"OPTIMAL FERTILIZER USE RECOMMENDATIONS IN MAIZE PRODUCTION: AN ANALYSIS OF EXPERIMENTAL DATA."

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A Thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Agricultural Economics of the University of Nairobi

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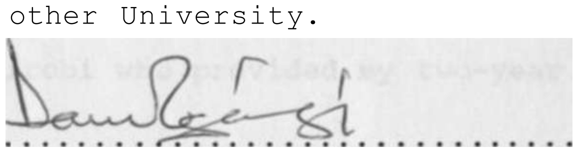
Peelaration:

This thesis is my original work and has not been presented for a degree in any other University.



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Dedication

This work is dedicated to my Parents Mr. Jeremiah Chege and Mrs Miriam Waithera Chege.

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A B S T R A C T

This study was conducted to enable the determination of economically justifiable fertilizer recommendations for maize farmers in Kisii and Busia Districts of Western Kenya. The study also sought to indicate the discrepancies between current recommendations and the economically optimal rates as calculated by the author. The study was conducted within the framework of the Neoclassical Profit Maximization assumption and employed the Production Function Approach to input recommendation. Experimental data from the Fertilizer Use Recommendation Project (FURP) were used. Crop Response Functions were estimated and the marginal products equated to the inverse price ratios. Principally the study showed that there are wide discrepancies between recommendations from the National Agricultural Research Stations (NARS) and the economically optimal rates which the author calculated. In Kisii the optimal recommendation for Nitrogen (N) during the long rains season was 119.3% higher than current NARS recommendation. The corresponding figure for Phosphate (P) was 127.6%. In the short rains season the required increases are for N* and P 36.4% and 81% respectively. Similar results were found in Busia. The study also found that blanket recommendations can be misleading since results from the two districts studied indicated that even locations in the same district may require very different recommendations. Season was found to be a very important factor when optimal recommendations are being made. There were wide differences between the recommendations for the long rains season and those for the short rains for the same locations. In the long rains optimal recommendations were on average 107.9% higher than the current MARS N recommendation and 118.8% higher for P. In the short rains the optimal recommendations were only 54% higher than the current NARS N recommendation. The study thus concluded that current recommendations are not economically justifiable and that Nitrogen and Phosphate recommendations for various locations in Kenya need reassessment. The study recommends that fertilizer trials be conducted with closer involvement of economists so that recommendations are made not only on the basis of agronomic but on economic principles also.

INTRODUCTION

1.1 Agriculture In the Kenyan Economy

Agriculture is the mainstay of Kenya's economy, providing the basis for the development of the other sectors. It provides the main livelihood for 85% of the total population, employs 75% of the labour force and contributes 30% of Kenya's GDP (Republic of Kenya, 1986; 1988) . Productive land has however remained scarce in Kenya. Of the country's 44.6 million ha. of land, only 8.6 million ha or about 19% are medium to high potential agricultural land. This calls for ways of intensification on the use of the land, a necessary prerequisite to rural development (Oluoch-Kosura, 1983) .

Methods of intensification include irrigation, fertilizer use and use of high yielding crop varieties. Irrigation potential in Kenya is however very limited and extremely expensive (Gerhardt 1974) . Other intensification methods include good husbandry practices especially timely planting, proper spacing, proper weeding, timely weeding and pest control. Just before independence commodity switching was an effective way of increasing output. It involved allowing Africans to grow cash crops and keep quality animals previously forbidden by the colonial government. This is no longer applicable as farmers may now cultivate any crop they consider economically rewarding provided they get a licence in the case of some crops. As the easy options for agricultural growth have been nearly exhausted in Kenya the country has to resort to intensification methods.

Area expansion has contributed up to 60% of total growth for most commodities over the past 20 years. Growth from area expansion in the limited fertile lands cannot however continue at past rates. There are areas of Kenya e.g. the expansive Narok district where area expansion is still a viable option. However, even in such areas problems of poor infrastructure, cultural hindrances and at times a harsh political climate will need to be overcome.

Intensification of agriculture will mainly involve emphasis on economic use of fertilizers (Kenya Agricultural Sector Adjustment Operation II, 1990 (ASAO II). With one of the world's highest population growth rates (3.34% p.a.) Kenya takes seriously the issue of the feeding of this burgeoning population which was 16.6m in 1980 but 22.4m in 1990. The projected 35m in the year 2000 will require increasing supplies of staple foods, especially maize (Republic of Kenya, 1986).

1.2 Maize in the Kenyan Economy

Maize is the major food crop in Kenya. Maize is such an important grain in Kenya that famine in the country is associated with lack of white maize even if there are other grains like wheat and rice. It is the staple food *for* over 95% of the people. It covers more area than any other crop (about 6.1 m ha in 1988). Maize grows in all medium and high potential AgroEcological Zones (AEZs) in Kenya and in 1988 it received between 20 and 28% of Kenya's total fertilizer use while no other food crop received more than 2-3% and some got no fertilizer at all (Fertilizer Use Recommendations Project (FURP) 1988). Mai ze tends to be the dominant crop in areas of high agricultural potential. These are also the areas with the greatest population densities and those which reguire the greatest intensification of output per acre to support rapidly increasing populations.

The 1989-93 National Development Plan recognises the necessity to manage a major intensification in the production of all basic food commodities. The implications for maize and wheat are shown in table 1.1 below.

Table 1.1: <u>Food Production Targets, 2000 AD</u>

Commodity	Average'a' 1984	Production 2000	Growth %	Total Demand	Unmet Demand
Maize ('000MT)	2100	4400	4.7	4400	0
Wheat C 000MT)	214	400	4	100	600

Source: Republic of Kenya, 1986
1981 - 84 average

The table shows that maize output will need to be increased by 4.7% p.a. until the end of the century. Wheat output would need to be increased at a rate much higher than 4% p.a. to meet demand by the year 2000. Clearly there is a big challenge in production of these major food crops.

To maintain self sufficiency in maize will require a concerted effort to increase land productivity through improved technology and intensification of input use combined with sound pricing and marketing policies. New technology is required urgently . But input intensification is a critical factor in generating increased maize productivity. Optimal use of modern inputs by all farmers could produce the required 4.7% percent rate of growth for the next decade. The current study is a step in the identification of these optimal rate for nitrogen and phosphate fertilizers.

1.3 FERTILIZER USE IN KENYA:

Fertilizer use experienced an average growth rate of 6.7% in Kenya during 1974-87 (World Bank 1988). The same data indicate that unlike other African countries, Kenya's progress is only stable but slow compared say to Nigeria or Cameroon where the comparable rates in fertilizer use has been greater than 10 percent per annum. While statistics are far from perfect there are indications that the growth rate slackened over the 5 years ending February, 1990. National Consumption of fertilizers is estimated at only 1/3 of a potential 600,000 - 650,000 tonnes of all fertilizer products. It is unfortunate then that in spite of generally increasing demand for fertilizers the use of this vital input is not quite widespread in Kenya (Ogutu and Odhiambo, 1985). This especially applies to food crops such as maize where thore is a wide scope for increasing the yields especially on smallholder farms through the economic use of fertilizers. The Kenya Agricultural Growth Prospect (KAGP) data indicate that there are 16 million people in smallholdings (with less than 12.5 ha per holding) on 2.7 million holdings. They produce about 75% of Kenya's agricultural output, 55% of marketed output and contribute 75% of farm jobs, making use of 2/3 of arable land. However they used only 43% of total fertilizers supplied in 1986.

1 . 4 PROBLEM STATEMENT

Fertilizer recommendations for different crops in Kenya have been made by various Research Stations. The Stations charged with the responsibility of conducting research on particular crops make recommendations in respect of these crops. Thus the Coffee Research Station makes fertilizer recommendations for coffee while the Tea Research Foundation does likewise for tea. Maize research is conducted by the National Agricultural Research Stations. Other institutions deal with such crops as cotton and sugarcane.

There are big divergencies between the present and recommended levels of nutrient use in almost all crops except estate tea in Kenya (see tables 1.2 and 1.3). The

Table 1.2: **The Gap Between Use and Optimal Levels of Nitrogen Consumption for Maize, Coffee and Tea in 1982/83.**

Crop. Estate/ Smallholder District/ Province	Estimated Levels of Use in 1982/83	Nutrient Rq'ment of Recommended levels (Tons of phosphate)	Additional Nutrients Requirement	Use as % of Recomm-ended
Coffee				
Estate	4760	6720	2140	72
Smallholder	4660	13390	8730	35
Subtotal	9420	20110	10690	47
Maize				
Trans-Nzoia	1520	3660	2140	42
Uasin Gishu	1270	3360	2090	38
Kericho	120	3480	3360	3
Nandi	300	2640	2340	11
Other RVP (inc. Meru)	620	2490	1540	25
Bungoma	220	1800	1580	12
Kakamega	320	2680	2360	12
Kisii	20	3440	3420	1
Other Nyanza	5	480	475	1
Central Province (inc.Embu)	850	3440	2200	26
Sub-total	5245	27,370	21,505	19
Tea				
Estate	4225	4225	-	100
Smallholder	2500	7600	5700	33
Sub-total	6725	11825	5700	57
TOTAL	21390	59305	37295	36

Source: Schluter and Ruigu (1990)
* - Optimal levels as recommended by the relevant research stations.
RVP = Rift Valley Province [1] = Requirement
[7] = Recommendod

Table 1.3: **The Gap Between Present and Optimal* Levla of Phoaphate Use of Maize. Coffee and Tea in 1982/83**

Crop., Estate/ Smallholder District/ Province	Estimated Levels of Use in 1982/83	Nutrient Rq'ment of Recommended levels (Tons of phosphate)	Additional Nutrients Requirement	Use as % of Recomm-ended
Coffee				
Estate	1760	2486	726	71
Smallholder	1460	4944	3484	30
Subtotal	3220	7430	4210	43
Maize				
Trans-Nzoia	2560	3660	1100	70
Ua3in Gishu	2144	3360	1216	64
Kericho	200	3480	3280	6
Nandi	506	2640	2134	19
Other RVP (inc. Meru)	1152	2880	1728	40
Bungoma	368	2250	1882	16
Kakamega	544	3350	2806	16
Kisii	30	3440	3410	1
Other Nyanza	8	480	472	2
Central Province (inc.Embu)	1328	3320	1992	40
Sub-total	8840	28,860	20,020	31
Tea				
Estate	1145	1145	-	100
Smallholder	500	1520	1020	33
Sub-total	6745	2665	1020	57
TOTAL	13705	38955	25250	35

* - Optimal levels as recommended by the relevant research Stations
Source: Schluter and Ruigu(1990)

largest gap in fertilizer recommendation and use is in maize where levels of use vary between 3% (for Nitrogen) and 5% (for Phosphorus) or less of recommended doses in Nyanza Province to the highest levels of 43% (N) and 60% (P) in Trans-Nzoia (Ruigu and Schluter, 1990). Integrated Rural Survey (IRS) (1977) data confirm very low levels of use in most districts. However, in some cases, around Kitale National Agricultural Research Stations (NARS) recommended levels are well below levels currently being used by 'best farmers'. In effect recommended levels are probably well below the economic optimum. Small-scale farmers as a whole achieve only about half the yields achieved by large scale farmers. One of the reasons may be sub optimal use of fertilizers. Most farmers in Kisii (one of the study districts) use fertilizer but at about half the rate recommended by extension staff (Egerton University, 1990).

Marginal returns to fertilizer use were in 1983/84 much higher in coffee and tea than in food crops e.g. maize and sunflower (Ogutu and Odhiambo, 1986; MOA 1984). It is clear however that the marginal returns to fertilizer use are high enough to justify fertilizer upe in maize and what may be lacking is the extension service to promote fertilizer use (Republic of Kenya, 1986) . Data further indicate that returns to fertilizers are almost twice as much as the returns to labour use on maize (Ogutu & Odhiambo, 1986). The increased use of fertilizers is clearly very warranted.

From table 1.4 below on fertilizer requirements and production projections, it is clear that a substantial

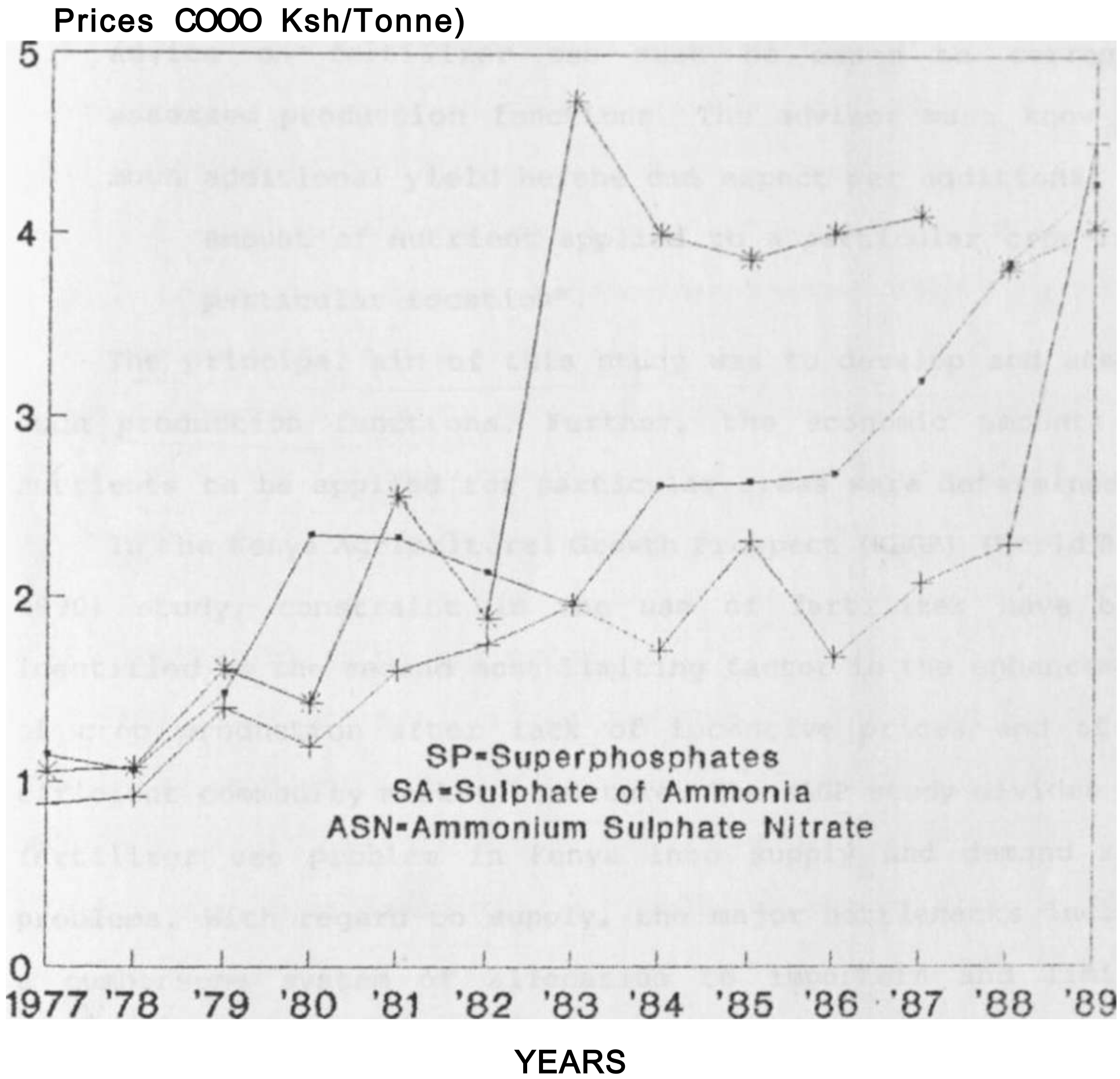
Table **1.4: <u>Fertilizer requirements in 2000 AD</u>**
<u>Production in ' 000 Tonnes</u>
<u>Fertilizers in '000 tonnes of Product</u>

CROP	PRODUCTION 1985-1987	FERTILIZER USED	CROP PRODUCTION PROJECTION 1999/ 2000	FERTILIZER REQUIREMENT
Coffee	105	61	354	84
Tea	156	41.9	262	77.4
Sugarcane	426	39.0	603	217.0
Maize	2548	46.5	4400	337.0
Wheat	257	18.0	400	44.0
Others		31.6		171.8
Total		236		991.2

Source: Republic of Kenya (1986, 1988).

increase has to occur in the application of fertilizer in the years towards 2000 AD. From 1985 no less than 627% more fertilizer will be required on the maize crop, 456% on sugarcane and 133% on wheat. To achieve this over 90% of additional fertilizer use would need to be on these food crops. (Republic of Kenya, 1986).

While returns to fertilizers are economically still attractive, fertilizer prices continue to take a worrying upward trend especially when fertilizers comprise the most important purchased input in agriculture (see fig 1.1) . Fertilizer accounts for about 27% of the total value of inputs. With the current high prices of oil and uncertainty over their future trends, fertilizer bills can be expected to soar evpn higher. This problem is compounded by the effect of the fast depreciating value of the Kenya shilling against major currencies. It then becomes imperative to identify the economically optimum levels of fertilizers recommended for specific regions.



SP SA ASN

Fig 1.1; Fertiliser Price Trends; All Prices c.i.f (Mombasa)'OOO Ksh/Tonne.
Source: Statistical Abstracts (various)

As noted by Jaetzold and Schmidt (1982);

> "Correct advice for fertilizer application can be based only on scientifically proven data. Good farm management advice on fertilizer use must be based on correctly assessed production functions. The advisor must know how much additional yield he/she can expect per additional amount of nutrient applied to a particular crop in a particular location".

The principal aim of this study was to develop and assess such production functions. Further, the economic amounts of nutrients to be applied for particular areas were determined.

In the Kenya Agricultural Growth Prospect (KAGP) (World Bank 1990) study, constraint in the use of fertilizer have been identified as the second most limiting factor in the enhancement of crop production after lack of incentive prices and of an efficient commodity market structure. The KAGP study divides the fertilizer use problem in Kenya into supply and demand side problems. With regard to supply, the major bottlenecks include a cumbersome system of allocation to importers and limited availability of foreign exchange. The demand side problem as recognized by the KAGP study has been the non-availability of proven fertilizer recommendations which are profitable to smallholders given their risk aversion.

This study dealt with the demand side problem, by doing economic analyses on experimental data. The study was conducted to determine the optimal fertilizer to be recommended at specific locations using experimental data obtained from these locations.

1.5 OBJECTIVES OF THE STODY

The specific objectives of the study were

(i) To develop yield response (to fertilizer N and P) functions for maize in the Agro-Ecological Zones (AEZs) traversed by the study districts viz Kisii and BusJa.

(ii) To estimate from the yield response functions the economically optimal levels of use of the nutripnts N and P under the predominant management practices in the respective districts.

(iii) To compare current fertilizer recommendations emanating from the NARS with the optimal levels of fertilizers which ought to be used as derived in this study.

1.6 JUSTIFICATION OF THE STUDY

The study of this problem was clearly justified by the following very pertinent issues:

(i) In order to pass from the stage of subsistence to commercial agriculture, there is always nred to adopt non-conventional inputs including fertilizer. The level of the appropriate type of fertilizer to use and its costs are important issues to a commercial farmer because this determines the achievable profit. It is therefore of importance to provide sound information to the farmer about the types, timing and quantities of fertilizers that should be used in order to obtain a sound return on investment,

(ii) According to the Sessional Paper No.l of 1986 (Republic of Kenya, (1986) research must be concentrated on those crops and those kinds of farms on which the long-term agricultural development strategy depends most heavily. The first priority is maize and especially maize grown by sma11-holdors. This study goes a long way to meet this goal.

(iii) Fertilizer consumption projections have been reported based on regional averages for fertilizer application rates and rates of increase in fertilized areas for the fertilized crops (Choksi *et al.*, 1980). This study forms a basis for such future projections in the study area.

(iv) The Kenya Agricultural Sector Adjustment Operation (KASAO) (1990) contends that "while crop technology as available today is reasonably adequate to substantially step up smallholder yields in cereals, more work needs to be done in fine tuning fertilizer dosage and recommendations for each district, location and sublocation on the basis of soil tests...." This study is an attempt in this direction,

v) The scientific basis for fertilizer use recommendations in Kenya is weak. Despite very wide variations in physical and chemical characteristics of soils in Kenya, the fertilizer use recommendation for each crop have been uniform throughout the country except for coffee and tea. Fertilizer recommendations say for maize, were made such that they do not respond to changes in economic conditions. They especially do not respond to the prices of fertilizers and maize.This means the prices are not consider<-"1 In these recommendations as reported by Mwangi (1^TR). In K^nya, in spite of the wide variations in physical and chemical characteristics of soils, optimal fertilizer levels for specific locations are not known hence the current reasons for nationwide recommendations which are sometimes inappropriate.

1.7 The Area of Study

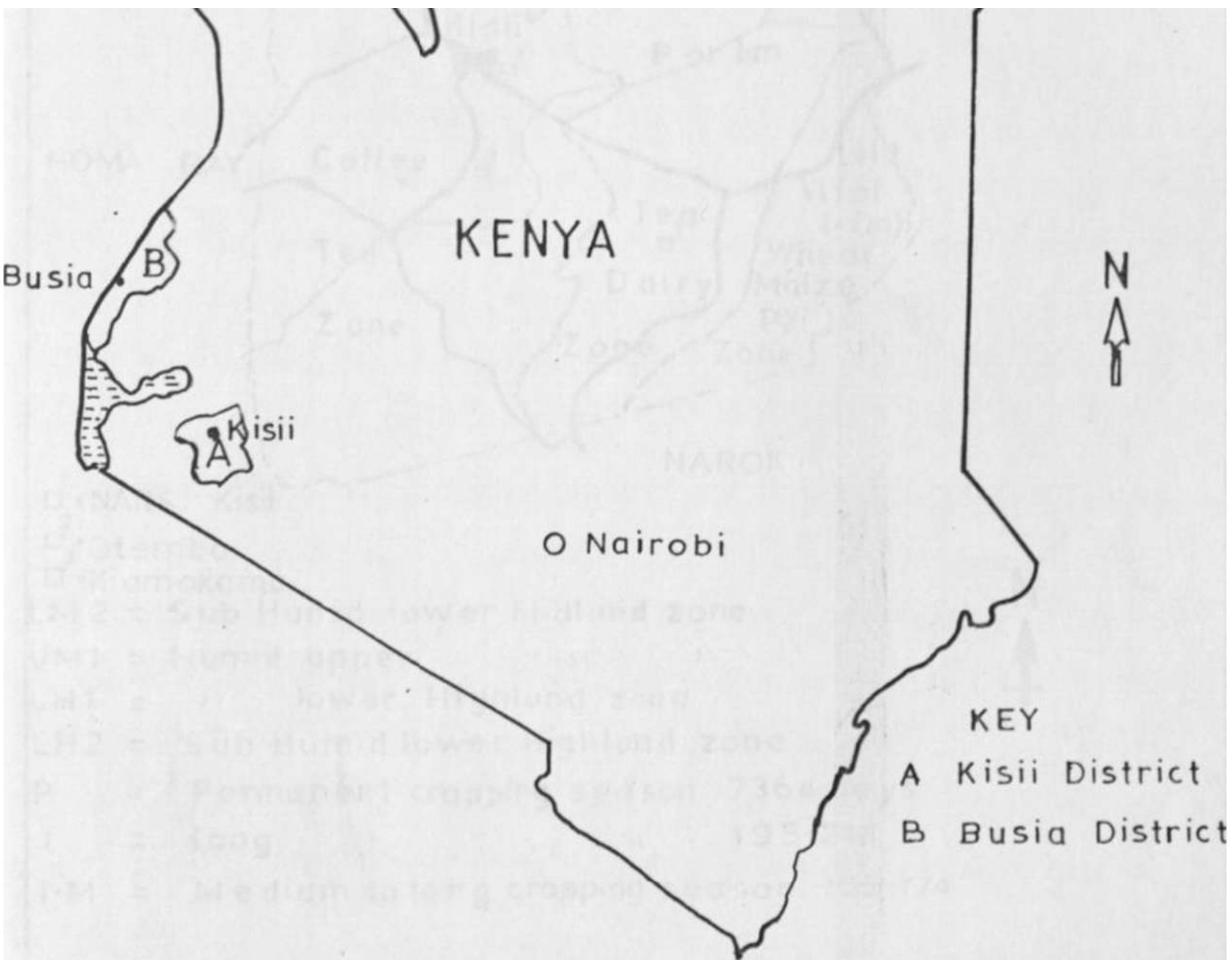
The area covered in the present study is shown in maps 1-6 in the following pages. It included the districts of Kisii and Busia in Kenya, west of the Great Rift Valley. Busia is in Western Province while Kisii is in Nyanza Province (Maps 1 and 4) . The basis for selection of these two districts was mainly the availability of experimental data required for this study and the possibility of comparing the results in the two districts. The two districts are briefly described below.

1.7.1 Kisii District

Kisii district covers 2196 sq. km. It lies about 80 km South of the equator, 65 km North of Tanzania and 50 km east of the Kavirondo Gulf on Lake Victoria. The district is mountainous and there is a range of altitude from 1700m to 2400m (Uchendu and Antony, 1975) .

Kisii district is one of the high potential agricultural areas in Kenya based on rainfall amounts and reliability. This is due to the fact that it is situated in the centre of the local convergence of the daily Victoria lake winds with the easterlies during the generally dry seasons in Kenya. Annual rainfall averages 1200-2100 mm . Rainfall reliability is high. The long

Map 1. The geographical Location of the Study Area of Kisii and Busia Districts

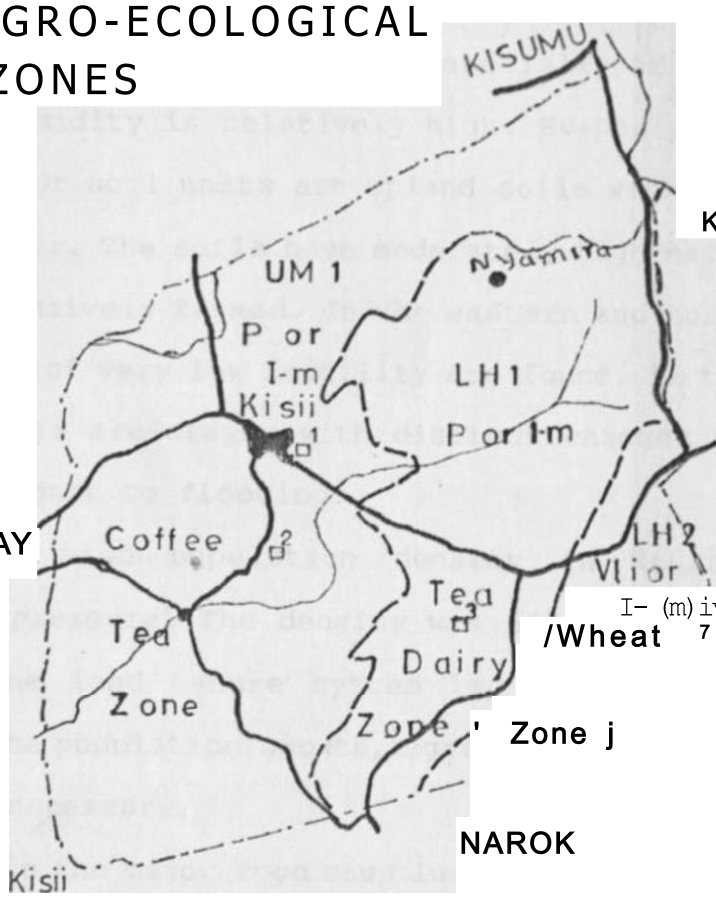


Source-. Author

Map 2

KISII

AGRO-ECOLOGICAL ZONES



DINARS

2 Otamba

3 Kiamokama

LM 2 - Sub Humid lower Midland zone

UM 1 Humid upper " "

LH 1 " lower Highland zone

LH 2 Sub Humid lower Highland zone

P Permanent cropping season 7364 days

I Long " " 195-214

I'M Medium to long cropping season 155-174

N

0 5 10 15 20 25 km

Source Jaetzold and schmidt (1982)

rainy season ranges between 215-230 days starting mid February. The short rains season is 135-150 days starting about October/November. Temperatures are generally higher than those normally found at this altitude especially to the west of the district. Humidity is relatively high. Evaporation is low.

The major soil units are upland soils with topsoil rich in organic matter. The soils have moderately high natural fertility and are intensively farmed. In the eastern and northern parts of Kisii, soils of very low fertility are found. In the bottomlands alluvial soils are clayey with distinct changes in texture and they are subject to flooding.

A very high population density in Kisii has led to population pressure. The density was 640 persons per square km in 1990. The land tenure system is predominantly free hold. Regarding the population growth, agricultural intensification is absolutely necessary.

Maize is the major food crop in Kisii having been cultivated here for over 60 years. Synthetic and hybrid varieties of maize are widely cultivated. Maize is mainly interplanted with beans, but single stand maize fields are becoming general practice. Maize and beans occupy roughly half of the annual crop area in the major AEZs viz the Humid Lower Highland Zone (LH1) and the Humid Upper Midland Zone (UM1) . Coffee and tea are the principal cash crops.

Output and input nutrient figures from Kisii currently reflect untapped production potential under the ideal natural conditions of the district. This can be achieved if **S'**-i*:ntific farming is introduced and the necessary economic preconditions created (Jaetzold and Schmidt, 1982). Intensive small-scale farming based on manual cultivation will continue to form the basis for a good and reliable income for the farming population of the district.

1.7.2 Busia District

Busia district is situated at the extreme Western edge of Kenya in Western Province. It occupies 1766 sq. km. This includes 137 sq. km of permanent water surface. Of a total 168,000 ha comprising the land surface, 151,900 constitute high potential land, 3100 ha medium potential and 32,000 ha low potential land characterised by rockiness and poor soils (Were and Soper, 1986).

The long and short rains come in the months of late March to May and in August to October respectively. Most of the district receives 1270-1790 mm mean annual rainfall generally decreasing from North to South. The marginal cotton zone is the main AEZ to the south followed northwards by the Cotton zone, Marginal sugarcane zone, Sugarcane zone, Marginal sugarcane zone and the Cotton zone in that order. The annual average temperature is between 21 and 22°C. Humidity is relatively high due to proximity of lake Victoria.

Altitude in Busia rises from about 1130 m to a maximum 1500 m above sea level in the Samia and North Teso Hills. The majority of the soils are moderately deep (Soil depth 50-80 cm to murram or parent material). Soils of the hills are shallow. They are generally rocky and/or stony. Soils of the uplands have a low

Map 3

BUSIA

AGRO-ECOLOGICAL ZONES

Source: Jaetzold and Schmidt (1982)

JLU

LM3 Semi-Humid Lower Midland Zone?
LM2 = Sub-Humid ,> ≫
LM 1 = Humid lower Midland Zone
LM4 = Transitional n
M/l — Medium to lony cropping season
M/s =r >' to short
l = Long cropping season

natural fertility. In most of the district they ar«* moderately deep. They are generally darker in the higher areas b<*cau.*^ of a higher humus content. In the Yala swamp, soils tend to have a very high to moderately high organic matter content (Jaetzold and Schmidt, (1982).

The population problem in Busia is not as serious as in Kisii district. The Midland Sugarcane zone and the lower Midland Marginal Sugarcane zones don't have a very high population density. The fact that upto 50 percent of the agricultural land in these zones is used for livestock means that any agricultural improvement possible becomes more and more necessary. Jaetzold and Schmidt (1982) have noted that "Despite the fact that intensification of land use in Busia is not very urgent because of the land/population ratio of the district, development of its potential is in the national interest".

Maize, finger millet and cassava are the major food crops. Sugarcane and cotton are the principal cash crops. With the expansion of area under sugarcane, which occupies the better soils of the region, the district is a net food importer. This then calls for intensification of farming to raise the maize yields in the district.

t

CHAPTER 2

LITERATURE REVIEW

Many studies have been conducted in the area of Crop Response to Fertilizers in various parts of the world. This chapter reviews some important studies in the area of Crop Rosponse to Fertilizers in as far as they have a bearing on the current study.

Heady's pioneering work during the 1950's on corn-fertilizer response functions formed the first firm bridge between work by agronomists and agricultural economists. Hitherto much of the farm input recommendations were based on agronomic studies. Such agronomy type approaches tended to emphasize the Analysis of Variance and related significance test procedures. Before long some agricultural economists and statisticians became critical of the inadequacy of these approaches. As noted by Throsby (1961:113) "Significance tests such as the Analysis of Variance (ANOVA) cannot alone extract from the data sufficient information to enable sound recommendations to be made". In response to such criticisms the agricultural economists resorted to neoclassical economic theory and adopted the Production Function Approach to fit both experimental and cross sectional data to compute resource productivity production surfaces and economic optima. The current study follows this procedure.

Heady and Dillon (1961) have reported on initial research on crop response surfaces initiated in Iowa in 1952. The experiments were done on corn and other crops with two variable inputs nitrogen (N) and phosphate (P,OJ . The design of the experiment was as illustrated in table 2.1.

Table 2.1 Design of Experiment For Corn. Each "X" Represents an Experimental plot

Pound! P, 05 per acre	Pounds of Nit rogen per ·ere								
	0	40	80	170	160	700	740	7«0	170
0	XX	XX	XX	XX	XX	XX	XX	XX	XX
40	XX	XX			XX	XX			XX
80	XX		XX		XX		XX		XX
170	XX			XX	XX			XX	XX
160	XX	XX	XX	XX	XX	XX	XX	XX	XX
700	XX	XX			XX	XX			XX
740	XX		XX		XX		XX		XX
760	XX			XX	XX			XX	XX
370	XX	XX	XX	XX	XX	XX	XX	XX	XX

Source: Heady and Dillon (1961)

This experimental design, with randomized plots, allows for continuous observations at the extremes of application rates with combinations of the two nutrients. It also provides sufficient observations over other points of the production surface.

Heady used the resultant data and estimated the following equations for corn.

$$Y, = 0.442\ P^{0-4090}\ N^{\circ " ?887} \quad \ldots \quad 2.1$$

$$Y = -7.51 + 0.584N + 0.664P - 0.0016N * \quad \ldots \quad 2.2$$

$$Y = -5.68 - 0.316N - 0.417P + 6.3512\ N^{14} + 8.5155P'^{4} +$$
$$0.3410\ N^*\ P^* \quad \ldots \quad 2.3$$

$$Y = -13.62 + 0.984N + 1.129P - 0.05N^{3'2} -$$
$$0.0576P^{3"} + 0.008NP \quad \ldots \quad 2.4$$

where Y_t = Yield above control plot

Y = Total yield per acre

N = Kg N per acre

P = " P_2O_5 per acre

Heady reported the R and t values for the four functions as shown in table 2.2

Table 2.2. Values of R for Two-variables Nutrients and Values of t for Individual regression coefficients

Equation	Value of R	Value of t for coefficient in order listed in the Equation				
2.1	0.9255*	18.62*	15.23*	-	-	-
2.2	0.9122*	9.21*	10.46*	5.24*	8.96*	10.19*
2.3	0.9582*	7.91*	10.44*	7.32*	9.81*	8.85*
2.4	0.9434	8.21*	10.35*	6.21*	7.31*	10.12*

* $0 < P < 0.01$

The results show some of the difficulties that may arise with econometric analysis of such data. Equation 2.4 for example indicates the impossible observation that if no nutrient is added to the plot the outputs are negative. The literal meaning of that situation is that one would in that case have to bring corn into the field.

This applies to equation 2.2 and 2.3 as well. The constants were found to be statistically significant and were therefore retained in the equation although the functions might have appeared more sensible if th^y had been forced to have zero intercepts.

Rukandema (1978) and Oluoch-Kosura (1983) expound on the difficulties of interpretation of the level of output at zero level of all inputs. Both consider the linear model where output JY) is a function of n inputs (X.) i.e

Bj^ 2.6
i-i

The two major objections to the linear production function are (1) that the marginal product of X_t i.e. B,, is constant regardless of the level of X, relative to other inputs and (ii) that output is positive (a>0) or negative (a<0) even when there are no inputs involved. These mathematical implications make no technological sense. However it may be assumed that the relationship between Y and X,, other things held constant, is depicted by curve OV in figure 2.1 but that all X_t observations fall between M and N. Then the estimated linear function represented by ST may summarize the data satisfactorily. Despite varying marginal products of X, across farms, B, is a reasonable approximation for all farms. In addition a does not pose any problem as the level X, = 0 is outside the relevant input range.

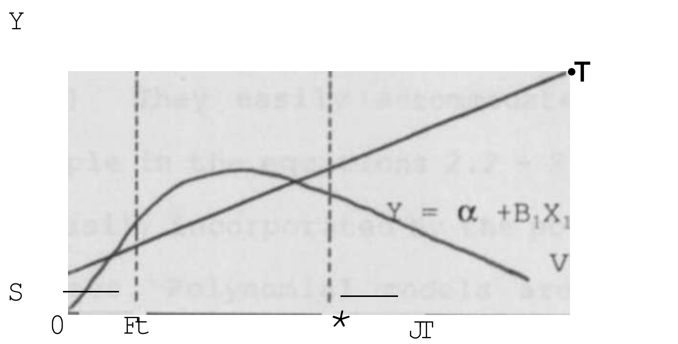


Figure 2.1 A Linear approximation of Production Data

Use of the quadratic and square root models in Heady's work is an indication of the popularity of these functional forms. These polynomials are quite widely used even today in crop response studies because of reasons cited by Colwell (1978) as mentioned below.

(i) They are easily fitted into data by standard multiple regression procedures.

(ii) They can be made flexible enough to describe most smooth trends, and rigid enough to smooth out observations or 'errors' in data, by appropriate choice of scale and degree. For example the quadratic models of general form,

$$Y = b_c + bj\ X^R + b_? X^{7s} \qquad 2.7$$

$$Y = b_{„} + b_t X,^8 + b_2 X_2* + b_3 X,' x_2" + b_4 X\text{^}* + b_5 X/* \quad ...2.8$$

are particularly popular, especially for the natural scalp (s = 1) and square root scale (s =0.5) because they allow discrete and simple algebraic calculations of maxima and opt-ima. The need for higher degree terms and the effect?

of scale can be judged from statistical tests of goodness-of-fit and data from series of fertilizer experiments .

(iii) They easily accommodate interaction effects.For example in the equations 2.2 - 2.4 the NP interaction term is easily incorporated by the polynomials at the different degrees. Polynomial models are particularly convenient for representing yield-fertilizer relationships because they allow direct calculations of optimal application rates under a variety of circumstances. Even then there is still scope for argument concerning an appropriate scale and degree for the polynomials.

Notice the expected negative sign for the power variable (N^2, (P^7) and $N^{3/?}$ and $P^{3/?}$. This is a good sign for these models as it caters for the expected diminishing returns to nutrient application. Diminishing returns to nutrient application is basic to the biological logic of the production process. The polynomials have a strong point in taking care of this phenomenon. To illustrate take the function in equation 2.2

$Y = - 7.51 + 0.584N + 0.664P - 0.016N^7 -0.0018P^1 + 0.0081NP$. The N^7 term in this function assumes low values for small applications of N and is outweighed by the constant and N terms. As higher N values are used then $N^'$ term predominates the value of the function and with its negative coefficient the function reaches a maximum before assuming a negative slope.

Thus in spite of the earlier mentioned weakness (i.e. the negative outputs for 'zero nutrients') these specifications can be regarded as very appropriate for Crop Response studies such as those undertaken by Heady. This current study used the Quadratic **model** and the Cobb-Douglas model with introduction of dummy variables to account for locational and seasonal differences in sources of data.

In Kenya however such research on crop Responses to Fertilizers was limited mainly to coffee and wheat during much of the colonial era[1]. Maize was chiefly a smallholder peasant farmer's crop and was not accorded much significant research. Maize experiments were mainly carried out as only one part of their large programmes by research officers in charge of general investigation stations dealing with several crops and also livestock (Allan, (1971), and (Eicher, 1988).

Early work on fertilizers in East Africa was reported by Holme & Sherwood (1948) . They reported on early fertilizer trials in Eastern Uganda, Nyanza province of Kenya and the Lake Province of Tanzania. This early work essentially tried to identify suitable sources of plant nutrients. From the experimental work reported it was also possible to make rough estimates of fertilizer needs for the study areas, an illustration of the use into which

[1] This was in line with policies many colonial regimes , which focused their research and development prooramrnes on expnri-crops and the needs of commercial farmers and manners c[F] piantations.

fertilizer trials and resultant recommendations may be put.

The current study doesn't engage in any work to identify suitable fertilizer types as this has already been done by agronomists. The fertilizer recommendations emanating from this study will however form a basis for the estimation of fertilizer needs in the respective study districts.

Doughty (1953) records perhaps the first economic analysis of experimental data on fertilizer responses in Kenya. Doughty's study involved estimating approximate increases in crops reguired to meet costs of dressing over a range of values of the crop (wheat). Doughty recorded that "as the profit motive is an important factor in increased crop production, it is important to have some idea of the relative costs and returns" Doughty's study was essentially a Break-even analysis. The current study departs from Break-even analysis and employs Profit Maximization procedures. Doughty didn't make estimates of continuous response functions. His work was based on point estimates of crop response. This may be attributed to a dearth of enough information from which continuous functions could have been estimated. Whatever results Doughty came up with, they would be of little use to present day agriculture since they were based on different crop varieties than the present ones. Further, **Foils** have been cultivated for a long time since Doughty's work.

Fertility of the soil has therefore changed and new recommendations are necessary.

Other early works on fertilizer trials in Kenya were by Gethin (1953), the Department of Agriculture (1960), Sherwood (1959) and Gathecha (1967) among others.

An active programme of agronomic research has been essential to determine appropriate fertilizer application, spacing, time of planting and other recommendations. Agronomic experiments date back as far as 1910, yet it is only beginning 1963 that Allan (1971) developed a systematic programme of agronomic research in Kenya. Prior to that time, the effects of husbandry, fertilizer application and plant population had been examined singly or at best in pairs. Experiments on maize were conducted by many people , at different times and places, using different methods. There was no longterm coordination of research work on maize. This made it difficult to interpret the results of the experiments and fit them into a coherent pattern (Allan, 1971.)

Allan set up a series of district - maize-variety and district cultural trials using a 3^3 factorial design with different levels of Nitrogen, phosphate and plant population from which annual recommendations for farmers were prepared (Allan 1971). At that time, the average yield of maize in Kenya was about five to six bags (1000-1200 pounds) per acre. In the district variety trials however, the unimproved local maize used in the control plots (with carefully supervised husbandry) yielded an average of 4000 pounds (20 bags) over the 1964-66 period. Clearly hybrids alone were not required to increase yields.

To test the effects of poor husbandry, Allan established a series of 2* factorial trials in which each of the six factors (time of planting, plant population, type of seed, standard of weeding, and use of nitrogen and phosphate) were deliberately set at a "high" and "low" level. Allan concluded from his results that time of planting and type of seed were the most important factors determining yield, followed by standard of weeding and plant population. Fertilizer application was not important and, in absence of good husbandry practices was actually unprofitable.

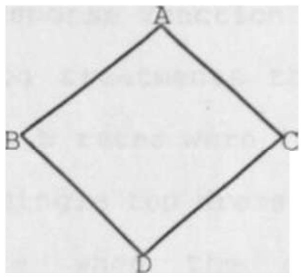
Allan's results were illustrated clearly in a maize "diamond" (Fig. 2.2) in which physical inputs (seeds, nitrogen, phosphate) and poor husbandry are compared with good husbandry (early planting, weeding, proper spacing) . The physical inputs alone produced a 66% increase over the original average of all practices taken at a low level, while good husbandry practices produced a 148% increase. All six practices taken at a high level produced a 307% increase. Allan concluded that "it is dangerous to recommend the use of expensive fertilizer in the absence of high levels of husbandry. A "Second-best" formula is implied, in which improved seed genotype is combined with improved husbandry practices for a low-cost, high return solut ions".

Fig. 2.2 Maize Diamonds in Kenya:

Husbandry; Physical Inputs, and Yip1

Bad husbandry, Local Maize seed,
no fertilizer
8.8 bags/acre

B. Bad husbandry
Hybrid seed
Fertilizer
14.6 bag/acre
(66% increase



C. Good husbandry
Local seed no
fertilizer.
21.fi bags/acre
(148% increase)

35.8 bags/acre
(307% increase)

D. Good husbandry, hybrid seed, fertilizer.

Source: Gerhart (1974)

While the results of Allan's work showed clearly how important good husbandry is to increased maize production, they didn't indicate at what level fertilizer was optimally to be used by the farmer. The separation of the application rates as "high" or "low" is a far cry from the experimental set up necessary to make economically useful recommendations. Indeed what Allan might call high fertilizer doses may in optimization studies like the current one turn out to be low. It is therefore necessary to use a wide range of application levels of the two nutrients N and P so a response curve can be estimated from which 'high' and Mow' levels of applicat'on may *bo* confirmed and only the optimal recommended for use by farmers.

Allan *et al* (1972) in their report on "Chanqes in Nitrogen and Population Response of Hybrids 611 and 613 after 3 cycles of selection:** give one of the initial experiments designed purposely to develop some Agricultural Response Function in Kenya. With three N and three population treatments they tested 8 genotypes at three sites. The N rates were 41, 141 and 241 kg per ha of N applied as a single top dressing in the form of Ammonium Sulfate Nitrate when the crop was knee-high. The population treatments were 33.4, 44.4 and 55.5 thousand plants per ha respectively. A uniform rate of 100 kg $P_2 0$ per ha was applied at planting.

The data collected from these experiments were subjected to an Ordinary Least Squares (OLS) regression[7] analysis to arrive at an estimate of a response model. The results were presented as a quadratic equation.

$$Y = X(adj) + b_1 N + b_2 S + b_u NS + b_{12} N^7 + b_7, S^2 \ldots \ldots 2.9$$

N = kg ASN per ha.

S = '000 plants per ha.

While the actual coefficients were not available for the current study, it is clear that in Allan's study the

[2] Implicit in the use of the procedure is the assumption that independent variables are fixed and uncorrelated, the error terms (e_i) have zero mean and constant variance for all observations. The e, are a!so uncorrelated and are normally distributed.

N treatments are varird enough, perhaps too widely given they are only three. Regression coefficients may as a result be biased. The uniform P application does not reflect any likely farm situation and th^ results may not be of much practical application. Given that there; have been numerous reports of interaction between N and P response it seems ill advised to use a single P treatment. Use of the Quadratic model is however a strong point of this study as this model is highly acclaimed in agricultural Production Function Studies (Colwell 1978).

During the early seventies the Food and Agriculture Organization of the United Nations (FAO) sponsored fertilizer trials in Kenya. This was part of the world FAO fertilizer Programme. This programme served a number of important purposes. The study demonstrated to farmers what fertilizers can do in the enhancement of crop yields. They collected a lot of data showing crop response to various fertilizers. They further attempted to show economic justification for using fertilizers by calculating net returns and Value Cost Ratios (VCR) (FAO,, 1974, 1980, 1981a, 1989).

Many economic calculations employ a value/cost or benefit/cost ratio. For yield response studies this ratio corresponds to An/1 where 7t is profit defined as

7l = VY - CX-Q

Where V = Value of a unit of crop yield

Y = Output per ha (Yield)

C = Cost of a unit of the nutrient X

Q « Other costs not affected by fertilizer rate e.g. cultivation costs.

X = Quantity of fertilizer used.

I = CX = Amount of money invested in fertilizer.

The important thing to note is thatArc/I is always larger than j>7t and is still large even for Invest mont
81
levels above the point of maximum profit where the rate of return <0. Thus the simple comparison of profit
81
from fertilizer, Arc with money invested (I) can thus give quite misleading indications of economic fertilizer needs. Many studies (e.g. the FAO fertilizer trials in Kenya during the 1970s) have employed this method. The rule of thumb is that it is economically rational to apply an input as long as one attains a VCR of 2.0. It is clear from the arguments above that this can result in an appreciable economic loss. This method is therefore discredited in favour of the production function approach. Table 2.2 shows some VCR results from the FAO Fertilizer program

The FAO study covered a large number of districts so that recommendations could be made at a local level. This is important because of the need for region specific recommendations necessitated by the great variability in agroecological conditions of even geographically proximal areas in Kenya. The districts covered by the FAO program are listed in Table 2.3. The districts of Kisii and Busia are not included thus there are no results from this program against which to compare the results of the current study.

Table 2.3. Value/Cost Ratios in Maize Production for Some Kenyan Districts

AVr*AT» TIKIO							»rt	V*
oi»n>irr	no. or PFW1S TH-AT 1CMS	CCWTKOI KC/HA	Tur-ATra «<: MA '	!»c»*A»ro una •C/IIA	WIT rr ·r* V> RSI '	cor nr •lur* IMH91.	nun.	
•AXAHTGA	11	ltrt	•0**	7374	*47	1*7	7*3	
BUHOOMA	45	>11*	4*74	1417	747	1*7	37*	J.*
HOMA HAY	to	2112	4111	7004	7(0	1*7	3*3	t.I
STAVA	7*	111*	4*?*	1771	44*	1(7	4*7	3.3
HUKAM'CA	14	MIt	441*	1*47	773	130	(71	3.7
»yr.*t	11	3411	1721	7044	(10	ISO	(41	14
rxrnj	20	7144	4317	1774	471	130	371	(.3
KACIIAKOS	4	1174	7747	771	711	130	131	|.(
Kr.mcHO	»		47*4	1474	731	1*7	334	3.7
rAIHKCO	•	JT«1	1104	1741	(77	1*7	4(0	3.4
NAftOK	•	31(7	4477	1440	(4(	1*7	44*	3.4
TAITA	»	347«	14*4	7070	7S4	130		1.7

SOUIWT.i Mvanqt (!*7(|

* This t• utoiUM uainq the 1*7? price or pair* which was (iki.n pe- *o k? hai

• The fertiliser used WAS (0.40.0 40-40 0 coated Kan*.1*7 and Ssha.130 r*r 100 kfT

The FAO programme paid attention to food crops' response to fertilizers, hitherto ignored. Kenya has traditionally conducted a fair amount of fertilizer research, on major crops viz coffee, tea, pyrethrum, sisal and large scale maize and wheat. This reflects the bias of policy makers towards cash crops and negligence of food crops (Mwangi 1978) . But if the growing Kenyan population is to be fed without resorting to food imports then resource allocation must be shifted more to fertilizer research on food crops. Mwangi (1978) had criticism for the FAO fertilizer trials. It was his contention that although the economic analysis was based on the Net Returns and Value Cost Ratios, some important aspects w«rr disregarded.

The recommendations were made with consideration of fertilizer purchase price and crop prices. Oth^r costs such as application costs, capital costs and transportation cost seem to have been ignored. Inclusion of these costs in the calculation of VCR would have resulted in different VCRs from those indicated in Table 2.2. The current study considered these other costs. The current study also made an attempt to compare the recommendations with and without consideration of these 'auxiliary' costs as mentioned by Mwangi (1978).

Mwangi went on to illustrate how a fertilizer demand function may be derived from a crop response function under assumption of:

(i) Perfect knowledge of the production function.

(ii) Perfect knowledge of factor prices.

(iii) Profit maximization.

Mwangi however did not use his illustration for an empirical estimate because he heeded the following criticisms by Timmer (1974).

(i) The assumptions of farmers maximising behaviour with no considerations of risks perceived are not correct.

(ii) The choice of the relevant fertilizer response function is chiefly arbitrary. This is a basic difficulty in describing the effects of fertilizers on yields. There is no fundamental theoretical model for the effects of nutrient application ^n crop yield. Consequently the model must be chosen on the basis of observation and experience, reflecting the biological logic i.e. it must be empirical and hopefully the mathematical form of the chosen model will not in itself influence the representation of the relationship in the region of interest (Colwell, 1978).

While the issues raised by Mwangi and Timmer are pertinent the problem of risk in formulation of crop response functions and subsequent derivation of input recommendations can be significantly reduced by a detailed consideration of all the costs as already mentioned above. This would most possibly be more cost effective than detailed modelling of the farmers risk situation.

Choice of the model is usually justified by the logic of the production process, relevant test statistics and if it fits the data better than others. An input demand function may indeed therefore be derived with accuracy from the crop response function. While this is not attempted in the current study, its results may form a basis for such input demand analysis in the future.

Olang (1980) after realizing a "lack of information about the effects of Nitrogen and Phosphate on the grain yield of maize" set up trials in six locations with the following objectives:

(i) To determine the effects of different rates of N and P on grain yields of maize.

(ii) To determine the optimum rates of these nutrients.

Five N and P levels, 0, 30, 60, 90 and 120 kg ha were tested in factorial designs. He concluded:

"...There were significant interactions between N and P and Location. There was a yield increment with increasing N levels up to 80 kg ha^{-1} after which the yield slightly declined. There was also a yield increment with increasing phosphate levels up to 60 kg ha"' P_2O_5 beyond which there was no significant increment. This suggests that the optimal nutrient combinations could be 80 kg ha"' N and 60 kg ha^{-1} P_2O_5

Olang's study had a good experimental design. Econometric analysis of the results would be appropriate and easy. The author however, summarized the results as a table of means for the six locations before finally doing an economically inappropriate analysis to make recommendations. Olang made his recommendations on the basis of the technical optimum by suggesting applications up to the point "beyond which there was no significant increase." A consideration of the input and output **prices** would have indicated recommendation of lesser amounts. It is notable however that if the value of the crop is very large relative to the cost of the fertilizer inputs, as it may be with certain special crops, then the optimal rate approaches that for maximum yield, calculated by solving the equations.

and

$$dx1 < 0$$

where Y = Crop Yield (Kg/ha)

X, = Nutrient Application (Kg/ha)

Theoretically the coincidence of the technical and economic optima implies that the relevant input is free. This case cannot however be said to apply for maize and the distinction between optimum and maximum is of importance. If farmers apply fertilizer at the technical maximum, they would be doing so at a loss. The current study considers the economic optimum as the appropriate level to recommend to farmers.

Ogutu and Odhiambo X1985) used aggregate data from six provinces and estimated production functions separately for large and medium and small scale farms. Data on such important factors as labour and land inputs were again wanting and these factors were not considered in the analysis. Fertilizers rainfall and capital were considered as independent variables but with the interest, depreciation, insurance etc. as one input, capital. The authors were able to derive output elasticities to fertilizer application for both large and small and medium scale farms as 1.5 and .43 respectively.

Ogutu and Odhiambo's study while not directly estimating fertilizer response functions for maize illustrated a number of issues as follow-;.

(i) There is a serious data problem on general fertilizer use in Kenya.

(ii) That improved technology is an important factor in enhancing maize output elasticity to fertilizer use.

(iii) There are increasing returns to scale in investment in small scale farms so that a farmer who doubles expenditure on improved technology (principally fertilizer) will more than double output per hectare. The assumption is that other factors non-fertilizer inputs are appropriately employed.

Jaetzold and Schmidt reported in 1982 the results of fertilizer trials in Kenya by NARS. In their report they noted;

> "The only exact method of establishing reliable information on crop yields in non-record-keeping farms is to harvest and weigh the crop of an exactly measured area by a specially employed team over a number of years (crop cutting)..."

At the time of their work this method had never been employed thus exact on-farm yield figures were not available. The authors however gathered information on crop yields from three sources;

(i) a large number of relatively small investigations previously carried out to acquire information about yields of some crops.

(ii) Comparatively long term information from farms where records are kept.

(iii) Results of 30 years of agricultural research work also gave some insight into levels of yields and the production potential of Kenya's agriculture.

The Kenya Soil Survey provided Jaetzold and Schmidt with information on approximate levels of soil fertility in the AEZs. These authors also conducted the Small Farm Survey (S.F.S.) from which they got additional information about the yield level in the smallholder sector.

Jaetzold and Schmidt further noted that the data available on fertilizer use and response were insufficient for the compilation of proper fertilizer recommendat.ions. In addition, research has concentrated on particular areas and crops while other areas, and the so-called subsistence crops have been virtually neglected. In order to arrive at some information for all areas suitable for rainfed agriculture and for the most common crops the assessment had to be done in two steps (a and b) and a number of assumptions made.

(a) The results of research work, demonstrations on farms, and results of book-keeping farms were analyzed to assess fertilizer response.

(b) The nutrient removal per weight unit of the different crops were compiled. The amount of nutrient to be applied was then assessed by using a set of nutrient "Recovery Rates" for the three major ecological regions as shown in table 2.4 below,

Table 2.4 **Recovery rate of nutrients (in %)**

Region	Nutrients		
	N	P>0$_5$	K;0
Upper- Lower Highlands, Upper midlands and lower Midlands in W. Kenya	60	15	70
Lower Midlands (East Kenya)	70	20	50
Lowlands (Coast)	50	20	50

Source: Jaetzold and Schmidt, 1982.

The recovery rate of different plants varies but, this was ignored because it is largely unknown. The data arrived at by way of these calculations have been altered somewhat according to (a) the natural fertility of the **20** most important soil types in the particular AEZ, (b> th®

length of the vegetation period and the kind of rainfall (c) knowledge of fertilizer use on the part of farmers of the particular region. Some of the results from th<* assessment are recorded in the appendices to this current study. A look at all the trial treatments indicates that they would not supply enough data for estimation of continuous functions. Such treatments are however very useful in indicating a nutrient deficiency (Colwell, 1978) . The trials were conducted mainly with only three fertilizer treatments and estimates made of the yield increase over the untreated plots. Such trials cannot indicate the marginal returns to fertilizer application as required for accurate fertilizer recommendations. The authors however came up with district fertilizer recommendations using the assessment given above. They stated that these recommendations could only serve as guidelines. The authors also made the conclusions that there is very little response to K_2O application in Kenyan soils. Further, they concluded that there is high response to both N and P_2O_5 application.

The method of using "Nutrient Recovery Rates" to arrive at fertilizer recommendations would seem quite accurate if the required information will be available. It would however be very involving as it would require not only accurate assessment of the plant and soil levels of each nutrient, but also the details of experimental set up required by other methods. Jaetzold and Schmidt were therefore forced to make several assumptions and Ignore many factors. They made many genera1i zat ions especially on the number of major soil types. Their method however illustrates the need to bring together three important scientists in the making of fertilizer recommendations, viz, soil scientists, agronomists and economists. Had each provided accurate data then the resultant recommendations would be reliable.

The data problem was solved for this study given the data now available from the FURP. Continuous production functions from fertilizer trials can be estimated for Kisii and Busia districts.

The Fertilizer Use Recommendations Project (1988) reported on the setting up all over Kenya of fertilizer trials with the following main objectives inter alia;

(i) to obtain reliable and up-to-date data on fertilizer responses for the main food crops in all the major Agro-Ecological Zones (AEZs) in the country.

(ii) To use the data to develop better fertilizer recommendations to be updated regularly and to cater for changes in farming and economic conditions.

(iii) To correlate the fertilizer responses to the soil analytical and climatic data.

In its studies the FURP realised that fertilizer use in Kenya is very limited and is actually nil in some districts. The FURP therefore concentrated its effort on indicating to farmers that there are indeed economic benefits in fertilizer ur.e. Fertilizer recommendations are therefore based on such criteria as (i) Maximum Marginal Profits, (ii) Fertilizer Use Efficiency (ili) Value Cost ratios. The profits are calculated considering fixed prices for fertilizers and maize, the major crop in the trials. The inclusion in the analysis of ot-h«»r costs in fertilizer use eg. transport costs, costs of labour in handling and harvesting would be a further refinement of the FURP method of recommendations. Use of the tabular value ratios to make fertilizer recommendations is quite an inaccurate method. The estimation of continuous functions as done in this current study is more accurate.

The current study takes up fertilizer recommendations to a further stage using the response function approach and allowing for the costs and prices as observed by farmers.

CHAPTER 3

METHODOLOGY

This chapter discusses the methodology applied in this study: the production function and profit maximization approach to input recommendation. The chapter describes both the technical and the economic considerations in identifying appropriate levels of inputs to recommend to farmers. The estimation method and data used are also described.

3.1 The Production Function Approach

The production function essentially estimates the yield responses that will be obtained for various application rates of inputs. To obtain economically optimal levels of the inputs, the prices of the inputs and the output(s) must be known. Considerations have then to be given to the economic circumstances of the farmers and to the alternative demands on the limited capital resources other than for the purchase of fertilizers. Allowances must also be made for the risks involved in using fertilizers.

3 - 2 TECHNICAL CONSIDERATIONS:

3.2.1 THE FUNCTIONAL FORMS

A general production function may be represented as

$$Y = B, + X_t + e, \qquad \qquad 3.1$$

where Y = the output of maize per ha (yield)

Xj = set of i inputs

ei = error term.

Such a model is chosen and values for its parameters (coefficients) are estimated from appropriate data, preferably by some Maximum Likelihood Statistical[1] procedure (or least squares regression). It is modelling these physical relationships that prove a major difficulty and assumptions are made to enable estimation.

The models adopted for this study were the Cobb-Douglas and the Quadratic forms as in equations 3.2 and 3.3

$$Y = aP^bN^ce^{1'1} \qquad \qquad 3.2$$

where a = constant

P = Kg Phosphate per ha

N = kg Nitrate per ha

e = base to natural logarithms

Ui = error term

and

[3] Both these methods obtain estimates of the vector of parameters ft by respectively maximizing or minimizing certain functions which are evaluated using the data of the problem. The MLE procedure under the assumption of normality also obtains an estimator for the variance of the error term ($o^?$) . For a ful[1] discussion see: Intriligator M.D. (1978).

$$Y = a + bN + cP + dN' + eP' + fNP \quad \ldots\ldots 3.3$$

where Y = maize yield Kg ha^{-1}

a = constant

e_i = error terms

b,c,d,e,f, = regression coefficients

N,P = kg Nitrate and Phosphate respectively per ha.

These functional forms were tried in estimating the Fertilizer Response Functions for each of the two districts of Kisii and Busia. Each function was studied and used on the basis of its theoretical assumptions and merits as it applied to the data. As in many econometric studies the problem of selecting the most appropriate specification was not easy.

3.2.2 THE ESTIMATION METHOD.

The Ordinary Least Square (OLS) regression method was adopted. The Quadratic and Loglinear models were estimated for both Kisii and Busia Districts. Backward elimination of variables, forward selection and stepwise regression procedures of Ordinary Least Squares were used to arrive at the model specifications used in the optimization procedure. These procedures help to select and eliminate the variables considered in the regression analysis on the basis of statistical significance. If variables eliminated are considered to be important theoretically, through *a priori* knowledge, then such variables were retained in the model.

To keep the estimation problem manageable some simplifying assumptions are made in OLS estimation. These are assumptions about the regularity of the populations. For example, consider the fertilizer-yield experiments. Suppose that an experiment could be repeated many times at a certain fixed level of fertilizer x. Even though fertilizer application is fixed from experiment to experiment not exactly the same yield would be observed each time. Instead there would be some statistical fluctuation of the Y values, clustered around a central value. If the probability of Y for a given x, is given by p(Y/x) there will be many possible values of Y forming a population. There will be similar probability distribution for Y at any other experimental level of x. These peculiar populations will be difficult to analyses thus the simplifying assumption of OLS;

1. The probability distribution p(Y,/x) have the same variance $a^?$ for all x,.
2. The random variables Y_t are statistically independent.'For example a large value of Y, does not tend to make Y_2 large i.e. for Y, = a + Bx, e, , the e, are independent with mean = 0 and variance = o
3. The error terms are also assumed to be uncorrelated and normally distributed[4].

OLS estimation of the Quadratic Model is straight forward. In the general form

* Assumptions 1 and 3 are necessary for statistical tests of r ignifinance

$Y = b_0 + b_j X' + b, X^{7m}$ 3.4

it is nonlinear in X. It is however linear in the parameters b_0, b, and b, . OLS is therefore applied quite easily after the transformation to g^t X* and X^{7}" from the variable X.

The Cobb-Douglas Function generally represented as

$Y = aN^{b} P^{c}$...

can be transformed for OLS estimation because it linearizes in logarithms. The result is

lnY= lnA + blnN + clnP................................ 3.6

The estimated coefficients are then interpreted as elasticities of maize output with respect to the nutrients N and P.

3.2.3. Statistical Measures of Goodness- of-fit and Significance.

The comparative assessment of alternative algebraic forms for the (expected) response function has boon a topic of abiding empirical interest (Dillon 1977). The usual criteria employed in the choice of a model are a mixture of :

a) statistical measures of goodness of fit and significance.

b) a *priori* considerations relating to the biology and economics of the response process.

c) subjective judgement and

d) computational ease.

This section describes some of the statistical measures of Goodness- of- fit and significance employed in this study.

3-2.3.1 The Coefficient of Multiple Determination (R^2)

Also referred to as the goodness- of- fit test, the R^2 statistic is an overall index of how well the dependent variable can be explained by all the regressors. It is thus a measure of how well the multiple regression fits the data. It is defined as the proportion of the total variance in the dependent variable that is explained by the regression. For example an R^2 of 0.704 means that 70.40% of the variance in the dependent variable is explained by the regression with 29.6% left unexplained. The R^2 is a measure of the explanatory power of a regression but it should be used carefully in comparing regressions. The value of R^2 can never decrease as more variables are added. It is also notable that R^r values tend to be high when using time series data, where both dependent and explanatory variables reflect certain underlying time trends. When using cross-sectional dita, by contrast, R^2 values tend to be low because of both the great variability that is possible across the individual entities and the lack of a common underlying trend. Thus an R^2 of 0.5 or higher may be acceptable with cross-sectional data, while a value of 0.9 or higher is usually expected with time series data.(Intriligator, 1978)

Due to the mentioned problems associated with the R^7 statistic a related measure, the coefficient cf determination adjusted for the degrees of freedom (adj R^7) is usually considered in determining the explanatory value of a regression. The degrees of freedom is simply the number of observations less the number of constraints imposed on the residuals in estimating the parameters. In general the adjusted $R^7 < R^7$ and it is possible for the adj. R^7 to be negative. While the unadjusted coefficient of determination can never decrease as the added explanatory variables are taken into account , the adjusted one can decrease if the reduction in unexplained variation is more than offset by the increase in the correction factor due to the degrees of freedom. Specifically,

$$tf^2=1-(1-J?^2)_{n-k} \qquad {}_{n-k}(1-r2) \quad \ldots\ldots\ldots\ldots 3.7$$

Thus adjusted R^7 increases if the decrease in $1-R^7$ is more than offset by the increase in

$$\frac{n-1}{n-k}$$

where n= number of observations

k= number of regressors.

The R^2 and the adj R^7 statistics are given in each table of regression results in Chapter 4.

3.2.3.2 The F-statistic:

The F-statistic is defined as the ratio of

$$\frac{\text{Explained variation in Y}}{\text{Unexplained variation in Y}}$$

where variation is defined as variance divided by the degrees of freedom. This statistic tests the null hypothesis that all coefficients of the regression other than the intercept are zero,

"O:PI=P$_2$= =P*-I=0. . . . . 3.8

It therefore tests the significance of the regression as a whole in testing for the existence of a linear relationship between the dependent variable and all of the explanatory variables specified by the model. If the F-ratio calculated for a regression exceeds the tabulated F value for a particular level of confidence, then the null hypothesis of no dependence on the explanatory variables is rejected. If so, the evidence indicates that not all regression slopes are zero and the model therefore has some explanatory power.

3.2.3.3 The t-statistic

As already noted the F-statistic tests the hypothesis that all of the coefficients in the model are zero. A related test is the test that one of these coefficients is zero, testing the hypothesis that the corresponding independent variable exerts no statistically significant linear influence on the dependent triable. For the coefficient j, the null hypothecs to be tested is

"o--Pj=0 >1 . 2. . . . . .k .

The t-statistic is a ratio of the estimated **regression** coefficient to its standard error. **This ratio determines** the significance of **a** coefficient; **in general the null** hypothesis that ft, is zero is not **rejected if the absolute** value of t is less than the **value of t** corresponding to a particular level of **significance, and it is** rejected if the absolute t exceeds **thl3 value.** A **low t**-ratio implies that the coefficient **is not significant** in that the dependent variable is **not linearly dependent** on the relevant explanatory variable. **If however the t**-ratio exceeds the critical value (at a **suitably chosen** level of significance) then the **coefficient is significant.** For large degrees of freedom (n-k**>30) the t** distribution is approximately the same as **the normal distribution** and in this case the rule of **thumb is that if the** t-ratio exceeds 2 then the **coefficient statistically** significant. Conversely, a t-r.it **lo len than** 2 in this case indicates lack of significance.

Anderson (1957) as quoted by Heady **and Dillon (1961) suggests** that the dropping of individual **nonsignificant terms** from an estimated model is not to **be recommended. The** authors argue that by its nature a **significance test merely** takes account of the strength of **evidence against the worst possible result. Even if the evid-M - *nalnr,t** the regression coefficient being zero is slioht, the best estimate of its size is still that obtained from the data. Indeed it is quite unlikely that the true value of the coefficient is exactly zero. Anderson (1957) has thus suggested a more lenient criterion; a variable should be dropped only if the standard error of the regression coefficient exceeds the absolute value of the estimated coefficient, and then only if there are no strong logical grounds for including the variable.

3.2.4 Description of The Data Used

Data from the Fertilizer Use Recommendation Project (FURP) were used in the estimation of the fertilizer response functions. The Experiments were set up in a 4N x 4P factorial design. Four N treatments and four P treatments of 0,25, 50 and 75 kg N and P per ha were given to each trial in a factorial design with two replications (see Table 3.1) .

Table 3.1 Design of the Maize Response Experiment by FURP. Each 'X' represents an Experimental Unit.

Kg P_2O_5 per ha	Kg Nitrogen per ha 0	25	50	75
0	XX	XX	XX	XX
25	XX	XX	XX	XX
50	XX	XX	XX	XX
75	XX	XX	XX	XX

Source: F'UkP (1488)

This was based on the findings that N and F arp the most important nutrients and a major aim therefore was to determine the response to them using a range of application rates. At the end of each season maize output per ha was determined in each trial site. It is from these data that the Response Functions were estimated.

The data were collected under varying year, season and location categories for two districts viz Kisii and Busia. These variations and their treatment are described in the rest of this section. Each district was however handled on its own with no pooling of the inter- district data at all. Use of the chow test indicated that the two districts had data that were statistically different and couldn't be pooled for estimation purposes.

3.2.4.1 Annual Variations in the Data

The data were collected over a three or four year period beginning 1987-1990 depending on the location. In some of the experimental stations data were available only over a three year period. In other stations data wore available over a four year period.

The weather conditions for the years of study are summarised in tables 3.2 and 3.3 below

Table 3.2 Weather conditions in Busia, 1987 - 1990.

Year	Total Rainfall (District average in mm)	Number of W^t days
1987	1254	128
1988	1850	141
1989	2239.5	149
1990	1752	135

Source: Ministry of Agriculture: Annual Reports (various)

In Busia 1988 was a good year for maize production. Rainfall was adequate and well distributed. 1989 was also a good year although floods reduced output in Southern Busia. 1987 and 1990 were moderately good with erratic rainfall.

Weather conditions in Kisii were more favourable for maize production during the study period. The conditions are summarized in table 3.3

Table 3.3 Weather conditions in Kisii 1987-1990

Year	Total Rainfall (District average in mm)	Number of Wet days
1987	1984	175
1988	2618	190
1989	2556	181
1990	1813	160

Source: Ministry of Agriculture: Annual Reports (various)

The three or four year time frame was considered very brief and not useful for any time series treatment. The input and output values in each experimental site were therefore averaged out to yield a simple average figure as illustrated in Table 3.4 below. The averaging process is significant in that it caters for the effects of certain uncontrollable factors in influencing experimental results. Effects of a bad crop year are for example ameliorated by the effects of a very good crop year.

Table 3.4: **Illustration of the Averaging of Output (Yield) Data_foj^a_si^ngie^xpprimenta1site.**

(a)			(b)		(c)
Output (Y) 'OOKg HA^{-1}			Nutrient KG ha		Average Output
1988	1989	1990	P	N	'OOKg ha"'
29.2	14.4	20.5	0	0	21.36
30.6	26.1	22.3	0	25	26.33
31.6	32.4	18.9	0	50	27.63
45.0	31.3	38.4	0	75	38.23
26.6	29.2	19	25	0	24.9
32.3	24.5	21.5	25	25	26.1
36.4	31.4	30.0	25	50	32.6

Source: FURP data and Author's calculation.

It is the entries in column (c) that enter into the Y vector in the regression matrix i.e column (c) corresponds to the Y column in appendices 1 and 2 of this study.

The treatment of the FURP experimental plots were the same *over* the four year period. There was no consideration of the residual effects of fertilizers on subsequent crops. This is jsually a major assumption in the calculation of fertilizer rates. This is mainly because reliable data on residual effects are not usually available (Ackello-Ogutu, 1982, Colwell, 1978). It is usual therefore to assume that residual effects are negligible and this tends to overestimate optimal rates.

3.2.4.2 Seasonal Variations in the Data

Both the investigated districts have two harvesting seasons per year. There is a short rains season and a long rains season. It was assumed in this study that fertilizer response during the two seasons was alike save for an upward or downward shift in the response function due to season. Season was thus entered as a dummy variable Si in the regression equation. S = 1 for season 1, otherwise zero. S_2 = 1 for season 2, otherwise zero.

3.2.4.3 Locational variations in the Data

Kisii and Busia Districts had three and two experimental sites labelled K,, K_2, and K_3 for Kisii and B, and B_2 for Busia respectively. The data from the three stations in Kisii were used together in estimating the crop response functions for Kisii. The data from the two sites in Busia was treated likewise, with dummy variables applied for each site. The data sets used in the estimations are given in the appendices to this study.

3.2.5 The Variables Considered

For the general model estimated in this study;

$Y=f(X_k)+e_1$ 3.10

Where Y = Output of maize per ha (yield)

X_k = Set of k inputs.

e_t = Error term

There was a general assumption in all the models that maize output Y is dependent on Nitrogen (N) and Phosphate (P) applications, individually or interactively. Other factors that influence the crop response to fertilizers were not studied as independent variables. Among important factors not considered independently were land preparation methods planting and weeding practices. The use of the dummy variables as described below catered for this shortcoming.

3.2.5.1 **The Dependent Variable Y**

The maize output per hectare in kilograms was the dependent variable used in the regression analysis. This study sought to explain how maize yield responds to fertilizer use. Thus, maize yield was the only logical dependent variable.

3.2.5.2 **The Independent Variables**

To get reliable and meaningful estimates of the coefficients of our model we need to include all of the variables relevant to maize .production in the study area. Omission of relevant input variables tends to bias one or more of the coefficients of the included variables. In this study however the problems associated with omission of relevant variables are not significant since the data used were experimental. Most factors in maize production were held constant. Such included the husbandry methods e.g. land preparation, planting and weeding practices. Weather or climatic differences between experimental sites were important in influencing maize yield. Dummy variables were used to cater for these differences. Seasonal differences in weather at the same experimental site were treated likewise. The explanatory variables that were important in determining maize yields and independent variables. Among important factors not considered independently were land preparation methods planting and weeding practices. The use of the dummy variables as described below catered for this shortcoming.

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vhich were measurable **were Nitrogen and Phosphate** fertilizers. They are described here.

3.2.5.2.1 Nitrogen Fertilizer (Kg N/ha)

Nitrogen is considered as a macronutrient vital for crop production. It is one of the nutrients included in the experiments to determine crop (maize) response. The variable was included in the estimation as kilograms of nutrient Nitrogen per hectare. The Nitrogen was applied as the straight fertilizer CAN.

3.2.5.2.2 Phosphate Fertilizer (Kg P/ha)

Phosphorus is another important nutrient in crop growth. Together with Nitrogen they are considered the two most limiting nutrients to crop growth in Kenya (FURP, 1988) . It was the second nutrient studied in the experiments that provided data for this study. It was measured in terms of plant available Phosphate in kilograms per hectare. The Phosphate was applied as the straight fertilizer TSP.

3.2.6 The Implication of the Dummy Variables in Estimation and Interpretation

The variables which are included as dummy variable in the regression analysis are interpreted as slope or intercept shifters. In this study two dummy systems were used both in the Quadratic and the Cobb-Douglas Models. There was one dummy system for location and another for season. For example the data frcm

Kisii was collected from three locations over two seasons each year. Location had three dummies: Kj = 1 if data from Kiamokama, Kisii and 0 otherwise; K, = 1 if data from Kisii NARS, 0 otherwise; K_3 = 1 if data from Otamba, Kisii, 0 otherwise. Season was treated likewise with S, = 1 for long rains, 0 otherwise; $S_;$ = 1 for short rains 0 otherwise.

The rule of thumb is that, whenever there are two or more dummy systems, drop one dummy term from each system for Ordinary-Least Squares Estimation. This stems from the fact that even in a single dummy system including all the dummy variables would result in perfect collinearity in the model i.e. the observation matrix X will have linearly dependent columns. When we drop a dummy term we avoid singularity of the X'X matrix.

When we exclude a dummy term for the purposes of OLS estimation the regression constant term then embodies the expected yield associated with that omitted dummy. The coefficients to other dummies (assuming they differ significantly from zero) are interpreted as the effects on Y of being in any of the respective dummy classes relative to the omitted one. If a coefficient is not statistically significant, then this suggests there was no measurable differences statistically between the two groups.

3.2.7. **<u>The interpretation of the Error Term</u>**

In equation = $f(X_{k1})$ + e,......................3.11

ej is the disturbance or error term. It reflects variability unaccounted for and subscript i represents in the rase of this study to a particular experimental treatment. The usual regression assumption about ei is that individual disturbances are independent of each other, have zero mean and a constant variance. Some of the reasons for the unexplained variation in maize yield would include (i) error of measurement (ii) omission of relevant variables which could not be measured. Measurement errors can be random or systematic and may arise in various ways. At the data collection level there are possibilities of over reporting, or under reporting e.g. output may be overreported or underreported due to human or weighing equipment error. Errors may also arise from the processing of information, such as transferring, copying or computing. In this study many steps were involved between the harvesting of the maize and the use of the resultant data for regression analysis. Many errors couid arise. At the setting up of the experiments this kind of error may also arise. On the other hand variables such as management of the experiments are very essential in explaining yield, but their measurement is problematic. They were left out. The dummy variables used for location and season are proxies for such factors as rainfall, temperatures and soil fertility. These proxies may not reflect the true variability of the real variables on maize yield.

3.3. ECONOMIC CONSIDERATIONS

3.3.1 The Optimization Procedure:

To determine the optimal fertilizer dosage, assume Y = f(N,P...) is the crop response function, where

Y = Maize output Kg per ha.

N = Kg N per ha

P = Kg P_7O_5 per ha

The levels of N and P maximizing net profits may be given by the combination at which the value of the additional produce obtained from a small increment of each fertilizer just balances the cost of added nutrients. In doing this considerations are given to the economic circumstances of the farmers and to the alternative demands on the limited capital resources, other than for the use of fertilizers. Allowances must also be made for the risks involved in using fertilizers. The amount of fertilizer that should be used, after all such considerations is termed optimal meaning that it is the best under all relevant circumstances.

Calculations of the rates at which fertilizers should be applied to a crop depend on representing the relationship between crop yield and fertilizer rate by a suitable mathematical function. The appropriate functional form for a given production system is both a logical and empirical problem, the biological basis of the form specified being an important consideration (Oluoch-Kosura 1983).

Let P_Y = Price of 1 Kg of Produce (Maize)

P_N = Price of 1 kg of N

P_p = Price of 1 kg of P

The optimum[5] application rates are then given by the levels such that:

[5] This assumes that all markets are perfectly competitive

$$P_N \Delta N = P_Y \Delta Y \qquad \ldots\ldots 3.12$$

$$P_P \Delta P = P_Y \Delta Y \qquad \ldots\ldots 3.13$$

which in the limit gives

$$P_Y \frac{\partial Y}{\partial N} = P_N \qquad \ldots\ldots 3.14$$

$$P_Y \frac{\partial Y}{\partial P} = P_P \qquad \ldots\ldots 3.15$$

and

$$\frac{\partial Y}{\partial N} = \frac{P_N}{P_Y}, \qquad \ldots\ldots 3.16.$$

$$\frac{\partial Y}{\partial P} = \frac{P_P}{P_Y} \qquad \ldots\ldots 3.17$$

from which we can solve for the optimal levels N_0 and P_0.

The elements of the costs, of production such as cultivation costs, sowing and weeding charges can easily be incorporated into this general framework. If we assume an interest rate on capital equal to **R**, then the definition for optimal fertilizer rates changes to:

$$\frac{\partial Y}{\partial N} = \frac{C_N}{P_Y}(R+1) \qquad \ldots\ldots 3.18$$

$$\frac{\partial Y}{\partial P} = \frac{C_P}{P_Y}(R+1) \qquad \ldots\ldots 3.19$$

where C_N = Cost of application of one kilo of N.*

C_p = Cost of application of one kilo of P

R = Interest on capital

This follows from the definition of Profit and investment

From 7t = VY - CX - Q and

I = CX,

where n = Profit

V = Price of Output

Y = Output

C = Cost of input

X = Input

i

Q = Fixed costs

using the rules for differentiation of a product and of a function of a function

$$\frac{drt}{dl} = \frac{d\ (VY)}{d\ I} - 1$$

$$= V \frac{dY}{dl} - 1$$

$$= V \frac{dY}{dX} . \frac{dX}{dl} - 1$$

$$= \frac{V}{C} \frac{dY}{dX} - 1$$

and $\frac{dY}{dX} = \frac{C}{V} \left(\frac{dn}{dl} + 1 \right)$

denoting $\frac{drc}{dl}$ by R

$$\frac{dY}{dX} = \frac{C}{V} (R + 1)$$

[6] C_K and $C_?$ both includes the price of the nutrients and ether costs

In this case the values given to C_N and C_r the costs of the nutrients allow for such costs as freight, handling, and the value of R is chosen from a consideration of alternative investments. These are considered in details in the following sections.

3.3.2 Fertilizer Costs and Product Prices

To arrive at the values of C_N and C_P of the previous section the following components were considered:

-price of nutrient (i.e. P_N, P_p) in sh/kg of nutrient

-Transport costs of fertilizer (T_p)

-Transport cost for the farmer, including opportunity cost of the farmer's time (T_F)

The price of nutrient was deduced from the price of the fertilizer (Fertilizer prices were controlled by the government and equal for both districts) . For example the price of phosphate nutrient was calculated on the knowledge that the price of 50kg of TSP the source of Phosphate used was Shs.275.00. TSP contains about 46% phosphate thus P_p can be calculated as:

$$P_P = sh \frac{275}{50x0.46} = sh\ 11.96 \text{ per kg} \quad \text{..........................3.20}$$

$$P_N = sh \frac{220}{50x0.26} = 16.92 \text{ per kg} \quad \text{..........................3-21}$$

To arrive at the cost of transport a working estimate of about 10% of the price of fertilizer was used. This approximation has been applied by Schluter and Ruigu (1990) for Kisii. The author approximated a rate of Sh. 24.8 per bag excluding transport for the farmer (T_f) . All the prices were converted to per kilogramme nutrient basis. C_N and C_P turned out to be:

$C_P = P_P + T_P + T_F$

$= Shs\ 11.96 + Shs\ 1.08 + Shs.0.75$

$= Shs.13.79/kg\ P$ 3.22

$C_N = P_N + T_N + T^r$

$= 16.92 + 1.08 + 0.75$

$= sh\ 18.75/kg\ N$ 3.23

To arrive at the value of a kilo of maize (V_B, the price of maize P_m at the National Cereals and Produce Board depots for 1990 (Sh.2.85/kg) was used. This was adjusted for the following costs provided by farm budgets for the area. (See Appendix)

Land preparation costs including sowing	(LJ =Shs.0.55/kg
Weeding costs	(WJ= Shs.0.44/kg
Harvesting costs	(H_m)= Shs.0.24/kg
Price of seed maize	(P_SJ = Shs.0.166/kg

Thus $V_M = P_M - (L_m + W_m + H_{„} + P_{Sffl})$

$= 2.85 - (0.55 + 0.44 + 0.24 + 0.166)$

$= Shs.\ 1.45/kg$ .3.24

3.3.3 Interest on Working Capital

For Kisii the interest on Working Capital was estimated at 23% by considering alternative investments in the district (Egerton University, 1990) . It is however, admitted that the choice of the rate of return R to use in these calculations is a very difficult task. The International Maize and Wheat Improvement Centre (CIMMYT) for example contends that th« rate of return to use should be no less than 50% (CIMMYT 1988) . The argument by CIMMYT is that "Experience and empirical evidence have shown that for the majority of situations the minimum rate of return acceptable to farmers will be between 50 and 100%". It further argues that if the technology simply represents an adjustment in current farmer practice (e.g. a different fertilizer rate for farmers that are already using fertilizer) then a minimum rate of return as low as 50% may be acceptable. Still, CIMMYT accepts that its range of 50-100% is rather crude "but it should always be remembered that the other agronomic and economic data used in the analysis will be estimates or approximations as well".

The other method of estimating the rate of return is through an examination of the informal capital markets. Local (village) moneylenders charge farmers certain interest rates per month which can be used as a guide on the rate of return. For example if it turns out that local moneylenders charge 10% per month then the cost of capital for five months (a maize crop cycle) would be 50%. To estimate the minimum rate of return in this case, an additional amount would have to be added to represent what farmers expect will repay their effort in learning and using a new technology. CIMMYT (1988) suggests that this extra amount may be approximated by doubling the cost of capital (unless the technology represents a very simple adjustment in practice). Thus in this example, the minimum rate of return would be estimated to be 100%.

r

If farmers have access to institutional credit, the cost of capital can be estimated by using the rate of interest charged ever the agricultural cycle; that is, the rate of interest should cover the period from when the farmers receive credit (cash or inputs) to when they sell their harvest and repay the loan. In addition it is necessary to include all charges connected with the loan. There are often service charges, insurance fees or even farmers personal expenses for such activities like transport to town to arrange the loan, that must be included in the estimate of the cost of capital. Once the cost of capital on the formal market has been calculated, an estimate of the minimum rate of return can be obtained by doubling this rate. This will provide a rough idea of the rate of return that farmers will find acceptable if they are to take a loan to invest in a new technology.

It is clear from the foregoing discussions that the estimation of the rate of return is a difficult task. The Policy Analysis Matrix study's figure of 23% is contestable using the arguments by CIMMYT but being the only available information it is used since "crude information is better than none at all".

CHAPTER 4

EMPIRICAL RESULTS

The results of the OLS analysis of the FUP.P data are shown in tables 4.1 - 4.4 below. These tables represent the specifications that fit the data best. The evaluation of the results was based on the R^2 and the adjusted R^2 statistics. Other statistics considered were the F- and the student t-statistic.

4 .1 The Response Function Results:

The FURP data were analyzed separately for the two districts Kisii and Busia. For both districts a Quadratic model and a Cobb-Douglas model were estimated. This section discusses these model estimates separately. The recommendations from each model are also discussed.

4.1.1 The Quadratic Model:

The results of OLS estimation of the Quadratic model are given in tables 4.1 and 4.2 below.

Table 4.1: Multiple Regression Results Usinq The Quadratic Model (Kisii Data)

$$Y = 1926.77 + 28.3P + 16.9N + 0.095PN - 0.12N^2 - 0.22P^2 + 1490.4K2 + 2916.7K3 - 944.7S_2 \qquad 4.1$$

Variable	B	SE B	t	sig t
S2	-944.729	192.406	-4.91	0.0000
K3	2916.719	235.645	12.377	0.0000
P^2	-0.218	0.154	-1.417	0.1600
N^2	-0.122	0.154	-0.793	0.4300
K2	1490.4	235.6	6.325	0.0000
PN	0.0951	0.123	0.772	0.4420
N	16.936	12.9	1.313	0.1927
P	28.3	12.9	2.194	0.3090
(constant)	1926.771	344.723	5.589	0.0000

H' = 0.70877

Adj.R^2 = 0.68199

SE = 9.425

F = 26.467 Sig F = 0.0000

N = kg ot nitrate per ha

P = kg of phosphatei per ha

K_2 = Dummy variable per Kisii NARS

K_3 = Dummy variable for Otamba

S_2 = Dummy variable short rain season

Table 4.2: Multiple Regression Results of the Quadratic jBusia Data)

$Y = 20.381P + 6.116N + 0.000126PN + 0.00742N' - 0.152P^2 - 960.59S_2 - 851.03B_?$ 4.2

Variable	B	SE B	t	Sig t
$B_?$	-8.51.03	145.586	5.846	0.0000
S_2	-960.594	145.586	· 6.598	0.0000
N*	0.00742	0.125	0.059	0.953
P^2	-0.152	0.125	· 1.212	0.2304
PN	0.000126	6.724	0.000	1.0000
P	20.381	11.789	1.729	0,.0894
N	6.116	11.789	0.519	0..6059
(constant)	2417.675	2.742	8.817	0.,0000

R^2 = 0. 636

Adj.R^2 = 0.590

F = 13.96 Sig **F** = 0.0000

N = kg of nitrate per ha

P = kg of phosphate per ha

B_2 = Dummy variable per Bukiri location

S_2 = Dummy variable short rain season

These results illustrate some of the difficulties in crop response analyses. The results were useful in identifying possibility of a measurement error in the data. But the t-statistics are too low for the N^2 and PN variables to be retained in the equations to be used in determining the optimal fertilizer recommendat ions. These two variables were eliminated and the resultant regression result are shown in tables 4.3 and 4.4.

Table 4.3: Multiple Regression Results Using The Modified Quadratic Model (Kisii Data)

$Y = 1869.31 + 31.87P + 11.35N - 0.218P^{?} + 1490K_{?} + 2916.72K_3 - 944.73S_{?}$ 4.3

Variable	B	SE B	t	sig t
P	31.866	11 .994	2. 657	0 .0093
N	11.349	3 .427	3. 312	0 .0013
P^2	-0.218	0 . 153	-1. 423	0 .1581
K*	1490.437	234 .619	6. 353	0 .0000
	2916.719	234 .619	12. 4 32	0 .0000
S;	-944.729	191 .566	-14 .932	0,.0000
(constant)	1869.308	280,! 891	6 .655	0..0000

R^2 = 0.704

Adj. R^7 = 0.685

F = 35.39 Sig F = 0.0000

n = 96

Table 4.4 <u>Multiple Regression Analysis Results Using the Modified Quadratic Model (Busia Data)^</u>

$Y = 2413 + 20.38P + 6.67N - 0.1525P^7 - 960S_2$ -

851B. . . 4.4

VARIABLE	B	SE B	t	sig t
P	20.38	8.96	2.275	0.0266
N	6.67	2.55	2.608	0.016
P^2	-0.1525	.114	-1.33	0.1878
B,	-851.03	143.06	-5.949	0.0000
S_2	-960	197.19	12.237	0.0000
(constant)	2413	197.19	12.237	0.0000

R^2 = 0.635 P = Kg P_2O_s per ha

Adj R^2 = 0. 604 N = Kg Nitrogen per ha

F =20.25 Sig F = 0.0000 B_2 = Dummy for Bukiri location

n = 64 S_2 = Dummy for short rain season

Attention is drawn to the variable P^7. It bears a negative coefficient in either case as it should if it is to correctly describe the biological response phenomenon'. The t-statisties

[1] Under present conditions of knowledge, the most satisfactory simple theory of biological response is that:
(i) There is a continous smooth causal relation between the input and output
(ii) Diminishing returns prevail with respect to each input factor Xi so that the additional output from succeeding units of X[becomes less and less
(iii) Decreasing returns to scale prevail so that an equal proportionate increases in all inputs results in less proportionate increase in output . (Dillon J.L., 1977)

are however only significant at the 85% and 82% confidence levels respectively for Kisii and Busia districts. These are quite low levels of confidence but the variable was retained in either case for a *priori* knowledge reasons. This is because it is clear that maize responds to phosphate fertilization according to the law of diminishing marginal returns. This then raises the same question for the nutrient N. It turned out that for all models that were tried there was no Quadratic response to N i.e. the N^2 coefficients were always statistically insignificant. This then indicates that Nitrogen is not limiting to maize production as long as P is. This means that only if P is adequate would N be limiting at least for the two districts of Kisii and Busia. This is quite a likely case given that P is known to help in proper utilization of N by crops.

To make OLS estimation of these equations the dummy variable K, was omitted from the Kisii observation matrix. This was one of the location dummies. S, was also omitted. S, was one of the season dummies. In the case of Busia B, and Sj were also omitted. All the dummies remaining in the observation matrices were included in the model specifications with coefficients significant at over the 99% level of confidence. This is a positive confirmation of the assumption made at the onset that maize response to fertilization is not the same for all locations considered and for the two seasons. The difference is in the extent of responsiveness i.e. the magnitude of response differs as described by the coefficients to the dummies in the equations. Thus maize output is lower in the second season by as much as

944.73 kg/ha compared to season 1 in Kisii district *Ceteris paribus.* The other coefficients are interpreted .similarly as described in Section 3.2.6. In the case of Busia these coefficients were significant at the 74% and 91% confidence levels respectively. These quite low levels of confidence notwithstanding, the variables were retained in the models.

As a result of the absence of an interaction term no N recommendations can be made from these model specifications as the marginal products of the nutrient are constant at 11.35 kg of maize per kg of N and 6.67 kg of maize per kg of N in Kisii and Busia respectively.

4.1.2 The Cobb-Douglas Model:

Like the Quadratic function, the Cobb Douglas function has the major advantage in crop response analysis viz it can accommodate diminishing marginal returns. It is therefore possible to describe the biological response to fertilizer using this model. This is very important when it comes to the interpretation of the model coefficients. The Cobb-Douglas function also easily incorporates dummy variables. This was a necessary feature in the current study as dummy variables featured prominently. This function is also quite easy to deal with because it is linear in logarithms so the slope coefficients are interpreted as elasticities of maize output with respect to the dependent variables.

The specifications estimated in this study are given in tables 4.5 and 4.16

These specifications explained 69% and 55.6% of the yield variation in the experimental data. These were determined from the R^2 statistics. The corresponding adjusted R^2 statistics were 65.8% and 49.9%.

Table 4.5 Multiple Regression Results Using the Cobb-Douglas Model (Kisii Data)

Y = 7.167 + 0.0941nN + 0.1291nP - 0.38S2 + 0.0589K? + 0.833K, . . a

Variable	B	SE B	t	sig t
InP	0.129	0.086f	1.498	0.1406
InN	0.094	0.086	1.091	0.2809
K_2	0.0589	0.096	6.154	0.0000
K_3	0.833	0.096	8.701	0.0000
S_2	-0.379	0.078	-4.851	0.0000
(constant)	7.167	0.472	15.193	0.0000

R^2 = 0.690 F = 21.4 Sig F = 0.0000

Adj R^2 = 0. 658 n = 96

P = kg P_2O_s per ha

N = kg N per ha

K_2 = Dummy for Kisii NARS experimental site

K_3 = Dummy variable for Otamba experimental site.

S_2 = Dummy variables for short rains season

Table 4.6: Multiple Regression Analysis Results: Cobb-Douglas Model Using Busia Data

Y = 7.117 + 0.097lnN + 0.148lnP - 0.362S, -

n_?ai R-. .46

VARIABLE	B	SE B	t	sig t
lnP	0.148	0.086	1.726	0.094
lnN	0.097	0.086	1.129	0.2674
B_2	-0.281	0.0778	-3.607	0.0011
S_2	-0.362	0.0778	-4.659	0.0001
(constant)	7.117	0.4678	15.124	0.0000

R^2 = 0.556

Adj R^2 = 0.499

F = 9.74 Sig F = 0.0000

n = 64

P = kg P_2O_5 per ha

N = kg N per ha

B_2 = Dummy variables for Bukiri experimental site

S_2 = Dummy variables for short rains season

The F-statistics were highly significant as recorded in tables 4.5 and 4.6.

The coefficients of the LnN and LnP variables in the estimation were significant respectively at 72% and 86% levels of confidence for the Kisii specification.

All the dummy variables had highly significant coefficients and were included in the Cobb-Douglas estimations apart from those left out for the purposes of OLS estimation. Thus data from all the five locations and both seasons were used. This means that the Kisii model is applicable to all three locations and both seasons. The same applies for the Busia model. The only variation necessary for each location or season is the use of the relevant dummy variable.

The Cobb-Douglas specifications were used to make the N and P recommendations for all the locations in both seasons.

4.2 The Fertilizer Recommendations Results

The fertilizer recommendations made in this study for the various locations studied are recorded in table 4.7.

Table 4.7: Summary of Results of Fertilizer Recommendations^ from the Quadratic (Q) and the Cobb-Douq1as (C-D) specifications

		KISII LOCATIONS						BUSIA LOCATIONS			
		K.		K,		K.		B.			
		N	P	N	P	N	P	N	P	N	P
	0	-	105.9	-	105.9	-	105.9	-	97.7	-	97.7
	C-0	54.7	60.6	116.7	179	158	175.4	116	1)6.6	80.1	9.6
It	0	-	105.9	-	105.9	-	105.9	-	97.7	-	97.7
	C-0	33.6	37.1	77.4	80.5	96.4	107.6	77	1 M	48.7	59.7

Source. Author'* calculations.

[1] - N recomtnendat1on* In kq CAN per ha.
P recommendation* In kq TSP per ha.
· - Results of N reronmendatIons from combined use of both the Quadratic and Cobb-Oouqlas models.

K, - Klamokaira Location
K, - NADS Kisii
K, - otamba Location
B, - Alupe Research Station
B, - Buklri Location
S, - Lonq rains season
S, • Short rains season

(i) From the Quadratic models; These gave the same recommendation for all three Kisii locations as 105.9 kg TSP per ha. This figure applied for both seasons. The corresponding amount for both Busia locations was 92.7 kg TSP per ' ha. From these models no N recommendations could be made.

(ii) From the Cobb-Douglas Models; These gave varying N ad P recommendations for all 5 locations and both seasons.

4.3 DERIVATION OF THE OPTIMAL FERTILIZER RECOMMENDATIONS

4.3.1 The Optimization Procedure ; An Illustration

This section gives examples to illustrate the general empirical methods used in the making of optimal recommendations from the various model specifications. They were repeated for all sites and seasons.

To arrive at the optimal fertilizer recommendation for the model : Y = f(N P. .)

we solve simultaneously

$$\frac{5Y}{5N} = \frac{C_N}{V_M}(R+1)$$

$$\frac{5Y}{SP} = \frac{C_P}{V_M}(R+1) \quad \ldots\ldots 4.7$$

4.3.2 Recommendations for Kisii

Using all the information above i.e. from (3.22) and (3.24)

$$\frac{5Y}{5P} = \frac{13.79(1.23)}{1.45} = 11.7 \quad \ldots\ldots 4.8$$

and from (3.23) and (3.24)

$$\frac{§Y}{8N} = \frac{18.75}{1.45}(1.23) = 15.9 \quad \ldots\ldots 4.7$$

4.3.2.1 The Cobb-Douglas specification;

Y = jjf.09 p0.129g<7.167 - 0.38S7' 0.83K3 • 0.59K?) 4.2

$$\frac{5Y}{8N} = 0.09\ N''^{0-91}\ P^{0-1}{}'\text{^} = 15.9 \quad \ldots\ldots 4.8$$

Letting K_3 = 1)
S_2 = 1) then K = $e^{7-''7}$ = 2032.46 . . . . 4.9
K_P = 0)

$\frac{\partial Y}{\partial N} = 0.09\ N^{-0.91}\ P^{0.129}\ K = 15.9$ 4.10

$\frac{\partial Y}{\partial P} = 0.129\ P^{-0.871}\ N^{0.09} K = 11.7$ 4.r

Solved simultaneously

$N_0 = 25.59$ $kgha^{-1}$ ≡ 98.4 kg CAN ha^{-1}
$P_0 = 49.5$ $kgha^{-1}$ = 107.6 kg TSP ha^{-1}

These are the optimal N and P recommendations for Area K_3 during season 2.

Likewise if we assume

$K_3 = 0$
$K_2 = 1$
$S_2 = 1$
then $K = e^{7.177}$

and following the same procedure the recommendation for K_2 the area around Kisii NARS will be:

$P_0 = 37.1$ kg ha^{-1} = 80.5 kg TSP ha
$N_0 = 18.9$ kg ha^{-1} ≡ 72.4 kg CAN ha^{-1}

4.3.2.2 The Quadratic Model :

$Y = 1869.31 + 31.87P + 1490.4K_2 + 11.35N - 0.218P^2 - 944.73S_2 + 2916.7K3$ was also used to solve for the optimal recommendation of P for location K3 and season 2 as

$\frac{\partial Y}{\partial P} = 31.87 - 0.436P = 11.7$ 4.12

$P_0 = 48.8$ kg Pha^{-1} = 105.9 kg TSP ha

Substituting this P value in the ∂y/∂N of the Cobb-Douglas function i.e. in equation 4.15.

$0.09N^{-0.91}\ P^{0.129}\ K = 15.9$ and solving for N we get

$N_0 = 25.42$ kg ha^{-1} = 97.6 kg CAN ha^{-1}

A similar substitution for Kisii NARS data (i.e. location K_2) gives the following recommendations.

$P_0 = 48.8$ kg ha^{-1} = 105.9 kg TSP ha^{-1}

$N_0 = 19.53$ kg ha^{-1} = 75.0 kg CAN ha^{-1}

4.3.3. Recommendations for Busia

The optimal recommendations for Busia are made by use of both models separately and in combination.

From **(4.3)** $Y = 2413 + 20.38P + 6.67N - 0.1525P^7 - 960S$

$851B_?$ 4.3

$$\frac{\delta Y}{\delta P} = 20.38 - .3050P \qquad 4.13$$

From appendix 5 $\frac{Cp}{V_m}$ (R+l) = 7.35 4.14

Thus

$$\frac{\delta Y}{\delta P} = 20.38 - .3050P = 7.35$$

P_o 42.7 Kg ha"[1] **h** 92.7 kg TSP ha

It is notable from table 4.5 that of the 30 recommendations presented, 8 recommendations lie within about plus or minus 20kg from the NARS rate of 50kg. This is about 20% of the recommendations. 13 recommendations or bout 43% of the total recommendations are over 100kg, double the NARS rate. These results are also illustrated in figure 6.2 and 6.3 of appendix 6.

The Cobb-Douglas specification gives a different recommendation for each of the locations. The quadratic function however gives the same recommendation for all the three locations in Kisii. Likewise the Quadratic function for the two locations in Busia. Since the two functions are quite comparable in terms of goodness-of-fit tests, then the Cobb-Douglas function and the resultants recommendations are preferred by this study for recommendations. The Cobb-Douglas function gives specific recommendations for each location. This seems more credible than the similar recommendations from the Quadratic for all locations in each district and both seasons.

It is however notable that should a blanket recommendation be necessary, the recommendation from the Quadratic model represents a good approximation for the average recommendation from the Cobb-Douglas function. For example in the long rains season the average P recommendation for the Cobb-douglas function is 121.7 kg TSP per ha. This is quite comparable to the blanket 105.9 kg per ha recommended by the Quadratic function.

4.4 A COMPARISON OF THE STUDY RECOMMENDATIONS WITH NARS RECOMMENDATIONS

The recommendations emanating from this study were compared with the current NARS recommendations of 50 kg CAN per ha and 50 kg TSP per ha. The percentage changes compared to the NARS recommendations are given in tables 4.8 and 4.9.

Generally, the NARS recommendations are low compared to the recommendations of this study. For both districts, in season 1, the long rains season the study results are 107% higher than the current recommendation for N and 118% higher for P.

rable 4.8: % Change in Fertilizer recommendations from the ms H^rommended 50 kg TSP and 50 kg CAN per Ha.

		RiIII LOCATIONS						BUST* IOCATIOHS				MrAN m OfV|
		111 H	P	112 *	P	K1 »	P	81 »	r	H7 v	p	ISI
SI	0		III.*		111.1		SS.4		It.4		II.I	II4.iI
	C-D	».«	21.2	132.4	IS*	216	2S0.S	112.4	177.2	«0.«	»?	125
												|7».»|
12	0		111.4		111.4		111.I		iS.4		CS.4	101
	CD	-32.4	-21.4	44.4	(1	.•	US.2	44	70.(	0	14.1	114.S|
												14*.41

Source: Author's calculations.

Table 4.9: Summary of % increase in fertilizer recommended by this study over amounts currently recommended.

		KISII	BUSIA	Both Districts Together
Si	N	119.3	96.5	107.9
	P	127.6	110	118.8
S_2	N	36.4	22	29.2
	P	81.0	64.9	73

Source :Author's calculations.

In the short rains season the study results are 29.2% higher for N and 73% higher than current NARS P recommendations. These results are shown in table 4.9.

This is a remarkable observation in as much as for the same location the short and long rains are assumed to have the same effect on crop production hence the same recommendation. Given the differences in the rainfall regimes over these two seasons both in terms of intensity and distribution, it seems irrational to make similar fertilizer recommendations. The possible explanation for the biq difference in optimal recommendations retween the two seasons may lie in two areas. First high rainfall -eans high rate of leaching and other methods of N loss from soil.During the long rains soils become more acidic due to the leaching of bases. This enhances the fixation of P by the soil which then requires more fertilization. Secondly the long rains -eans a longer period of N uptake so that finally the crop's production function is shifting both upwards and to the right This is because as the cropping season increases in length, the production function moves to the right. The upwards translation of the production function is a function of the average difference between rainfall amounts during the two seasons. Given the same fertilizer cost structure for both seasons, then the recommendations must be higher for the long rains season.

Overall for the two districts there is a greater need to apply more phosphate fertilizer than N. This is also important as there seems to be a general tendency by farmers to prefer Nitrate fertilizers to phosphate ones. The results suggest that P is more deficient in the soils studied. The trends described above apply in the same way for the two districts taken separately.The comparisons are illustrated in Fig 6.4 (appendix 6) .

In the case of the specific districts the study recommendations are in the case of Nitrogen 119.3% higher than those currently in use in Kisii during the long rains. The corresponding figure for Busia is 96.5%. In the short rains the study results are 36.4% higher for Kisii and 22% higher for Busia. The study's recommendations for phosphate are in both ustricts 127.6% and 110% higher than current for the long rains. The figures for the short rains are 81% and 65% respectively.

Overall Kisii district would do better with higher fertilizer applications. Busia likewise requires big increases .n fertilizer applications. The requirements for each location are however quite different as indicated by high standard :eviation from the mean of the recommendations. The specific locational and seasonal recommendations must be calculated independently as done in this study.

Chapter 5

5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary and Conclusion

This study set out to estimate various production functions on crop response data. For the two districts of Kisii and Busia the author selected a Cobb-Douglas and a Quadratic specification as giving the best fits for the data. It is quite apparent from the goodness-of-fit, tests that the FURP data were econometrically acceptable in these two districts. It would however be expected that better fits would result from experimental data of this kind. The experimental set up would be more appropriate if it included two more N and P treatments. The increase in costs at least may however not justify the expected change in results.

The study also set out to make recommendations for use of the nutrients N and P in maize Production for the two districts. Notice the recommendations made were for three locations in Kisii viz Otamba, Kiamokama and the area around Kisii National Agricultural Research Station. For Busia recommendations are made for the Alupe Research Station and Bukiri areas.

To arrive at the recommendations partial derivatives from the response functions estimated were equated to the inverse price ratios. The price ratios were themselves adjusted for all the major indirect costs e.g. price of maize is adjusted for transport costs and costs of harvesting . Fertilizer prices are adjusted for transport costs, application costs and Interest On Capital Charges. The recommendations for Kisii are as follows:

Table 5.1 Summary of N and P Recommendations for Kisii District

	N Recommendation (Kg CAN per ha'[1])			P recommendations (Kg TSP per ha"')		
	Ki	K2			K2	K_3
Long rains season	54.7	116.2	158	88.2	117.4	140.6
Short rains	33.6	72.4	98.4	71	98.4	106.7

Ki = Kiamokama K_2 = NARS Kisii

K_3 = Otamba Location

Source : Author's Calculations

The NARS recommended rates of application of both N and P are 50 Kg ha Thus this study suggests a 116.7% Increase in the optimal N recommendation for the long rains season and a 127.6% increase in the optimal P recommendation for the same season. For the short rains the recommended increases are respectively 38.7% and 80.8%. These are quite substantial changes in the recommendations. The big disparities discovered in this study support the idea running throughout this study that fertilizer recommendations should be fine tuned for particular locations on the basis of experiments in the different AEZs. Reason can now be found for the observation made at the beginning of this work that some farmers appear to do well with fertilizer applications over and above the NARS recommendations. The latter are on the lower end. The explanation may be found in the method of recommendation used. If the Fertilizer Use Efficiency or Value Cost ratios are used then the recommendations will be low as they are made at the point on the production surface where the slope is steepest i.e. in stage I of the production function.

The results for Busia were as in table 5.2.

Table 5.2 Summary of N and P Recommendations for Busia District

	N Recommendation (Kg CAN per ha)		P Recommendation (Kg TSP per ha)	
	B,	B_2	B.	B?
Season 1 (long rains)	116.2	80.3	115.6	94.8
Season 2 (short rains)	72.0	49.7	84	72.8

Bj = Alupe Research Station

B_7 = Bukiri Location

Source: Author's Calculation

The major observation here was the very slight response to Nitrogen in Busia and a dramatic response b P. The 50 kg ha"' N and P recommendations for Busia were also therefore disputed in this study. The MARS N recommendations for the long rains should be raised by an average 93.1% while that of P should be raised by 110%. In the short rains the NARS recommendations should be 25% and 65% higher than currently for N and P respectively.

In terms of locations the study recommends a 126.8% increase in N and a 131.2%, increases in P for the long rains for Alupe Research Station. The corresponding amounts for the short rains are 46.2% and 78%. Similar results are observed for Bukiri.

5.2 Study Recommendations and Policy Implications

The recommendations emanating from this study are:

(i) That fertilizer recommendations be based on marginal analysis. Since the current studies by the FURP use the Fertilizer Use Efficiency and the Value Cost Methods to give very rough guidelines, a further step should be taken to make exact recommendations. These FURP methods will give lower rates than appropriate.

(ii) That further experiments be set up in the areas where FURP data are not adequate so that each AEZ has a fine-tuned recommendation that will need slight adjustment in future as prices change or as the crop response changes in the area. This can be done by a decentralized system of setting up the experiments. Experiments controlled from a central station are quite likely not to give very accurate data as required by this kind of study.

(iii) That there be greater involvement of economists in the setting up of experiments and analysis of results for input recommendations. Biological Scientists seem to lay more emphasis on the crop response and downplay the important role of factor and product prices in the making of input recommendations. The experimental set ups encountered in this study were generally acceptable for economic analysis. The recommendations made without considering costs of inputs and product prices however were not economically justifiable.

The study also found out that at no location did the optimal level of nutrient N or P exceed 30 kg per ha. This is an indication that any future experiments should not include treatments well above 30 kg of the nutrient per ha. Rather the treatments should be concentrated between about 10 and 50 kg of nutrient per ha. The 75 kg ha"^{1} treatment may be avoided.

This is an important finding in that omitting the 75 kg ha"- nutrient treatment and including more treatments in the 10-50 kg ha"^{1} range wouldn't necessarily increase costs. For example a 0, 10, 20, 30, 40, 50 kg ha"^{1} TSP treatment would cost the same as a 0, 25, 50, 75 kg ha": treatment. The former would however provide more data points in the relevant range for the estimation of the Crop Response Functions. Since the marginal opportunity cost of on experimental setup should be equated to the expected value of the information it will generate,the recommendation from this study is to be chosen as it generates more information than the FURP setup.

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Appendix 1 : Data Used in Model estimation for Ki3ii

Y	P	N	s,	S_2	K,	K,	K
3570.00	0	0	1	0	0	1	0
3110.00	0	25	1	0	0	1	0
4260.00	0	50	1	0	0	1	0
4860.00	0	75	1	0	0	1	0
4910.00	25	0	1	0	0	1	0
4379.00	25	25	1	0	0	1	0
5330.00	25	50	1	0	0	1	0
5650.00	25	75	1	0	0	1	0
4210.00	50	0	1	0	0	1	0
5130.00	50	25	1	0	0	1	0
5285.00	50	50	1	0	0	1	0
5048.00	50	75	1	0	0	1	0
4290.00	75	0	1	0	0	1	0
5155.00	75	25	1	0	0	1	0
5390.00	75	50	1	0	0	1	0
5730.00	75	75	1	0	0	1	0
2490.00	0	0	0	1	0	1	0
2040.00	0	25	0	1	0	1	0
3130.00	0	50	0	1	0	1	0
2160.00	0	75	0	1	0	1	0
2370.00	25	0	0	1	0	1	0
3290.00	25	25	0	1	0	1	0
4370.00	25	50	0	1	0	**1**	0
3460.00	25	75	0	1	0	1	0
2580.00	50	25	0	1	0	1	0
4246.00	50	50	0	1	0	1	0
3640.00	50	75	0	1	0	1	0
2290.00	75	0	0	1	0	1	0
4020.00	**75**	25	0	1	0	1	0

Appendix 1 cont.

4180.00	75	50	0	1	0	1	0
4540.00	75	75	0	1	0	1	0
2290.00	0	0	1	0	1	0	0
2225.00	0	25	1	0	1	0	0
2480.00	0	50	1	0	1	0	0
1980.00	0	75	1	0	1	0	0
3815.00	25	0	1	0	1	0	0
3810.00	25	25	1	0	1	0	0
3890.00	25	50	1	0	1	0	0
3070.00	25	75	1	0	1	0	0
4110.00	50	0	1	0	1	0	0
4230.00	50	25	1	0	1	0	0
4650.00	50	50	1	0	1	0	0
4950.00	50	75	1	0	1	0	0
4720.00	75	0	1	0	1	0	0
4940.00	75	25	1	0	1	0	0
3670.00	75	50	1	0	1	0	0
5290.00	75	75	1	0	1	0	0
645.00	0	0	0	1	1	0	0
660.00	0	25	0	1	1	0	0
990.00	0	50	0	1	1	0	0
630.00	0	75	0	1	1	0	0
960.00	25	0	0	1	1	0	0
1165.00	25	25	0	1	1	0	0
1210.00	25	50	0	1	1	0	0
1400.00	25	75	0	1	1	0	0
1580.00	50	0	0	1	1	0	0
1390.00	50	25	0	1	1	0	0
1580.00	50	50	0		1	0	0
1370.00	50	75	0	1	1	0	0
2025.00	75	0	0	1	1	0	0
1745.00	75	25	0	1	1	0	0
1880.00	75	50	0	1	1	0	0
1950.00	75	75	0	1	1	0	0
5360.00	0	0	0	1	0	0	1

Appendix 1 contd

Y	P	N	**S,**	S,	K,	K
5700.00	0	25	0	1	0	0
5730.00	0	50	0	1	0	0
5560.00	0	75	0	1	0	0
5960.00	25	0	0	1	0	0
6180.00	25	25	0	1	0	0
6370.00	25	50	0	1	0	0
6160.00	25	75	0	1	0	0
4860.00	50	0	0	1	0	0
5980.00	50	25	0	1	0	0
6850.00	50	50	0	1	0	0
5840.00	50	75	0	1	0	0
5650.00	75	0	0	1	0	0
5770.00	75	25	0	1	0	0
6800.00	75	50	0	1	0	0
7140.00	75	75	0	1	0	0
3280.00	0	0	1	0	0	0
4390.00	0	25	1	0	0	0
4890.00	0	50	1	0	0	0
5330.00	0	75	1	0	0	0
4150.00	25	0	1	0	0	0
4610.00	25	25	1	0	0	0
5490.00	25	50	1	0	0	0
6580.00	25	75	1	0	0	0
4160.00	50	0	1	0	0	0
4410.00	50	25	1	0	0	0
5040.00	50	50	1	0	0	0
5425.00	50	75	1	0	0	0
4500.00	75	0	1	0	0	0
4665.00	75	25	1	0	0	0
5545.00	75	50	1	0	0	0
6260.00	75	75	1	0	0	0

Y = Yield of maize kg ha

P = Applied nutrient P in kg ha"[1]

N = » « N " " [n]

S! = Dummy variable for long rains seasons

S, = Dummy variable for short rains season

K, = Dummy variable for Kiamokoma.

K_2 = Dummy variable for Kisii NARS

K_3 = Dummy variable for Otamba

Source: FURP (1990)

Appendix 2 : Data used in model estimation for Busia

Y	P	N	S_1	S_2	B_1	B
2490.00	0	0	1	0	1	0
3040.00:	0	25	1	0	1	0
3190.00	0	50	1	0	1	0
4240.00	0	75	1	0	1	0
2820.00	25	0	1	0	1	0
3140.00	25	25	1	0	1	0
3390.00	25	50	1	0	1	0
4070.00	25	75	1	0	1	0
3920.00	50	0	1	0	1	0
3270.00	50	25	1	0	1	0
4270.00	50	50	1	0	1	0
3400.00	50	75	1	0	1	0
3000.00	75	0	1	0	1	0
4051.00	75	25	1	0	1	0
4200.00	75	50	1	0	1	0
4080.00	75	75	1	0	1	0
1190.00	0	0	1	0	0	1
970.00	0	25	1	0	0	1
1400.00	0	50	1	0	0	1
1130.00	0	75	1	0	0	1
1930.00	25	0	1	0	0	1
1880.00	25	25	1	0	0	1
1570.00	25	50	1	0	0	1
1750.00	25	75	1	0	0	1
1780.00	50	0	1	0	0	1

Appendix 2 Cont...

2210.00	50	25
2230.00	50	50
2710.00	50	75
2160.00	75	0
1480.00	75	25
2010.00	75	50
2418.00	75	75
1230.00	0	0
1410.00	0	25
1420.00	0	50
2220.00	0	75
1380.00	25	0
1700.00	25	25
700.00	25	50
1800.00	25	75
1480.00	50	0
1900.00	50	25
2230.00	50	50
1510.00	50	75
1290.00	75	0
1755.00	75	25
1900.00	75	50
2140.00	75	75
1290.00	0	0
1055.00	0	25
1290.00	0	50
930.00	0	75

Appendix 2 Cont

1440.00	25	0	0	1	0
1850.00	25	25	0	1	0
1310.00	25	50	0	1	0
1890.00	25	75	0	1	0
1900.00	50	0	0	1	0
1960.00	50	25	0	1	0
2170.00	50	50	0	1	0
2510.00	50	75	0	1	0
1740.00	75	0	0	1	0
2050.00	75	25	0	1	0
1870.00	75	50	0	1	0

Y = Yield of maize kg ha

P = Applied nutrient P in kg ha^{-1}

N _ it n N ff * tf

s, = Dummy variable for long rains seasons

s* = Dummy variable for short rains season

Bi = Dummy variable for Alupe NARS

B? = Dummy variable for Bukiri

Source: FURP (1990)

3: Example of Fertllliar Response Data as collected by the FU»P.

Tr»at»eni	'	″	Malie ri*10 '00 kg/ha
	(Kg ha		
1	0	0	22.65
2	0	25	23.4
J	0	50	27.25
4	0	75	21.45
5	25	0	37.8
«	25	25	38.35
7	25	50	41.8
•	25	75	44.9
*	50	0	41.05
10	50	25	49.25
11	50	50	46.25
12	50	75	49.90
13	75	0	50.2
14	75	25	48.10
IS	75	S0	50.85
1*	75	75	47.05

Trial site No. 1.2 Klamokama (Kisii)

Year 1987 Season 1

Source: FURP (1988)

Appendix 4: Klsll Farm Budget

Maize: Acre/Season

Output	Ylald (kg)	Price/Unit	Revenue	Total
Halt*	1800	2.85	5130.00	
Kali* stover			180.00	
Kilie cobs			100.00	
				5410.00

Act ivlty	Rate/Acre	Price/Unit (Shs)	Cost	
Land preparation Labour MD	25	25.00	625.00	625.00
Planting Labour MD	15	25.00	375.00	
Maize seed (kg)	10	10.40	104.00	
Dusting (kq)	5.5	36.00	198.00	677.00
Fertilizer DA? (kg)	50	7.40	370.00	370.00
Weeding Labour MD	32	2S	800.00	800.00
Harvesting Labour MD	10	25	250.00	250.00
Shelling Labour MD	4	25	100.00	100.00
Bags	20	5	100.00	100.00
Working capital charge 8 23%				224.00
Total variable cost				3146.00
Total Revenue - Total Cost				

Source. PAM report by Egerton University, (1990).

Appendix 5: Bjsla Farm Budget

Mai to Acre/Season

Output	Yield (kg)	Price/kg	Revenue
Kalza Grain	1530	2.95	4511.50
Katze stover			150.00
Malz* cobs			100.00
			4763.50

OperarIon	Cost/Unit	Cost/Acre	Total	
Land preparation MD	15	IS	775.00	
Plantlng Labour HD	6	15	90.00	
Maize seed (kg)	10	13.77	137.70	457.70
Fertilizer DAP		7.40	370.00	370.00
Weed!ng Labour HD	20	15	300.00	300.00
Harvestlng Labour MD	10	15	150.00	
Shelling Labour MD	6	15	90.00	
Bags	17	5	85.00	375.00
Working capital charge I 70%				96.50
Total variable cost				1134.70
Total revenue - Total cost				3679.30

Source. PAM Report by Egerton University (1990)

APPENDIX 6

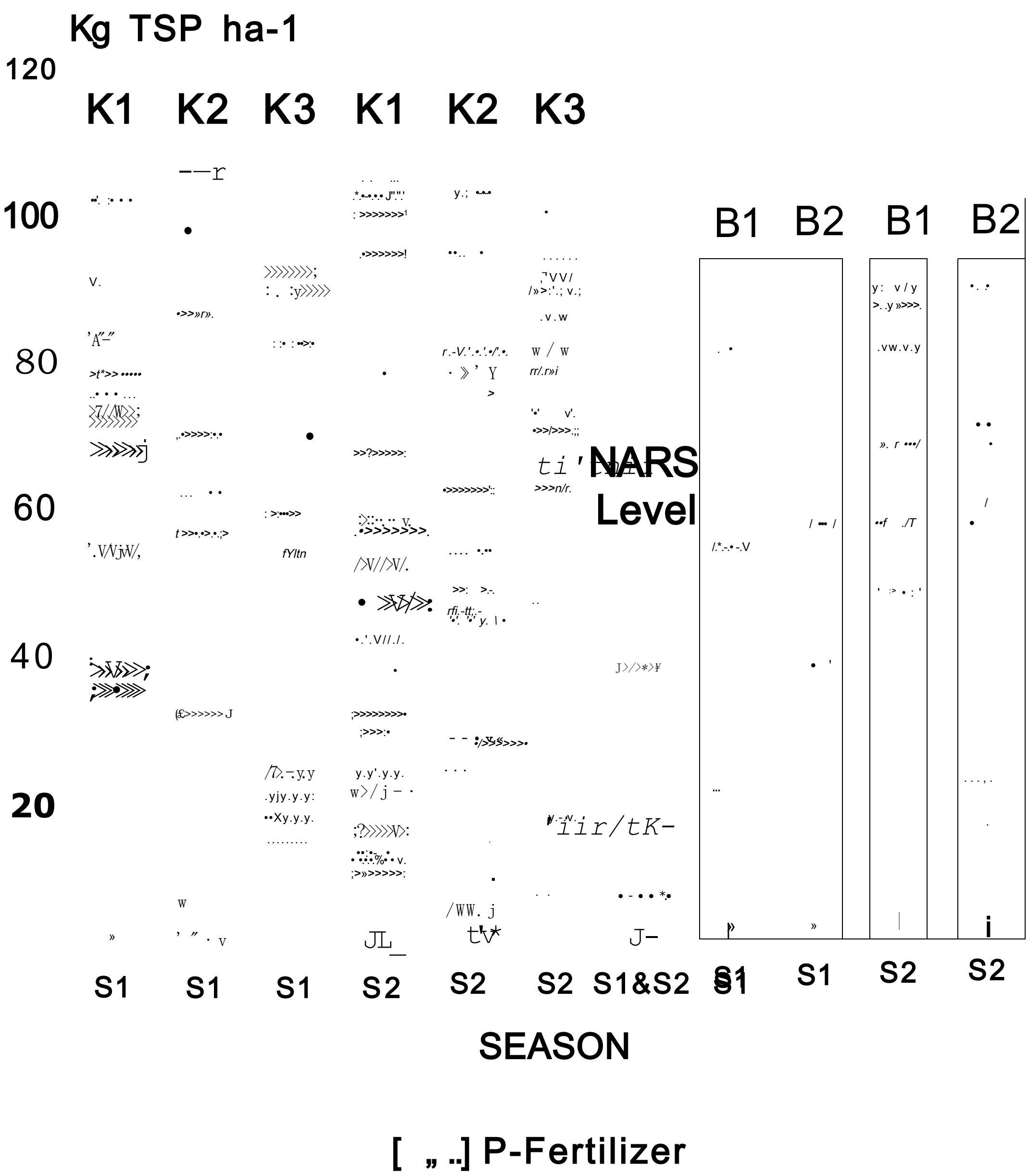
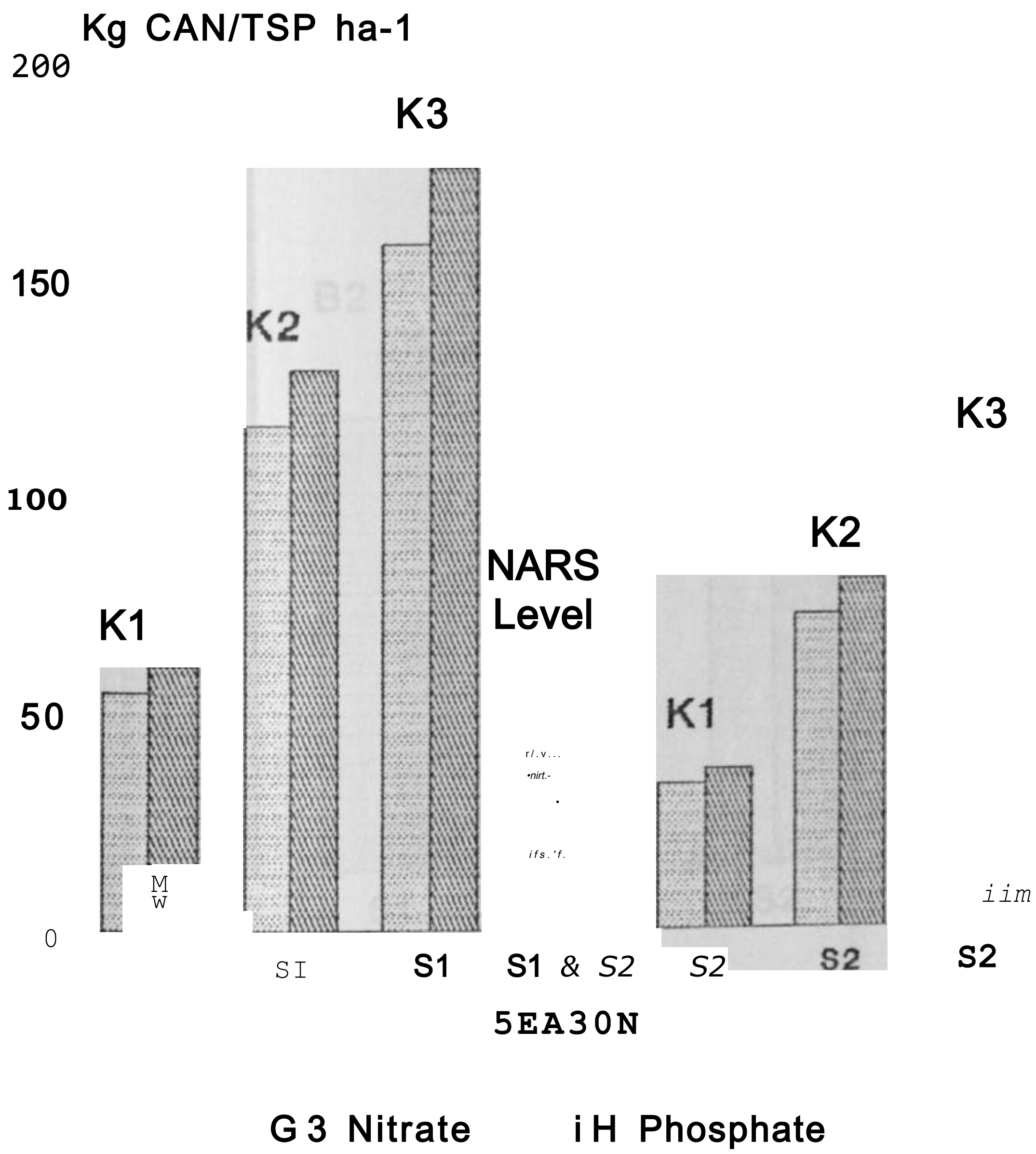


Fig 6.1; Comparison between P-Fertilizer Recommendations using the Quadratic Model and NARS Recommendation.



:ig 6.2;Comparison between N and P Recommendations using the Cobb-Douglas nodel and NARS Recommendations for Kisii

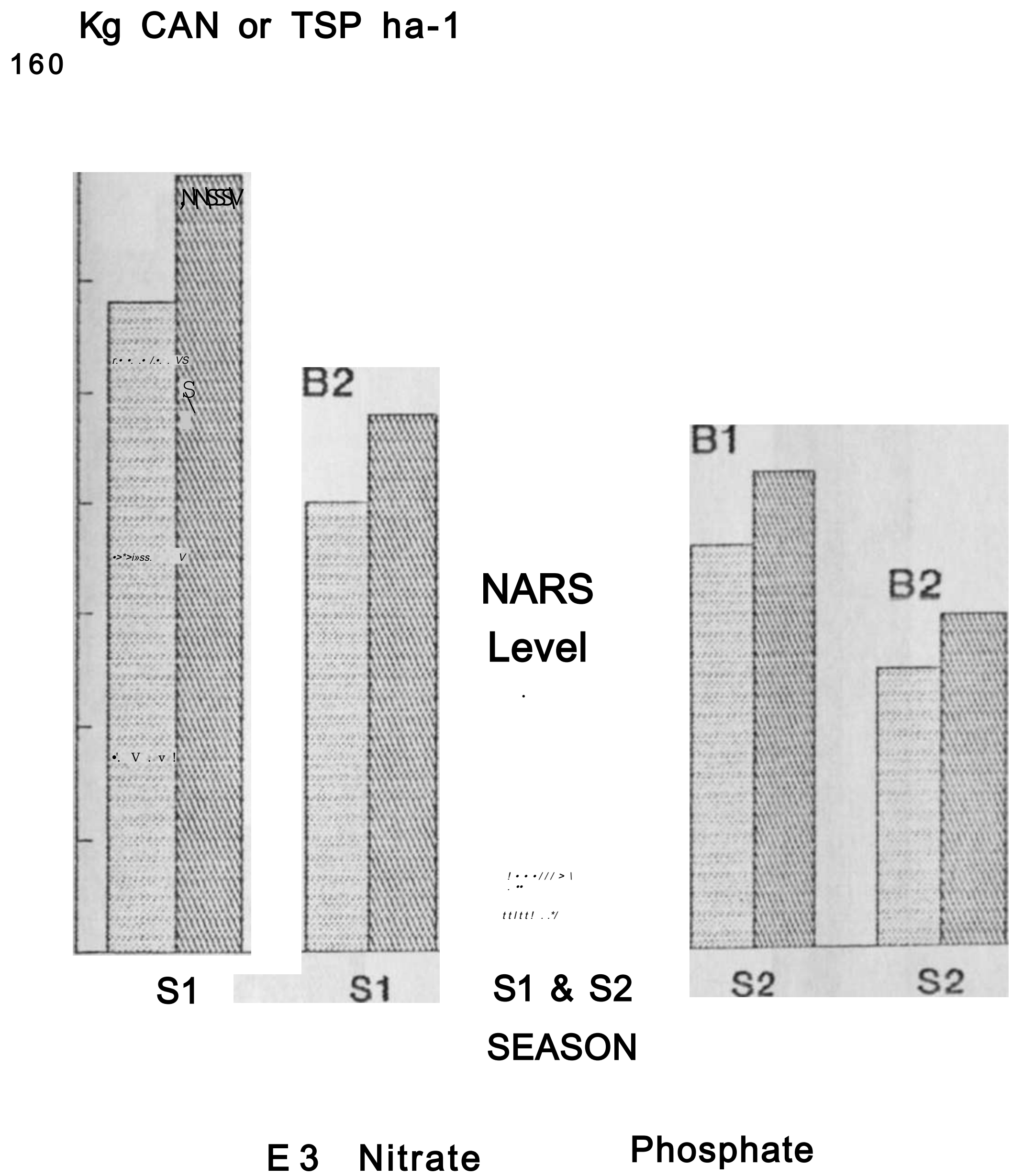
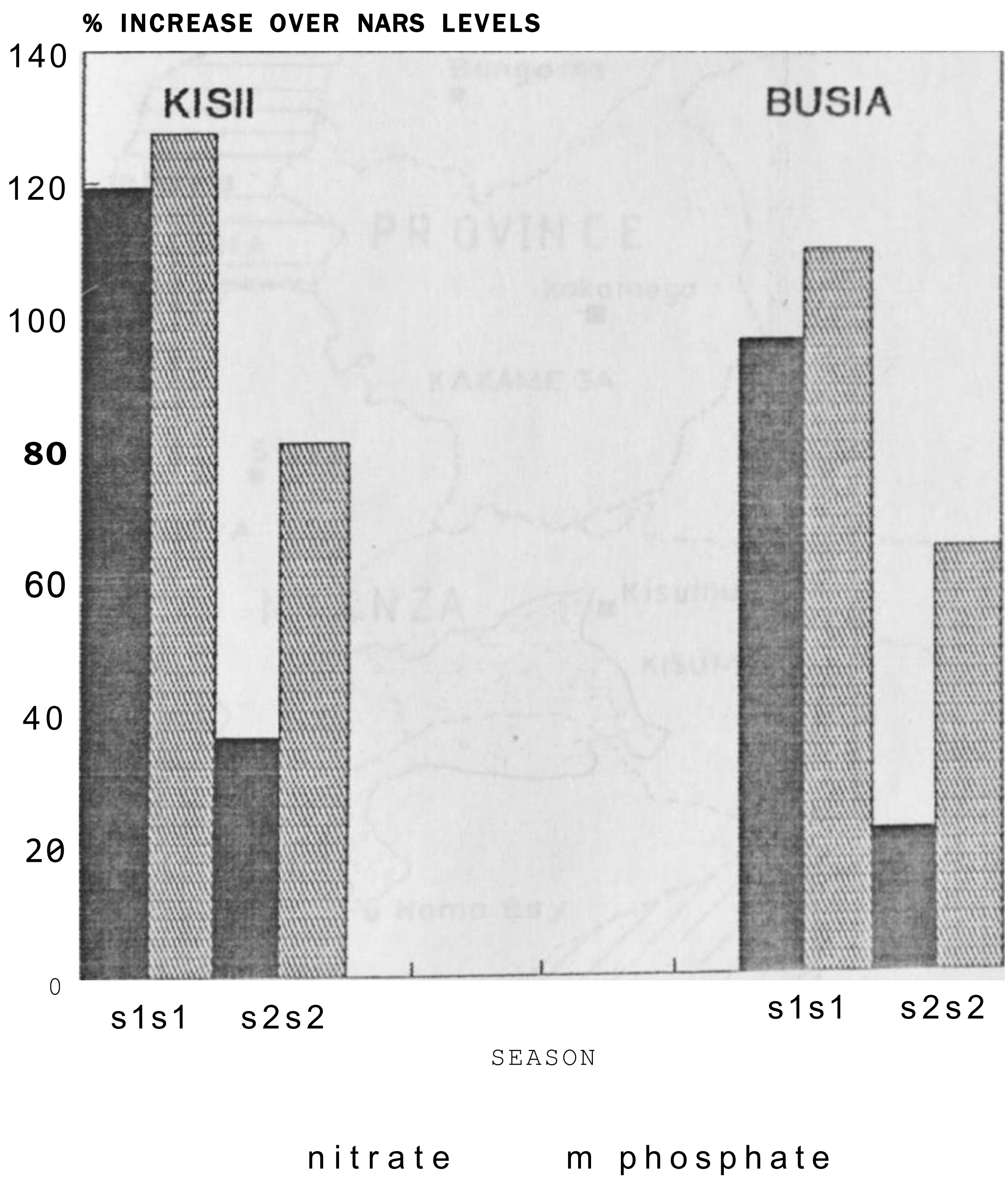
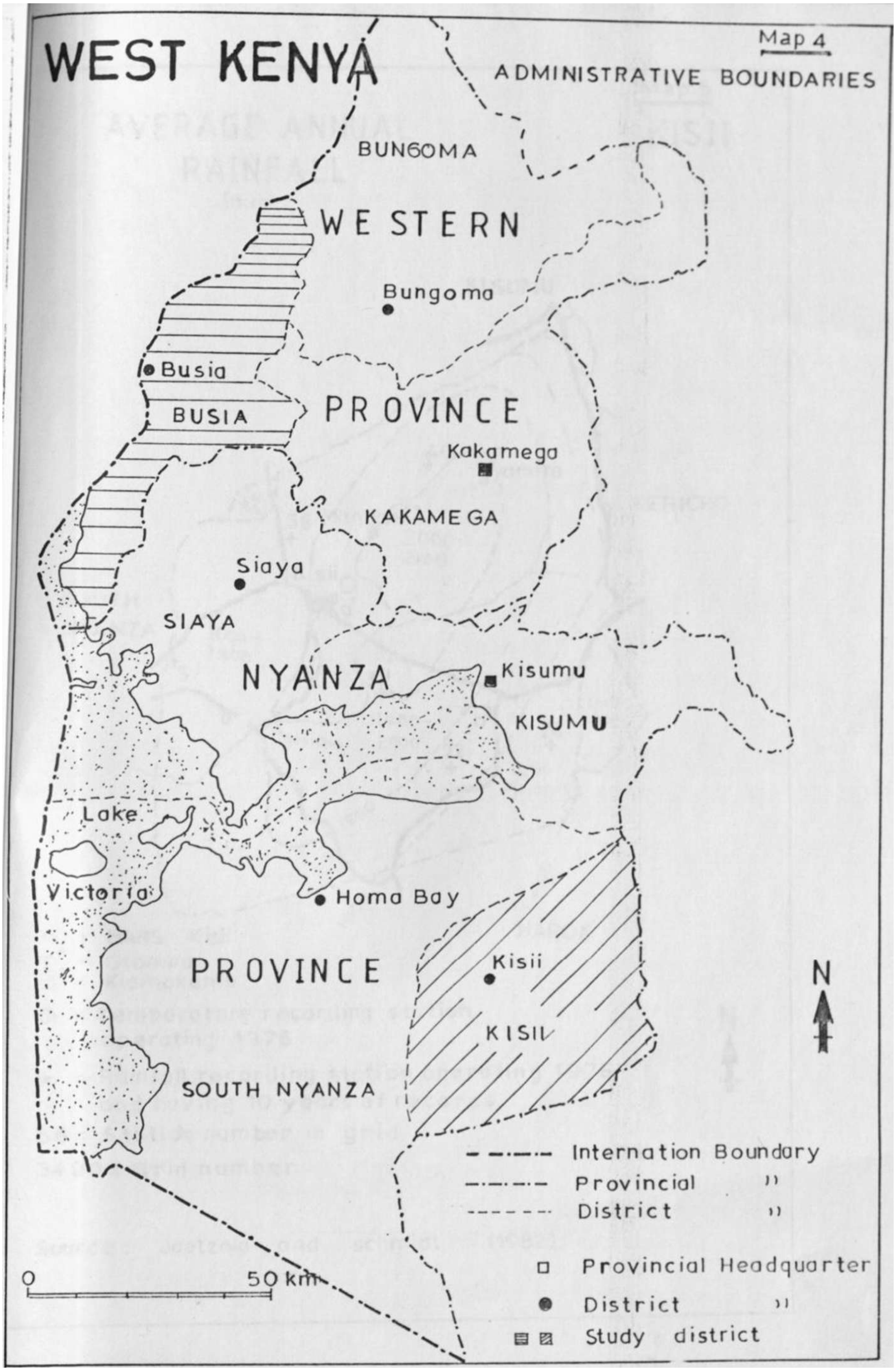


Fig 6.3; Comparison between N and P Recommendations using the Cobb-Douglas Model and NARS Recommendations for Busia

Fig 6.4 % Increase In Fertilizer Recomm endation Over NARS Levels.



NARS Laval • 0.



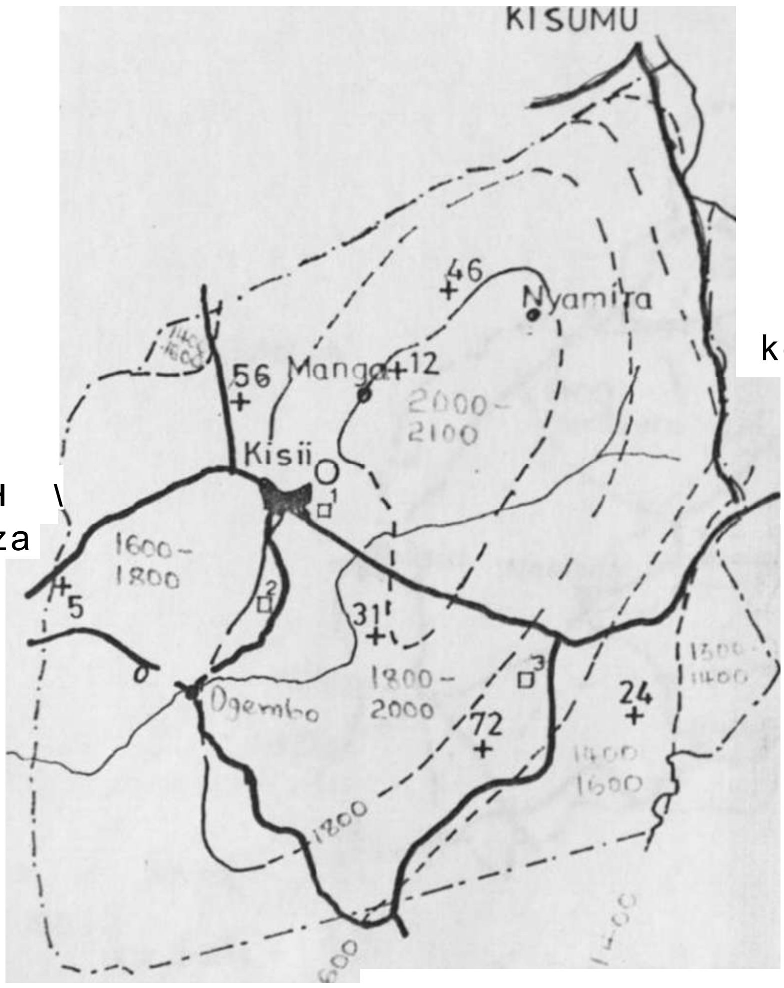
Source.- Author

Map 5

AVERAGE ANNUAL RAINFALL

in mrn

KISII



n¹ * nars Kisii "

* Otamba

• = Kiamokama

O = Temperature recording stotion operating 1976

\+ ^ Rainfall recording station operating 1976 and having 10 years of records

56= Staticfci number in grid

34 90 = Grid number

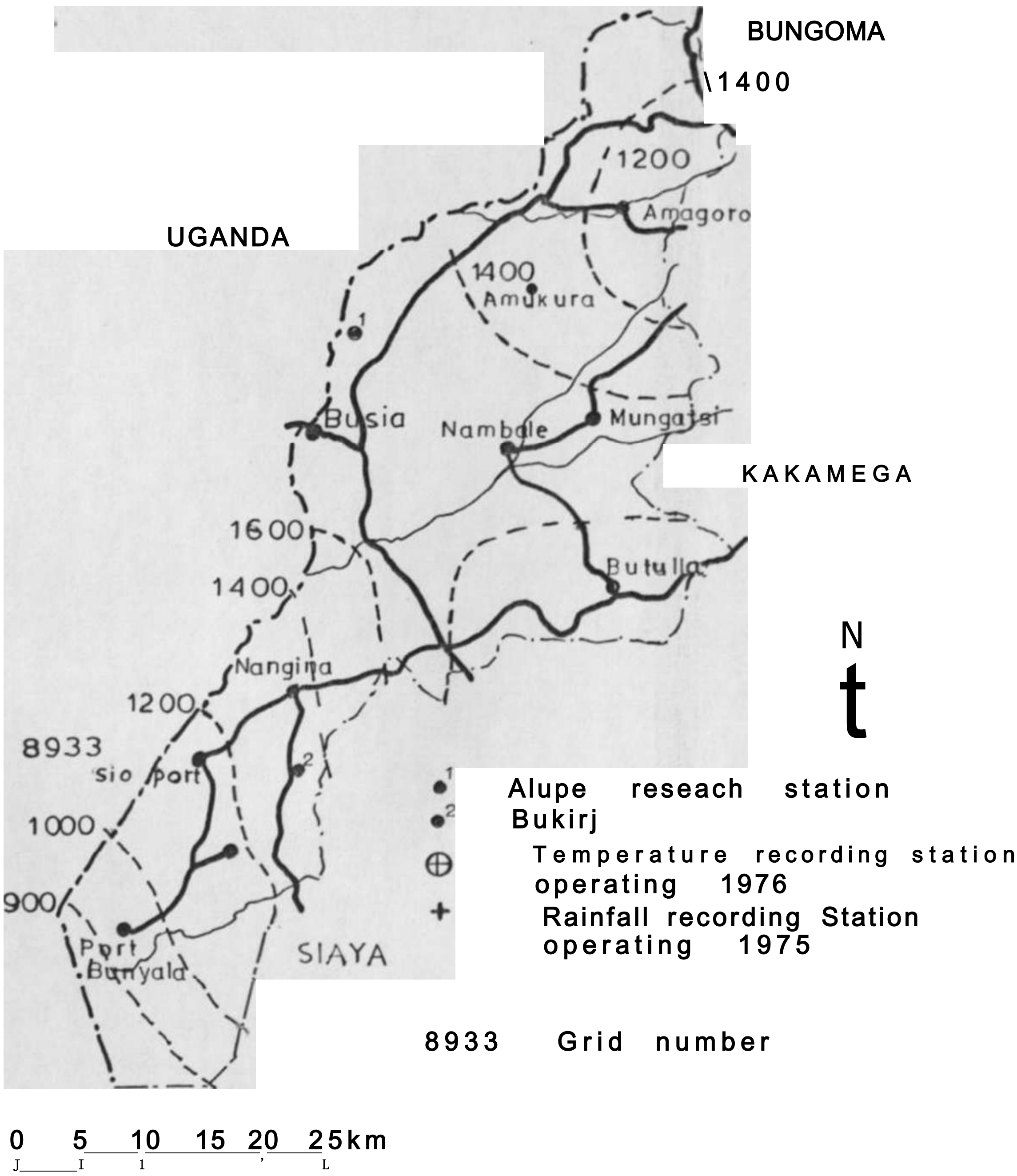
N
t

Source : Jaetzold and schmidt (1982)

AVERAGE ANNUAL
RAINFALL

Map 6

BUSIA



Soure Jaetzold and schmidt (1982)