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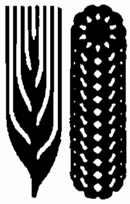

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Response of Four Maize Varieties to Nitrogen at Lisungwi Extension Planning Area, Mwanza, Malawi

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Introduction

Lisungwi Extension Planning Area (EPA) in Mwanza Rural Development Project (RDP) has insufficient rainfall for optimum maize growth (Figure 1). The soils are generally low in organic matter, nitrogen, phosphorus, and magnesium. Farmers in this area grow cotton for sale and use the money realized from cotton sales to buy maize. In the past, Blantyre Agricultural Development Division (ADD) Management Unit offered no credit package for maize in this area, as it was thought that farmers would not produce enough additional maize to pay back the loan. On the initiative of the Blantyre ADD adaptive research team, a survey was conducted to monitor the farming systems of the area and assess farmers' opinions of producing maize as a staple food.

The survey confirmed the ADD Management Unit's findings that farmers grow cotton for sale. However, it was also found that many farmers from areas such as Thyolo, Blantyre Central, Blantyre North, and Chiradzulu have migrated to Lisungwi. These farmers have been growing maize for a long time and were interested in a maize credit package.

Objectives

This study was undertaken to evaluate the performance of four maize varieties and determine the response of these varieties to increasing levels of nitrogen.

Materials and Methods

There were four experimental sites in Lisungwi EPA, located at Kandoje and Waiyatsa (1986-87 season), Kamwamba (1987 88 season), and Symon (1988-89 season) At these sites the soils were slightly alkaline to neutral in reaction. Texture ranged from sands to loamy sands. Organic matter, nitrogen, phosphorus, and magnesium were low. Potassium was medium whereas calcium was moderately high (Table A1, Appendix). The design of the experiment was a randomized block laid as a 4 x 4 factorial replicated two times at Kandoje, Waiyatsa, and Kamwamba and three times at Symon. Plots consisted of 4 ridges 4.5 m long as gross and 2 middle ridges 3.5 m long as net. Treatments consisted of four maize varieties fertilized at four rates of nitrogen. The maize varieties were local, NSCM 41, Tuxpeño, and MH 15, which were fertilized at 0, 30, 60, and 90 kg of nitrogen ha^{-1}.

Statistical (ANOVA) and agronomic evaluations of the trial were done. In addition, the relationship between treatments and environmental index was also investigated. Finally, economic analysis of nitrogen response was done using both discrete yield data and continuous response functions obtained by regression analysis. Economic assumptions in both the discrete and continuous cases were the same.

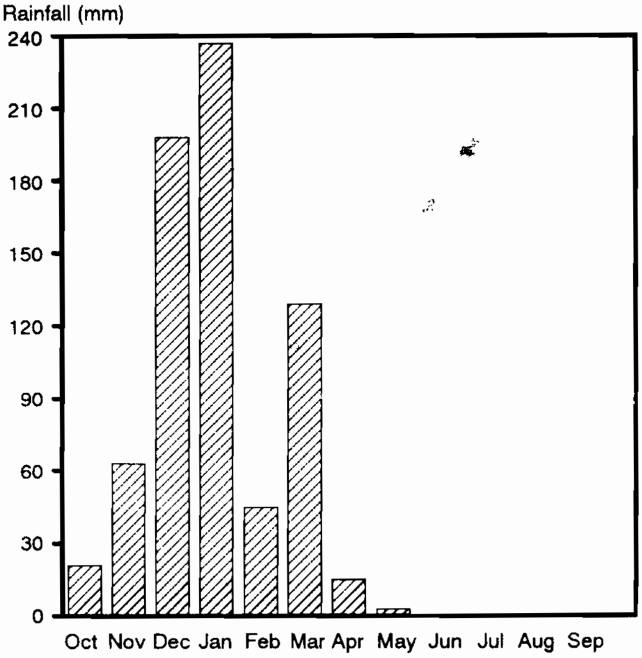


Figure 1. Monthly rainfall, Lisungwi, Malawi, 1986-87.

Results

Tables 1 and 2 show the results of the first statistical analysis. It should be noted that in analysis of variance of the data pooled over all sites, though the variety x nitrogen interaction was not significant, both variety x site and nitrogen x site interactions appeared to be significant.

Maize yields as affected by maize varieties— Table 1 shows that at two locations, Waiyatsa and Symon, there were no significant differences in maize yields among the maize varieties. Though statistically insignificant according to Student-Newman-Keul's test based on means, MH 15 was the highest yielder at these locations, and NSCM 41 also yielded relatively well at Waiyatsa. At Kandoje, NSCM 41 yielded significantly better than the other three maize varieties. No significant yield differences existed among local maize, Tuxpeño, and MH 15 at this location, although both MH 15 and Tuxpeño yielded 1 t ha^{-1} more than local maize. At Kamwamba, NSCM 41 was still the highest yielding variety. However, no statistical differences existed between NSCM 41 and MH 15. The local variety and Tuxpeño were the lowest yielding maize varieties at this site. No significant yield differences were observed among local maize, Tuxpeño, and MH 15.

(text continued below)

Table 1. Usable maize yield (kg ha^{-1}) at 12.5% moisture content

	Year and site				
	1986-87		1987-88	1988-89	
	Kandoje	Waiyatsa	Kamwamba	Symon	Pooled
Maize variety					
Local	3,866 b	3,220	2,243	1,873	2,697
NSCM 41	6,885 a	3,987	3,953 a	2,388	4,090
Tuxpeño	4,913 b	3,212	2,295 b	2,491	3,146
MH 15	5,350 b	4,296	3,095 ab	2,770	3,744
Nitrogen (kg ha^{-1})					
0	2,317 b	1,790 c	1,545 b	1,993 b	1,921 b
30	5,710 a	3,598 b	2,829 a	2,078 b	3,390 a
60	6,296 a	4,403 ab	3,463 a	2,623 ab	4,021 a
90	6,690 a	4,874 a	3,747 a	2,828 a	4,345 a
Significance					
Variety	**	NS	*	NS	*
Nitrogen	***	***	***	*	***
V x N	NS	NS	NS	NS	NS
S.E.					
Variety	239	160	335	239	243
Nitrogen	239	160	335	239	243
V x N	478	320	670	478	486
CV (%)	26	25	33	35	30

Note: Means followed by the same letter are not significantly different from each other according to the Student-Newman-Keul's test (P=0.05).

Table 2. Interaction effects in the variety x fertilizer level trial

	Maize variety and yield (kg ha^{-1})				
	Local	NSCM 41	Tuxpeño	MH 15	Means
N (kg ha^{-1})					
0	1,457	2,435	1,912	1,878	1,921
30	2,631	4,056	3,097	3,775	3,390
60	2,937	4,710	3,784	4,655	4,021
90	3,764	5,160	3,790	4,617	4,345
Means	2,697	4,090	3,146	3,744	

Pooled analysis across locations and years indicated no significant differences in maize yields between NSCM 41 and MH 15, MH 15 and Tuxpeño, and Tuxpeño and local maize. Nonetheless NSCM 41 and MH 15 outyielded Tuxpeño by 600-900 kg ha^{-1} and Tuxpeño outyielded the local variety by 450 kg ha^{-1}.

Maize yields as affected by nitrogen rates— Maize yields from fertilized plots at Kandoje and Kamwamba were significantly higher than those from unfertilized plots. No significant yield differences on the basis of simple means comparison were observed by increasing nitrogen rates from 30 to 90 kg ha^{-1} at these sites, although at both sites yields did appear to increase somewhat with increasing application of nitrogen. The same pattern of increasing yields with increasing nitrogen application was also observed at Waiyatsa and Symon. Nonetheless, at Waiyatsa, means comparison indicated that fertilization gave significantly higher yields than no fertilization. No significant differences appeared to exist between 30 and 60 kg ha^{-1} at Waiyatsa, and again between 60 and 90 kg ha^{-1}. At Symon, means separation failed to determine any differences between application rates up to 60 kg ha^{-1}, and again between 60 and 90 kg ha^{-1}. Oddly enough, however, at Symon maize yields appeared to increase more between 30 and 60 kg ha^{-1} than between any other two adjacent nitrogen treatments. Increased yields with successive increases in nitrogen application rates at Symon thus did not appear to be either linear or concave, the two most commonly expected forms of response.

Pooled analysis across locations indicated that maize yields from unfertilized plots were significantly lower than from fertilized plots. Though yields increased with increasing application levels from 30 to 90 kg ha^{-1}, no significant yield differences were observed among the three rates.

Response of maize varieties to environment at Lisungwi—A linear regression of the mean yield of each maize variety at each location on environmental index (mean yield of the four maize varieties evaluated per location/year) was run as a measure of varietal stability. Theoretically, varieties with above average phenotypic stability ($b < 1$) are relatively insensitive to environmental changes and do not show large changes in yield. Such varieties may be more productive under poor management. Varieties with below average phenotypic stability ($b > 1$) are relatively more productive under high management and are very sensitive to environmental changes (Finlay and Wilkinson 1963).

Figure 2 shows the response of maize varieties to environment at Lisungwi. The regression coefficients (R^2) indicated very good fits for the regression lines. Below an e-value of 1.5 t ha^{-1}, local maize performs better than Tuxpeño and vice versa as management becomes better. The response of NSCM 41 was steep, indicating response to higher levels of management by the Finlay-Wilkinson criterion. Regression lines for Tuxpeño and MH 15 were almost parallel, indicating that the response of these varieties to environment was similar.

Despite the fact that by the Finlay-Wilkinson criterion local maize had above average stability ($b < 1$), MH 15 had average stability (b approximately equal to 1), and NSCM 41 was below average ($b > 1$), it should be noted that even at the lowest value of e ($e = 0$), both hybrids performed better than local maize.

Response of nitrogen rates to environment at Lisungwi—Figure 3 shows the effect of environment on different nitrogen application rates at Lisungwi. Maize yields for each of the nitrogen rates were related to environment by a simple linear regression

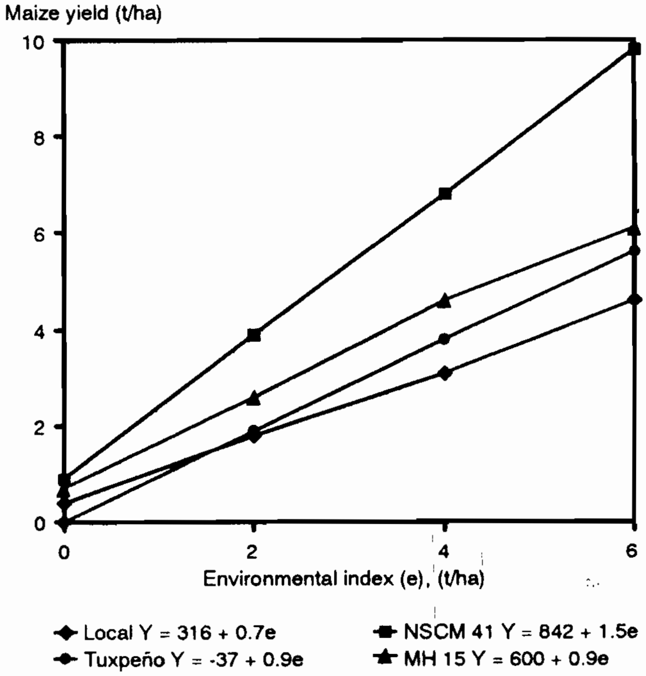
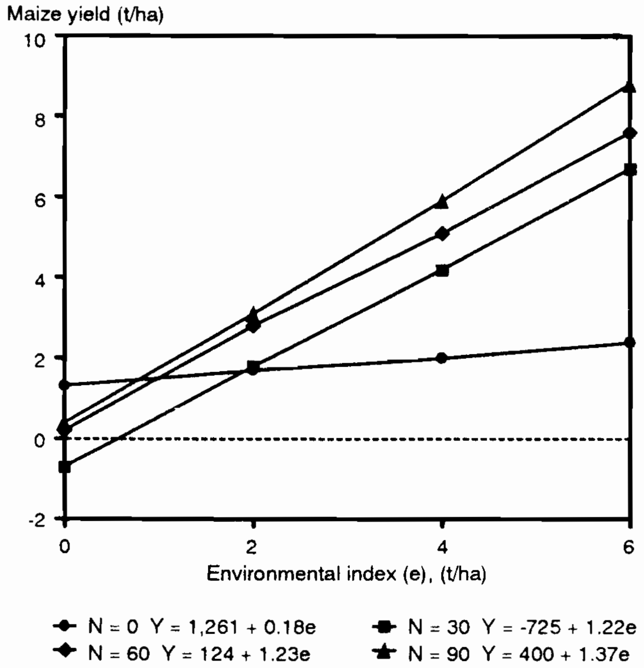


Figure 2. Response of maize to the environment at Lisungwi, Malawi.



Note: N rates are in kg/ha.

Figure 3. Response of nitrogen to the environment at Lisungwi, Malawi.

Y = a + bx (Hildebrand and Poey 1985). The analysis indicated that applying fertilizer resulted in below average stability, and by not applying fertilizer, the result was above average stability. Maize yields increased with increasing nitrogen rates and management except for control plots, where maize yields were fairly stable around 1.6 t ha^{-1} across the environment. Coefficients of determination showed good fits for the regression lines for fertilized plots. Unfertilized plots showed a relatively poor fit for the regression line ($R^2 = 0.43$).

Economic Analysis

Assumptions—The following assumptions were used in the economic analysis. The field price of maize was assumed to be MK .278 kg^{-1}, reflecting the selling price to ADMARC minus adjustments for harvesting and transport. The field price of nitrogen was assumed to be MK 2.02 per kg N, based on the price of urea plus an adjustment for transport. In the discrete (partial budget) analysis based on actual yield data, the labour cost of a single fertilizer application was assumed to be MK 4.30 ha^{-1}. In the continuous analysis, the field price of nitrogen was adjusted upward to MK 2.12 per kg N, to reflect the labour costs of application as well as the urea price and transport costs. When seed costs were also considered in the partial budget analysis, seed of NSCM 41 and MH 15 was valued at MK 2.50 kg^{-1}, seed of Tuxpeño at MK 2.00 kg^{-1}, and local seed at the grain price.

In both partial budget and continuous analysis, yields were adjusted downwards by 25%. The minimum acceptable marginal rate of return was set at 100%, partially because fertilizer use appears to be fairly risky in Lisungwi.

Procedures—Initially, partial budget analysis (CIMMYT 1988) was applied to each variety at each location, and to each variety in the pooled data, to find the desired level of nitrogen application. In addition, the partial budget analysis also looked at *all* varieties at each location, and in the pooled data, including seed costs, to find the overall recommended treatment (e.g., variety plus nitrogen level).

Initially regression analysis was based on the finding of the pooled analysis of variance that there was no variety x nitrogen interaction. Response curves were fitted at each site along with dummy variables that maintained the hypothesis that variety only shifted the intercept, but not the shape, of the response curve. In the pooled data, response curves were fitted along with dummy variables maintaining the hypotheses that both variety and location shifted intercepts but again not the shapes of the response curve. Both at each location, and in the pooled data, the optimum nitrogen application rate was found by solving for N in the equation:

$$f'(N) = \frac{p_N(1 + R)}{Ap_M},$$

where f'(N) was the first derivative of the yield response function f(N); p_N was the field price of nitrogen; p_M was the field price of maize; A was the yield adjustment factor in decimal form (100% - 25% = 75% = 0.75); and R was the minimum acceptable marginal rate of return in decimal form (100% = 1) (Jauregui and Sain 1992).

The initial partial budget analysis, the initial continuous analysis, and reconsideration of the actual yield data all suggested two things. First, the response at Symon seemed quite atypical of the response at the other three locations for the following reasons. At most locations the hybrids NSCM 41 and MH 15 appeared, as expected, to be more responsive to nitrogen than Tuxpeño or local maize. However, at Symon the reverse appeared to be true with the hybrids exhibiting very little response while local maize and Tuxpeño did appear to show response to increasing rates of nitrogen. Furthermore, the response of local maize at Symon appeared very unusual, with the largest increase in yield occurring between 60 and 90 kg ha^{-1}. Finally, fitting of response curves at Symon was fairly difficult, with very low measures of goodness of fit. Therefore, in the economic analysis presented below, results are presented for the individual sites and for pooled data excluding Symon (i.e., for Kandoje, Waiyatsa, and Kamwamba only).

Second, though statistical analysis indicated no variety x nitrogen interaction, perusal of the initial economic analysis as well as the raw data suggested that the large differences between sites may have obscured differences in the ways in which the different varieties responded to increasing nitrogen. Therefore, continuous response functions were re-estimated under the assumption that response slopes for local maize, Tuxpeño (a composite), and the hybrids were all different. The response slopes for NSCM 41 and MH 15 were assumed to be the same, but intercepts (i.e., yield at N = 0) were assumed to vary between the two hybrids.

In all cases of continuous response estimation, two functional forms were used. The first was the quadratic response curve,

$$Y = b_0 + b_1N + b_2N^2 .$$

This is probably the most commonly fitted functional form in response analysis and is easy to estimate with standard statistical packages. However, it may not always be consistent with the response predicted by agronomic theory, and economic optima suggested by the quadratic function may be somewhat overstated.

Alternatively, the Mitscherlich-Baule response function,

$$Y = b_0\{1 - \exp[b_1(b_2 + N)]\} ,$$

was also fitted to the response data. A functional form such as the Mitscherlich-Baule may be appropriate in situations in which yield response to additional increments of nitrogen application may approach a plateau, as is suggested by agronomic theory (Tronstad and Taylor 1989; Frank, Beattie, and Embleton 1990). A major disadvantage of the Mitscherlich-Baule functional form is that it must be estimated by non-linear regression and therefore requires a specialized statistical package. This may make it impractical in many instances.

Results of the Economic Analysis

The results of the economic analysis are shown in Table 3.

Most results will be discussed by variety. Before beginning this discussion, it should be noted that even when the anomalous site (Symon) is excluded from the analysis, there appear to be substantial differences in response by location. (When Symon is included, the significance level for the location x nitrogen interaction is .17, which is non-significant at standard levels but still suggests there may be differences in response by site.) Responses may differ because of differences in other components of soil fertility or because of differences in the type of season, since the trial was run over three years. This in turn means it may be somewhat difficult to obtain universal recommendations for Lisungwi based on these data.

Local maize—Economic optima based on standard partial budgeting and on the Mitscherlich-Baule response function are fairly similar at Kandoje and Kamwamba. At Kandoje no economic response is observed beyond about 30 kg N ha^{-1}, and at Kamwamba beyond 50 to 60 kg ha^{-1}. The quadratic function probably overestimates the economic optimum at Kandoje. At Waiyatsa both response functions appear to substantially overestimate the economic optimum. This is in part because of the strange pattern of response, with no difference in yield at 30 and 60 kg N ha^{-1} but an increase of 1 t between 60 and 90 kg ha^{-1}. Waiyatsa also affects the pooled analysis based on continuous response functions. As a fairly conservative recommendation, the optimal application rate for local maize in Lisungwi may be somewhere around 30 kg N ha^{-1}.

Tuxpeño—Responses for the composite Tuxpeño vary widely from site to site. The partial budget analysis selects any application rate from 0 to

Table 3. Economic optimum nitrogen application rates (kg ha^{-1}) for three sites, separately and pooled, Malawi

	Kandoje		
	Method of analysis:		
Variety	Partial budget	Quadratic	Mitscherlich-Baule
Local	30	56	35
Tuxpeño	90	107	134
MH 15	60	..	..
NSCM 41	90	..	..
Hybrid	..	56	36

Overall optimum treatment, partial budget: NSCM 41 at 90 kg ha^{-1}

	Waiyatsa		
	Method of analysis:		
Variety	Partial budget	Quadratic	Mitscherlich-Baule
Local	30	77	65
Tuxpeño	30	41	NC
MH 15	60	..	..
NSCM 41	90	..	..
Hybrid	..	83	100

Overall optimum treatment, partial budget: MH 15 at 60 kg ha^{-1}

	Kamwamba		
	Method of analysis:		
Variety	Partial budget	Quadratic	Mitscherlich-Baule
Local	60	53	49
Tuxpeño	0	LR	NC
MH 15	90	..	..
NSCM 41	60	..	..
Hybrid	..	53	42

Overall optimum treatment, partial budget: NSCM 41 at 60 kg ha^{-1}

	Pooled (excluding Symon)		
	Method of analysis:		
Variety	Partial budget	Quadratic	Mitscherlich-Baule
Local	30	56	46
Tuxpeño	30	57	NC
MH 15	60	..	..
NSCM 41	60	..	..
Hybrid	..	60	53

Overall optimum treatment, partial budget: NSCM 41 at 60 kg ha^{-1}

Note: NC = non-convergent (estimation of non-linear Mitscherlich-Baule equation failed to converge). LR = linear response (estimation of quadratic function suggested response was in fact linear rather than quadratic).

90 kg ha^{-1} as optimal, depending on the location. Neither functional form used in the continuous analysis appears to fit very well from location to location or in the pooled data. Furthermore, the application rates selected as optimal by continuous analysis at Kandoje are greater than 90 kg ha^{-1}; in other words they lie outside the range of the experiment and therefore are not reliable. It does not appear possible to draw even tentative conclusions about optimum application rates for Tuxpeño.

Hybrid maize—Optimum nitrogen application rates for hybrid maize as determined by either partial budget or continuous response analysis appear to be relatively consistent at Kandoje, Waiyatsa, and Kamwamba. Nonetheless the purported optimum based on the Mitscherlich-Baule function appears to understate the optimum at Kandoje and Kamwamba. This may be because yields of MH 15 at Kandoje decline at 90 kg N ha^{-1}, and the same result is true for NSCM 41 at Kamwamba. In other words, at these two locations the quadratic function appears to give a better fit for one hybrid and the Mitscherlich-Baule function to give a better fit for the other. In the pooled data, both response functions and partial budget analysis give fairly similar results. Tentatively, optimal nitrogen application rates for hybrid maize in Lisungwi may be around 50 to 60 kg ha^{-1}.

Conclusions

Maize varieties—Based on the agronomic and economic analysis, farmers can grow either NSCM 41 or MH 15. High yields can be achieved under high management. Though yields of NSCM 41 appear to be more variable over different environmental conditions, both hybrids still appear to yield better than local maize in poor environments. The use of MH 15 might be constrained by seed availability, and recent semi-flint releases might be preferable to both of these hybrids by virtue of grain texture, assuming the response of the new releases to nitrogen at Lisungwi is similar to that of the two hybrids tested here.

Fertilizer use—It is not possible to make firm nitrogen application recommendations for Lisungwi. Though statistically over the entire data set response to nitrogen rates over 30 kg ha^{-1} appears to be minimal, further economic analysis suggests that the optimum rate for local maize may indeed be around

30 kg ha^{-1}, but the optimum rate for hybrid maize may be somewhat higher, perhaps in the range of 50 to 60 kg N ha^{-1}.

Further work—Firmer fertilizer recommendations for Lisungwi may await either further analysis, further experimentation, or both. Further experimentation may require the use of a single hybrid and local maize as a control, since in the present experiment use of local maize, an improved composite, Tuxpeño, and two hybrids, all with somewhat different expected responses, considerably complicated the analysis. Furthermore, the assumption of equal variances used both in the ANOVA and regression analysis may not be warranted. Differences in sites might be examined to determine to what extent they result from differences in soils and to what extent from differences in seasonal rainfall patterns. For example, is the apparently higher overall fertility at Kandoje related to the higher levels of soil P and/or Mg at that location (Table A1, Appendix)? Risk analysis might also be applied to the results of future fertilizer response experiments, since it appears that the use of any nitrogen, which has a real cost to the farmer, also increases the variability of results.

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Appendix A
Soil and Rainfall Data

Table A1. Soil analysis data

Location	Depth	pH	C	Texture	%C	%N	C/N	P	Na	K	Mg	Ca
Kandoje	Top	7.0	10	LS	0.78	0.07	11	12	7.4	2.9	**25.8**	156.3
	Bottom	6.2	16	SL	0.51	0.04	13	12	6.3	1.6	**17.9**	123.8
Waiyatsa	Top	6.6	6	Sand	0.66	0.06	11	3	6.9	3.3	11.6	106.8
	Bottom	6.4	11	LS	0.40	0.04	10	3	6.3	1.6	13.3	115.5
Kamwamba	Top	6.3	6	Sand	0.43	0.04	11	4	6.0	2.6	7.9	74.8
	Bottom	6.0	8	Sand	0.31	0.03	10	2	6.0	1.2	12.9	82.3
Symon	Top	6.2	10	LS	0.81	0.07	12	2	6.3	3.6	18.3	123.3
	Bottom	6.3	12	LS	0.81	0.07	12	2	6.6	2.9	19.1	123.3

Table A2. Rainfall analysis data

Number of years analysed	10
Mean annual rainfall total	746 mm
Mean start of rainy season	17 November
Mean end of rainy season	22 March
Mean net season length	132 days
Quality of season (%)	63
Mean season index	426
Rainfall reliability (%)	21
Number of pentades with > 67% chance of rain occurring	8