Simulating Nitrogen Fertilizer Response in Low-Input Farming Systems of Malawi

1. Validation of Crop Response

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Abstract: This paper reports on the validation of the Agricultural Production Systems Simulator (APSIM) model for simulating the response of maize to N fertilizer in low-input maize production systems in Malawi and Zimbabwe, with a special focus on the marginal benefit from using small amounts of fertilizer, rather than applying it at optimal rates. In 1998/99, in experimental plots where no N fertilizer was applied, yields varied from 442 to 4,800 kg/ha across 5 sites. The model simulated yields in the range of 1,277-4,784 kg/ha for the same locations. Actual response to 69 kg/ha of applied N varied over the 5 experimental sites chosen for the validation exercise using data for 1997/98 and 1998/99. The model accurately simulated a response to applied N at four of the five trial sites selected for the validation test.

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1. Introduction

Whereas simulation models have been used to explore issues of nitrogen fertilizer response in high-input agriculture, the approach has received less attention in low input situations, such as those found on most smallholder farms in Africa, particularly in semiarid areas. We are exploring the application of the Agricultural Production Systems Simulator (APSIM) model to questions of N fertilizer response in low-input maize production systems in Malawi and Zimbabwe, with a special focus on the marginal benefit from using small amounts of fertilizer, rather than applying it at optimal rates. This paper reports on the validation of the APSIM cropping systems model for simulating the response of maize to N fertilizer.

2. Materials and Methods

2.1. Sites, soils, and crop management

In 1997/98, the response of maize to four rates of applied N (0, 35, 69, 92 kg/ha as urea) was assessed at Chitedze Research Station, Malawi. The site had previously been under fertilized maize. In 1998/99, another experiment was carried out at Chitedze and an additional four sites (Table 1). The location of sites within Malawi is shown in Figure 1. The 1998/99 experiments used two rates (0 and 69 kg/ha) of N applied as urea. The five sites were designed to cover a range of agro-ecological environments in Malawi. Cropping history varied among sites (Table 1). At all sites, basal nutrients of P and S were applied at 21 kg/ha and 4 kg/ha, respectively.

Table 1. Sites where N response experiments were conducted in Malawi.

Location	Latitude and longitude	Elevation (masl)	Agro-ecology	Land use history	Soil type	In-crop rain (mm)
Chitedze RS	-13.97 33.64	1,150	Midaltitude plateau	Fertilized maize	Sandy clay loam	966
Chitala	-13.68 34.27,	600	Lakeshore plain	Fertilized maize	Sandy clay loam	1,178
Chitedze RS	-13.97 33.64	1,150	Midaltitude plateau	Sweet potatoes	Sandy clay loam	1,299
Lisasadzi	-13.17 33.51	1,100	Midaltitude plateau	Fertilized maize	Sandy loam	838
Makoka	-15.53 35.21	1,030	Midaltitude plateau	Pigeon peas	Sandy clay loam	1,148
Ngabu	-16.48 34.73	100	Lower shire valley	Pigeon peas	Sandy loam	1,005

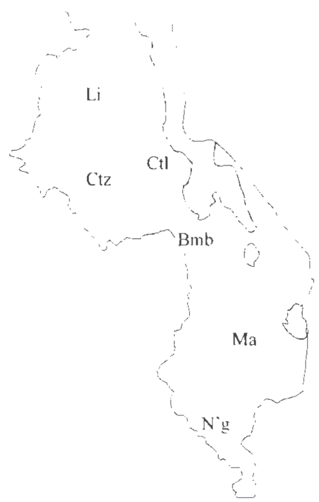


Figure 1. Geographic location of sites within Malawi.

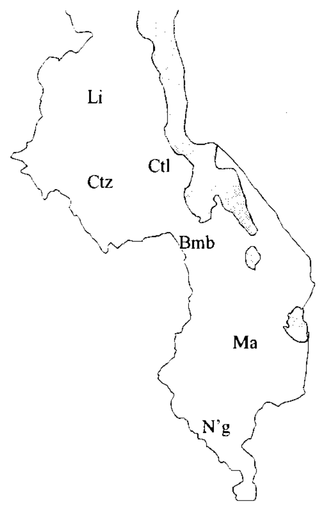
In both sets of experiments, plots comprised nine 9 m rows spaced 0.9 m apart. One seed was planted every 0.25 m to achieve a target population of 4.44 plants/m^2. There were two replications in the 1997/98 experiment and three replications in the 1998/99 experiment. In both sets of experiments, the cultivar used was MH18, a short-to-medium duration, semi-flint hybrid suited to the low altitude areas of Malawi but popular throughout the country. Fertilizer was applied as a basal dressing prior to sowing and as a topdressing five weeks after emergence. At some sites establishment was poor, so attempts were made to fill gaps in the crop stand with pre-germinated seedlings. This was not always successful in achieving the target density, however, so the plant count at the anthesis biomass sampling was used to determine the final established plant population. Weeds were controlled by hand.

2.2. Measurements

Prior to sowing, two or four auger holes 180 cm deep were made in each plot to determine soil water content, soil texture, and levels of nitrate, organic carbon, and phosphorous. Samples were analyzed in increments: 0-15, 15-30, 30-60, 60-90, 90-120, 120-150, and 150-180 cm. A pit was dug adjacent to each site to determine bulk density.

Observations were made on when 50% of the maize plants in each plot had flowered and when the crop had reached physiological maturity (black layer formation). Biomass, biomass components, and the number of plants close to anthesis were measured from a quadrat of 1 row x 7 m (6.3 m^2). Final grain yield and biomass were calculated from a quadrat of 5 rows x 7m (31.5 m^2). A subsample of every fifth maize plant, when arranged from smallest to largest, starting at the second smallest plant, was taken to observe partitioning into the leaf and stem.

To account for grain yield loss from the termites present at certain sites, consumed cobs were counted and classified into general size categories of large and small. Grain yield was then adjusted using standard grain weights for each large or small missing cob. At



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Chitedeze in 1997/98, some cobs were stolen before harvest, so a similar correction method was applied by assuming that all stolen cobs were large. Climatic data (daily minimum and maximum temperature, rainfall, and solar radiation) were recorded as close to each site as possible. In some instances where solar radiation could not be recorded, sunshine hours were converted and substituted.

2.3. Simulation setup

To simulate the experiments, the APSIM-Maize module was linked with the soil water module SOILWAT, the soil nitrogen module SOILN, and the surface residue module RESIDUE (Probert *et al.* 1997). The genetic coefficients for MH18 have been determined by Dr. A. du Toit at Potchefstroom Agricultural Research Station, South Africa, for the CERES-Maize model. The genetic coefficients for the two models are similar and hence can be converted for use with APSIM.

The initial soil nitrate values determined from pre-sowing sampling at each site did not fit expectations. Following a sensitivity analysis, it was determined that this was most likely due to either a sampling or laboratory error. Nitrate profiles were substituted, these values were two to four times lower than the values determined by the laboratory. Due to the uncertainty in the precise initial values for soil nitrate, the nil fertilizer treatments was used as a calibration standard i.e. the initial soil nitrate values used in the model run were changed until the simulated yield was close to the observed yield. The model was then tested for its ability to simulate the yield of the fertilized treatment; i.e., response to inputs of N. This approach was considered valid, since the aim of the study was to assess the simulation of N response, rather than the yield, under pre-defined conditions.

While initial values for soil water, bulk density, and organic carbon (Table 2) were available from pre-sowing soil samples, detailed characterization of the drained upper (DUL) and lower limit (LL) of plant available water in each soil layer was not determined. Consequently the DUL and LL values had to be derived as follows. Soil samples taken per sowing after the dry winter season are indicative of LL. Soil texture was used to gauge the difference between DUL and LL, using the relationships developed by Ratcliff et al. (1983). It was assumed that, at each site, maize roots were able to reach a depth of 180 cm, since pH (Table 2) and bulk density measures did not indicate any likely constraints to root exploration above this depth.

Table 2. Organic carbon (OC, %) and pH levels by depth at each site in Malawi.

	Chitala		Lisasadzi		Chitedeze		Ngabu		Makoka	
Layer (cm)	**OC**	**PH**	**OC**	**pH**	**OC**	**pH**	**OC**	**pH**	**OC**	**pH**
0-15	0.99	5.30	0.24	6.10	2.68	5.27	1.33	7.30	0.68	5.10
15-30	1.17	5.30	0.33	5.90	2.58	5.13	1.47	7.23	0.68	5.13
30-60	0.67	5.73	0.09	5.50	1.60	5.47	1.00	7.83	0.27	5.50
60-90	0.73	6.00	0.08	5.60	1.12	5.57	0.81	7.93	0.07	5.67
90-120	0.60	6.33	0.06	5.57	0.56	5.70	0.92	7.90	0.05	5.77
120-150	0.35	6.73	0.04	5.63	0.55	5.80	0.93	7.87	0.05	5.73
150-180	0.57	6.97	0.07	5.73	1.28	5.87	0.92	7.90	0.03	5.83

Weather data were measured at each site. Management information (sowing date, established plant population, timing and amount of fertilizer application) were also used as model inputs (Table 3). Simulations were run from the date of pre-sowing soil sampling until the observed date of maize physiological maturity.

Table 3. Key agronomic information for the N response experiments in Malawi.

Location	Sowing date	Anthesis date	Harvest date	Topdressing date	Initial NO_3 (kg/ha)*	Plant pop'n density (plants/m^2)
Chitedze	19/11/97	26/1/98	7/4/98	23/11/97	27	3.7
	27/11/98	8/2/99	10/5/99	6/1/99	47	4.4
Chitala	5/12/98	10/2/99	29/4/99	27/1/99	12	0.8 (UF), 1.8 (F)
Lisasadzi	1/12/98	1/2/99	27/4/99	20/1/99	8	2.7
Makoka	8/12/98	7/2/99	5/5/99	12/1/99	26	4.2
Ngabu	17/12/98	9/2/99	15/4/99	14/1/99	34	4.0

* Calibrated input to achieve agreement between observed and simulated grain yield in the nil fertilizer treatment.
UF = unfertilized; F = fertilized.

3. Results

3.1. Observed response to applied N

In 1997/98, the crop at Chitedze showed a marked response to applied N (Figure 2). Yields varied from 4,742 kg/ha at zero applied N to 6,500-7,000 kg/ha at rates of above 69 kg/ha. APSIM simulated this response to N as well as the response of biomass at maturity. Observed and simulated agronomic responses to N at 69 kg/ha were 32 and 29 kg/kg, respectively, and at 92 kg/ha rate were 20 and 22 kg/kg, respectively.

In 1998/99, soil fertility varied widely over the sites (Table 2). For instance, levels of organic carbon in the 0-15 cm layer varied from 0.24% at Lisasadzi to 2.68% at Chitedeze. These levels were confirmed independently at CIMMYT, Mexico (P. Grace, personal communication). The high levels of organic carbon at some sites were thought to be caused by charcoal in the soil profile.

In plots where no N fertilizer was applied, yields varied from 442 kg/ha at Lisasadzi to 4,800 kg/ha at Chitedze (Table 4). This variation could not be explained by significant drought stress, given that preliminary simulations using APSIM indicated sufficient rainfall at all sites (Table 1). Although plant density varied among sites (Table 3), the calculated 10-fold variation in grain yield was probably due to site-to-site differences in soil N supply.

Response to 69 kg/ha of applied N also varied over the sites. The best response was observed at Chitala (2,682 kg/ha) and the worst was at Ngabu (678 kg/ha), which corresponded to agronomic responses of 38.9 and 9.8 kg of grain per kg of N, respectively

(Table 4). The poor response observed at Ngabu was difficult to explain. Rainfall had been adequate. Similarly, the density of 4.0 plants/m^2 should not have limited yield to a comparatively low 4,984 kg/ha at 69 kg/ha of applied N, particularly as the yield at zero applied N was 4,306 kg/ha. A large rainfall event in early crop growth may have leached much of the fertilizer; however, similar rainfall events were experienced at other sites where quite good responses to fertilizer were obtained.

At three of the five sites, agronomic responses of more than 30 kg grain per kg N applied were achieved.

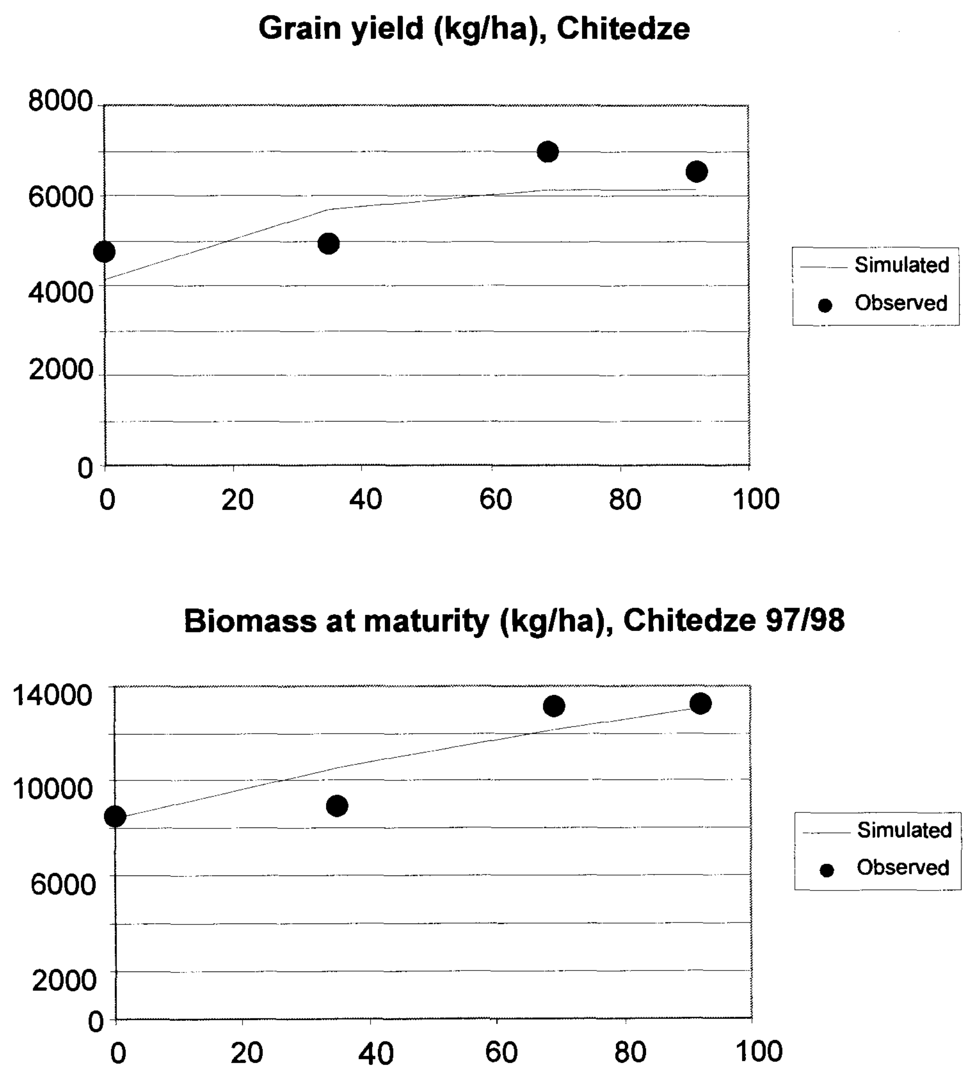


Figure 2. Observed and simulated responses of grain yield and mature biomass to N fertilizer, Chitedze, 1997/98.

Table 4. Observed and simulated maize grain yield, response to applied N, agronomic response, and total biomass in unfertilized and fertilized treatments, Malawi, 1998/99.

		Grain yield (kg/ha)		Response to N (kg/ha)		Agronomic efficiency (kg grain/kg N)		Total biomass (kg/ha)	
Location	N applied (kg/ha)	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.
Chitala	0	803	1,256	2,684	1,647	38.9	23.9	2,232	1,905
	69	3,487	2,903					6,936	4,847
Chitedze	0	4,800	4,784	1,652	2,173	23.9	31.5	7,621	9,927
	69	6,452	6,956					10,931	13,219
Lisasadzi	0	442	1,277	2,477	2,555	35.9	37.0	1,311	2,681
	69	2,919	3,832					5,822	6,955
Makoka	0	2,319	2,520	2,300	3,006	33.3	43.6	6,812	5,749
	69	4,619	5,526					11,532	10,614
Ngabu	0	4,306	4,420	678	1,215	9.8	17.6	8,327	7,942
	69	4,984	5,636					10,487	10,305

3.2. Simulation of response to applied N

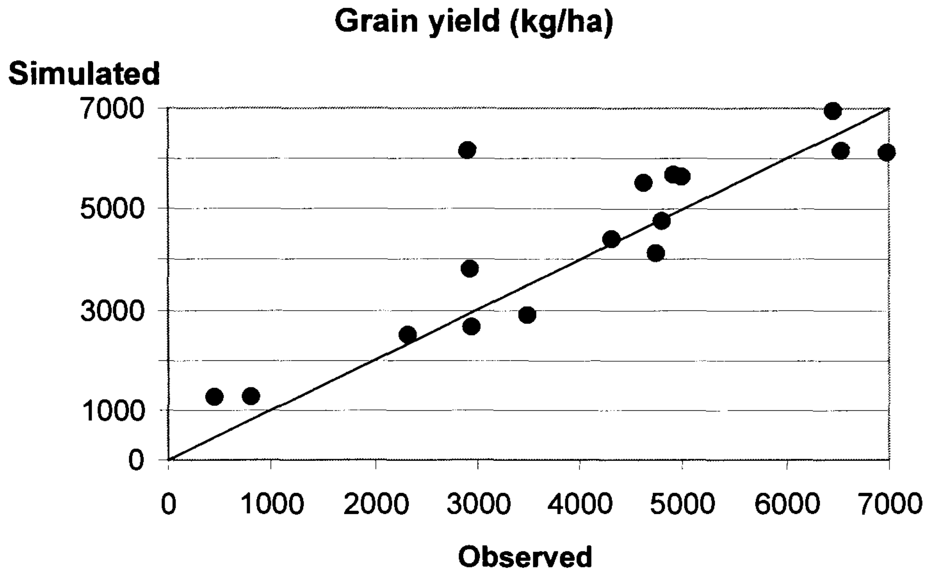
For an accurate simulation of yield response to N fertilizer, the model must adequately account for associated crop growth and development factors. Crops were sown during 27 November-17 December, but flowered within a narrow window of 1-9 February. Weather varied over the study area, with the lowland sites having a mean daily temperature of 26-28°C between sowing and silking, compared with 22-24°C at the remaining midaltitude sites (Table 5). Differences in temperature were reflected in flowering dates; e.g., flowering occurred first at Ngabu, a lowland site. At Chitala, the other lowland site, flowering occurred at about the same time as at midaltitude sites, because poor early-season rain delayed emergence and flowering. Thus, the model predicted an earlier flowering date than that observed. Delayed emergence due to dry conditions is difficult to simulate because of the need to accurately simulate soil water conditions in the thin zone of soil around the seed and the elongating seedling.

Table 5. Observed and simulated maize phenology at five sites in Malawi, 1998/99.

Location	Sowing date	Date of silking: Observed Date	Observed DAS*	Simulated	Mean daily temp sowing to silking (°C)
Chitedze	27/12/98	5/2/99	70	8/2/99	22.8
Chitala	5/12/98	7/2/99	64	27/1/99	26.6
Lisasadzi	1/12/98	1/2/99	62	2/8/99	23.7
Makoka	8/12/98	9/2/99	63	12/2/99	23.1
Ngabu	17/12/98	9/2/99	54	6/2/99	28.0

*Days after sowing.

It was possible to vary the initial soil nitrate values so that the model simulated the productivity of the nil fertilizer treatments reasonably accurately (Table 3). However, it was difficult to calibrate soil N supply low enough to achieve the low yield measured at Lisasadzi. Calibrated initial soil nitrate values varied from 8 kg/ha at Lisasadzi to 47 kg/ha at Chitedze in 1998/99. The model accurately simulated the response to applying 69 kg/ha N. The exception was at Ngabu, where the poor response observed was difficult to explain. Figure 3 shows the observed vs. predicted plot for grain yield and biomass at maturity for 1997/98 and 1998/99. These plots include the yields that were used to "calibrate" the soil nitrate values and so are not an independent test of the model.



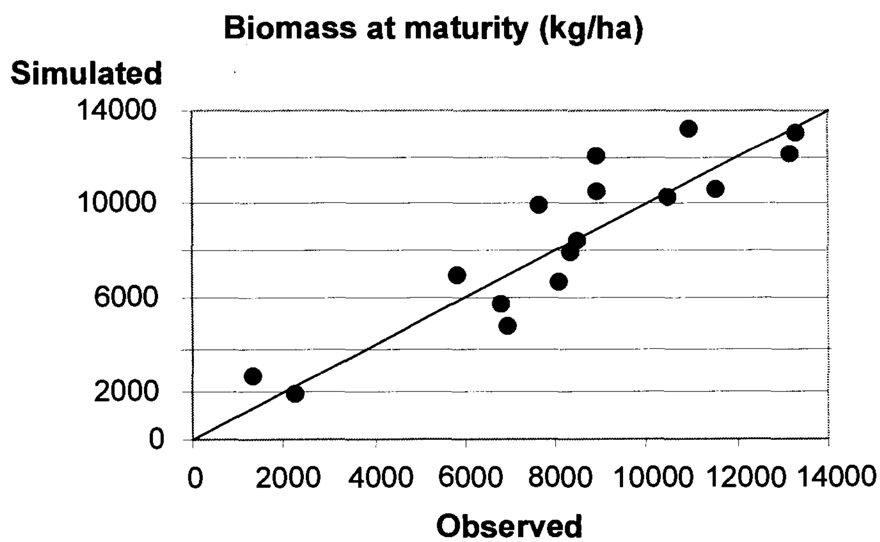


Figure 3. Observed and simulated grain yield and maturity biomass for the N response experiments, Malawi, 1997/98 and 1998/99.

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