African Crop Science Journal, Vol. 11. No. 3, pp. 181-187, 2003
Printed in Uganda.
ISSN 1021-9730/2003 $ 4.00

ECONOMIC ANALYSIS OF MAIZE YIELD RESPONSE TO NITROGEN AND PHOSPHORUS IN THE SUB-HUMID ZONES OF WESTERN KENYA

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(Recieved 17 December 2000; accepted 8 May, 2003)

ABSTRACT

Experiments were conducted in western Kenya to determine the agronomic and economic benefits of applying Nitrogen (N) and Phosphorus (P) to maize. These factors were identified through an informal survey to be the main cause of low maize yield in the area. The experiments were conducted in 2 locations on farmers' fields in 1994,1995 and1996. Four levels of Nitrogen (0, 30, 60, 90-Kg ha^{-1}) were combined with three levels of Phosphorus (0, 40, 80-Kg ha^{-1}) to constitute twelve treatments which were tested on a randomized complete block design. Statistical analyses of yield data revealed that N application consistently affected grain yield significantly in all locations. Phosphorus had a significant effect on yield once in each location. There was significant nitrogen by phosphorus interaction (N*P) effects once in each location. Analysis across sites showed N and N*P interaction to be statistically significant. The statistically significant treatments of this experiment were subjected to economic analysis using the partial budget procedure to determine rates of N: P that would give acceptable returns at low risk to farmers. Economic analysis on the interaction across location showed that two N: P combinations i.e. 30:0 and 60: 40 kg ha^{-1} are economically superior and stable within a price variability range of 20%.

Key Words: Dominance analysis, grain yield, interaction effects, partial budget, price variability

RÉSUMÉ

Les expériences étaient conduites à l'Ouest du Kenya pour déterminer les bénéfices agronomiques et économiques de l'application de l'azote (N) et le phosphore (P) dans le champs de maïs. Ces facteurs étaient identifiés à travers un survey informel comme les causes majeures de faible rendement du maïs dans le milieu. Les expériences étaient conduites dans deux locations dans les champs de fermiers en 1994, 1995 et 1996. Quatre niveaux d'azote (0, 30, 60 et 90 kg ha^{-1}) étaient combinés avec trois niveaux de phosphore (0, 40, 80 kg ha^{-1}) pour constituer douze traitements qui étaient testés dans des blocs complétement au hazard. Les analyses statistiques des données de rendements ont montré que l'application de l'azote a affecté de manière consistente et significative le rendement en grains dans les différents endroits. Le phosphore avait un effet significatif sur le rendement à chaque endroit. L'interaction entre le phosphore et l'azote était significative. Les traitements statistiquement significatifs ont été soumis à une analyse économic utilisant la procédure du budget partiel pour déterminer les taux N:P qui donneraient des dividendes acceptables pour des faibles risques des fermiers. L'analyse économique sur l'intéraction entre les différentes locations a montré que les deux combinaisons i.e 30:0 et 60:40 kg ha^{-1} étaient économiquement supérieures et stables et avait une marge de variation de 20%.

Mots Clés: Analyse de dominances, rendement en grains, effects d'intéraction, budget partiel, variation du prix

INTRODUCTION

Kenya's agricultural sector faces the challenge of producing food for a rapidly increasing population estimated to be growing at 2.5% per annum (CIMMYT, 1996, 2002). The need to raise productivity is greatest on small farms where paradoxically the population is rising faster than the capacity to sustain decent livelihoods. Over the 1985 to 1995 CIMMYT (1996) has estimated that Kenya's per capita cereal production grew at negative 3.2%. In the last decade, the estimated national production of the main staple food, maize, has been declining with some years being as low as 22 million (90 kg) bags compared to over 30 million (90 kg) bags attained during bumper harvests (Kenya Economic Survey, 1993). Kenyan small-scale farmers apply lower rates of inorganic fertilisers on their maize crop than is usually considered economically optimal (Hassan *et al.*, 1998). Allan (1972) demonstrated the importance of inorganic fertiliser in maize yield production in Kenya.

Hassan *et al.*. (1998) have observed that due to differences in agroclimatic conditions, soil type and farmer groups, potential productivity gains from fertiliser use on small scale farms are bound to vary hence the need for careful targeting of fertiliser recommendations. Broad or 'blanket' fertiliser recommendations that assume homogeneity of farming conditions have thus, partly contributed to the low diffusion of fertiliser technologies within Kenya's small-scale farm sector.

An experiment was conducted in Yala division located in the lake region of western Kenya in the long rains season of 1994, 1995 and 1996 on the effects of nitrogen and phosphorus application on maize grain yield. These two plant nutrients were identified as the most yield-limiting factors in maize during an informal survey conducted during the long rains season of 1993. As no previous research work had been done in the area, a 'blanket' recommendation of 60-kg N and 60 kg P ha^{-1} was being advocated by the extension workers to farmers. This recommendation was based on experiment station results of a distant location having little similarity to conditions of the study area. Small-scale farmers lacked the financial outlay required to apply the recommendation due to their limited resource base, which pointed to the need for a lower fertiliser rate in line with their low economic status.

Striga (*Striga hermonthica*), a parasitic weed of cereals and sugarcane is endemic in this region and to avoid its confounding effects, the experiment was sited on relatively clean fields with respect to the weed. The presence of the weed diminishes crop yield response to management inputs such as fertiliser (Hassan and Ransom 1998). Where Striga parasitism causes economic yield loss to farmers, priority should be given to its control before emphasizing improvement in soil fertility. A significant proportion of farmland in this area is relatively free of this weed.

Cognizant of the need to identify lower fertiliser rates for low-income farmers and the urgency of raising on-farm maize productivity on small-scale farms, this study tested a range of possible alternatives with the specific objective of selecting economically appropriate rates of N and P. This paper outlines the findings from the experiment and particularly highlights the economic implications of the different alternatives for local farmers.

MATERIALS AND METHODS

The study area has an average annual rainfall of 1200-1600 mm received in two seasons a year and a mean temperature of 21^{o}C. It is situated at an elevation of between 1200 and 1500 m above sea level. The soils are well-drained, sandy clay loam (orthic-Ferrasols) of moderate to high fertility (Jaetzold and Schmidt 1982).

Field trials were conducted for three years at two on-farm locations, Lihanda and Jina of Yala division, Siaya district, during the long rain season between 1994 and 1996.

Response to nitrogen was tested at four levels, viz., 0, 30, 60, and 90 kg ha^{-1} while phosphorus was tested at 0, 40 and 80 kg of ha^{-1}. Nitrogen was applied as urea fertiliser and phosphorus as triple super phosphate. The levels of N and P rates were combined in a complete factorial arrangement to constitute twelve treatments which were laid out on a randomized complete block design in three replications. Since farmers do not commonly use fertiliser for crop production in the area, the nil treatment was the control representing the farmers' practice. A cropping density of 44,444 ha^{-1} plants of maize was maintained as recommended for the area by the Kenya Agricultural Research Institute (KARI). Implementation of this study involved active participation by farmers who applied routine management under the facilitation of the researcher.

Statistical analysis of variation in grain yield response to application of N and P was done according to the procedures outlined by Steel and Torrie (1987). To assess the costs and benefits associated with different treatments the partial budget technique as described by CIMMYT (1988) was applied on the yield results. Economic analysis was done using the prevailing market prices for inputs at planting and for outputs at the time the crop was harvested. All costs and benefits were calculated on hectare basis in Kenya shillings (KShs ha^{-1}).

The following concepts used in the partial budget analysis are defined as follows:

- Mean grain yield is the average yield (t ha^{-1}) of each treatment in both locations.
- The field price of maize grain is its point-of-sale retail price minus the costs of harvesting, bagging and transporting.
- The gross field benefit (GFB) ha^{-1} is the product of field price of maize and the mean yield for each treatment.
- The field price of Nitrogen or Phosphorus kg^{-1} is the nutrient retail cost kg^{-1} plus the cost of transport from the point of sale to the farm.

- The field cost ha^{-1} of N or P is the product of the quantity required by each treatment per hectare and the field price of fertiliser.
- The cost of fertiliser application is the product of man-days used in applying the fertiliser and wage rate.
- The total variable costs (TVC) is the sum of field cost of fertiliser and the cost of fertiliser application.
- The net benefit (NB) ha^{-1} for each treatment is the difference between the GFB and the TCV.

The Dominance analysis procedure as detailed in CIMMYT (1998) was used to select potentially profitable treatments from the range that was tested. The selected and discarded treatments using this technique are referred to as Undominated and Dominated' treatments, respectively. The Undominated treatments were ranked from the lowest (the farmers' practice) to the highest cost treatment. For each pair of ranked treatments, a % marginal rate of return (MRR) was calculated. The % MRR between any pair of undominated treatments denotes the return per unit of investment in fertiliser expressed as a percentage. To obtain an estimate of these returns we calculate the MRR, which is given by the following formula:

MRR (between treatments, a & b) =

$$\frac{\text{Change in NB } (NB_b - NB_a)}{\text{Change in TCV}(TCV_b - TCV_a)} \times 100$$

Thus, a MRR of 100% implies a return of one shilling on every shilling of expenditure in the given variable input. A quadratic response on returns to incremental fertiliser application is assumed and therefore the undominated treatments that fail to satisfy this criterion were discarded from the MRR analysis. In other words diminishing returns to higher fertiliser applications is assumed.

RESULTS AND DISCUSSION

Statistical analysis of yield data showed that in both years N had a significant effect on grain yield ($P<0.001$) at Lihanda (Table 1). There was also a significant, though lower, yield response to N ($P<0.05$) at Jina in both years. Analysis across locations revealed a significant ($P<0.001$) N effect on maize grain yield. P had a significant yield effect in 1995 and 1996 ($P<0.05$ and 0.01, respectively) in Lihanda. No significant response to P was observed across locations. In both Lihanda and Jina there was a significant N by P interaction 1996 ($P<0.01$) and 1995($P<0.05$), respectively. Across location analysis also revealed a significant N*P interaction effect ($P<0.05$) at both locations.

The foregoing statistical results have indicated that a significant interaction effect within and between the two locations. An economic analysis on the combined results using the partial budget technique is thus appropriate (CIMMYT 1988). The result of the partial budget analyzes and the economic data used in the development of the partial budget is given in Table 2.

Dominance analysis (Table 3) led to the selection of treatments N_1P_1 (farmers' practice), N_2P_1 (30 kg N), N_3P_1 (60 kg N), N_3P_2 (60 kg N 40 kg P) and N_4P_3 (90 kg N 80 kg P) which are ranked in increasing order of total costs that vary.

Applying this formula: Marginal Rate of Return (MRR) =

$$\frac{\text{Change in NB } (NB_b - NB_a)}{\text{Change in TCV } (TCV_b - TCV_a)} \times 100$$

The following rates of return were realised:

MRR between treatment N_1P_1 and N_2P_1 =

$\underline{20.5 - 14.7}$ x 100 =363%

1.6 - 0

And in a similar way the other MRRs were as follows:

N_2P_1 and N_3P_1 = 187%

N_3P_1 and N_3P_2 = 222%

N_3P_2 and N_4P_3 = 36%

The MRR between treatments N_2P_1 and N_3P_1 was lower than that of treatments N_3P_1 and N_3P_2. We therefore eliminated treatment N_3P_1 from the analysis in keeping with the expected behavior of a quadratic response and calculated MRR between treatments N_2P_1 and N_3P_2, which we found to be 206%. It is apparent that changing from N_1P_1 (farmers' practice) to N_2P_1 to N_3P_2 and finally to N_4P_3 in that order would give positive MRRs of 363%, 206% and 36%, respectively. As a guideline an MRR of below 100% is considered low and unacceptable to farmers (CIMMYT, 1988). This is because such a return would not offset the cost of capital (interest) and other related transaction costs while still giving an attractive profit margin to serve as an incentive. We therefore, eliminated the change to N_4P_3 for this reason to remain with changes to N_2P_1 and N_3P_2 which gave more than 100% MRR as promising new practices for farmers under the prevailing price structure.

The input and output prices used in the economic analysis were those prevailing during the period of the experiment. Market prices are ever changing and as such a recalculation of the partial budget using a set of likely future prices i.e., sensitivity analysis, is necessary to pinpoint treatments which are likely to remain stable and sustain acceptable returns for farmers despite price fluctuations. In the present case, we assume an increase in the field price of both N and P of KSh.10 per kg and a fall in the price of grain of KSh.1800 per ton (Table 4). An assumption of price change of KShs, 10 per kg of nitrogen and phosphorus and KShs. 1800 per ton of maize is borne out of our own experiences and represents a price fluctuation of 20%. These price changes are realistic under the liberal market conditions prevailing in Kenya at the time. Some of the considerations in projecting prices were; increased maize supply due to dumping and informal imports from Uganda and Tanzania; and a deteriorating business environment in Kenya. The new prices were used to obtain the partial budget (Table 4). The resulting dominance analysis (Table 3) selected treatments N_1P_1, N_2P_1, N_3P_1 and N_3P_2 as the undominated treatments with N_4P_3 now having been eliminated. Thus the effect of a worsening in the terms of trade between maize and fertiliser is to make hitherto marginally profitable practices unprofitable. As observed N_3P_1 was also eliminated from the MRR calculation for giving a lower MRR than that of the subsequent change. Changing from treatments N_1P_1 to N_2P_1 and finally to N_3P_2 gave 210% and 103% MRR, respectively which are all above the minimum acceptable MRR of 100%. The latter MRR was just above the minimum acceptance threshold. These results agree with Saha *et al*., (1994) whose findings from coastal Kenya on maize showed that the application of 30 Kg N ha^{-1} consistently gave acceptable economic returns.

Agricultural extension advice in Kenya has stressed the use of compound forms of fertilisers like Diammonium phosphate (DAP) which are commonly available in the market but which are low in nitrogen than phosphorus (Muriithi and Shiluli 1993; Hassan *et al*. 1998). This has thus resulted in net mining of soil nitrogen. There is thus, a need to re-examine the fertiliser importation to ensure that the types in the market are in line with the actual crop mineral requirements.

From the range of treatments tested against the farmers' practice, (30 kg N) and (60 kg N, 40 kg P) give an economic yield response and also sustain acceptable returns even under a projected worsening in terms of trade. On a tentative basis farmers could thus choose either of the two new fertilizer rates depending on their resource. The results of this research can be used to make tentative recommendations, which can be refined through multi-location testing over a wider area.

REFERENCES

Allan, A.Y. 1972. The Influence of Agronomic factors on Maize Yield in Western Kenya with Special Emphasis on Time of Planting. Ph.D Thesis, Makerere University.

Byerlee, D. 1987. From Adaptive Research to Farmer Recommendations and Extension Advice. *Agricultural Administration and Extension* 27:231-244.

CIMMYT, 1988. From Agronomic Data to Farmer Recommendations: An Economics Training Manual. Completely revised edition. Mexico, DF.

CIMMYT, 1996. Mexico, D.F.: CIMMYT 1995/96. World Wheat Facts and Trends: Understanding Global Trends in the Use of Wheat Diversity and International Flows of Wheat Genetic Resources. Mexico, D.F., CIMMYT.

CIMMYT, 2002. CIMMYT in 2001-2002. Diversity to Heal the Earth and Feed its People. Mexico, D.F., CIMMYT.

Kenya Economic Survey Report, 1993. Republic of Kenya. Central Bureau of Statistics. Nairobi, Kenya.

Hassan, R.M., Muriithi, F. and Kamau, G. 1998. Determinants of Fertilizer Use and the Gap between Farmers' Maize Yields and Potential Yields in Kenya. In: *Maize Technology Development and Transfer: A GIS Application for Research Planning in Kenya*. Hassan, R.M. (Ed.). CAB International in Association with International Maize and Wheat Improvement Center (CIMMYT) and Kenya Agricultural Research Institute (KARI).

Hassan, R. M. and Ransom, J. K. 1998. Determinants of the Incidence and Severity of *Striga* Infestation in Maize in Kenya. In: *Maize Technology Development and Transfer: A GIS Application for research planning in Kenya*. Hassan, R.M.(Ed.). CAB International in Association with International Maize and Wheat Improvement Center (CIMMYT) and Kenya Agricultural Research Institute (KARI).

Jaetzold, R. and Schmidt, H. 1982. Farm Management Handbook of Kenya: Natural Conditions and Farm Management Information Vol. II/A. Published by Ministry of Agriculture, Kenya, in Collaboration with the German Agricultural Team (GAT) of the Germany Agency for Technical Cooperation (GTZ).

Muriithi, F.M. and Shiluli, M. 1993. Effects of the Liberalization of Fertilizer Markets on the Distribution and Use of Fertilizer on Food Crop Production: A study on Embu and Meru Districts of Kenya. In: *Analysis of Cereal Grain Policy in National Agricultural Research Systems of Eastern and Southern Africa.* Mwangi, W., Rohrbach, D. and Heissey, P.W. (Eds.). CIMMYT, SADC and ICRISAT, Addis Ababa, Ethiopia.

Saha, H.M., Gacheru, E.N., Kamau, G.M, O'Neill M.K. and Ransom, J.K. 1994. Effect of Nitrogen and Plant Density on the Performance of Pwani hybrid Maize. *African Crop Science Journal* 2:63-67.

Steel, R.G.D. and Torrie, J.H. 1987. Principles and Procedures of Statistics, McGraw-Hill Book Co., New York, USA. 633pp.

TABLE 1. Statistical results on the response of maize grain yield to applied nitrogen (N) and phosphorus (P) in Yala

	Statistical significance			Grain yield (kg ha^{-1})		
	N	P	N*P	Control	Mean	C.V.(%)
Lihanda 1995	***	*	ns	1484	3813	23.21
Lihanda 1996	***	***	**	834	1413	51.14
Jina 1994	*	ns	ns	619	998	49.95
Jina 1995	*	ns	*	3604	4595	31.43
Across locations	***	ns	*	1638	2702	36.34

*, **, *** Indicate significance at P < 0.05, 0.01 and 0.001 respectively; ns: Indicates statistical non-significance (P< 0.05)

TABLE 2. Partial budget of nitrogen and phosphorus at current prices in Lihanda and Jina locations of Yala Division

N:P Level	N1 PI*	N1 P2	N1 P3	N2 PI	N2 P2	N2 P3	N3 PI	N3 P2	N3 P3	N4 PI	N4 P2	N4 P3
Mean grain yield t ha^{-1}	1.6	2.0	1.4	2.5	2.3	3.1	2.9	3.6	2.9	2.8	3.2	
**GFB ('000'KSh ha^{-1})	14.7	18.1	12.7	22.1	20.4	28.3	26.4	32.2	26.0	25.5	29.2	
Field cost N ('000'Sh ha^{-1})	0	0	0	1.5	1.5	1.5	3	3	3	4.5	4.5	
Field cost P '000'Sh ha^{-1})	0	1.8	3.6	0	1.8	3.6	0	1.8	3.6	0	1.8	

Fert. Appl. cost ('000'Sh ha^{-1})	0	0.1	0.1	0.1	1	.1	.1	.1	.1	.1	.1
TVC ('000'Sh ha^{-1})	0	1.9	3.7	1.6	3.4	5.2	3.1	4.9	6.7	4.6	6.4
Net benefits ('000'Sh ha^{-1})	14.7	16.2	9.0	20.5	17.0	23.1	23.3	27.3	19.3	20.9	22.8

*N_1, N_2 N_3 & N_4, (Nitrogen at 0, 30, 60 and 90 kg ha^{-1} respectively) P_1, P_2 and P_3, (Phosphorus at 0, 40 and 80 kg ha^{-1} respectively)
Field price of N = Sh.50 per kg; Field price of P = Sh. 45 per kg; Wage rate = Ksh.50 per dayl Labour to apply fertilizer per ha = 2 man-days; Retail price of grain = Sh. 10800 per ton; Harvesting margin = Sh. 300 per ton; Shelling margin Ksh. 600 per ton; Transport margin = Sh.550 per ton; Bagging margin = Sh.350 per ton
**GFB = Gross field benefit, TVC = Total variable costs

TABLE 3. Dominance analysis

A. At Current Prices
Field price of N = Sh.50 per kg
Field price of P = Sh. 45 per kg
Retail price of grain = Sh. 10800 per ton

B. At projected future prices
Field price of N = Sh. 60 kg^{-1}
Field price of P = Sh. 55 kg^{-1}
Retail price of grain = Sh. 9000 ton

Treatment*	**TVC ('000')	NB ('000')	Treatment	TVC ('000')	NB ('000')
N_1P_1	0	14.7	N_1P_1	0	11.8
N_2P_1	1.6	20.5	N_2P_1	1.9	15.8
N_1P_2	1.9	16.2D***	N_1P_2	2.3	12.2D
N_3P_1	3.1	23.3	N_3P_1	3.7	17.4
N_2P_2	3.4	17.0D	N_2P_2	4.1	12.2D
N_1P_3	3.7	9.0D	N_1P_3	4.5	5.6D
N_4P_1	4.6	20.9D	N_4P_1	5.5	14.4D
N_3P_2	4.9	27.3	N_3P_2	5.9	19.9
N_2P_3	5.2	23.3D	N_2P_3	6.3	16.3D
N_4P_3	6.4	22.8D	N_4P_3	7.7	15.6D
N_3P_3	6.7	19.3D	N_3P_3	8.14	12.7D
N_4P_3	8.2	28.5	N_4P_3	9.9	19.4D

*N_1, N_2 N_3 & N_4, (Nitrogen at 0, 30, 60 and 90 kg ha^{-1} respectively) P_1, P_2 and P_3, (Phosphorus at 0, 40 and 80 kg ha^{-1}, respectively)
**TVC = Total variable costs, NB = Net benefit
***D denotes dominated treatments

TABLE 4. Partial budget analysis at projected future prices of nitrogen and phosphorus in Lihanda and Jina

N:P Level	N1 PI*	N1 P2	N1 P3	N2 PI	N2 P2	N2 P3	N3 PI	N3 P2	N3 P3	N4 PI	N4 P2	N4 P3
Mean grain yield t ha^{-1}	1.7	2.0	1.4	2.5	2.3	3.1	2.9	3.6	2.9	2.8	3.2	
**GFB ('000' Sh ha^{-1})	11.8	14.5	10.1	17.7	16.3	22.6	21.1	25.8	20.8	20.4	23.3	
Field cost N ('000'Sh ha^{-1})	0	0	0	1.8	1.8	1.8	3.6	3.6	3.6	5.4	5.4	
Field cost P ('000'Sh ha^{-1})	0	2.2	4.4	0	2.2	4.4	0	2.2	4.4	0	2.2	
Fert. Appl.. ('000'Sh ha^{-1})	0	.1	.1	.1	1	1	0.1	0.1	0.1	0.1	.1	
TVC '000'Sh ha^{-1})	0	2.3	4.5	1.9	4.1	6.3	3.7	5.9	8.1	5.5	7.7	
NB ('000'Shha^{-1})	11.8	12.2	5.6	15.8	12.2	6.3	17.4	19.9	12.7	14.9	15.6	

*N_1, N_2 N_3 and N_4 = Nitrogen at 0, 30, 60 and 90 kg ha^{-1} and P_1, P_2 and P_3 = P_2O_5 at 0, 40 and 80 kg/ha respectively; Field price of N = Sh. 60 kg^{-1}; Field price of P = Sh. 55 kg^{-1}; Retail price of grain = Sh. 9000 t^{-1}; Harvesting margin = Sh. 300 per ton; Shelling margin sh. 600 per ton; Transport margin = Sh.550 per ton; Bagging margin = Sh.350 per ton; Labour to apply fertiliser per ha = 2 man-days; Wage rate = sh.50 per day
**GFB = Gross field benefit; TVC = Total variable costs; NB = Net benefit