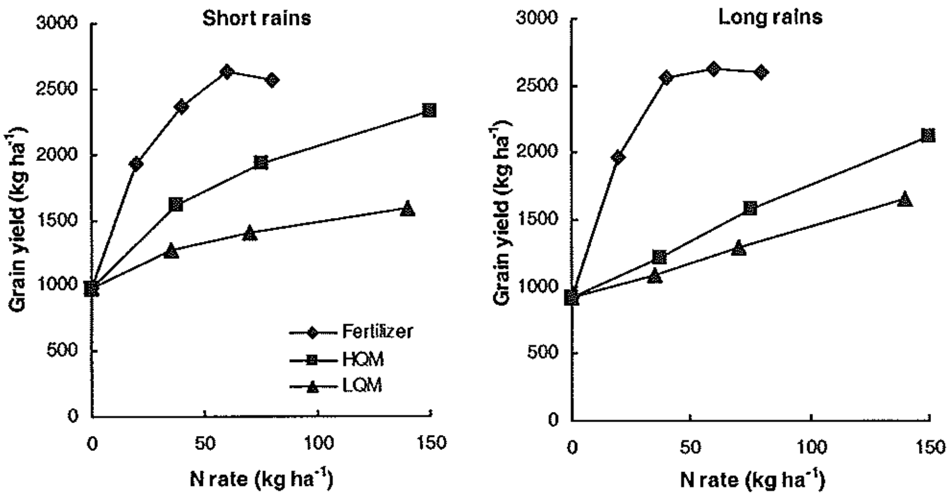

Figure 1. Simulated maize yields (averaged over 40 years) in response to high (HQM) and low quality manure (LQM) incorporated into soil in September each year. The fertilizer inputs were made to crops grown in both the short and long-rain seasons.

Table 2. Simulated response to additional 20 kg ha^{-1} of fertilizer-N applied at sowing, expressed as yields of maize (kg ha^{-1}). Data reported are averages for the 40 crops simulated

Treatment	Short rains		Long rains	
	Yield	Response to extra 20 kg N ha^{-1}	Yield	Response to extra 20 kg N ha^{-1}
Control	981	953	913	1052
Fertilizer 20 kg N ha^{-1}	1934	434	1965	589
5 t ha^{-1} LQM	1267	766	1080	982
2.5 t ha^{-1} HQM	1819	577	1215	942

materials with high C:N ratios are added to soil their decomposition causes net immobilization of N. Under these conditions, an interaction between manure and fertilizer will arise if the immobilization demand cannot be met from the unfertilized soil.

Where manure is used to replenish/maintain soil fertility in farming systems, the residual effects from previous applications become cumulative. The situation above where the simulations were re-initialized each year corresponds to an experiment that aims to compare different inputs (manure, fertilizer). To simulate cumulative residual effects, a second set of simulations were undertaken whereby the model was initialized once only on 1 September 1957. The same manure treatments were applied every year prior to the short rains and compared with treatments where fixed amounts of fertilizer-N were applied to every crop.

Cumulative yields in four of the manure treatments relative to that for fertilizer-N (using 60 kg ha^{-1} of N applied to each crop as the standard) are plotted through time in Figure 2. It can be seen that the effect of manure increases during the first few years after application. In the case of the HQM, the phase where performance is improving relative to fertilizer lasts about 5 years. For the LQM, the 'catching up' phase lasts longer but the advantage of the higher quality material is maintained.

It needs to be stressed that these simulations have only examined manure as a source of N compared to fertilizer-N. There will be other situations where manure provides other benefits, such as supplying other nutrients or preventing the soil from acidifying.

Case study 2: Effects of weed competition on agronomic efficiency

Shamudzarira et al. (1999) reported that simulated agronomic efficiencies of fertilizer-N (kg grain per kg

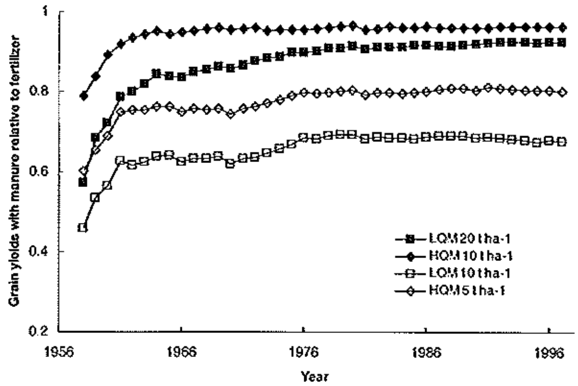

Figure 2. The effect of repeated application of different rates of high and low quality manures on the yields of maize. The cumulative yields (for crops in both the short and long-rain seasons) are expressed as a proportion of the cumulative yields obtained with 60 kg ha^{-1} of fertilizer-N applied to each crop.

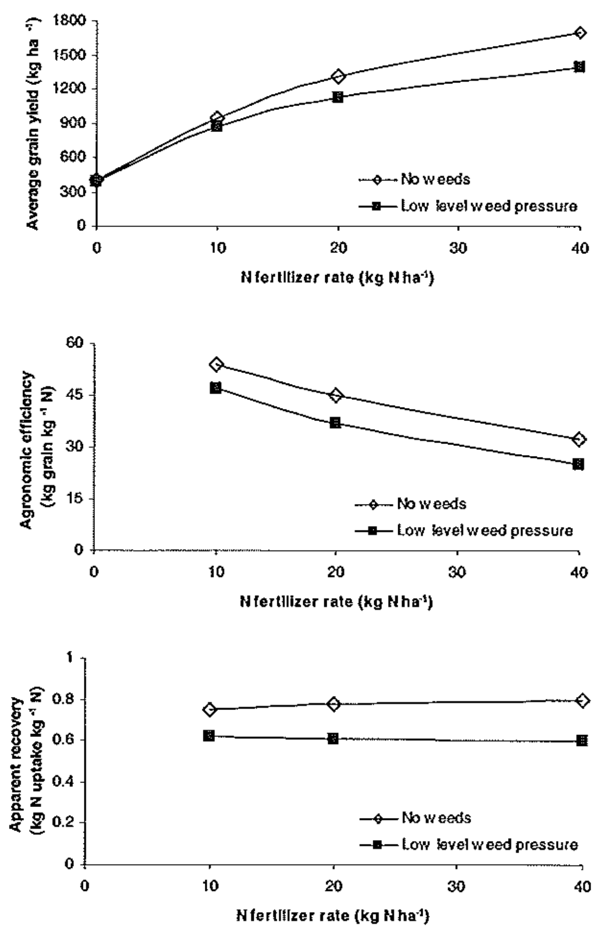

Figure 3. Effects of weed competition on simulated N response in maize, Bulawayo, Zimbabwe. (a) Average grain yield (kg ha^{-1}), (b) Agronomic efficiency (kg grain kg^{-1} N fertilizer), (c) Apparent N fertilizer recovery (kg N uptake to tops kg^{-1} N applied).

N fertilizer applied) were similar to those measured from on-station trials in Zimbabwe but were generally higher than those found in farmers' fields. In exploring this issue further, Keating et al. (1999) used APSIM to explore the hypothesis that this differential may be due in part to the impact of low levels of weed competition on maize response to fertilizer. This second case study examines the analyses of Keating et al. (1999).

Keating et al. (1999) configured APSIM v1.55 to simulate inter-species competition between maize and a grass weed as per the intercropping capability described by Carberry et al. (1996b). A maize production system was simulated (cv. Makoholi) growing on an infertile light textured soil (118 mm of plant available water, seasonal mineralisation capacity of approximately 16 kg N ha^{-1}) for the climate record (1981–1991) of Bulawayo, Zimbabwe (20.1° S, 28.4° E). Maize sowing (2 plants m^{-2}) was conditional on rainfall after 23 November. The weed population was 25 seeds m^{-2} and, as seeds were assumed to germinate from depth (100 mm), the weed population emerged approximately 5 days after the emergence of the maize crop.

The model configuration provided a seasonally variable, but generally low level of weed competition. In the presence of N fertilizer, APSIM simulated that maize-weed competition reduced yields (Figure 3a). As the systems were all strongly N constrained, this competition was primarily for N and not for water or light. Competition was least in the unfertilised systems–due to there being insufficient N for the weeds to establish. The value of the fertilizer-N (agronomic efficiency) declined from 54 to 32 kg grain kg^{-1} N as fertilizer rate was increased from 10 to 40 kg N ha^{-1}. Agronomic efficiency was reduced in the presence of weed competition (e.g. 45–25 kg grain kg^{-1} N) (Figure 3b). These shifts in agronomic efficiency were associated with shifts in apparent recovery of the fertilizer-N, that was reduced from 0.8 without weeds to 0.6 with weed competition (Figure 3c).

At the low fertilizer rates relevant to the economic circumstances of Zimbabwe's smallholders, small amounts of weed competition can significantly reduce the benefits of the fertilizer inputs. On-farm experimentation on fertilizer usage in these low-input systems needs to quantify and/or manage such constraints. Experiments on weed competition tend to give highly variable results depending on rainfall patterns, soil constraints, crop agronomy and weed demography. Systems simulation models such as APSIM can help to address this variability and assess the likely impact of 'less than ideal' agronomy on investments in inputs such as N fertilizers.

Case study 3: Cowpea canopy morphology in maize / cowpea intercrops

This case study has been previously described by Robertson et al. (2000b) as an example of using models to assist in the identification of genetic traits best-adapted to particular cropping systems. It addresses the question of the impact of different morphologies of cowpea, when intercropped with maize under low-input production systems. As cereal-legume intercrops have been widely promoted as a means of improving the biological efficiency of resource use in low-input systems (Fukai, 1993; Willey 1979a,b), identifying genotypes with traits best suited to intercropping systems is a key requirement in maximizing the benefits of such systems.

Robertson et al. (2000b) configured APSIM v1.55 to simulate maize and cowpea sole and intercrops grown under rainfed conditions for 31 years (1957–1988) using climatic data at Katumani (latitude 1.5° S) in semi-arid eastern Kenya. Simulations treated each year independently; all parameters were re-initialised at sowing–soil water was initialised at the lower limit of plant available water and soil mineral N was initialised to 30 kg ha^{-1}. Maize cultivar KCB was sown during the short and long-rain seasons, with no fertilizer application, consistent with local practice. A sowing density of 4 maize and 5 cowpea plants m^{-2} was used, and all crop residues were removed at harvest.

For this exercise, cowpea morphology was modified in the APSIM-Cowpea module by changing both the maximum attainable height of the canopy (80 vs. 160 cm), to mimic bush versus climbing types, and the radiation extinction coefficient (0.47 vs. 0.80) to mimic types with erect versus prostrate leaf posture. Results were evaluated in terms of the impact on both maize and cowpea grain yields.

In narrow (50 cm) maize rows, the cowpea yield responded best to increases in maximum height, with little response to an increase in the extinction coefficient of the cowpea (Figure 4). However, there was an interaction, where the biggest response to increasing height was at the larger extinction coefficient. In contrast, in the wide maize rows (100 cm), the biggest increase in cowpea yield was obtained when the extinction coefficient was increased, with a much smaller response to increasing height (Figure 4).

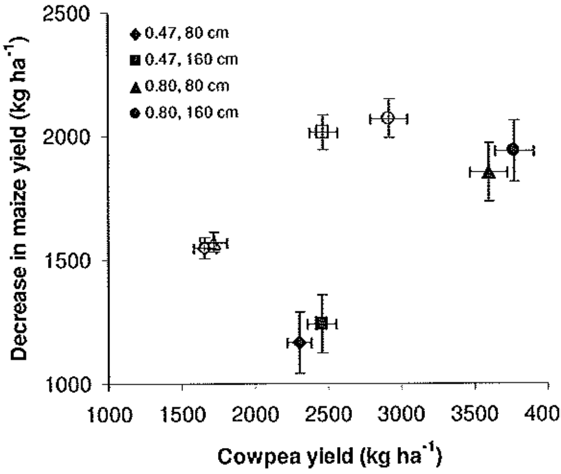

Figure 4. Relationship between the mean decrease in maize yield *versus* cowpea yield for cowpea genotypes differing in extinction coefficient (0.47, 0.80) and maximum height (80, 160 cm) grown in 50 cm maize row spacing (hollow symbols) and 100 cm row spacing (filled symbols). Error bars are ± standard error of the mean.

This case study highlights the complex interactions between agronomic management (such as row spacing) and the performance of different genotypes in competing mixtures. Models such as APSIM can help analyse some of these interactions by quantifying the likely trade-off between increasing the yield of one species at the expense of the other.

Case study 4: Simulating the effect of a more phosphorus-efficient plant

Crops that are efficient at utilizing soil-P can be conceived as employing one of two strategies. Firstly, without access to a greater pool of available soil-P, some plants are able to take up more P through a more efficient root system–i.e. more roots and/or greater root absorbing power (Nye and Tinker, 1977). The second strategy would rely on gaining access to P that was unavailable to other plants; this could be achieved where root exudates result in solubilization of otherwise unavailable forms of P (Kirk, 1999).

The manner in which soil-P dynamics and P uptake by a crop are represented in APSIM should allow the capture of the consequences of a cultivar with a more efficient root system, but at present there is no ability in the model to cope with concepts such as root exudates. Simulated P uptake is limited either by the crop's demand to maintain its internal P concentration, or by

Table 3. Predicted yield advantage of the more efficient cultivar with increasing cropping history for systems without and with inputs of P fertilizer. Values shown are averages of the ratios of the yields for the two cultivars

Crop number	Without fertilizer	With 5 kg P $ha^{-1}crop^{-1}$
1–20	1.21	1.11
21–40	1.18	1.05
41–60	1.16	1.05
61–80	1.13	1.02

the supply of P from the soil. The latter is defined on a soil layer basis as a function of the amount of available P, the soil's P-sorption properties, the moisture content and the distribution of roots. The 'P uptake coefficient' of this function has some semblance to the root absorbing power of the plant.

The SoilP routines in APSIM v1.55 were used to examine two situations. The first was in the absence of fertilizer-P inputs when it was hypothesised that a cultivar with a greater ability to take up available P from soil will have some short-term advantage but that this advantage may decline in the longer-term as the non-renewable soil-P resource is depleted. Secondly, where modest inputs of P are used, it might be expected that residual P would accumulate in the soil and eventually the advantage of the P-efficient cultivar would be cancelled.

The simulation study involved maize (cultivar KCB) grown on a typical Chromic Luvisol in the semi-arid tropics of Kenya. Each crop was fertilized with 50 kg N ha^{-1}. The soil initially contained 4 mg kg^{-1} bicarbonate-extractable P in the surface soil, declining with depth, and had moderate capacity to sorb P. The weather file used was that for Katumani (1957–1997). The parameterization for the 'standard' maize plant is that which has been found to give satisfactory prediction of the experiments on Mutua Farm described by Probert and Okalebo (1992), with the P-uptake coefficient calibrated to a value of 4 (unitless). For a more P-efficient cultivar, this coefficient was increased by 25% to a value of 5.

When grown on a soil with a much higher P status, there was no difference between the two cultivars (non-limited yield was 3889 kg ha^{-1} for the season shown) (Figure 5). The longer-term effects are shown in Figures 6 and 7, and summarized in Table 3. In the absence of fertilizer-P, the run down in the soil-P status through time was slightly quicker for the more efficient cultivar (Figure 6). The relative yields (the ratio of crop yield to non-limited yield) for both cultivars decreased over time (Figure 7) and many crops produced low yields (below 500 kg ha^{-1}) irrespective of cultivar. There was some tendency for the advantage of the more efficient cultivar to diminish as it progressively depleted the soil-P resource (Table 3).

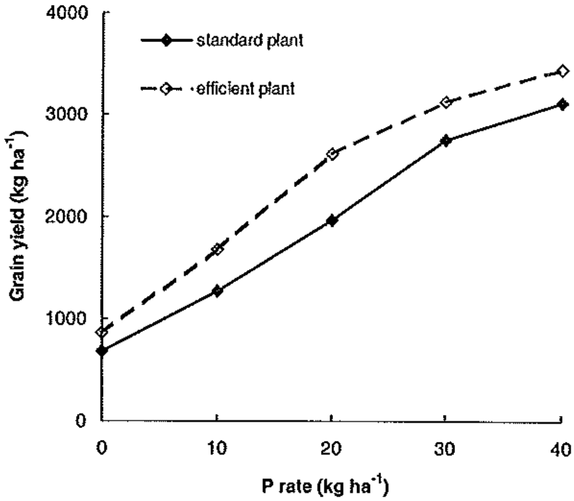

Figure 5. Simulated yields of maize cultivars differing in their efficiency in utilizing soil-P in response to increasing inputs of P fertilizer applied as a banded application. Data shown are for short rains 1958.

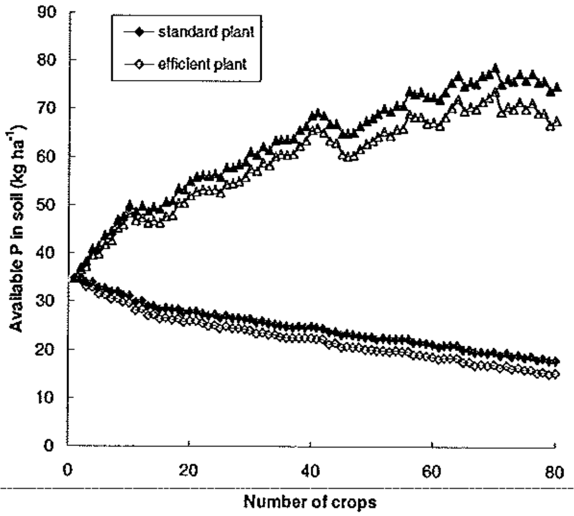

Figure 6. Prediction of soil-P status under continuous maize cropping with fertilizer-P inputs of 0 and 5 kg $ha^{-1}crop^{-1}$ for two cultivars differing in their efficiency in utilizing soil-P.

Repeated applications of fertilizer-P to each crop resulted in increasing soil P status and an increase in the relative yields of the two cultivars (Figures 6 and

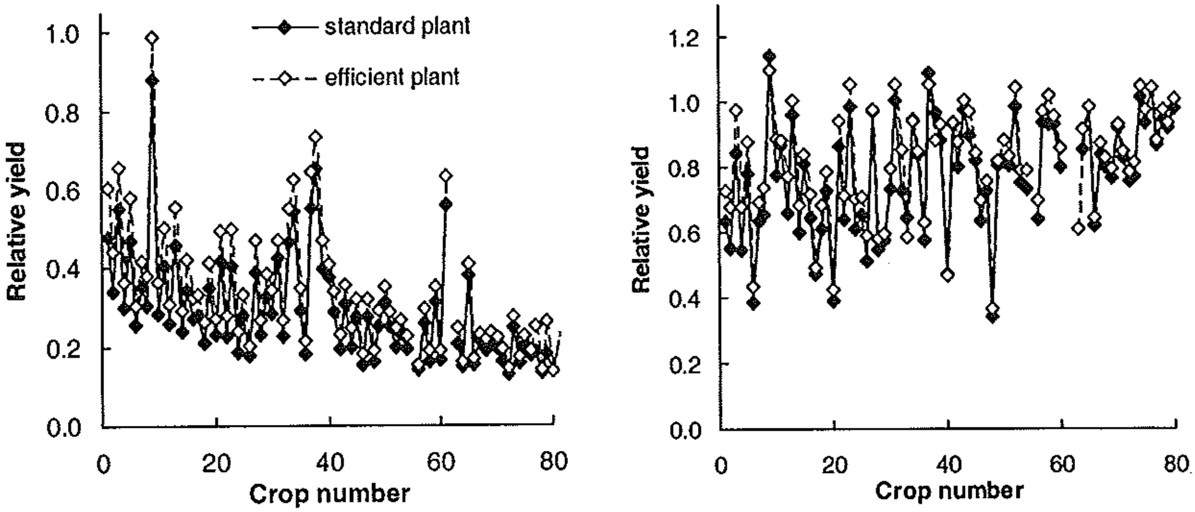

Figure 7. Relative yields of maize for two cultivars differing in efficiency in utilizing soil-P. The left hand frame shows the predictions for a cropping system without inputs of fertilizer-P; the right hand frame is for a cropping system that has 5 kg ha^{-1} of fertilizer-P applied to every maize crop.

7). Simulations were run with inputs of 3, 5 and 10 kg ha^{-1} as banded P to each crop but results are shown only for the 5 kg ha^{-1} rate. As the residual effects of past applications accumulated, the difference between the two cultivars became smaller (Table 3).

These simulations showed that the P routines in APSIM can represent the expected response of soil-P and crop growth–with the exception of dealing with the impacts of root exudates. The simulated results supported the hypothesis that a crop with a greater ability to take up P from soil has a yield advantage over a crop with less ability to source soil-P. However, the simulations indicated that this advantage persisted for at least the 40 years of this case study even though soil P was specified as a fixed, non-renewable resource.

Can models assist in improving farming practices?

The Australian experience

FARMSCAPE (Farmers, Advisers, Researchers, Monitoring, Simulation, Communication And Performance Evaluation) is an acronym employed to represent a participatory R&D approach that explicitly addresses the question of relevance of systems models to commercial farming in Australia (Carberry and Bange, 1998; McCown et al., 1998). It involves research to explore whether farmers and their advisers could gain benefit from tools such as soil characterisation and sampling, seasonal climate forecasts and, in particular, simulation modelling and, if so, how such tools could be delivered cost-effectively to industry.

FARMSCAPE has been based on the key elements identified in its name:

1. Close collaboration of farmers, their advisers and researchers in discovering together how best to explore management options;
2. Implementation of research on commercial farms, especially incorporating improved soil monitoring to gain better knowledge of actual soil water and nitrogen resources in individual fields;
3. Application of APSIM to exploring management options of interest to participants in interactive, co-learning 'What-if?' analysis and discussion sessions (WifADs), with the pre-requisite requirement that simulations be credible against participants' real-world experiences;
4. Broader communication of project outcomes not only through public extension activities but particularly through agribusiness client services, and
5. Continual assessment of project activities and impacts via formal evaluation processes.

As part of FARMSCAPE a number of evaluation activities have been undertaken. The following is an extract from an evaluation activity undertaken by Coutts et al. (1998):

> *"The evaluation process provided strong evidence that (FARMSCAPE) was having a positive impact on: learning within each participant group, attitudes, decision-making and practice. The eval-*

uation highlighted the complexities in the management of dryland crops and the limitations of simulation-aided decision making. However, the evaluation has shown that simulation, adequately contextualized, was valued by participating farmers and advisers in (a) gaining insights into production system function and (b) augmenting their farming experience in making judgements required in tactical responses and the evolution of improved production strategies."

FARMSCAPE has helped demonstrate that a key to farm managers in Australia valuing simulation is the positioning of these simulations in the context of their own farming situation. A simulator enables information to be specified to an individual field, its results can be tested against one's own crop performance and a simulator such as APSIM can be used to explore a range of issues of interest to participants. In Australia, a market now exists for timely and high quality interactions based on soil monitoring and simulation amongst a growing sector of the farming community.

Relevance of models to smallholder agriculture

The productivity of dryland crop production systems throughout the semi-arid tropics is of clear concern (Shapiro et al., 1999). One explanation for the apparent low incentive of farmers to invest scarce capital in soil fertility may be due to their perception of the benefits and risks associated with investments such as inorganic fertilizer. Simulation models are appropriate tools to help explore such investment options under climatic uncertainty, not only in terms of returns and risks but also future productivity. However, are such tools relevant to farmers in the semi-arid tropics?

In addressing this question, both the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and Centro Internacional de Mejoramiento de Maïz y Trigo (CIMMYT) are currently collaborating with APSRU on two projects targeted at testing the relevance of APSIM to smallholder agriculture in the semi-arid tropics–the initial focus is in both India and Zimbabwe. Both projects are aimed at using APSIM with farmers, national agricultural research systems (NARS) professionals and non-government organizations (NGOs) in the evaluation of farm management options. Accordingly, a number of on-farm case studies are being implemented as part of these projects, whereby participatory on-farm research trials are negotiated and conducted with farmers on issues identified via simulation analyses relevant to the participating farmers' own livelihood strategies.

Whether the model has a role in direct intervention with smallholder farmers is viewed differently among the researchers involved in these projects and, consequently, this question forms the basis of a researchable issue in itself. The consensus view is that APSIM may identify management options worth testing in on-farm experimentation, with the expectation that the process of identification and development of new technologies could be expedited. Some consider that it is also possible to directly engage smallholder farmers with the model in 'What if?' analysis and discussions sessions on issues of interest to them. Whether this is the case is being explored using a Participatory Action Research (PAR) methodology, where each researcher-farmer interaction involving APSIM follows an iterative cycle of *planning* the interaction, *acting* on the plans, *observing* and documenting what happens and *reflecting* on the interaction's outcomes in order to repeat the process a next time.

Conclusions

Strong argument that simulation models can have a significant role in contributing to research on nutrient efficiency in cropping systems has been presented. Four case studies were used to address the primary objective of demonstrating how models can contribute to such research. Two cases addressed issues of augmenting traditional manuring practices with fertilizer, and another two cases applied APSIM to identifying plant traits of benefit in low-input cropping systems. While these cases were innovative in addressing issues that capitalized on APSIM's emerging systems capabilities (i.e. manure, weeds, intercropping & P), the application of models in this manner is not new (see Cooper and Hammer, 1996; Muchow and Bellamy, 1991). In fact, on the issue of trait identification, some have argued that the contribution of crop physiology and modelling to plant breeding has been relatively modest to date (Jackson et al., 1996).

The second objective of questioning whether models can assist the research community in contributing to purposeful change in farming practice is really the key question. The FARMSCAPE experience with commercial farmers in Australia provides strong evidence that this can indeed be the case. The current initiatives of ICRISAT and CIMMYT will test whether the models can also contribute to improving the nutrient efficiency of smallholder farmers in the SAT.

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