Exploring Farmer Options for Maize Production Strategies via Scenario Analyses Using the APSIM Model – an Example of the Approach

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This paper reports on work emerging from collaboration amongst the following institutions:
CIMMYT
ICRISAT
APSRU/CSIRO Tropical Agriculture

This collaboration is possible through the support of AUSAID and ACIAR through the following projects:
CS1/97/38 Risk management in southern African maize systems
CS1/96/4 CARMASAT: Increasing the effectiveness of research on agricultural research management in the semi-arid tropics by combining cropping systems simulation with farming systems research.

Abstract: This report summarizes a workshop in which the APSIM (Agricultural Production Systems Simulator) farming systems model was applied to the analysis of management options critical to maize production in Zimbabwe. The modeling analysis focused on responses to investment in nitrogen fertilizer inputs, in terms of investments in timely sowing and weeding. The study evaluated a number of alternative scenarios of land, labor, and financial constraints for a farm household which were based on local information. Scenarios were established whereby the resources available could be deployed in different ways over multiple fields on the farm. In one scenario, fertilizer inputs, and weeding and plowing/sowing efforts were concentrated on a portion of the farm and the remainder was left idle. In another scenario, the resources were spread evenly over the whole farm; others involved the shifting of resources between investments in fertilizer inputs, early sowing, and more effective weeding regimes. The study was configured for a farm in Natural Region II using a Harare climate data on a shallow, infertile, sandy soil. Since the farm household constraints were very simply defined, the study needs to be repeated with more careful specification of the constraints and in other drier regions of the country. Despite these deficiencies, the study does highlight the challenges that smallholders face when investing in fertilizer inputs, and provides some direction for future on-farm research.

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1. Introduction

The overall goal of the CIMMYT-AUSAID Risk Management project is to increase the productivity and sustainability of smallholder maize-based farming systems in southern Africa by accelerating the adoption of productivity-enhancing, resource-conserving practices in rainfed, drought-prone areas. Specifically, the project aims to help farmers, extension agents, researchers, and policymakers improve their understanding of the trade-offs among different crop and cropland management strategies under scenarios of climatic risk. These objectives are also consistent with those of the related ICRISAT-ACIAR project, known as CARMASAT (Collaboration on Agricultural/Resource Modeling Applications in the Semi-Arid Tropics).

The project's goal cannot be met by direct experimentation alone. The farming systems are complex in terms of crop and soil management options, and are highly variable in space and time. For these reasons, the project comprises a modeling dimension to better equip researchers in dealing with issues of complex biophysical interactions, high soil and climatic variability, and long-term consequences of soil management strategies. The APSIM (Agricultural Production Systems Simulator) model is being used because of its ability to deal with the complex interactions between climate, soil fertility, and crop and residue management. APSIM has been widely evaluated under low-input farming systems in Australia, India, Kenya, and (as a component of current activity with CIMMYT and ICRISAT, and NARS collaborators) in Malawi and Zimbabwe. Information on model performance will be made available through other papers in this working paper series (e.g., Robertson *et al.* 2000) and in other reports (e.g., Shamudzarira *et al.* 1999; Keating *et al.* 1999).

In this paper, we report on recent experiences in "scenario analysis" using the APSIM model. These experiences centered on a joint ICRISAT/CIMMYT Modeling Workshop, supported by APSRU (Agricultural Production Systems Research Unit) and held in Bulawayo, Zimbabwe, in September 1999. The scenario analyses explored some issues of maize crop management from a somewhat novel perspective, certainly with respect to simulation modeling. Traditionally these models have been deployed to answer questions about "what is optimal?", for instance, with respect to fertilizer rates, planting time, weeding, etc. In these scenario analyses, we focused more on "what is possible?", with regards to farmer management of multiple fields with tightly constrained resources of labor and capital. The specifications given to the teams are reproduced in Appendix 1. This working paper reports on the analyses undertaken by one of the teams.

This paper is intended to report on the approach used and provide an overview of the insights that might be gained from this form of model application. The specification of farmer circumstances was crude, to say the least, and the scenario analysis needs to be repeated with more carefully specified constraints and resources. Data being gathered in diagnostic studies of farmer circumstances (e.g., resource flow mapping activities) could contribute to more accurate specification of these scenarios in future work.

2. Methods

The scenario analysis began with the session organizers specifying a farming situation and challenging the modeling teams (researchers and extension staff from a diverse range of disciplines) to develop alternative scenarios in terms of resource allocation and other farm management decisions. The idea was to explore tradeoffs between production and risk. Different teams focused on different regions and there was considerable flexibility in how teams chose to develop their scenarios. This paper reports on the work of Team 4, who chose to explore a range of scenarios for maize production in the wetter zone Natural Region II of Zimbabwe.

2.1 Soil type and climate

The soil type was an infertile shallow sand. The parameters used to characterize this soil in terms of water holding capacity, run-off and nutrient status are outlined in model ready form in Appendix 2. Long term monthly rainfall totals for Harare, 1951-1991, are shown in Figure 1. Daily climate information (maximum and minimum temperature, solar radiation and rainfall) were used in the simulation exercise.

2.2. Farm specifications

The hypothetical farm used in the simulations had four equal-sized fields. Labor and oxen for land preparation were limited; only one field could be prepared (approximately) every 20 days from 15 October each year. Accordingly, planting dates for the different fields were 15 Oct, 5 Nov, 25 Nov, and 10 Dec. The farm had a "base" fertilizer supply of two (50 kg) bags of N fertilizer, supplying a total of 35 kg N. Funds for an extra two bags of fertilizer were available and the farmer could choose whether to use these funds for fertilizer or another purpose. The farm only had sufficient in-house labor resources to weed two of the four fields and this took place approximately 20 days after sowing. The farmer could choose to purchase additional labor for weeding or land preparation, but this was competitive with the decision to buy additional N fertilizer. The simulations assume that N was the only constraining nutrient; a major and often unjustified assumption that will be revisited in the discussion.

2.3. General crop management

Maize cultivar SC501 was used in the simulations at a plant density of 3 plants/m^2. Planting was simulated to take place as soon as possible after the dates listed above, but not before there had been 40 mm of rain over a five-day period. The first fertilizer application (if present) took place seven days after sowing. The second side-dressing (if present) took place 28 days after sowing. A moderate level of short statured (max. height 20 cm) weed species (non N fixing) was assumed to germinate at the same time as the maize.

2.4. Simulations

Six scenarios were established, as outlined in Table 1. APSIM was run without re-initialization over a 10-year period (1981-1991) of the weather file. Any aboveground residue was incorporated at sowing. Output from each field in each scenario was transferred to a database and whole farm production was calculated by summing the outputs of the four fields.

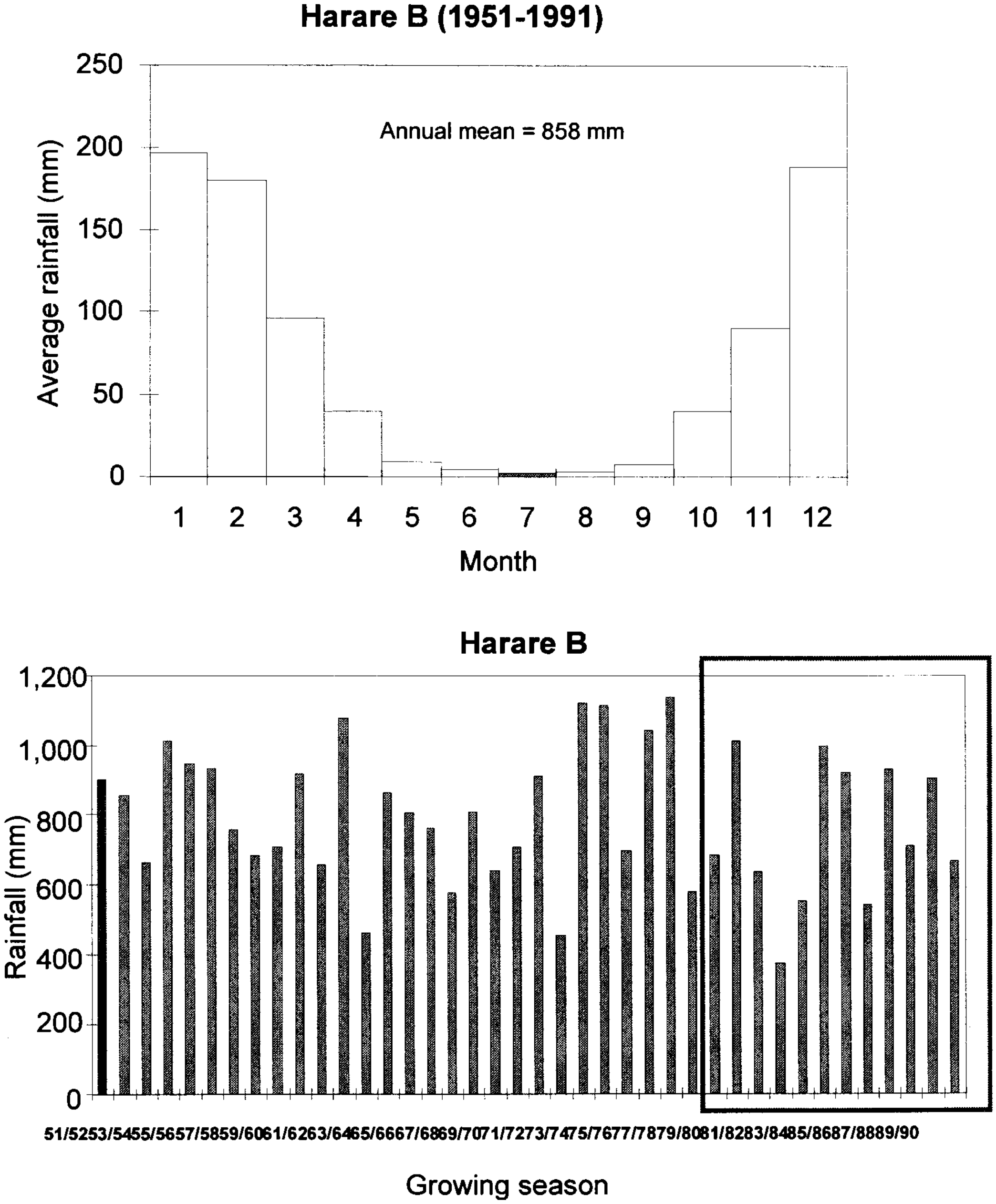


Figure 1. Rainfall details for Harare, 1951-1991. (a) Mean monthly totals (long term) and (b) annual totals. Note: To speed up the simulation analysis, the rainfall record was restricted to 1981-1991, as highlighted in Figure 1b.

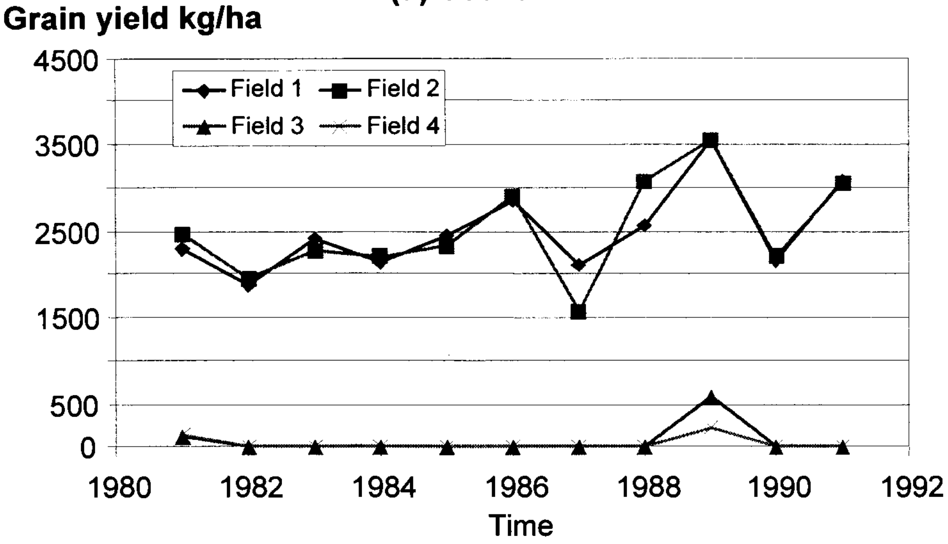
Table 1. Summary of the six scenarios examined in the modeling study

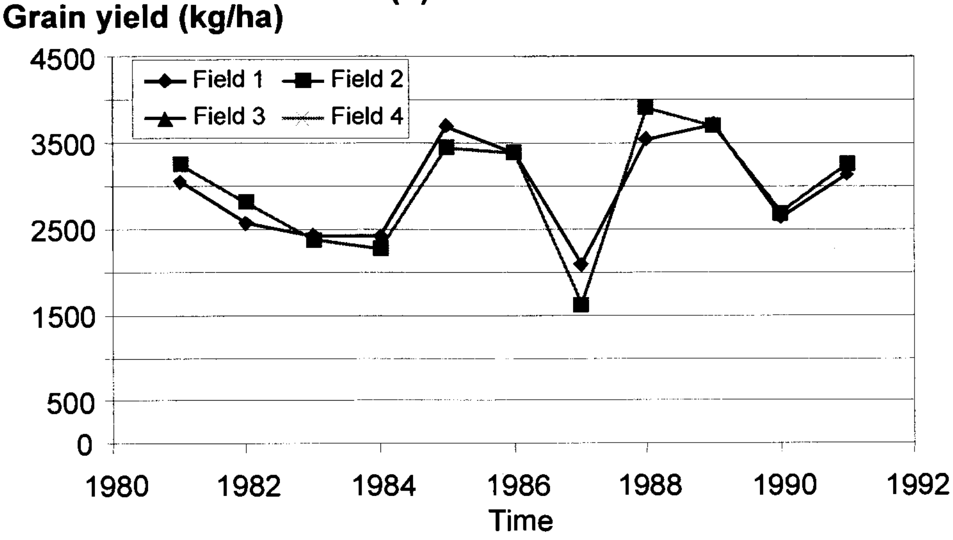
Scenario	**Name**	**Details**
1	"Expected" good farmer practice	• Sow: 4 fields (15 Oct, 5 Nov, 25 Nov, 10 Dec) • Fertilizer: Base 35 N on field 1, split at 7 and 28 days • Fertilizer: Extra 35 N on field 2, at 7 and 28 days • Weed: Fields 1 and 2 only, at 20 days
2	Concentration strategy	• Sow: 2 fields (mid Oct, early Nov) • Fertilizer: Purchase 2 extra bags from weeding and plowing resources not invested in fields 3 and 4 • Fertilizer: 52.5 kg N on fields 1 and 2, each split 50% at 7 and 28 days
3	"Extensive" strategy	• As per Scenario 1 but spread fertilizer to 4 fields • Fertilizer: 17.5 kg/ha N applied once, at 14 days • Weed: Fields 1 and 2 only, at 20 days after sowing
4	Sell fertilizer and invest in more weeding	• Sow: As per Scenario 1 • Fertilizer: 35 kg N applied to field 2 only • Weed: All fields weeded at day 20
5	Sell fertilizer and invest more in early planting	• Sow: Field 1 (15 Oct), Fields 2, 3 and 4 (5 Nov). • Fertilizer: 35 kg N applied to field 2 only • Weed: As per Scenario 1
6	"No-cares" strategy	• Sow all fields late to mid Dec • Sell fertilizer and buy and drink chibuku • Late topdressing with only 2 bags applied to field 1 (35 kg/ha N) • No weeding due to illness

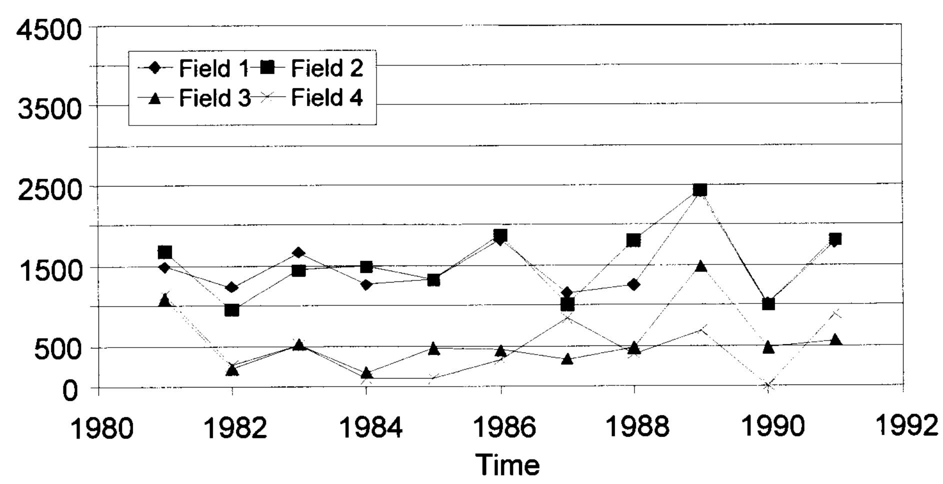
3. Results and Discussion

Simulated maize grain yields for each of the four fields in all six scenarios are shown in Figure 2 (a-f respectively). Note the limited year-to-year variation due to the generally favorable climate in Natural Region II and also to the moderately-to-strongly limited supply of N in all systems.

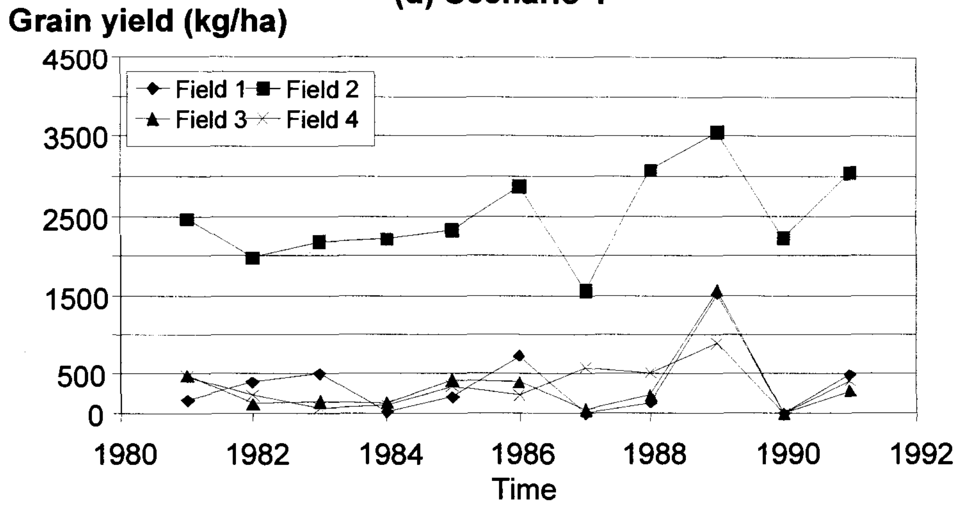
Also note in Figure 2 the large differences in yield simulated for the different fields. The soil selected for the study is very low in N, hence, in the absence of N fertilizer inputs, yields are low (e.g., 300-600 kg/ha). When weeds are also present and the crop is planted late, the N supply constraint is extreme and, in many years, no grain yields are predicted by the model. In contrast, grain yields of 2,000-4,000 kg/ha are simulated in situations of early planting, good weed control, and moderate levels of N fertilizer input (e.g., Scenario 2, Figure 2b).


(a) Scenario 1

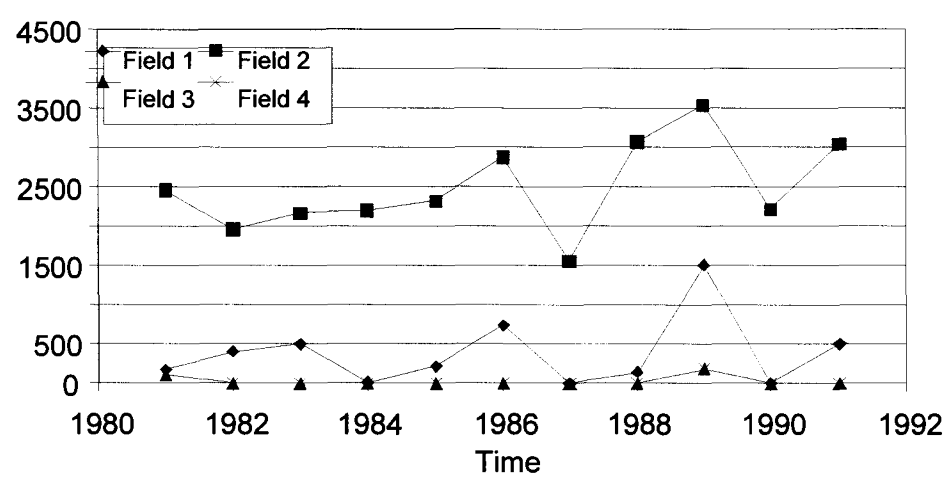

(b) Scenario 2


(c) Scenario 3

(d) Scenario 4



(e) Scenario 5



(f) Scenario 6

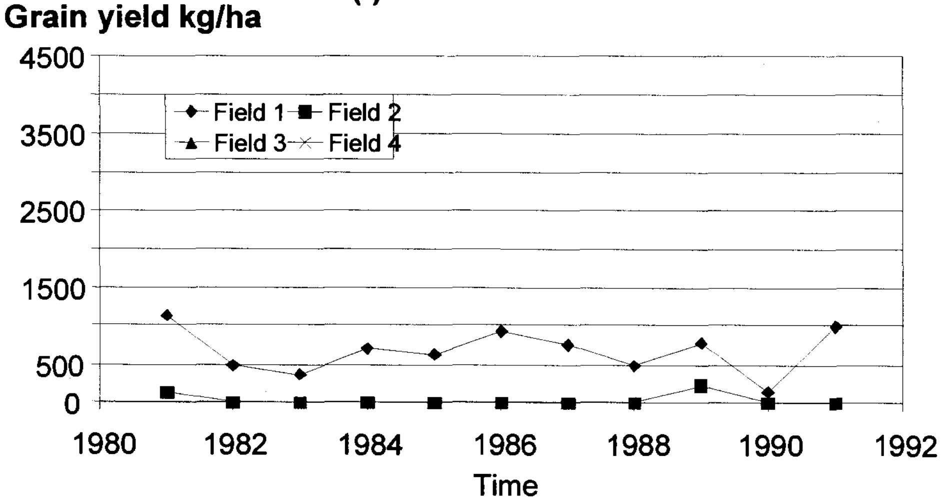


Figure 2. Maize grain yields simulated by APSIM for Scenarios 1 to 6.

Gross margins were calculated on the basis of whole farm grain production less the costs of fertilizer purchased (Figure 3). While a more comprehensive economic analysis is warranted, there is an obvious separation between the economics of Scenarios 1-5, which include N fertilizer inputs and weeding on at least some fields, and Scenario 6, the "no-cares" scenario, which was included as a "worst case" reference point. Among the more serious scenarios, 1 and 2 gave the best average returns (Figure 4) and neither involved high levels of variability (Figure 3). It is worth noting that Scenario 2 involved leaving half the cropping land fallow. This strategy of concentrating fertility and labor resources is worthy of further investigation. There may be household or cultural considerations that limit its acceptability. For instance, in some situations, land tenure may be put at risk by not sowing all of the cropping land to food crops.

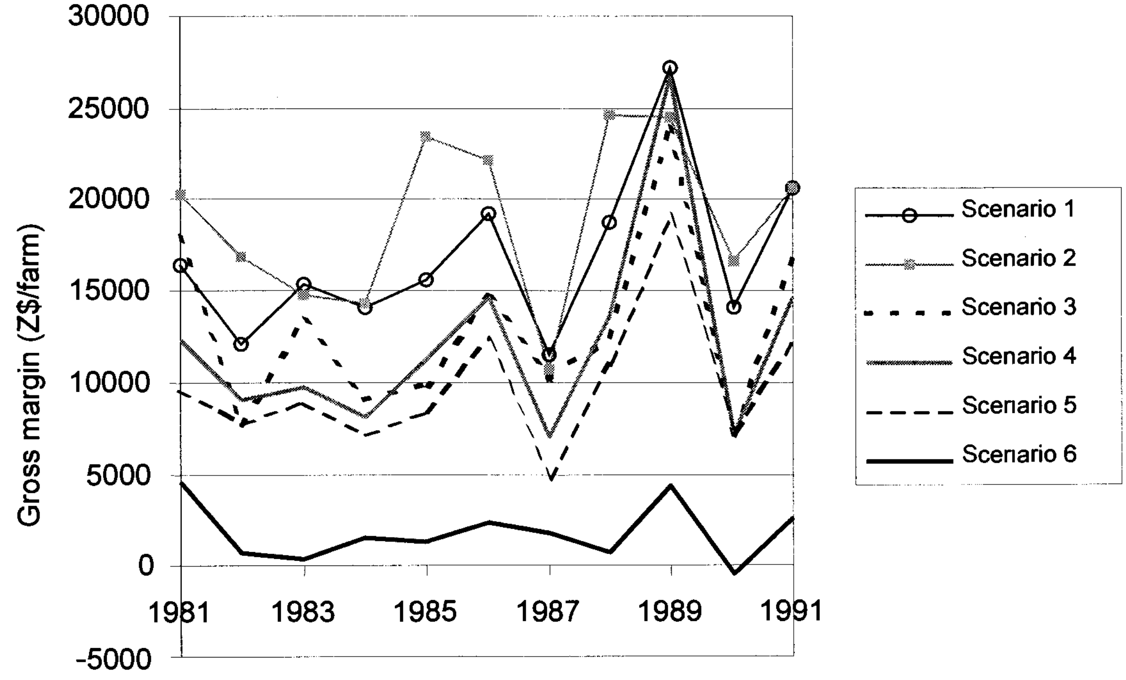


Figure 3. Time trends in estimated gross margins at the farm level (sum of four fields) for the six scenarios. Gross margins calculated on value of maize at Z$3.70/kg and N fertilizer at Z$29/kg. No other fixed or variable costs were considered.

4. Conclusions

This study was intended to open up new perspectives of how simulation models can assist the thinking on the options available to resource-constrained smallholders. There should be value in talking with farmers and extension staff on the issues raised in this study. There is an ongoing need to "reality check" the outputs of the models and, in particular, consider the implications of on-farm constraints not captured in these models. Soils in some regions are deficient in multiple nutrients or are sufficiently acid to affect crop nutrition and growth.

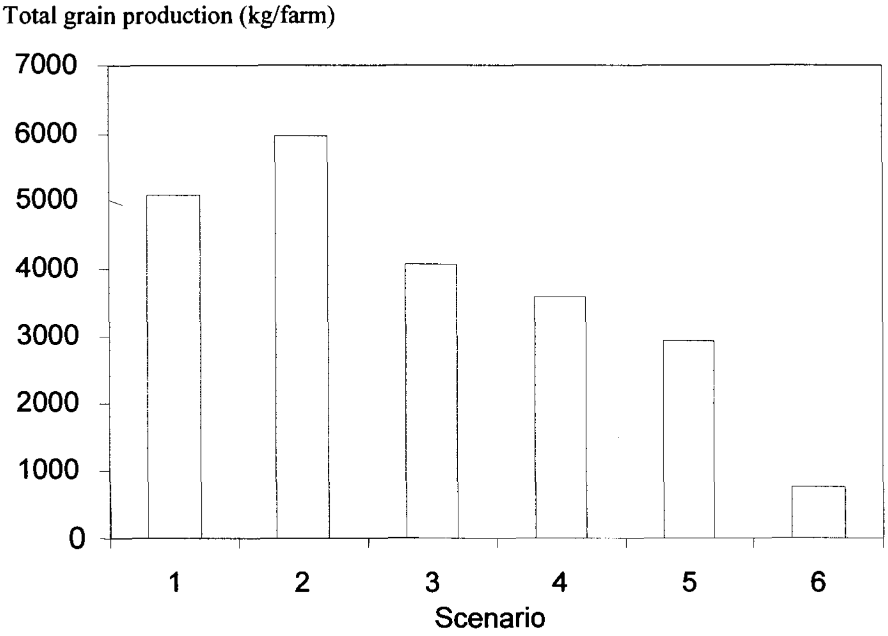


Figure 4. Average grain production for the six scenarios, expressed in terms of kg of maize grain per farm (4 ha of cropping) per year.

We have focused solely on N inputs, and while N is clearly one of the most important soil fertility constraints, it may not be the only soil factor in need of amendment. The cost and availability of liming, manuring, or applying compound fertilizer products need to be factored into these analyses.

This study highlights the importance of matching fertilizer inputs with other good agronomic practices, most notably early sowing and good weed control. The models suggest that fertilizer responses of around 40 kg grain per kg N fertilizer should be possible with fertilizer rates of 20-40 kg/ha N. Other reports (e.g., Shamudzarira *et al.* 1999) demonstrate that similar responses are regularly achieved on-station and sometimes on-farm, but often the on-farm responses are lower. The constraints examined in these scenarios, namely late planting and poor weeding, are important examples of why poor N responses are sometimes observed on-farm. Other soil fertility constraints, such as acidity and deficiencies in P, multiple cations, and micro-nutrients, will also sometimes contribute to poor N responses.

With fertilizer/maize price rations in Zimbabwe approaching 10:1 (i.e., price of N fertilizer per kg is 10 times the maize market price), farmers need to achieve response efficiencies well above this level for the investment to pay off. Farmers who achieve fertilizer response efficiencies in the order of 40:1 (i.e., produce an extra 40 kg grain per kg of N applied) should be well disposed to investing in fertilizer, but where response efficiencies of only 10-20 are being achieved, fertilizer is a far less attractive option.

Measuring fertilizer response efficiencies on-farm and exploring reasons for variation in responses with farmers seem to be important activities resulting from these modeling studies.

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Appendix 1. Specifications for the scenario analyses given to workshop participants.

Consider a situation in which a group of researchers (with modeling tools) have an opportunity to explore a set of on-farm management issues with a group of smallholder farmers.

Initial discussions with farmers reveal:

- Farm size: 5 ha
- Family details: female-headed household, 4 children
- Cropping area: 4 ha
- Main crops: maize, sorghum, and groundnut
- Moderate level of weed pressure
- Grazing area: 1 ha (3 cattle)
- Soil: shallow infertile sand

The focus of the interaction is soil fertility management. Two bags of fertilizer (AN containing 35 kg N) is available. This is valued at $700.

Consider how this could be used. Options include:

1. Maize vs. sorghum.
2. Spread over whole farm or concentrate on some fields.
3. Apply all at planting or split in some way.
4. Sell fertilizer (value $350) and use funds to enable early weeding.
5. Sell fertilizer and use funds to buy plowing services, and crop planted earlier (see below).

Other choices:
Teams to decide on cultivars, plant density, sowing windows (constraint on timeliness of planting.

Timeliness of planting constraint:
With no additional resources, it takes four rainfall opportunities (2 months?) to sow all of the farm's cropping area. With additional resources, the 4 ha can be planted in two rainfall events (1 month?).

Questions:

- Identify some feasible investment options and describe the benefits from these options?
- How risky are the investment options? How often will they provide zero or negative returns?
- What options to reduce risks (e.g., using rainfall patterns to direct fertilizer inputs)?
- What constraints might limit the farmer's ability to implement the investment options?
- What should be the next steps for research and extension?
- What communication strategies might be deployed to explain the results to farmers?

Data:
Maize price = Z$3.50 per kg
Sorghum price = Z$3.00 per kg
N fertilizer price = Z$350 per 50 kg bag of ammonium nitrate (35% N)
Updated to Z$500 per bag to reflect current prices at the time of report preparation, January 2000).
Weeding labor = $35 per day (1 ha requires 10 days)
Plowing services = $350 per ha

Include baseline scenario: No fertilizer, sell fertilizer and use for school fees.
In wetter areas, use two bags of fertilizer in baseline scenario.

Appendix 2. APSIM parameter files outlining physical and chemical characteristics of the infertile shallow sand used in the scenario analysis.

Soil water parameters.

Depth (mm)	Air_Dry (mm/mm)	LL15 (mm/mm)	DUL (mm/mm)	SAT (mm/mm)	SW (mm/mm)	BD (g/cc)	Runoff (wf)	SWCON
0-150	0.030	0.040	0.140	0.440	0.050	1.431	0.762	0.700
150-300	0.070	0.070	0.150	0.450	0.078	1.420	0.190	0.700
300-450	0.090	0.130	0.200	0.450	0.137	1.418	0.048	0.700
450-600	0.090	0.130	0.200	0.400	0.137	1.546	0.000	0.700
600-750	0.090	0.180	0.220	0.400	0.184	1.551	0.000	0.700
750-1,000	0.090	0.220	0.240	0.380	0.222	1.610	0.000	0.700

Soil water holding capacity.

Depth (mm)	Unavailable (LL) (mm)	Available (SW-LL) (mm)	Max avail. (DUL-LL) (mm)	Drainable (SAT-DUL) (mm)
0-150	6.00	1.53	15.00	45.00
150-300	10.50	1.22	12.00	45.00
300-450	19.50	1.07	10.50	37.50
450-600	19.50	1.07	10.50	30.00
600-750	27.00	0.61	6.00	27.00
750-1,000	55.00	0.51	5.00	35.00
Totals	137.50	6.00 5	9.00	219.50

Insoil	Salb	Dif_Con	Dif_Slope
0.10	0.20	250.00	22.00

Runoff is predicted using scs curve number:

Cn2	Cn_Red	Cn_Cov	H_Eff_Depth (mm)
85.00	20.00	0.80	450.00

Cuml evap (U): 8.00 (mm^0.5)
CONA: 3.50 ()

Soil profile properties.

Layer	pH	OC (%)	NO_3 (kg/ha)	NH_4 (kg/ha)	Urea (kg/ha)
1	6.00	0.40	1.07	0.54	0.00
2	6.00	0.40	0.53	0.53	0.00
3	6.00	0.20	0.53	0.53	0.00
4	6.20	0.20	0.58	0.46	0.00
5	6.50	0.20	0.35	0.47	0.00
6	6.70	0.20	0.60	0.81	0.00
Total			3.67	3.33	0.00

Initial soil organic matter status.

Layer	Hum-C (kg/ha)	Hum-N (kg/ha)	Biom-C (kg/ha)	Biom-N (kg/ha)	FOM-C (kg/ha)	FOM-N (kg/ha)
1	8,436.0	581.8	150.0	18.8	62.8	1.4
2	8,453.2	583.0	66.8	8.4	40.1	0.9
3	4,238.3	292.3	15.7	2.0	25.5	0.6
4	4,633.4	319.5	4.6	0.6	16.3	0.4
5	4,650.7	320.7	2.3	0.3	10.4	0.2
6	8,049.2	555.1	0.8	0.1	4.9	0.1
Total	38,460.7	2,652.5	240.3	30.0	160.0	3.6