ECONOMIC ANALYSIS OF FERTILIZER USE IN MAIZE PRODUCTION IN THE NORTHERN GUINEA SAVANNA OF NIGERIA

BY

BENJAMIN AHMED
B.Sc. (Agric.) & M.Sc. (Agric. Economics)

A dissertation submitted to the Postgraduate School, Ahmadu Bello University, in partial fulfillment of the requirements for the award of Degree of Doctor of Philosophy (Agricultural Economics)

Department of Agricultural Economics and Rural Sociology
Ahmadu Bello University, Zaria
Nigeria

September, 1995

DECLARATION

I hereby declare that this dissertation has been written by me and that it is a record of my own research work. It has not been presented in any previous applica-tion for a higher degree. All borrowed ideas have been duly acknowledged by means of references and quotation marks.

Benjamin Ahmed — Date: 22-11-95

The above declaration is confirmed.

Professor A.O. Ogungbile
Chairman
(Supervisory Committee) — Date: 24/11/95

CERTIFICATION

This dissertation with the title "**Economic Analysis of Fertilizer Use in Maize Production in the Northern Guinea Savanna of Nigeria,**" meets the regulations governing the award of Degree of Doctor of Philosophy of Ahmadu Bello University, Zaria and is approved for its contributions to scientific knowledge and literary presentation.

Prof. A.O. Ogungbile
Chairman
Supervisory Committee

Prof. J.O. Olukosi
Member
Supervisory Committee

Dr. M.I. Kolawole
Member
Supervisory Committee

Prof. A.O. Ogungbile
Head, Dept. of Agric.
Econs. & Rural Soc.

26/7/95
Dean, Postgraduate School

AHMADU BELLO UNIVERSITY
ZARIA

DEDICATION

This dissertation is dedicated to maize farmers in the savanna of Nigeria who are willing to increase production through the use of inorganic fertilizers but are unable to see it to buy at reasonable prices.

ACKNOWLEDGEMENTS

I wish to express my sincere appreciation and gratitude to my major supervisor Prof. A.O. Ogungbile, who not only assisted me in getting the research fellowship used to collect the data but also helped greatly in providing guidance throughout the preparation of the dissertation.

I wish to thank Prof. J.O. Olukosi and Dr. M.I. Kolawole who accepted to be members of my supervisory committee even at the finishing touches of the dissertation as replacement for my former committee members, Dr. J. Smith and Dr. C.I. Agbo who left the services of IITA, Ibadan and ABU, Zaria respectively during the period. They all contributed greatly to the successful completion of this work.

My sincere thanks go to the International Institute for Tropical Agriculture (IITA), Ibadan for granting me a Research Fellowship for a period of 2 years which made it possible for me to collect the data used in the study. I wish to thank Messrs K. Makinde, H. Ade Freeman and Tunde Oyewole of RCMP, IITA for their assistance during the data collection and processing stages.

I am grateful to the authority of Ahmadu Bello University, Zaria, who granted me a study fellowship during the period of my data collection and for the research grant given to enable me complete the work.

I acknowledge with appreciations the words of encouragements from my friends, relations and colleagues toward the completion of this dissertation.

I want to thank Mr. Danladi Jarma for his assistance with the computer analysis and Mr. David Inim for the wordprocessing. My sincere appreciation goes to Dr. V.O. Chude for allowing me use his fertilizer data for the response analysis.

I wish to express my sincere thanks to my wife, Mary Ahmed and the children for their endurance and understanding during the study.

Above all, I thank the Almighty God for the wisdom and strength given me to complete this work.

ABSTRACT

The main objectives of this study are to determine the main factors affecting crop choice and fertilizer use decisions among the farmers in Northern Guinea Savanna (NGS) and to estimate the on-station response of maize to N, P and K fertilization. In doing so, the position of maize in the cropping system and how such position would be affected by fertilizer subsidy withdrawal was investigated. Input-output data were collected from 50 farm households made up of 84 farmers selected at random in five villages selected purposely from Kaduna and Katsina states in 1990 and 1991 cropping seasons. The primary information were gathered through the use of questionnaires and interviews. The primary data were supplemented with secondary data while the data were analysed using descriptive statistics, regression, correlation, linear and parametric linear programming methods.

The result of the crop choice factors shows that rainfall, soil fertility, availability and cost of inputs, the need for self-sufficiency in food and cash requirements were the main factors affecting crop choice and combinations. Maize was produced more in a situation where the farmer's goal was to obtain more cash income while sorghum was produced more where the main aim was to feed the family. Maize, however, serve the dual roles of being a food and a

cash crop and therefore it is the dominant crop in terms of hectarage cultivated and income earned.

Fertiliser use decisions were affected by the types available and crops grown. Inorganic fertilizers were used along with the organic fertilizers in most fields but preferential application was given to inorganic fertilizers especially on maize crop. The on-station maize response analyses showed that at the three test sites, the technical optimum levels of N- were lower than the recommended rate of 120kg N/ha. However, the economic optima shows that the recommendation is still valid. In the case of phosphorus response, except in Samaru, the technical and economic optima were lower but closes to the recommended rate of 60kg P_20_5/ha. In the case of potassium response, the technical optima were about the same level with the recommended rate of 60kg K_2O/ha. However, in all the test sites, the economic optima exceeded the rate and were indeed close to 90 kg/ha and thus, it was suggested that the recommendation should be increased to 90kg K_2O/ha. This was confirmed when all the three elements were varied simultaneously as the maximur profit was obtained at the 150-60-90 kg/ha of N, P and K.

The farm setup shows that 70 crop types were grown in a 98 different combinations in the zone. Out of the crop types, maize and sorghum were dominant and were grown in and 16 different combinations respectively. The net Earn

Abstract

income from the representative farm improved from an unplanned farm setup of N17,780 to N25,502 when the farm was planned. Under a larger farm size, production activities were limited by family labour in the months of June, July and August when farm labour demands were at peak.

In terms of nutrient-crop-price ratios, except for P, the ratios for N and K were lower than 2:1 suggested tor efficient uses of fertilizer on crops. The ratios, however improved considerably when fertilizer prices were Increased indicating that, reduction in fertilizer subsidy levels wil] enhance efficiency of fertilizers use on maize in the zone. Further analysis shows that the improved efficiency Leads sole maize cropping system and production of mainly commercial crops.

CONTENTS

	Page
Title Page	i
Declaration	ii
Certification	iii
Dedication	iv
Acknowledgements	v
Abstract	vii
Contents	xiii
List of Tables	xv
List of Figures	xx
INTRODUCTION	1
1.1 Background	1
1.2 Statement of the Problem	3
1.3 Objectives of the Study	6
1.4 Justification for the Study	6
1.5 Organization of the Study	7
LITERATURE REVIEW	9
2.1 Cropping System of Northern Guinea Savanna	9
2.2 Fertilizer Use in Crop Production in Nigeria	11
2.3 Maize Response to Fertilization in Nigeria	15
2.4 Fertilizer Price Subsidy in Nigeria	16
METHODOLOGY	24
3.1 Research Approach	24
3.2 Area of Study	24
3.3 Sampling Frame and Size	26
3.4 Sources and Methods of Data Collection	29
3.5 Analytical Framework	30
3.5.1 Production function analysis	31
3.5.2 Linear programming method	35
3.5.3 Parametric analysis	37
3.6 Specification of the Empirical Models	39
3.6.1 Single nutrient response	39
3.6.2 Multiple nutrient models	40
3.6.3 The linear programming model	42
RESULTS AND DISCUSSIONS	61
4.1 *Socioeconomic Characteristics of the Farm Households*	61
4.1.1 Age/sex distribution	61
4.1.2 The main occupation of household members	62

		Page
4.1.3	Land tenureship and farm ownership.....	63
4.1.4	Costs and Returns from Farm Enterprises.	66
4.2	Crop Choice Decision of the Farm Households ...	67
4.2.1	The physical factors	69
4.2.2	The social/political factors	71
4.2.3	Economic factors	73
4.3	Fertilizer Use Decisions	77
4.3.1	The use of farm yard manure	78
4.4	Maize Response to Fertilization	79
4.4.1	Physico-chemical properties of the soil.	79
4.4.2	Response to single nutrient	83
4.4.3	Response to multiple nutrients (NPK) ...	112
4.5	Analysis of the Linear Programming Model	123
4.5.1	Optimum farm plan of the representative farm	123
4.5.2	Resource use efficiencies	128
4.5.3	Penalties for forcing into the optimum plan excluded activities	132
4.6	Sensitivity Analysis	133
**SUMMARY, POLICY IMPLICATIONS, LIMITATIONS AND SUGGESTIONS FOR FURTHER STUDY		**147**
5.1	Summary	147
5.2	Policy Implications of the Study	156
5.3	Conclusion	160
5.4	Limitations of the Study and Suggestions for further Studies	161
BIBLIOGRAPHY		164
APPENDICES		168

LIST OF TABLES

Table		Page
2.1	Approved prices of low and high nutrient fertilizers in Nigeria, 1986-1991.	21
2.2	Planned retail prices and subsidy levels on fertilizers in Nigeria, 1989-1994.	22
3.1	Important characteristics of the selected villages.	27
3.2	The number and distribution of households in five villages in the NGS, Nigeria, 1989.	28
3.3	The distribution of 84 farmers by farmer category in five villages in NGS, Nigeria, 1990.	28
3.4	Crop production activities in the optimum farm plan model.	46
3.5	Labour hiring activities by months in the optimum farm plan model	48
3.6	Capital borrowing, fertilizer buying, seed buying and the use of owned seed activities in the optimum farm plan model.	50
3.7	Crop selling, grain consumption and buying activities in the optimum farm plan model.	52
3.8	The age/sex composition of households and the derived consumption unit for the study villages, NGS, Nigeria, 1990.	58
4.1	Age/sex distribution and average household composition among 50 farm households in NGS, Nigeria, 1990.	61
4.2	The main occupational distribution among 463 respondent household members in NGS, Nigeria, 1990.	64
4.3	Types of access to the respondents' 327 farm plots, NGS, Nigeria, 1990.	65
4.4	Travelling time between homes and farms in NGS, Nigeria, 1990.	65
4.5	Farm plot ownership among the farming household members in NGS, Nigeria, 1990.	66

Table		Page
4.6	Costs and returns from farm enterprises, NGS, Nigeria, 1990.	67
4.7	The dominant crop enterprises and their mean, minimum and maximum hectarage in five villages, NGS, Nigeria, 1990.	68
4.8	Soil texture distribution of farms in NGS, Nigeria, 1990.	71
4.9	Seed variety and sources of seed used by farmers in the NGS, Nigeria, 1990.	74
4.10	Physico-chemical properties of soils in three villages, NGS, Nigeria, 1990.	80
4.11	Rainfall distribution in three villages in the Northern Guinea Savanna, Nigeria, 1990 and 1991	82
4.12	The parameters of the selected functions of maize response to N-fertilization in three villages in the Northern Guinea Savanna, Nigeria, 1990-1991.	84
4.13	The predicted yield response of maize to N-fertilization in Samaru, Daudawa and Maigana, NGS, Nigeria, 1990 and 1991 (kg/ha).	88
4.14	The total yield, and cost parameters for maize production at various levels of N-fertilization in three villages in the Northern Guinea Savanna (1990)	91
4.15	The parameters of the selected functions of maize response to P-fertilization in three villages in the Northern Guinea Savanna, Nigeria, 1990-1991	94
4.16	The predicted yield response of maize to P-fertilization in Samaru, Daudawa and Maigana, NGS, Nigeria, 1990 and 1991 (kg/ha).	96
4.17	The total yield, and cost parameters for maize production at various levels of P-fertilization in three villages in the Northern Guinea Savanna, Nigeria, 1990.	99
4.18	The parameters of the selected functions of maize response to K-fertilization in three villages in Northern Guinea Savanna, Nigeria, 1990-1991	102

Table		Page
4.19	The predicted yield response of maize to K-fertilization in Samaru, Daudawa and Maigana, NGS, Nigeria, 1990 and 1991 (kg/ha).	104
4.20	The total yield, and cost parameters for maize production at various levels of K-fertilization in three villages in the Northern Guinea Savanna, Nigeria, 1990.	108
4.21	Recommended N,P and K rates, the obtained technical and economic levels of N,P and K and their corresponding yields in three villages in Northern Guinea Savanna, Nigeria, 1990.	110
4.22	Pearson correlation coefficients (r) between yields and villages, between nutrients and villages, and between nutrients in three villages in Northern Guinea Savanna, Nigeria, 1990.	113
4.23	The parameters of the selected quadratic, and double logarithm functions for maize response to N,P and K-fertilization in three villages in the Northern Guinea Savanna, Nigeria, 1990-1991	115
4.24	The parameters of the selected square root functions for maize response to N,P and K-fertilization in three villages in the Northern Guinea Savanna, Nigeria, 1990-1991.	116
4.25	The predicted yield response of maize to N,P and K-fertilization in Samaru, Daudawa and Maigana, NGS, Nigeria, 1990-1991.	119
4.26	The total yield, returns, and cost parameters for maize production at various levels of N-P-K fertilization in three villages in the Northern Guinea Savanna, Nigeria, 1990.	121
4.27	Optimum organization of the representative farm and existing activity levels.	124
4.28	Resource use levels in the optimum farm plan.	127
4.29	Marginal value products (MVP) and unit cost of the resources in the optimum farm plan.	129
4.30	Sensitivity models and the levels of price changes in fertilizers and maize used.	134

Table		Page
4.31	Optimum farm organization and existing activity levels when the prices of fertilizers were increased by 150% and that of maize by 68.8%.	135
4.32	Resource use levels when fertilizer prices were increased by 150% and maize by 68.8%.	137
4.33	Optimum farm organization and existing activity levels when the prices of fertilizers were increased by 300% and maize remained constant at ₦319/bag.	138
4.34	Resource use levels when the prices of fertilizer were increased by 300% and maize remained at ₦319/bag.	139
4.35	Optimum farm organization and existing activity levels when the prices of fertilizers were increased by 400% and maize remained constant at ₦319/bag.	141
4.36	Resource use levels when the prices of fertilizer were increased by 400% and maize remained at ₦319/bag.	142
4.37	Optimum farm organization and existing activity levels when the prices of maize was increased by 111.6% while fertilizer remained at ₦300/bag for NPK and urea and ₦200 for CAN and SSP.	143
4.38	Resource use levels when the prices of maize was increased by 111.6% while that of fertilizer remained at ₦300/bag for NPK and urea and ₦200 for CAN and SSP.	144
4.39	Optimum organization of the representative farm and existing activity levels under a land constraints, NGS, Nigeria, 1990.	145
4.40	Response use levels under a land constraint, NGS, Nigeria, 1990.	146

LIST OF FIGURES

Figure		Page
1	The predicted response curve of maize to N-fertilization in three villages in Northern Guinea Savanna, 1990-1991.	87
2	The marginal returns and marginal cost from nitrogen fertilization of maize in three villages in NGS, 1990.	92
3	The predicted response curve of maize to phosphorus fertilization in three villages in NGS, 1990-1991.	97
4	The marginal returns and marginal cost from phosphorus fertilization of maize in three villages in NGS, 1990.	100
5	The predicted response curve of maize to potassium fertilization in three villages in NGS, 1990-1991.	105
6	The marginal returns and marginal cost from potassium fertilization of maize in three villages in NGS, 1990.	109
7	The predicted response curve of maize to NPK fertilization in three villages in NGS, 1990	120

Chapter 1

INTRODUCTION

1.1 Background

Before the middle of the 1970s, maize production in Nigeria was concentrated mainly in the rain forest and southern guinea savanna zones where, apart from the relatively more fertile soils, the rainfall allowed two crops to be grown in one year. In the 1970s, maize production in the Northern Guinea Savanna (NGS) was of minor importance when assessed by hectarage cultivated and its use for food and cash generation (Kassam *et al.*, 1975 and; Norman *et al.*, 1976).

However, through experimental work of scientists at the Institute for Agricultural Research (IAR), Samaru and the work of the "Joint Project 26 Group" on major cereals in West Africa in the late 1960s, it was discovered that maize has the greatest production potential in the NGS of Nigeria. The works of Baker (1975), Kassam *et al.* (1975), Norman *et al.* (1976) and Balasubramanian *et al.* (1978) all indicated that the physical environment of NGS was well suited to maize production. They cited the low incidence of pests and diseases, well distributed rainfall, good sunshine during growth and drying periods and the absence of bird and

rainfall damages to the crop as some of the environmental factors which favoured the production of maize in the zone.

In addition, the woodland vegetation of the savanna was found to be much easier to clear and therefore easier to put more land to cultivation than the thick rain forest and southern guinea savanna vegetation zones. It was discovered that the use of chemical fertilizers enhances the yields obtained from a unit area of land cultivated to cereals in the zone and particularly maize production. Maize production was found to require relatively more fertile soils and hence, fertilizers than sorghum and millet. The yields of maize from such treatments were found to be 2 to 3 times more than that obtained from sorghum and millet (Kassam *et al.*, 1975).

It can therefore, be argued that the introduction and use of chemical fertilizers in the NGS was the main driving force behind the widespread adoption and cultivation of maize in the zone. In fact, maize that was a minor crop in the early 1970s became so popular among farmers in the zone that by 1987, it was ranked second after sorghum among the cereals in terms of hectarage cultivated and amount consumed as food (Ologunde, 1987). The popularity was enhanced by the fact that it became not only a major food crop for many homes but also a major cash crop which became a replacement for earlier cash crops such as groundnut and cotton in the area.

1.2 Statement of the Problem

The widespread acceptance of maize as both food and cash crop in NGS led to higher demand for the crop than the hitherto popular crops like sorghum and millet. Thus, the production increased and therefore more fertilizers were needed by the farmers in the zone. In the past, it was reported that over 70 per cent of fertilizers consumed in Nigeria took place in the northern states. About two-third of these fertilizers went into the production of cash crops mainly groundnut and cotton (Sodangi, 1981). The decline in the production of these crops and the emergence of maize as a cash crop in the 1980s simply signifies that a lot of the fertilizer requirements of the farmers in recent times went into the production of maize.

Fertilizer is required for yield increases in many crops. Maize, in particular, is known not to produce any meaningful yield without the use of fertilizer. Vachhrajani (1990) attributed 60 per cent increase in food crop production in Nigeria to fertilizer use alone. Since the introduction of fertilizers into the country in the 1930s, the prices have remained heavily subsidized at the retail level. Prices of fertilizers were subsidized for many reasons. First, to create awareness among farmers on the yield advantage which fertilized crops had over those unfertilized crops. Secondly, the crop-to-fertilizer price

ratios for many crops especially food crops were very low and would have been unattractive to the farmers without the subsidy. The subsidy policy made the fertilizer prices to be low and attractive to the farmers to use on many of the crops grown.

In the NGS, farmers that used fertilizers on maize reaped the economic and technical advantages by obtaining higher yields and revenue from its production and sale than from the yields and revenue from the production of sorghum and millet. In the light of recent recession in the Nigerian economy and the rising foreign debt, government introduced the Structural Adjustment Programme (SAP) in 1986. SAP was aimed at allowing the free market forces to control prices of goods, interest rates and foreign exchange rates. Government banned the importation of certain food items including maize. In addition, the level of subsidies in the economy was reduced drastically. Prior to 1986, fertilizer enjoyed heavy subsidy like most agricultural inputs. In 1976-78 fertilizer enjoyed a subsidy level of 75 per cent, in 1986 it declined to 34 per cent while in 1989 it rose again to 80 per cent (Vachhrajani, 1990).

In spite of the high subsidy level in fertilizers, the unofficial (open market) prices remained high, sometimes by as much as three to four times the official prices. But the fact, opinion of farmers showed that the problem was more of

non-availability at the right time rather than high prices. The government therefore felt that by removing the subsidy and allowing the free market forces to determine supply and demand, the commodity will be made available more readily and at much lower prices. Consequently, the government embarked upon gradual removal of the subsidy from 1989 cropping season.

Since the tremendous increase in maize production in northern guinea savanna was attributed to the ready availability of fertilizers at low retail prices and the growing importance of the crop for food and cash, its continued increase in production will depend much on the nature of response of the crop to fertilizer use, and the future relative prices of fertilizer and maize in the market. It is therefore pertinent to ask the following research questions:

1. What are the main factors that influence crop choice and fertilizer use decisions among farmers in the zone?
2. What is the present nature of response of maize to fertilizer use in the zone?
3. What is the optimum farm plan of the farmers in the zone and what is the position of maize in the plan?
4. How will change in the prices of maize and fertilizer affect the position of maize in the optimum farm plan?

1.3 Objectives of the Study

The general objective of the study is to determine the factors affecting crop choice and fertilizer use on maize and the implications of increased fertilizer price on its production in the NGS zone. The specific objectives of the study are:

1. to identify and describe the major factors influencing crop choice and fertilizer use decisions among the farmers in the zone;
2. to estimate the present technical and economic levels of maize responses to N,P,K and NPK fertilizers in the zone using on-farm experimental data;
3. to describe the optimum farm plan of the zone and determine the position of maize in the plan;
4. to describe the effects of changes in the prices of maize and fertilizers on the optimum farm plan; and
5. to draw conclusion and make suggestions based on the study.

1.4 Justification for the Study

The issue of fertilizer use efficiency for crop production in Nigeria has become important of recent because of lack of enough foreign exchange to import the commodity as before. On one hand, farmers, especially those that produce maize are crying out to the government to make the

commodity more available for purchase. On the other hand, the World Bank and International Monetary Fund which provides credit used for the importation insist that unless the subsidies in the economy are removed, credit will no longer be provided. Maize is the crop on which most of the fertilizers used in Nigeria especially in the northern guinea savanna are applied and the crop is very important to the farmers in terms of cash generation and food use.

The study is intended to provide answers to the research questions which are required to determine the states of maize in the cropping pattern, income generation, food use and whether or not fertilizers are being efficiently used at present on maize. In addition, it will provide guidance in the issue of sustainability of maize production in the zone given a situation in which fertilizer subsidy is withdrawn and the open market prices have to go up.

1.5 Organization of the Study

Chapter One is introduction in which a brief background to the study as well as the statement of the problem with the justifications and objectives were presented. In Chapter Two, brief literature review is given on maize and the cropping system of Northern Guinea Savanna, maize response studies in Nigeria and fertilizer subsidy programs in Nigeria. Chapter Three is the methodology in which a description of the study area, sampling frame and size, methods used in the collection

of the data, analytical framework for the production functions and linear programming model and their model specifications are presented.

In Chapter Four, the results and discussions are presented based on the socio-economic characteristics of the farm households, crop choice decisions, crop fertilizer use decisions, maize response functions, optimum farm organization and the sensitivities of the optimum farm plan to changes in fertilizer and maize prices.

In the last and concluding chapter, the summary of the findings, policy implications of the study, conclusion and the limitations of the study as well as the suggestions for further study are presented.

Chapter 2

LITERATURE REVIEW

2.1 Cropping System of Northern Guinea Savanna

According to Rastogi (1980), the cropping system of any region is essentially determined by experiences gained over the years on a given soil and the climatic and environmental condition. For example, in dry land areas, rainfall consideration often tend to overshadow other considerations in the choice of crops and cropping patterns. Economic consideration on the other hand may be the determinant factor where cash crops have a major influence in the economy.

In the northern guinea savanna, the climate has been found to be well suited to a wide range of crops particularly cereals and legumes. However, the emerging cropping pattern is influenced by the level of production technology, the tradition of the people, resource availability and time. Crops in general are either grown in single stand or in mixtures. Growing crops in mixtures has been described as the practice whereby two or more crops are grown on the same piece of land at the same time (Norman, 1972). Crop mixtures form a major cropping pattern in the zone. For instance, Norman (1972) reported that over 75 per cent of total land area under cultivation in Zaria area was in crop mixtures. Also, Balcet and Candler (1982) reported that over 87 per

cent of land under cultivation in the Funtua Agricultural Development Project was in crop mixtures.

Maize is a major crop in the cropping system of these areas. Ahmed (1985) reported that in Daudawa, maize accounted for 49 and 53 per cent in 1981 and 1982 respectively in the total land cultivated. In these years, maize was found to be grown in sole stands and in mixtures, sole maize crop accounted for 72 per cent of total maize production, while maize grown in mixture with sorghum accounted for 18 per cent. Other mixtures involving maize were maize/cotton, maize/cotton/cowpea, maize/sorghum/-groundnut, maize/sorghum/cowpea and maize/cowpea/sweet potatoes.

The preference of crop mixtures over sole crops by farmers in northern Nigeria can be justified on economic and technical grounds (Norman,1973). On technical ground, farmers were said to derive mutual benefits of labour use, soil protection and reduced pests and diseases incidence. On economic ground, farmers derived maximum benefits from the land by obtaining more than one crop and spread the labour and fertilizer use among the crops in the mixture.

Maize is a major cereal crop in northern guinea savanna. In 1981 and 1982, IAR reported that, it accounted for 72 and 75 per cent respectively of the total cereal production in Daudawa area of the zone. In 1983, a nation-wide survey by the Federal Office of Statistics showed that maize was the

second most popularly cultivated crop after sorghum in Nigeria (Federal Office of Statistics, 1983). The report further showed that maize was mainly produced in the savanna areas of northern Nigeria. The use of maize as food crop and as cash crop was responsible for its growing importance. As food crop, it is prepared and eaten in form of *tuwo*, *pete*, and *akamu*. It is also eaten green by boiling or roasting while the dry grains are often fried and eaten. Maize also had commercial value in the industrial sector where it is used as a source of energy in livestock feed and as raw materials in brewing and confectionery industries.

2.2 Fertilizer Use in Crop Production in Nigeria

Falusi (1973) identified two main factors influencing fertilizer use decisions among farmers. One of the factors is agronomic characteristics which consist of the nature of crops and the soils on which the crops are grown. Crops have been observed to absorb nutrients at different rates and capacities depending on whether they are shallow or deep rooted, the stiffness of their stalk and whether or not they are improved varieties. The improved crop varieties normally require more fertilizer than the traditional or local varieties.

The fertility regime and moisture content of soils play a major role on the type and amount of fertilizers to apply on crops grown on it. The relatively more fertile soils

require less fertilizer than the relatively poor soils for crops grown on them to do well. Furthermore, adequate water is needed in the soil for the fertilizer to be efficiently utilized. However, excess water in the soil is also detrimental to the planted crops. For instance, the absorption of nitrogen and potassium under high moisture content is reduced due to leaching and erosion.

Norman and Hays (1978) reported that the rainfall of northern guinea savanna was adequate for rainfed crops while the soils are also well drained. The soils consist of loamy soils derived from crystalline basement complex and classified as ferruginous tropical soils (Ologunde, 1987).

The second factor which guide farmers in their choice and use of fertilizers is socio-economic variables like yield of crop, price of crop and fertilizers, availability of capital and the risks associated with the use of fertilizers (Falusi, 1973).

Although crop yield is determined by the level of response of the crop to fertilization, the most profitable amount of fertilizer to use is often determined using economic principle which equate the marginal cost with the marginal revenue from using the fertilizer. In doing so, however, it should be noted that some of the benefits of the fertilizer on the crops that follow the application have not been considered. Falusi (1973) reported residual benefits

from phosphatic and potassic fertilizers in the second year of their application. The residual effect of nitrogenous fertilizers on the other hand in the second year is minimal because of heavy leaching and erosion in the year of application.

Low unit cost of fertilizer and high unit price of produce are great incentives to farmer to use fertilizers. In the 1960s and 1970s, it was not the situation. According to Sodangi (1981), the fertilizer-to-crop price ratio was high for many food crops. This was a disincentives to farmers and so, many did not use fertilizer and so shifting cultivation was extensively practised. In addition, the cropping system commonly found among the farmers was mixed cropping for which there were no fertilizer recommendations. The consequence of all these is that there was low use of fertilizers by farmers in the 1960s and early 1970s.

Between 1968 and 1973, food crop prices with the exception of rice more than doubled while the prices of fertilizers remained relatively stable. For example, Sodangi (1981) reported that in 1970, one tonne of sorghum could buy one tonne of N-P-K fertilizer while in 1980, one tonne of sorghum could buy two tonnes of the same N-P-K fertilizers.

There are essentially four types of fertilizers in Nigeria market. They are the phosphatic fertilizers which supply phosphorus in the form of P_2O_5, nitrogenous

fertilizers which supply nitrogen, potassic fertilizers which supply potassium in the form of K_2O and complete fertilizers which supply N, P and K in different ratios shown by the formulation on the bag.

The commonest phosphatic fertilizer in the market is the single super phosphate (SSP) which contains 18% P_2O_5. Among the nitrogenous fertilizers are urea which contains 40-46% N and Calcium Ammonium Nitrate (CAN) which contains 26% N. The commonest potassic fertilizer is muriate of potash which contains 48-60% K_2O. Among the complete fertilizers, there are formulations containing 15:15:15, 20:15:0 and 27:13:13 of N,P and K in the markets. The 27:13:13, a recent formulation, is meant specifically for cereal crops.

The element P is required by crops for good root and stem development, N is required for bulk increase in the crops while K is required for vigour and resistance to diseases (Balcet and Candler, 1982). For these reasons, P is often applied as basal application while N is applied 2-3 weeks after sowing followed by a side dressing application which in maize must be before tasselling.

In the northern guinea savanna, the level of K available in the soil is said to be enough for most crops. However, heavy yielding crops like maize which are under intensive cultivation needs additional supply through fertilization (Balcet and Candler, 1982).

2.3 Maize Response to Fertilization in Nigeria

Maize yield was found to respond to nitrogen fertilizer application at Omu-Aran and Mokwa, all in the southern guinea savanna up to 150 kg N/ha and with basal application of 60 kg/ha each of P_2O_5 and K_2O. However, the most profitable level was found to be at 100 kg N/ha (Ogungbile and Ologunde, 1986). In a study conducted by Wedderburn *et al.* (1988) to determine crop yield response to fertilizer use at selected Agricultural Development Project Areas, in 1985 and 1986, maize was found to be the most responsive crop to fertilizer use among the cereal crops. Although the general response was low due to either methodological problems or the use of improved variety, average response of maize was 0.60 kg per kg of nutrient while that of millet was 0.10 kg per kg of nutrient in Kaduna area. The study further noted that there was an increase in the numbers of farmers producing maize and who gave priority application of fertilizers on maize crops. Cases of high fertilizer application rates were observed and Kaduna zone was found to have applied as much as 284 kg N/ha.

In a similar study, Lombin *et al.* (1989) found that five out of eight sites in northern guinea savanna showed appreciable maize response to fertilization. However, the optimum rate varied from 50 to 200 kg N/ha. At Daudawa and Samaru, the optimum rate was found to be 200 kg N/ha each while at Maigana it was 150 kg N/ha. Using the organic

carbon, total N, mineral nitrogen (NO_3-N and NH_4-N) in top and sub-soils to predict maize response to N-fertilizers, responses were obtained where the organic carbon, total N and mineral nitrogen were less than 1%, 0.1% and 20 ppm respectively.

For responses to phosphorus, it was found that there exist a correlation between Bray-I-P and response to P-fertilizers. Response was expected on soils with less than 10 ppm Bray-I-P. Optimum response of maize to phosphorus was found to be 60 kg/ha and 100 kg/ha at Samaru and Maigana respectively. In Daudawa, it was found to be 80 kg/ha.

In the case of potassium, the study showed that there was response of maize to potassium fertilizers in almost all the sites at rates between 30 kg/ha and 60 kg/ha especially where the exchangeable K is less than 0.2 Me/100g soil.

The criteria for rating soil fertility classes in Nigeria is spelt out in Enwezor *et al.* (ed) [1989]. Based on these criteria, fertilizer recommendation for open pollinated maize in the northern guinea savanna was specified as 120 kg N/ha, 60 kg P_2O_5/ha and 30 kg K_2O/ha and at a plant population of 54000/ha.

2.4 Fertilizer Price Subsidy in Nigeria

Many governments of the world assist their farmers in various ways to meet the cost of fertilizers where there was

a need to increase agricultural production. In Britain for instance, N- and P-fertilizers were subsidized up to 1974. As at 1978/79, thirty eight countries of the world provided subsidies on N-fertilizers, twenty seven countries on K-fertilizers and thirty six on P-fertilizers while thirty one countries assisted their farmers in the purchase of mixed and complex fertilizers (Cooke, 1982).

Although fertilizer bring benefits to farmers, purchasing them is often difficult especially among the poor resource farmers. In the developing countries, there is neither sufficient foreign exchange for importing fertilizers nor for building fertilizer companies (factories). This results in inadequate supply of the right type and quantity of fertilizers when they are needed. The use of fertilizer in Nigeria increased rapidly from less than 20,000 metric tons of the nutrient in 1972 to 1,410,000 metric tons in 1992 (Ogunfowora, 1989). In spite of this increase in fertilizer consumption, there is considerable evidence that non-availability of fertilizers at the farm level is one of the most important obstacles to increased usage by farmers (Zalla *et al.*, 1977). The cause of the non-availability is often attributed to distribution problems arising from high cost of transportation and bad roads.

In order to encourage the farmers to use more fertilizers, the government has been subsidizing the cost of

the fertilizers at the retail level in order to make them more readily available and affordable. The subsidy on fertilizer takes one of two forms. The first form is a direct subsidy in which government pays the amount of subsidy directly to the agencies responsible for the production, importation and distribution of the fertilizers. The second form which is an indirect subsidy, the government offsets the cost of transportation, reduce the fees charged on services rendered to the concerned agencies and also give concession on taxes and levies paid by such agencies (Vachhrajani, 1990). Sodangi (1981) reported that the federal government alone bore the cost of importation and port handling of fertilizers while the costs of transportation to the state headquarters were shared with the state on a 50:50 ratio.

The subsidy on fertilizer between 1976 and 1979 according to Idachaba (1987) amounted to 75 per cent of the landed cost of the fertilizer at the state headquarters. The price farmers paid for fertilizers was expected to be 25 per cent of the cost. The state governments were to bear the cost of intra state transportation. Idachaba (1987) reported that most of the northern state governments where over 70 per cent of fertilizer consumption in Nigeria takes place, rarely were able to recover the 25 per cent cost from the farmers. Consequently, the actual subsidy on fertilizer was about 85 per cent.

Subsidy on farm inputs have always been used in agricultural production as instrument for encouraging the use of such inputs and the production of a particular product (crop). The goal of fertilizer subsidy in Nigeria has been the encouragement of fertilizer use among the small-scale farmers in order to enhance their productivity.

The small-scale farmers form the bulk of farmers in Nigeria and therefore, an increase in the price of fertilizer means an increase in their production costs and probably a reduction in income. The farmers would have to increase the prices of their crops in order to remain at their real level of income before the price increase in fertilizers was made.

On the other hand, if government does not remove the subsidy or reduce the amount substantially, the impact of its cost on the annual budget is enormous. For example, in 1987, fertilizer subsidy alone took about 75 per cent of the federal agricultural budget (Lele *et al.*, 1989).

Cheap food pricing and trade policies tend to discourage the adoption and use of productivity increasing technology such as fertilizers. According to Zalla *et al.* (1977), the use of subsidy on food crops appeared to reflect political expediency rather than economic wisdom. It was the low world crop production of late 1970s and early 1980s coupled with the recent high fertilizer prices in the world market, that made many governments to consider enforcing some regulations

was 72 per cent, for 15-15-15 N-P-K fertilizers that were imported, it was 77 per cent while that on 15-15-15 N-P-K fertilizers produced by National Fertilizer Company (NAFCON) was 87 per cent. For the single super phosphate fertilizers, it was 75 per cent while the blended 27-13-13 fertilizers produced in Kaduna had 87 per cent subsidy. Average subsidy on fertilizer therefore remained at about 79 per cent.

Table 2.1. Approved prices of low and high nutrient fertilizers in Nigeria, 1986-1991.

Year	Type of Fertilizer	
	Low nutrient (₦/bag*)	High nutrient (₦/bag)
1986	8.50	10.00
1987	8.50	10.00
1988	12.00	12.00
1989	12.00	12.00
1990	17.00	20.00
1991	30.00	40.00

**1 bag = 50kg.*

Source: Announced official prices for the various years.

As the oil revenue and the ability of Nigeria to transfer resources continued to decline, it was proposed by the World Bank that the current fertilizer-crop price ratio of less than 2:1 be increased through privatization of fertilizer wholesale and retail businesses in order to enhance high efficiency in their usage. According to Vachhrajani (1990), the following retail prices and subsidy

levels on fertilizers have been planned for Nigeria by the World Bank (Table 2.2) in order to bring about efficiency in its usage. The table shows that the level of subsidy will be removed gradually over five years by increasing the retail prices of the fertilizer over the same period of time.

However, at the time of the study, the above plan has not been implemented. Even though the official retail prices were increased from 1989, the approved prices remained lower than the planned prices for each year except in 1994 when the approved prices were ₦150/bag for high nutrient fertilizers and ₦100/bag for the low nutrient ones. The subsidy level has indeed not been reduced significantly because the small nominal increase in the prices has been overtaken by the more than 700% devaluation of naira against most of the international currencies.

Table 2.2. Planned retail prices and subsidy levels on fertilizers in Nigeria, 1989-1994

Year	Price of Fertilizer (₦/bag)	Level of Subsidy (%)
1989	15.00	87
1990	52.00	45
1991	75.00	35
1992	87.00	25
1993	102.00	12
1994	116.00	0

Source: Vacchrajani (1990).

The literature review has shown that maize occupies very important position in the farming system of NGS in terms of usage for food and cash by farmers and in terms of quantity of fertilizer applied. This study will provide an update in these knowledge and show also how a reduction or complete removal of fertilizer subsidy may affect its production in the zone.

Chapter 3

METHODOLOGY

3.1 Research Approach

Two approaches were used in carrying out this study. The first approach was based on a single crop enterprise in which experimental data from three on-farm research farms (villages) in the zone were used to estimate response functions for maize. The response functions were estimated using production functions to predict the level of maize yield from a given level of nutrient application. This helps to evaluate the current levels of fertilizer recommendations for maize in the zone and determine whether or not such recommendations are economically feasible with the farmers given the current and future prices of maize and fertilizers.

The second approach was based on a whole-farm modelling of a representative farm in the zone using linear programming methods. In this method, optimum farm plan was derived for the zone using a farm survey data collected from five villages in the zone during the 1990/91 production season.

3.2 Area of Study

The farm survey and the fertilizer experiments were conducted in villages spread across Kaduna and Katsina States which fall within the Northern Guinea Savanna ecological

zone. The farm survey was conducted at Gwanki, Kaya and Tsibiri in Kaduna State and in Barde and Borindawa in Katsina State. The fertilizer experiments were conducted in Daudawa in Katsina State and in Samaru and Maigana in Kaduna State during the 1990 and 1991 cropping seasons. These villages are located between longitude 7° and 8°E and latitude 10° and 12°N which correspond to the area denoted as the northern guinea savanna ecological vegetation zone of Nigeria.

According to Kowal and Knabe (1972), the vegetation of the zone is made up of short grasses of which *Hyperrhenia Andropogon* spp is dominant and with trees which flourish during the dry season. The area covers about 597,012 km² of land and has a rainfall duration of 90 - 230 days in a year and with annual fall of 508 mm to 1,399 mm. The zone supports main crops like sorghum, millet, maize, groundnuts, cowpea, cotton, yam, rice, sugar cane and pepper.

The survey villages were selected based on an earlier diagnostic survey of the northern guinea savanna conducted by Institute for Agricultural Research (IAR), Samaru and International Institute of Tropical Agriculture (IITA), Ibadan during the 1989 farming season. In the survey which covered 29 villages selected randomly, cropping system, level and history of crop intensification, availability and use of fertilizer and other data were collected.

The five villages have similar characteristics in terms of maize as a crop of importance and the importance attached to fertilizer use on crops. These characteristics and others are shown in Table 3.1.

3.3 Sampling Frame and Size

The sampling frame for each village survey was based on the list of households obtained through a complete enumeration of all household heads in the villages. In Kaya and Barde however, complete enumeration of the household heads were not possible because of the large size of the villages. Therefore, in Kaya, the enumeration was confined to one internal and three external wards while in Barde, it was confined to one internal and two external wards. In all, 450 household were enumerated as shown in Table 3.2.

A household survey was then conducted to obtain information on major and minor occupations, crops produced and consumed and the size and composition of the households. On the basis of the household survey, fifty households consisting of ten from each village and representing 11% of the total households were selected randomly using random numbers. During the farm survey, information on demography, crop production, consumption, input use and prices for inputs and outputs were obtained. The fifty households were made up of eighty-four farmers which were later classified into small

scale, intermediate and large scale categories on the basis of their ability to feed the households and income obtained from crops produced on their farms (Table 3.3).

Table 3.1 Important characteristics of the selected villages in NGS of Nigeria, 1989.

Observation	Villages				
	Gwanki	Borindawa	Tsibiri	Barde	Kaya
Food crop					
1st	Maize	Sorghum	Maize	Sorghum	Maize
2nd	Sorghum	Maize	Sorghum	Maize	Sorghum
3rd	Millet	Millet	Millet	Cowpea	Yam
Cash crop					
1st	Chilly Pepper	Maize	Cotton	Maize	Maize
2nd	Sugarcane	Cotton	Yam	Sugarcane	Yam
3rd	Maize	Cowpea	Maize/Rice	Cotton	Rice
Use of fertilizers (%)	100%	100%	100%	100%	100%
Years of growing maize	10	7	10	10	6-10
Maize inter-crop	Sorghum	Sorghum and Cowpea	Sorghum and Cowpea	Sorghum	Sorghum
Problem of fertilizer	Important	Important	Important	Important	Important

Source: IAR/IITA (1989) "Some characteristics of different representative villages in northern guinea savanna of Nigeria."

Table 3.2 The number and distribution of households in five villages in the NGS of Nigeria, 1990.

Village	Number of households	Number of households in farm survey	% of households in farm survey
Barde	88	10	11.36
Borindawa	48	10	20.83
Gwanki	115	10	8.70
Kaya	101	10	9.90
Tsibiri	98	10	10.20
Total	450	50	11.11

Source: Household survey data.

Table 3.3 The distribution of eight-four farmers by farmer category in five villages in the NGS of Nigeria, 1990.

Village	Farmer category			Total
	Large-scale	Intermediate	Small-scale	
Barde	2	4	12	18
Borindawa	6	8	9	23
Gwanki	3	6	5	14
Kaya	6	3	2	11
Tsibiri	2	5	11	18
Total	19	26	39	84

Source: Farm survey data.

3.4 Sources and Methods of Data Collection

In order to estimate the response function for maize in the zone, secondary data was used. The data consisted of nitrogen (N), phosphorus (P) and potassium (K) calibration trials for 1990 and 1991 conducted by IAR, Samaru as part of the national fertilizer trials. The trials were sited at Daudawa, Samaru and Maigana all within the Northern Guinea Savanna. The trials were made of 7 treatments each of N, P, K and NPK replicated 3 times in a Randomised Complete Block (RCB) design. Soil data were collected and analysed for each site during the period.

Primary data were collected and used for the crop choice and fertilizer use decisions and for the determination of optimum farm plan. In the crop choice and fertilizer use decisions, randomly selected farmers were interviewed using unstructured questionnaire to obtain the relevant information. In the case of farm survey, cost-route or multiple visit approach was used to collect the data. Enumerators were stationed on the field to collect information pertaining to farm activities such as input use and crop disposal activities using both structured and unstructured questionnaires on a weekly basis throughout the study period. This approach was used because most of the farmers were not literate and therefore could not keep farm records and because some of the information required were

continuous and non-registered especially daily family and hired labour input use.

In the *gandu* fields (farms), the *gandu* head provided the information about the farm while on *gayanna* farms, the operator provided the information himself or herself. *Gandu* according to Balcet and Candler (1982), is a complete farming unit made up of more than one nuclear family and with the working family members cooperating to operate a common farm. In return for their labour, the *gandu* head provides the members with food, shelter, and other essentials like clothing on ceremonial occasions, marrying for male members and providing plot of land for male members to farm independently at specified times. *Gayanna* fields, on the other hand, are fields operated by household members other than the gandu head i.e. fields operated by the household sons and nephews.

3.5 Analytical Framework

There are three aspects of this study, each requiring a different analytical technique. For the crop choice and fertilizer use decisions in objective one, descriptive and inferential statistics were used to identify and describe the factors affecting them. For the response function estimation for maize, in objective two, regression techniques were used to estimate the production functions.

In the case of determining optimum farm plan, in objective three, linear programming method was used to develop the optimum farm plan for the zone. Finally, objective four was attained by subjecting the optimum farm plan to parametric or sensitivity analysis.

3.5.1 Production function analysis

Crop response to fertilizer application have been determined by several researchers through the use of production functions (Heady and Dillon, 1961; Paschal and French, 1956).

A production function is a mathematical relationship between inputs and the output. Fertilizer response function therefore show the level of crop yield that is obtained at each level or dose of fertilizer over a range of fertilizer rates. Production functions are estimated as continuous functions using regression techniques.

The following functional forms have been used by researchers to estimate fertilizer response functions:

Spillman function

The functional form of the Spillman function is given by equation 3.1

$$Y = M - AR^{x} \quad \text{.....(3.1)}$$

where,

Y = Output level.

M = Maximum yield from using the fertilizer.

A = Maximum incremental yield from the fertilizer.

x = Fertilizer level.

R = The ratio by which the marginal physical product of *x* declines.

This function was first used by Spillman but was developed by Mitcherlich. Paschal and French (1956) used it to estimate corn response functions to fertilizer use in United States of America. A, M and R are constants and were found to vary in values depending on the other nutrient levels of the soil, plant population and the nature of the soils itself. They also found that although the function is consistent with the law of diminishing marginal returns, the function does not provide for decrease in yield and therefore not accurate at fertilizer rates above that which is economically feasible.

Cobb-Douglas production function

The Cobb-Douglas functional form for a single input-output is given by equation 3.2.

$$Y = AX^{b} \quad \text{.....(3.2)}$$

where

Y = Crop yield.

A = Constant.

X = Fertilizer level.

b = Elasticity of production of *X*.

The Cob-Douglas production function is normally estimated in the logarithmic form either as semi-log or double-log. In the semi-log form, either the input or the output is in the log form while in the double-log form both the input and the output are in the log form.

The Cobb-Douglas production function can only show one stage of the production function (constant, increasing or decreasing marginal return) at a time. In addition, zero yield is obtained at zero level of fertilizer use and therefore realistic for some crop response estimation.

Polynomial Production Functions

The Polynomial production functions can take either of two forms; quadratic or square root functions. In a single input-output production, the quadratic form is given by:

$$Y = a + bX - cX^2 \text{.....(3.3)}$$

where

Y = Crop yield.

X = Fertilizer level.

a,b and c = Constants determined in the regression.

The square root form is given by:

$$Y = a - bX + cX^{0.5} \text{.....(3.4)}$$

In these functions, *a* represent yield attributed to the unit of fixed inputs and the value will be zero if the response was measured to only one variable input (Heady and Dillion, 1961). A negative sign of *c* in the quadratic form indicates diminishing marginal returns to the variable input. In the case of square root function, it shows diminishing total physical product as well as marginal physical product. *b* shows the marginal physical product.

The single equations have been used extensively in agricultural studies where response functions revolve around single variable resources. In practice, agricultural production involves the use of more than one input. Multiple variable equations are used in such cases. In this study, both the single and multiple variable equations were used at the appropriate places.

The choice of the functional form used in predicting the response function in the study was based on the practical expectation of the model. Fertilizer response functions are expected to show diminishing returns. However, Heady and Dillon (1961) indicated exception to this rule by observing that potassium fertilizers may not exhibit this behaviour under certain soil and climatic conditions. In the study, the quadratic, square root and double log of Cobb-Douglas functional forms were fitted to the fertilizer data. The choice of the best functional form was based on the magnitude

of the R^2, expected sign of the parameters, statistical significance of each parameter using t-values and the statistical significance of the whole equation using the F-values.

3.5.2 Linear programming method

Linear programming is one of the mathematical programming methods which uses a global objective function in finding optimal farm plan or strategy by putting together the best combination of activities or objectives (Thampapillai, 1978). Linear programming method is widely used in farm management research. According to Etuk (1979), the technique is capable of handling a large number of linear constraints and activities at the same time and efficiently too. Linear programming is a tool based on the premise that peasant farmers tend to behave in ways which optimise their objectives given the constraints within which they work.

The method consists essentially of the objective function, the activities and the linear constraint components. The method has underlying assumptions which include additivity, linearity, divisibility and finiteness of the resources and activities. In addition, there is a single value expectation of the input-output coefficient and prices (Heady and Candler, 1973).

Linear programming method can be applied to solve problems in which all the objective have been specified in one dimension. For this reason, where the problem has multiple objectives, Thampapillai (1978) suggested the use of either combined optimization or constrained optimization methods. In a combined optimization, the different objectives are transformed into one dimension. In constrained optimization, the maximizing objective is in one dimension while the other objectives in the other dimension serves as contraints. Many researchers in agricultural production economics who have used the constrained optimization include Miller and Byer (1973) and Etuk (1979).

The use of linear programming method has several advantages over other analytical methods. First, it allows for several production activities at the same time. Secondly, it allows for use of seasonal labour and land constraints. Thirdly, more than one production technique is allowed in addition to the substitution between land, labour and capital under different economic, resources and behavioural constraints (Mudahar, 1974). The fourth advantage of linear programming method is that from the optimum farm plan, changes in net revenue of each enterprise needed to bring about a change in the activity level can be determined. Fifthly, the productivity of farm resources as well as the constraints facing the optimum plan can be evaluated.

Linear programming as a planning tool has limitation. These limitations include the assumptions of linearity, additivity, single value expectation in addition to the fact that it is a simplification of reality.

The general form of a linear programming model is given by:

$$Max\ Z = \sum_{j=1}^{n} C_j X_j \quad (j=1,2,\ldots,n) \ldots\ldots\ldots (3.5)$$

Subject to

$$\sum_{i=1}^{m} a_{ij} X_j \leq b_i \quad (i=1,2,\ldots,m)$$

and $X_j \geq 0$ for all *js*

where,

Z = Objective function.

X_j = Activities.

C_j = Marginal contribution of each variable.

b_i = Total amount of i^{th} resource available.

a_{ij} = Resource requirement per unit of activity

n = Number of activities.

m = Number of resources.

3.5.3 Parametric analysis

Estimates of quantities of inputs and outputs are usually approximate and the prices are subject to change. Parametric or sensitivity analysis is a technique used to

explore how sensitive benefits are to changes in assumed level of inputs, outputs and prices. In its simplest form, the change in the profit level associated with change in one of the parameters is considered. For instance, let the Gross margin from a given enterprise on the farm be:

$$GM = Py - VC \quad \ldots\ldots\ldots \quad (3.6)$$

where,

GM = Gross margin.

P = Unit price of the output.

Y = Quantity of the output.

VC = Variable cost associated with the production of the output.

If either *Y* or *P* change, the gross margin will change. It is therefore possible to calculate Gross Margin within the range that the yield or price are expected to vary. Furthermore, it is also possible to vary the two parameters simultaneously and determine the combinations of yield and price that will result in equal gross margins at some desired level. In this study, the effects of changes in the prices of fertilizer and maize on the optimum farm plan were determined. The various level of changes on which the analysis was based are shown in Table 4.30. These changes were based on changes observed in the open market prices of the two commodities.

3.6 Specification of the Empirical Models

3.6.1 Single nutrient response

3.6.1.1 N-response models

$Y = a + bN - cN^2 + U$ ..... (3.7) Quadratic.

$Y = a - bN + cN^{0.5} + U$ ..... (3.8) Square root.

$LnY = LnA + b\ln N + U$ ..... (3.9) Double logarithm.

3.6.1.2 P-response models

$Y = a + bP - cP^2 + U$ ..... (3.10) Quadratic.

$Y = a - bP + cP^{0.5} + U$ ..... (3.11) Square root.

$LnY = LnA + b\ln P + U$ ..... (3.12) Double logarithm.

3.6.1.3 K-response models

$Y = a + bK - cK^2 + U$ ..... (3.13) Quadratic.

$Y = a - bK + cK^{0.5} + U$ ..... (3.14) Square root.

$LnY = LnA + b\ln K + U$ ..... (3.15) Double logarithm.

where, in all the equations (3.7 - 3.15).

Y = Yield of maize (tonne/ha).

N = Nitrogen level (KgN/ha).

P = Phosphorus level (kg P_2O_5/ha).

K = Potassium level (kg K_2O/ha).

a = Constant

b = Coefficient

c = Coefficient

U = Error term

The error term was assumed to be normally distributed with a mean value of zero and constant variance. It represents the effect of those variables not specified in the model but which may account for the variability in the yield of maize.

For each of the single variable equations, as the level of one of the nutrient was being increased, the levels of the other two nutrients were kept at fixed levels. Thus, when N-levels were varied from 0 - 300 kg/ha, P and K levels were kept at 40 and 60 kg/ha respectively. When P was varied from 0 to 120 kg P_2O_5/ha, N and K were kept at 100 and 60 kg/ha respectively. When K was varied from 0 to 180 kg/ha, N and P were fixed at 100 and 40 kg/ha respectively.

3.6.2 Multiple nutrient models

In these models, the levels of N, P and K were varied simultaneously in order to determine the response of maize yield to the increasing level of fertilization. As was the case with the single equation models, quadratic, square root and the double logarithm or Cobb-Douglas functions were fitted with the data as below:

$$Y = a + b_1N + b_2P + b_3K - b_4N^2 - b_5P^2 - b_6K^2 + b_7NP + b_8NK + b_9PK + b_{10}NPK + U \quad (3.16)$$

$$Y = a - b_1N + b_2P - b_3K + b_4N^{0.5} + b_5P^{0.5} + b_6K^{0.5} + b_7N^{0.5}P^{0.5} + b8N^{0.5}K^{0.5} + b_9P^{0.5}K^{0.5} + b_{10}N^{0.5}P^{0.5}K^{0.5} + U \quad (3.17)$$

$$LnY = LnA + b_1LnN + b_2LnP + b_3LnK + U \quad (3.18)$$

where,

Y, N, P, K and U are as defined for the single equations *a* in equation 3.16 and 3.18 and A in equation 3.17 are constants.

b_1 to b_{10} in equations (3.15 and 3.17) are the coefficients of the parameters in the equations. In equation (3.18), b_1 to b_3 measures the elasticity of production of N, P and K in that order. Each of these equations were fitted to the fertilizer data from Maigana, Samaru and Daudawa for the separate years of (1990 and 1991) and for the combined years (1990-1991).

An analysis of variance test was performed on the combined data to determine whether or not the variances of 1990 data was significantly different from that of 1991. Theoretically, if the two variances were statistically different, then they cannot be combined in the form of a pooled regression.

In all the sites, open pollinated maize was used and the plant population was maintained at 54000/ha. The source of N was NAFCON urea, *P* was SSP while *K* was derived from Muriate of Potash. Fertilizers were applied two weeks after planting using band uncovered method while pre-emergent herbicide (Laso-Atrazine) was applied immediately after planting.

3.6.3 The linear programming model

In literature objectives of peasant farmers were identified to include; profit maximization (Hopper, 1965), maximization of status (Wolf, 1966), maximization of food security (Norman, 1973), maximization of flow of consump-tion (Upton, 1974) and maximization of number of people fed (Etuk, 1979). In this study, two objectives pursued by the farmers were identified through the crop choice interview as;

(a) maximization of farm income through crop sales.

(b) maximization of household food security through the production and consumption of staple food derived from sorghum, maize and cowpea.

The two objectives are in different dimensions and as such the constrained optimization was used. In this approach, the different objectives were optimized in a single decision criterion by employing a hierarchy of objectives and treating all but one as constraints. This approach also known as lexicographic approach has been used for similar studies by Low (1974), Ogunfowora (1972) and Etuk (1979).

The model of the representative farm was given by;

$$Max\ \pi = -\sum_{t=1}^{9} W_t X_t - \sum_{j=n,u,k} f_j X_j^f - \sum_{j=1}^{7} a_j^c X_j^p + \sum_{j=1}^{5} U_j X_j^a \quad \ldots\ldots\ 3.19$$

Subject to:

$$\sum_{j=1}^{7} X_j^p \leq L \text{ (Land constraint)}$$

$$\sum_{j=1}^{7} a_{tj} X_j^p - X_t^l \leq H_l \text{ (Labour constraint)}$$

$$\sum_{j=1}^{7} a_j^n X_n^p - X_n^f \leq 0 \text{ (Nitrogen fertilizer constraint)}$$

$$\sum_{j=1}^{7} a_j^u X_j^p - X_u^f \leq 0 \text{ (Phosphorus fertilizer constraint)}$$

$$\sum_{j=1}^{7} a_j^k X_j^p - X_k^f \leq 0 \text{ (Potassium fertilizer constraint)}$$

$$\sum_{j=1}^{7} a_j^c X_j^p - X^c \leq 0 \text{ (Capital constraint)}$$

$$\sum_{t=1}^{9} W_t X_t^l + \sum_{j=n,u,k} r_j X_j^f + \sum_{j=1}^{9} a_j^c X_j^p \leq K \text{ (Capital limit)}$$

$$-y_j X_j^p + X_j^s = 0 \quad (j = \text{Cotton and groundnut})$$

$$-y_j X_j^p + X_j^s = d_j \ (j = \text{Maize, sorghum, cowpea})$$

and

X_j^p, X_t^l, X_j^f and $X_j^c \geq 0$ (non-negativity condition).

NB: a_j^c does not include cost of hired labour, fertilizer and seeds because separate purchasing activities have been included in the model.

Explanation of notations in the model

X_j^0 = j-th crop production activity j = 1,2 ...., 7

X_j^l = labour-hiring activity in t-th period.

X_n^f, X_u^f, X_k^f = Purchase activity for nitrogen, phosphorus and potassium fertilizer respectively.

X_j^s = Sale activity for the j-th crop (kg)

L = Available hectare of land for crop production (ha)

a_{lj} = Amount of labour required per ha in the t-period (man-hrs).

X^c = Borrowing activity for working capital.

a_j^n, a_j^u, a_j^k = Required N, P and K nutrient per ha to produce j-th crop (kg/ha).

a_j^c = Working capital required per ha to produce j-th crop (₦).

W_t = Wage paid per hour of hired labour in t-period (₦).

y_j = Yield of j-th crop per ha of land (kg).

d_j = Consumption requirement of the j-th crop per household per annum (kg).

f_n, f_u, f_k = Prices of N,P and K nutrients (₦/kg).

3.6.3.1 Activities in the Model

The following activities were identified and included in the model:

(a) Crop production activities

Although several crop production activities were found in the study villages, only those that were found to be common to at least four out of the five villages were included in the representative farm. Each crop production pattern constituted an enterprise. The crop enterprises used were sole maize, sole sorghum, sole cowpea, two crop mixtures of sorghum/maize, maize/cotton, sorghum/groundnut and a three crop mixture of maize/sorghum/cowpea. They are represented in the matrix as columns 1 to 7 in Table 3.4. They are the most important crop production opportunities in the zone in terms of contributions to the household income and food. For each activity, the unit of production is one hectare.

(b) Labour hiring activities

In the study villages, it was common to see that both family and hired labour were used on the farms. The hired labour is represented as an activity in the matrix while the family labour is represented as a constraint. Hired labour was divided into periods of January - April, May, June, July, August, September, October, November and December. This is represented as columns 8 to 16 in the matrix (Table 3.5). Their coefficients in the family labour row are negative meaning that an increase by one unit relaxes labour constraint by one unit. The activity unit is one man-hour

Table 3.4: Crop production activities in the optimum farm plan model[2]

Row No.	Objective function (cj) / Resources	Unit	Crop Production Activities 1 MZ 1 Ha	2 SG 1 Ha	3 CP 1 Ha	4 MZ/SG 1 Ha	5 MZ/CP 1 Ha	6 SG/GN 1 Ha	7 MZ/SG/CP 1 Ha	Sign	RHS
			0	0	0	0	0	0	0		
1.	Land	Ha	1	1	1	1	1	1	1	≤	6.47
2.	FL Jan Apr	Hrs								≤	2520
3.	FL May	Hrs	40			44	50	55	47	≤	630
4.	FL Jun	Hrs	106	146	54	50	72	100	150	≤	630
5.	FL Jul	Hrs	153	150	97	78	116	62	98	≤	630
6.	FL Aug	Hrs	103	44	157	100	70	137	100	≤	630
7.	FL Sep	Hrs	24	32	53	95	49	16	60	≤	630
8.	FL Oct	Hrs	50		53	53	60	100	90	≤	630
9.	FL Nov	Hrs	150	50	56	80	141	163	90	≤	630
10.	FL Dec	Hrs	100	143	60	56	95	133	90	≤	630
11.	Operating capital	₦	38	11	1026	13	21	11	28	≤	16,630
12	N	kg	120	64	20	150	120	80	150	≤	0

Table 3.4: Crop production activities in the optimum farm plan model (cont'd.)

Row No.	Objective function (cj) / Resources	Unit	Crop Production Activities							Sign	RHS
			1 MZ 1 Ha 0	2 SG 1 Ha 0	3 CP 1 Ha 0	4 MZ/SG 1 Ha 0	5 MZ/CP 1 Ha 0	6 SG/GN 1 Ha 0	7 MZ/SG/CP 1 Ha 0		
13	P	kg	60	32	40	75	75	75	75	≤	0
14	K	kg	60	32	20	75	60	75	75	≤	0
15	MZ Balance	kg	-3238			-1329	-1519		-1166	≤	0
16	SG Balance	kg		-2025		-1093		-1192	-390	≤	0
17	CP Balance	kg			-842				-192	≤	0
18	CT Balance	kg					-643			≤	0
19	GN Balance	kg						-338		≤	0
20	MZ Cons.	kg								≥	830
21	SG Cons.	kg								≥	1090
22	CP Cons.	kg								≥	216
23	MZ Seed	kg	25			12	12		12	≤	0
24	SG Seed	kg		15		7		8	6	≤	0
25	CP Seed	kg			25				12	≤	0
26	CT Seed	kg					12			≤	0
27	GN Seed	kg						20		≤	0

a. See Appendix E for explanation of abbreviations.

Table 3.5: Labour hiring activities by months in the optimum farm plan model[a].

Row No.	Objective function (ci) Resources	Unit	Labour Hiring Activities 8 HL Jan-Apr 1 Hr 0	9 HL May 1 Hr -5	10 HL Jun 1 Hr -5	11 HL Jul 1 Hr -5	12 HL Aug 1 Hr -5	13 HL Sept 1 Hr -5	14 HL Oct 1 Hr -5	15 HL Nov 1 Hr -5	16 HL Dec 1 Hr -5	Sign	RHS
2	HL Jan-Apr	Hr	-1									≤	2520
3	HL May	Hr		-1								≤	630
4	HL Jun	Hr			-1							≤	630
5	HL Jul	Hr				-1						≤	630
6	HL Aug	Hr					-1					≤	630
7	HL Sept	Hr						-1				≤	630
8	HL Oct	Hr							-1			≤	630
9	HL Nov	Hr								-1		≤	630
10	HL Dec	Hr									-1	≤	630

a. See Appendix E for explanation of abbreviations.

while the wage rate (W_t) is given as naira per hour. W_t is negative in the objective function which implies that it decreases the return by its value.

Evidence from the crop choice showed that selling of family labour among the farmers were not a common practice in the zone.

(c) Capital borrowing activities

Capital is a constraint in agricultural production. Farmers tend to augment their production capital by borrowing from outside the farm. Sometimes however, instead of borrowing, farmers may sell some livestock or crops to raise the needed operating capital. Capital borrowing activity was included to enable us evaluate the potential of credit on the optimum farm plan. In the model, capital borrowing activity is indicated as column 17 in Table 3.6 on an annual basis. The cost of credit was assumed to be 30% which represent the average rate of interest in the economy at the time. Its coefficient in the capital row and objective function are both negative.

(d) Fertilizer buying activities

Fertilizer is the major input on which farmers spend cash in acquiring for producing crops in the area. The activity was included in the model to allow the farmer

Table 3.6: Capital borrowing, fertilizer buying, seed buying and the use of owned seed activities in the optimum farm plan model[a]

Row No.	Objective Function (ci) / Resource	Unit	Borrowing Activity 17	Fertilizer Buying Activity				Seed Buying Activities					Use of Owned Seed Activities				Sign	RHS
			Borrow Capital	18 B-NPK	19 B-SUPA	20 B-CAN	21 B-UREA	22 B-MZS	23 B-SGS	24 B-CPS	25 B-CTS	26 B-GNS	27 U-MZS	28 U-SGS	29 U-CPS	30 U-GNS		
			1₦	1kg	1kg	1kg	1kg	1kg	1kg	1kg	1kg	1kg	1kg	1kg	1kg	1kg		
			-0.30	-1.2	-0.8	-0.8	-1.2	-5.0	-5.0	-15.0	-5.0	-20.0	0	0	0	0		
11	Operating Capital	₦	-1														≤	16630
12	B N-	kg		-0.15		-0.26	-0.46										≤	0
13	B P-	kg		-0.15	-0.18												≤	0
14	B K-	kg		-0.15													≤	0
15	MZ BL	kg											1				≤	0
16	SG BL	kg												1			≤	0
17	CP BL	kg													1		≤	0
18	CT BL	kg															≤	0
19	GN BL	kg														1	≤	0
23	MZS BL	kg						-1					-1				≤	0
24	SGS BL	kg							-1					-1			≤	0
25	CPS BL	kg								-1					-1		≤	0
26	CTS BL	kg									-1						≤	0
27	GNS BL	kg										-1				-1	≤	0

a. See Appendix E for explanation of abbreviations.

purchase from the different brands of fertilizers available in the market in order to meet its N, P, and K nutrient requirements. Four brands, namely compound fertilizer containing 15:15:15 NPK, Single Super Phosphate fertilizer containing 18% P_2O_5, Calcium Ammonium Nitrate containing 26% N and urea containing 46% N were the sources of N,P and K.

The coefficients in the objective function shows the price per kg of each fertilizer while the coefficient in the rows show the amount of each nutrient present in the fertilizer brand. The fertilizer buying activities are shown in the matrix columns 18 to 21 in Table 3.6.

(e) Seed buying and use of owned seed activities

The model allows the farmers to use seeds from their farm (previous farm harvest) and also to buy from the market. The seed buying activities are shown as columns 22 to 26 in Table 3.6 while the use of owned seed activities are shown on the same Table as columns 27 to 30. The value of seed buying activity in the objective function represent the unit purchase price and it is negative. In the rows, the values are also negative which shows that it takes from the resource available on the farm. For the use of own seed, their objective function values were zeros since they have already been accounted for in the individual crop balance rows. However, their values in the seed balance rows were negative meaning that the resources have been used up.

Table 3.7: Crop selling, grain consumption and buying activities in the optimum farm plan model[a]

Row No.	Objective function (cj) / Resources	Unit	Grain selling Activities					Grain Consumption Activities			Grain Buying Activities		Sign	RHS
			31 SMZ	32 SSG	33 SCP	34 SCT	35 SGN	36 CMZ	37 CSG	38 CCP	39 BMZ	40 BSG		
			1kg 1.89	1kg 2.05	1kg 4.93	1kg 3.35	1kg 5.38	1kg 0	1kg 0	1kg 0	1kg -2.59	1kg -3.15		
15	MZ-BL	kg	1					1			-1		≤	0
16	SG-BL	kg		1					1			-1	≤	0
17	CP-BL	kg			1					1			≤	0
18	CT-BL	kg				1							≤	0
19	GN-BL	kg					1						≤	0
20	CMZ	kg						1					≥	830
21	CSG	kg							1				≥	1096
22	CCP	kg								1			≥	216

a. See Appendix E for explanation of abbreviations.

(f) Selling activities

Provision was made in the model to allow the farmer to sell his crop. However, for sorghum, maize and cowpea, sales were only allowed after meeting the minimum consumption requirement of the family. Crop selling activities were represented in the model as columns 31 to 35 (Table 3.7). The objective function values of each activity represent the unit selling price of the crop at their harvest time. Their values were positive on the transfer rows.

(g) Consumption activities

The farm family consumption of carbohydrates were derived mainly from sorghum and maize while that of proteins was derived mainly from cowpea.

These food crops were obtained from their farms or purchased from the markets. For those obtained from farmer's farm, their objective function values were zero, while those bought from markets, their objective function values represents the unit purchase price and they were negative. The row values of consumption activities for crops produced on the farm were positive in both the transfer and balance rows. However, for crops purchased from the markets, their row values were negative. The consumption activities for crops produced on the farm were represented as columns 36 to 38 in Table 3.7 while those bought from the market were

represented as columns 39 and 40 on the same table. Farmers only purchase these food crops from market after their stock from farm have been exhausted. Most farmers do not need to buy these food crops but those who could not produce the minimum of each crop required to feed the household or family for the year, normally buy. This is usually done between the months of June and August each year. The grain purchase prices therefore are for the months of June. In all, there were 40 activities in the LP model.

3.6.3.2 Resource constraints in the model

Farmers are often constrained in their production activities due to certain factors which becomes limiting. In the model, the following constraints were identified and specified at some levels using maximum (≤) minimum (≥) or equality (=) signs as the case may be.

(a) Land restriction

Farm land in the zone were classified into two basic types; the upland and fadama lands. The upland are dry lands used in producing rainfed crops while the fadama lands are flooded river valleys or banks which are used to grow water loving crops like sugarcane, rice and cocoayam. The dominant land for production is the upland as it is not all farmers that have fadama land. Therefore it is the upland that restrict the area of each crop enterprise cultivated. The

maximum available upland farm size in the zone was taken as the limit of land available for cultivation. It was specified as row 1 in the model.

(b) Labour restrictions

The farm work force was provided by labour from both the farm household and that hired from outside. The amount of labour provided by family source was determined by the composition and size of the farm household. The average household was found to be made up of 6 man-equivalent and each man was assumed to be capable of working on the farm for 5 hours each day and for 30 days in a month i.e. available monthly man-hour was 900 hrs.

However, because of fatigue, illness and other incidentals, only about 70% efficiency was assumed for the available family labour in each month (i.e 630 man-hrs). Family labour were allowed in the model to be augmented by hired labour for which a wage rate (wt) was paid per man-hour. Nine labour constraint periods were identified and represented in the model as rows 2 to 10. January-April months corresponds to the off-season for most of the farmers in the zone and therefore referred to as period 1. Other periods referred to the various months following April.

(c) Operating capital restrictions

Farm production activities cannot take place without the farmer incurring costs. These costs include fixed costs and variable costs. For most of the farmers in the zone, the fixed costs were little or nothing as they used mainly hand hoes, cutlasses and oxen for which depreciation charges were small. However, variable costs like cost of hired labour, payment for fertilizer, seeds and agro-chemicals were may be incurred for a good harvest. In the model, capital restriction was indicated as row 11 and its limit was the amount required to buy the necessary fertilizers, pay for hired labour, and interest rate on any borrowed capital.

(d) Fertilizer restrictions

Fertilizer has been identified as the driving force behind crop intensification in the Northern Guinea Savanna. The implication of this assertion is that these crops which can only be grown well on the basis of using inorganic fertilizers will be restricted by the availability and prices of the fertilizers. The N, P and K nutrient requirement of each crop production activity determines the nutrient constraints which have been shown as rows 12 to 14.

(e) Food consumption restrictions

There are two ways of representing food consumption in a linear programming model. According to Hazel and Norton

(1986) one of the ways is to add lower bound constraint on the production of the required food crops. In this method, the family consumption of each food crop is assumed to be fixed. The second way allows the amount of each food crop to be consumed to change with the change in the income of the farmer. In such cases the consumption of the food crop is assumed to be linearly related to the income. The relationship is given by:

$$C: \infty + BY \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.20)$$

Where

C = Annual consumption of each crop (kg).

∞ = A constant representing the subsistent requirement for each crop (kg).

β = A constant representing marginal propensity to consume each crop (kg/₦).

Y = Annual income of the household (₦).

Although Hazel and Norton agreed that this second method was more realistic, it was found to be more difficult to use as it involves determining the value of consumption through the consumption function. The first method was therefore used in the model.

In order to determine the minimum requirement for each food crop, the report of Food and Agriculture Organization (F.A.O.) and World Health Organization (WHO) was used. The

report contained data on minimum energy and protein requirements for different categories of people and also the protein and energy contents of different food crops.

The report showed that an average adult of about 65 kg body weight requires a minimum energy of 2925 k.calories daily or 1,070,550 k.calories annually. The report further showed that a subsistence consumption of 1 kg each of sorghum, maize and cowpea daily will supply 3420 k. calories, 3610 k.calories, and 3470 k.calories respectively to the body (FAO & WHO, 1973).

From the crop choice interview, the preference given to the consumption of sorghum, maize and cowpea were in the ratio of 50:40:10. The average consumption unit in a household was earlier derived to be 7 (Table 3.8).

Table 3.8: The age/sex composition of households and the derived of the consumption unit for the study villages, NGS, Nigeria, 1990.

Age/Sex	Number in household	Consumption Unit	Total Consumption Unit
Male adult	2	1.00	2.00
Male working youth	1	1.00	1.00
Female adult	3	0.75	2.25
Female working youth	1	0.75	0.75
Male child	1	0.50	0.50
Female child	1	0.50	0.50
Total	9		7.00

Source: Computed from survey data.

In arriving at the consumption unit, it was assumed that the male adult and male working youth consumes equal amount of food. The working female and female youth consumes the same quantity of food but this amount is only 75% of the male consumption. The male and female children consume the same quantity which were assumed to be 50% of the male adult consumption.

Based on these assumptions, the minimum quantity of each crop needed per annum per household were estimated as follows:

$$\text{Sorghum (kg)} = \frac{1,070,550 \times 0.50 \times 7}{3420} = 1096 \text{ kg}$$

$$\text{Maize (kg)} = \frac{1,070,550 \times 0.40 \times 7}{3610} = 830 \text{ kg}$$

$$\text{Cowpea (kg)} = \frac{1,070,550 \times 0.10 \times 7}{3470} = 216 \text{ kg}$$

These values were used as the restriction levels in the model. They were represented as row 20 to 22.

(f) Balance rows

These are rows introduced into the model to ensure that the total quantities of each crop produced were accounted for in the model. Rows 15 to 19 represents the crop balances; while rows 23 to 27 represents seed balances. The balance rows have zero values as their restriction levels.

(g) Non-negativity restrictions

It was specified in the model that none of the activity and resource levels will be carried out or used at negative levels.

Chapter 4

RESULTS AND DISCUSSIONS

4.1 Socio-economic Characteristics of the Farm Households

4.1.1 Age/sex distribution

The age distribution of the farm households is shown in Table 4.1. Out of the 463 farm households members, 21% were found to be male adults, 30% to be female adults, 11% to be male youths capable of farm work, 9% female youths capable of farm work, 15% and 14% male and female children respectively who were not capable of farm work and 0.4% were elderly people not capable of work.

Table 4.1: Age/sex distribution and average household composition among 50 farm households in NGS, Nigeria, 1990.

Age/Sex Category	Frequency	%	Average household composition[a]
Male adult	96	20.73	2
Female adult	138	29.81	3
Male youth capable of farm work	52	11.23	1
Female youth capable of farm work	41	8.86	1
Male not capable of farm work	69	14.90	1
Female child not capable of farm work	65	14.04	1
Elderly people not capable of farm work	2	0.43	0
Total	464	100.00	9

a. This is obtained by dividing the frequency by 50 which is the total households sampled.

Source: Farm survey.

In terms of farm work-force in the study area, about 71% of the household members were capable of providing the work force required. However, because in some operations women labour cannot be used, only 32% of the family members were capable of providing the labour for all the farm work. In terms of dependency, only 29% of the farm family members were dependent and cannot do any form of work on the family farms. On the average, a farm household is made up of nine people comprising of two males, three females and one each of male youth and female youth capable of work, male and female children not capable of work. On the average, it is difficult to find elderly people not capable of farm work in the study area. The implication of this finding is that most of the farm labour requirements can be provided by the family work force.

4.1.2 The main occupation of household members

An attempt was made in the study to investigate the pattern of occupation among the people in the study area. Table 4.2 clearly shows the distribution of the main occupations among the household members. It was found that 23.97% of the household members took crop farming as their major occupation. However, when those involved in the related areas of fishing, livestock husbandry and processing/ milling/trading of agricultural products were taken into account, the population of the people involved in

agricultural sector rose to 38.23% while those involved in other occupations was 7.35%. The larger proportion of 54.43% of the population who were not engaged in paid jobs was attributed to the female population which accounted for about 53% of the whole population. Islam, the religion of the people forbids women from engaging in open commercial activities. Hence, the women are secluded in a system called *purdah*.

4.1.3 Land tenure and farm ownership

Land tenure describes the social relationship between people and the land in terms of the arrangement between men in the use of land resources and the rights that people have on land. These relationships may be legal, quasi-legal or customary. The land tenure system in the study area is shown in Table 4.3.

Out of the 327 plots of farm lands covered in the study, 84.1% were acquired through inheritance, 2.75% through purchase and 12.84% through borrowing from family members. What this suggests is that land tenure in the study area is based on customary systems. Under this form of tenure, land belong to the family and every member of such family has usufructuary rights of the farm land but the individual has no right to alienate his right of occupancy by sale or mortgage without the consent of his family members. This probably accounts for why land ownership by sale was 3%

whereas ownership through inheritance plus borrowing from family members accounted for 97%. Those who acquired land through purchase were mainly migrant settlers who have no access to family land.

Table 4.2: The main occupational distribution among 463 respondent household members in NGS, Nigeria, 1990.

Main occupation	Frequency of People	Percentage of Total (%)
Farming	111	23.97
Livestock husbandry	3	0.65
Fishing	2	0.43
Processing/milling/trading of agricultural Products	61	13.18
Trading in non-agricultural products	20	4.32
Salary workers	3	0.65
Merchants	1	0.22
Students	7	1.51
Not self employed	252	54.43
Others	3	0.65
Total	463	100.00

Source: Farm survey.

The implication of this form of land tenure system is that although every member of the family can get land for farming, the size of holding is often small and the farms are scattered. This leads to precious time being wasted in moving between farms and between the home and farms. It was revealed that farmers spent up two hours travelling to their farms (Table 4.4).

Table 4.3: Types of access to the respondents' 327 farm plots in NGS, Nigeria, 1990.

Type of Tenure	Frequency of Plots	Percentage Response (%)
Inheritance	275	84.10
Purchase	9	2.75
Borrowed from family members	42	12.84
Borrowed from village members	1	0.31
Total	327	100.00

Table 4.4: Travelling time between homes and farms in NGS, Nigeria, 1990.

No. of observation	Time (minutes)			
	Minimum	Maximum	Mean	Standard deviation
327	1.00	120	13.16	16.27

Source: Farm survey.

In terms of actual ownership of farm land, only 18.4% of the household members have right of use of the lands while the remaining 81.6% did not own farm lands and either work for the owners or borrowed the land (Table 4.5). This finding was not surprising given the fact that only about 21% of the farm household members were adult males who, usually are given their own shares of the family land by the family heads. Even among these group of adults, those who belong to *gandu* may not own land although they may own farm plots.

Table 4.5: Farm plot ownership among the farming household members in the NGS, Nigeria, 1990.

	Frequency of Response	Percentage of Response (%)
Owned farm plot	85	18.40
Do not own farm plot	378	81.60
Total	463	100.00

4.1.4 Costs and returns from farm enterprises

An economic analysis involving the computation of actual costs and returns for each farm enterprise was done and reported in Table 4.6. The analysis shows that the total net receipts for all the enterprises was N17,780. Some of the enterprises showed very little net receipt because the amount of produce from such enterprise used for home consumption have not been reflected in the receipts. The operating expenses were high because in the case of fertilizers, transportation and handling charges were included in the cost while in the case of seeds, the cost of seed treatment has been included. It is the total operating expense here that was used as the upper limit for operating capital in the farm plan.

Table 4.6: Costs and returns from farm enterprises in Northern Guinea Savanna, Nigeria, 1990.

Item	Enterprise						
	Maise	Sorghum	Cowpea	Maize & sorghum	Maize & cotton	Sorghum & groundnut	Maize, sorgum & cowpea
Operating Expenses (₦/ha)							
Labour	1795	1589	1086	1337	1953	2854	1959
Fertilizer	423	179	578	160	198	266	504
Seeds	51	26	477	94	40	67	205
Spraying	-	-	786	-	-	-	-
Total	2269	1794	2927	1591	2191	3187	2668
Total receipts (₦/ha)	4222	1866	7755	3124	3961	9375	4104
Net farm income (receipts)	1953	72	4828	1533	1770	6188	1436

Source: Farm survey data.

4.2 Crop Choice Decisions of the Farm Households

A variety of crops were found to be grown in the study area by the farmers. Most of these crops have become a part of the farmers because overtime, they have become adapted to the soil, climate, technology, food habit and the economic needs of the people. The dominant sole crops grown in at least four of the five study villages were maize, sorghum and cowpea. The two crop mixtures were maize/cotton, maize/sorghum and sorghum/groundnut while the three crop mixtures were maize/-sorghum/cowpea (Table 4.7).

Table 4.7: The dorminant crop enterprises and their mean, minimum and maximum hectarage in five villages, NGS, Nigeria, 1990.

Crop Enterprise	Proportion of plots devoted to each Crop enterprise each Village (%)						Hectarage devoted to each crop enterprise (ha)			Standard Deviation
	Barde Dawa	Borin	Gwanki	Kaya	Tsibiri	All Villages	Mean	Minimum	Maximum	
Maize	4.70	1.20	16.30	16.90	11.50	10.60	0.267	0.030	0.990	0.28
Sorghum	30.20	9.30	7.10	6.20	1.00	8.30	0.455	0.030	1.93	0.51
Cowpea	2.30	8.10	1.00	3.10	-	2.80	0.254	0.010	1.10	0.35
Maize/Cotton	2.30	8.10	-	-	2.90	2.80	0.419	0.050	0.87	0.24
Maize/Sorghum	18.60	24.40	7.10	43.10	1.00	16.40	0.695	0.020	6.47	0.91
Sorghum/G'Nut	-	1.20	3.10	1.50	3.80	2.30	0.290	0.040	0.87	0.26
Maize/Sorghum/ Cowpea	7.00	4.70	1.00	-	1.00	2.30	0.378	0.020	0.95	0.28

Source: Farm survey data.

In all, ninety eight crop enterprises were found in the study area. Twenty six of these were maize based while sixteen were sorghum based. The crops include maize, sorghum, cowpea, cotton, groundnut, yam, pepper, soybean, rice, cocoyam, onion, okra, sweet potato, cassava, sugarcane, millet and pumpkin (In terms of distribution of the various crops and the importance attached to the various cropping patterns), Table 4.7 was derived to reflect the crops and cropping system which are common to the zone. Except in the case of maize/cotton mixtures, which was found in three of the five villages, all the other enterprises were found to be dominant in at least four of the five villages. According to Baker and Norman (1975), the choices of crops or crop combinations to be grown are made annually or seasonally and are guided by the physical, social, economic and political considerations. These factors invariably guided the farmers in the zone in their choice of crops and cropping system.

4.2.1 The physical factors

The physical factors are responsible for the physical growth of the crops on the field. Prominent among these are rainfall distribution and soil types. The rainfall pattern of the northern guinea savanna show a unimodal distribution. The rains usually get established in June and ceases mid-October, covering a raining period of about five months in a year and a total fall of about 1600 mm annually. The

rainfall is therefore sufficient in normal years to carry cereals, legumes and fibre crops from planting to maturity. The temperatures were also adequate for the crop growth to maturity and for drying. This is why maize, sorghum, cowpea, cotton and groundnut formed the dominant crops in the zone. In drought years, maize does not do well because of short rainfall period.

The soils of the zone is mainly Alfisols or Luvisols which are generally slightly acidic and less leached. In addition, they have low organic matter content, low total N-content, low cation and low water retention capacities (Enwezor *et al.*, 1989). The crops needed additional fertility through fertilizer application and that probably accounted for why the greatest fertilizer application said took place in the zone (Sodangi, 1981). In drought years and in situations where the farmers do not have sufficient fertilizer to use, farmers often preferred to grow sorghum to maize because sorghum is more drought tolerant and also required less nutrient to do well. The soil texture distribution of the study area (Table 4.8) show that loamy and sandy loam soils were the dominant soil textures in the study villages. These classes of soils are well suited to cereals and legume crops that do not require too much water[1].

---

1. *Rice, cocoyam, tomatoes, sugarcane and other crops which requires more water are grown on Fadama lands.*

Table 4.8: Soil texture distribution of farms in the NGS, Nigeria, 1990.

Type of Soil	Frequency	Percentage of Total Soil (%)
Sandy	22	5.61
Loamy	161	41.07
Clay	14	3.57
Sandy loam	160	40.82
Clay loam	30	7.65
Coarse sandy loam	5	1.28
Total	392	100.00

Source: Farm survey.

4.2.2 The social/political factors

In the study area, it was observed that farmers' choice of a cropping system was influenced by the need to be self-sufficient in family food requirements. For this reason, all farmers cultivated sorghum and maize which were the main food grains. The proportion of land devoted to each of these crops as sole crops or as mixture was determined to a large extent by the family size and which of them was consumed more by the family. Although both crops were used as staple food grains, sorghum was preferred to maize by most of the households interviewed for the following reasons:

1. Sorghum food was said to be easier to prepare in terms of the time it takes to make it ready.
2. The sorghum prepared meals were said to taste better and last longer in the stomach than maize prepared meals.

3. The sorghum grains contained more flour per unit than maize grains.
4. The night left over sorghum meal (*tuwo*) which was often eaten in the morning was said to be of better quality than that of left over maize meal.

For these reasons, farmers preferred sorghum as the food crop and only supplement with maize meals which incidentally was said to have better appearance (usually white) and provided wider variety e.g. *pete*. In spite of the preference of sorghum over maize, most of the farmers grew maize to meet the food requirement of the family early in the season when the old stock of sorghum would have been exhausted and the new one was yet to be in the market. Thus, it was the belief of the farmers that a good farmer should be able to grow enough sorghum and/or maize to feed his family throughout the year.

Cowpea was grown by most farmers in order to supplement their protein requirement since the main meals were carbohydrate. Meat, egg and milk were occasional diets. Those who don't grow cowpea sometimes buy from the market.

Wheat was the only known crop in the area to have been grown under political pressure. However, wheat was grown as irrigated crop and not as rainfed crop. The choice of crop mixtures by farmers was justified on the need to obtain

maximum benefit by getting more than one product from a given land, distribute labour and fertilizer use among crops on a given land and to forestall a complete crop loss from a given land that may be caused by drought, disease or pest or a fall in price of a particular crop in a year. Sole cropping to them was a waste of land resources as it tends to keep land idle for most part of the season. In some cases like Gwanki, pepper was a traditional crop and everybody grew it for cash.

4.2.3 Economic factors

Economic considerations play a major role in the choice of crop and crop combinations in the study area. These considerations include the availability and prices of inputs, prices of the products and availability of credit (capital).

Availability and prices of inputs: The availability of seeds for most of the crops was considered. The seeds of all the crops grown in the zone were readily available. The farmers used both local and improved varieties of the seeds. It is only in maize that hybrid seed was available for sale. Table 4.9 shows that except for groundnut and cowpea seeds, over 50% of the farmers used improved variety of seeds. The less of improved variety of cowpea was used because it was more susceptible to pests and diseases and hence needed more spraying than the local varieties. In the case of groundnut, farmers preferred their local variety because of the better taste since most of the groundnut are consumed either fresh or in dried forms.

Table 4.9: Seed variety and sources of seed used by farmers in the NGS, Nigeria, 1990.

Seed	Variety Users (% a of Response[a])			Source of Seed (% of Response)	
	Local	Improved	Hybrid	Own	Market
Maize	12	94	6	89	11
Sorghum	31	79	-	94	9
Cowpea	57	47	-	18	91
Cotton	9	91	-	18	82
Groundnut	78	22	-	22	78

Source: Farm survey.

a. *The percentage of response could be more than 100% where more than one variety or source are used by one person.*

For most of the crops, farmers relied on their previous years' harvest as their source of seed for the next cropping season (Table 4.9). For sorghum and maize, about 90% of the seeds were farmers owned mainly because they produce more than enough for consumption and because farmers can store them well without loss in germination qualities. Cowpea and groundnut which get spoilt quickly are often bought from the market for planting. In the case of cotton, farmers rarely gin the seed cotton themselves and so have to rely more on market to buy the seed from those that are involved in ginning.

The price consideration in growing these crops affect mainly fertilizer, chemical sprays and cost of labour input. For sorghum, farmers were of the view that it could be grown well with little or no fertilizer whereas, maize could not

be grown with the expectation of good yield without applying adequate fertilizers. For this reason, sorghum and other crops that use less fertilizers are preferred to be grown by farmers when fertilizer is scarce and expensive. Sorghum was also said to require less labour than maize for weeding and harvesting. Two weedings may be enough for sorghum whereas, a minimum of three weeding are required for maize. In harvesting sorghum, less operations are involved than in harvesting maize so that where wage rate is high, more costs are involved in producing the same unit of maize than sorghum. The high cost of chemical and the frequency of spray was responsible for low cowpea and cotton production in the zone.

Price of Products: The market price of a commodity can be an incentive or disincentive to farmers if their main objective of production was to get the maximum income from the land. There were two groups of farmers in the study area; married *gandu* and unmarried *gandu*. These groups of farmers differed in their goals of production. While the married gandu members produce with the main goal of feeding their immediate family and other *gandu* members, the unmarried *gandu* produce to make money. Thus, for the former group, the driving force in farming is food self-sufficiency and as such whether or not the market price of certain food crops especially sorghum and maize goes up, they will still produce them because they need them for food. For the latter group, cash crops are their

main crops and a price drop necessarily means a drop in the level of production. For instance, such farmers often produce maize, cotton, pepper and sugarcane which they can easily dispose of by selling. A married *gandu* farmer lives and eats from the *gandu* food pot. However, he is expected to once in a while contribute food from his farm to the pot. In addition, he provides food to his immediate family especially when food from the general pot is inadequate, unavailable or not liked by his nuclear family. Thus, he must produce food crops. The unmarried *gandu* farmer has no obligation to feed anybody and therefore go for crops which can fetch him money. Where a food crop is produced by him, he may out of his wish give some to the *gandu* head. In general, the farmers were found to be willing to respond to price increases in crops only after the food crop requirements have been satisfied. Maize was a crop which was introduced in the 1970s and which because of its increasing prices and its dual role as food crop has overtaken the traditional crop like millet and now competing favourably with sorghum.

Availability of credit to farmers: Credit plays a major role in the choice of crop and cropping patterns among the farmers. Since farmers need to buy seeds, pay for fertilizers, hired labour and chemicals, they need money on hand. The money could be obtained through savings or borrowing. Farmers in the study area were found to hardly borrow money from the formal sources of credit like banks.

However, they do borrow or take money from their relatively richer relations to finance farm operations.

Most of the farmers relied more on the sale of their crops (maize and other cash crops) and sometimes livestock for financing farm work. A few of the farmers, usually unmarried *gandu* members, offered their labour for wages and use such money to finance their personal farm operations. Thus, the crop enterprise which requires much money to grow has its scale reduced whenever farmers' income is low or sources limited.

4.3 Fertilizer Use Decisions

According to Falusi (1973) fertilizer use decisions among farmers are influenced by agronomic and economic factors. In the study area, it was found that all farmers used inorganic fertilizer although the degree of use varied from farmer to farmer and from crop to crop. Since all farmers grow cereals, fertilizer was used to enhance their yield. Of all the crops grown, fertilizer was used most on maize crops followed by sorghum. This was not surprising because maize crop is known to respond more to fertilization than sorghum or any other crop. Maize, although a shallow rooted crop has a high capacity for absorbing nitrogenous fertilizer without much lodging. The improved varieties required more fertilizer hence small scale farmers could hardly afford to grow the hybrid maize given its demand for fertilizer.

In terms of the price of fertilizer itself, farmers said they could not be bothered about how much the fertilizer would cost them provided they have money and fertilizers are available for sale when they need them. When they were asked to prioritise the problem confronting them in fertilizer use, scarcity of fertilizer at the right time and place came first followed by the problem of money to purchase the fertilizer and the least of them was fertilizer price. The argument was that since they must farm, they have to use fertilizer and if they have to use fertilizer, they must find money to buy it provided it was available. However, they agreed that in terms of total usage, the quantity will reduce if the price was too high (some say about ₦200.00 per bag). As for the market price of the crop produced, farmers were of the opinion that for food crops, they would not be bothered about their prices because they could be consumed in the home if not sold. However, for crops produced mainly for sale, if the prices are not favourable compared to the price of fertilizer being used, they would stop producing. In other words, fertilizer-crop-price ratios are considered as a secondary factor in the use of fertilizers by farmers in the area.

4.3.1 The use of farm yard manure

Most of the farmers interviewed used farm yard manure (FYM) to enhance the fertility of their soil. However, they all believed it was to supplement the nutrients from the

application of inorganic fertilizers. In most cases, where F.Y.M is used, it consists of cow dung, house sweeps and other animal droppings. It is used on the farms near the homes because, according to them, F.Y.M is bulky and difficult to transport to the farm and to spread. The farmers believed that in the absence of inorganic ferti-lizers in the zone, organic manure can be used to produce millet, sorghum and sugarcane on small scale operations. For maize, they all claimed that no meaningful yield will be obtained without the application of inorganic fertilizers. Thus, farmers were aware of the fact that organic manure cannot be a substitute for inorganic fertilizers in improving the fertility of soils in the zone. Sustainability of maize production in the zone therefore depends on the continued use of inorganic fertilizers to improve the fertility of the soils.

4.4 Maize Response to Fertilization

4.4.1 Physico-chemical properties of the soil

In order to explain the differences in the responses of maize on the different sites to the different fertilizer nutrient, the physico-chemical properties of the soils were studied and reported in Table 4.10. The table show that in terms of NH_4-N, the top soil at Samaru contained the highest (20.6 kg/ha) followed by Daudawa (12.50 kg/ha) and the least was Maigana (6.0 kg/ha) in 1990. In 1991, Daudawa contained the highest (24 kg/ha) followed by Maigana (15.0 kg/ha) and

Table 4.10: Physico-chemical properties of soils in three villages, NGS, Nigeria, 1990-1991.

Variables	Location											
	Daudawa				Samaru				Maigana			
	(0 - 15cm)		(15 - 30cm)		(0 - 15cm)		(15 - 30cm)		(0 - 15cm)		(15 - 30cm)	
	1990	1991	1990	1991	1990	1991	1990	1991	1990	1991	1990	1991
pH (H_2O)	5.9	5.6	6.1	6.2	5.2	5.2	5.0	5.1	5.3	5.3	5.2	5.1
Sand (%)	86	86	76	76	50	50	46	46	52	52	50	48
Silt (%)	4	4	6	6	38	38	40	40	36	36	36	36
Clay (%)	10	10	18	18	12	12	14	14	12	12	14	16
Organic carbon	1.5	4.8	1.2	4.0	8.0	5.0	5.0	4.6	4.6	4.0	3.8	4.0
Organic matter ($kgha^{-1}$)	2.58	8.26	2.06	6.9	13.8	8.6	8.6	7.9	7.9	6.9	6.5	6.9
NO_3-N	10.80	20	8.9	12	12.6	2.5	12.6	2.0	5.2	2.0	4.3	0.00
NH_4-N (kg ha^{-1})	12.50	24	14.0	24	20.6	14	24.0	12.0	6.0	15.0	5.5	10.20
Bray-1-P (kg ha^{-1})	20.40	19.2	17.2	16.2	17.2	16	13.0	12.8	8.0	7.2	8.0	6.0
Exch K (Cmol kg^{-1})	0.19	0.18	0.18	0.16	0.19	0.22	0.18	0.16	0.20	0.16	0.15	0.14
Exch Mg (Cmol kg^{-1})	0.45	0.42	0.52	0.45	0.51	0.36	0.50	0.28	0.30	0.30	0.25	0.21
Exch Ca (Cmol kg^{-1})	1.30	1.87	1.61	1.80	2.14	1.87	1.75	1.56	0.75	0.62	0.72	0.59

the least was Samaru with 14.0 kg/ha. The phosphorus content of the soils was also measured as Bray-1-P. In 1990, Daudawa contained the highest 20.40 (cmol/kg soil) followed by Samaru 17.2 (cmol/kg soil) and the least was Maigana with 8.0 cmol/kg soil). In 1991, Daudawa still contained the highest of 19.2 cmol/kg followed by Samaru (16 cmol/kg) and the least was Maigana (7.2 cmol/kg). In terms of N and P_2O_5, Daudawa and Samaru soils fall into medium class fertility while Maigana soils fall into low class fertility. The difference are caused by differences in soils, vegetation and cultural practices like bush burning. At Samaru, the vegetation or soil cover was never burnt before cultivation.

The exchangeable potassium also shows in 1990, Daudawa and Samaru soils had 0.19 cmol/kg each while Maigana soil had 0.20 cmol/kg. All the villages were low in potassium. In all cases, high response to nutrient is expected in a low nutrient class; some reasonable response in a medium class and very little response in a high nutrient class. In addition to these three factors discussed, there were other factors not shown in the table which affect the response of the crop to fertilization in the zone. One of such factors is rainfall (Table 4.11).

The amount of rainfall and the distribution is very important in crop production. Maize crop is normally planted in the month of June and it requires three months of rainfall of between 760-1260 mm for a good yield.

Table 4.11: Rainfall distribution in three villages in the Northern Guinea Savanna of Nigeria (1990 and 1991).

Month	Samaru (mm)		Daudawa (mm)		Maigana (mm)	
	1990	1991	1990	1991	1990	1991
January	0	0	0	0	0	0
February	0	0	0	0	0	0
March	0	45.0	0	13.5	0	4.2
April	0	48.0	0	49.1	31.40	48.4
May	123.0	243.0	154.70	199.3	142.20	209.4
June	156.0	87.0	190.70	122.0	82.90	103.5
July	222.0	190.0	161.30	146.0	162.70	181.1
August	255.0	329.0	276.80	274.0	277.40	265.8
September	132.0	51.0	136.10	107.3	164.10	47.0
October	0	29.0	0	20.8	0	25.7
November	0	0	0	0	0	0
December	5	0	0	0	0	0
Total	888.0	1022.0	919.60	932.0	860.70	885.1

Sources: Meteorological Stations at Samaru, Daudawa and Maigana.

In 1990, between the months of June and September the total amount of rainfall in Samaru was 765mm whereas in 1991, it was 657mm. Thus, the maize crop would therefore be expected to perform better in 1990 than in 1991 since the distribution was also better in 1990 than in 1991 (Table 4.11). There was a dry spell at the planting time in June 1991 which brought the crops under severe water stress and some wilted completely and had to be replanted. At the time of grain filling and maturity in the month of September, the

same year there was another dry spell which resulted in poor grain formation. Consequently, in all the sites, the 1990 yields were better than the 1991 yields.

4.4.2 Response to Single Nutrient

4.4.2.1 Nitrogen response

The response models specified in equations 3.7 to 3.9 were fitted to the 1990 and 1991 data separately and then the combined years' data. The best fitted functions were reported (Table 4.12). In addition an analysis of variance was performed on the pooled data to test the equality of the variances of the data for the two years in each village. The result of the test reported in Appendix A1 to A3 indicated that for Samaru, the variances were not statistically significant at the 5% probability level. In the case of Daudawa and Maigana, the variances were statistically significant at the 5% level of probability. This means that the two year data cannot be pooled and used to represent the true yield for each village.

Given the argument presented in favour of the 1990 data over the 1991 data, the 1990 responses were used in subsequent discussions. Thus, the yield functions for Samaru, Daudawa and Maigana are given by:

Samaru $Y = 2.695 - 0.0077N + 0.1503N^{0.5}$ ..... (4.1)

Daudawa $Y = 1.899 - 0.0071N + 0.1466N^{0.5}$ ..... (4.2)

Maigana $Y = 2.512 - 0.0113N + 0.2292N^{0.5}$ ..... (4.3)

Table 4.12: The parameters of the selected functions of maize response to N-fertilization in three villages in the Northern Guinea Savanna, Nigeria, 1990-1991.

Village	Year	Functional Form	No. of Observations	Coefficient				R^2	F-value	Mean Level of N (kg/ha)	Mean Yield of Maize (tonne/ha)	Mean Response
				Const.	N	$N^{0.5}$	N^2					
Samaru	1990	Square Root	21	2.695* (0.419)	-0.0077 (0.005)	0.1503** (0.099)		0.11	1.16^{ns}	150	3.191	21.27
	1991	Quadratic	21	1.955* (0.300)	0.0103** (0.005)		-0.00002 (0.00002)	0.37	5.21**	148.81	2.784	18.71
	1990-91	Quadratic	42	2.423* (0.251)	0.0083** (0.004)		-0.00002** (0.00001)	0.14	3.14^{ns}	149.41	2.987	19.99
Dandawa	1990	Square Root	21	1.899* (0.321)	-0.0071 (0.004)	0.1466** (0.076)		0.18	1.99^{ns}	150	2.441	16.27
	1991	Square Root	21	1.280* (0.307)	-0.0114* (0.004)	0.1843** (0.075)		0.31	4.08**	148.81	1.591	10.69
	1990-91	Square Root	42	1.582** (0.282)	-0.0093** (0.004)	0.1676* (0.068)		0.14	3.20^{ns}	149.41	2.016	13.49
Maigana	1990	Square Root	21	2.512* (0.206)	-0.0113* (0.003)	0.2292* (0.049)		0.56	11.56*	150	3.332	22.21
	1991	Quadratic	21	1.485* (0.480)	0.0068 (0.008)		-0.00001 (0.0001)	0.11	1.11^{ns}	148.81	2.076	13.95
	1990-91	Square Root	42	1.981 (0.399)	-0.0056 (0.005)	0.1434 (0.096)		0.09	1.98^{ns}	149.41	2.704	18.10

NB: $t_{0.05,\ 20} = 1.725$ $F_{0.05,\ 2,18} = 3.55$
$t_{0.05,\ 20} = 2.528$ $F_{0.01,\ 2,18} = 6.01$
$t_{0.05,\ 41} = 1.684$ $F_{0.05,\ 2,39} = 3.32$
$t_{0.01,\ 41} = 2.423$ $F_{0.01,\ 2,39} = 5.39$

*. Parameter is significant at 1% probability level.
**. Parameter is significant at 5% probability level.
( ). Standard error of parameters.

In all the cases, the signs of the parameters were consistent with the expected. For Samaru and Daudawa, all the coefficients with the exception of that of N and the equations were statistically significant at the 5% probability level. For Maigana, all the coefficients were significant at the 1% level of probability. The R^2 in the case of Samaru was very low (0.11), which means that only 11% in the maize yield variability is attributable to variations in N-level. In Daudawa, the R^2 was 0.18 meaning that only 18% in the variability in the yield of maize was due to nitrogen. For Maigana, the R^2 was 0.56 which means that 56% of the variability in yield was caused by variation in N-level. This result confirms that where there is less N-in the soils the variability in yield of maize attributed to an added N- is more (N-was 6, 12.5 and 20.6kg ha^{-1} each at Maigana, Daudawa and Samaru).

The mean nitrogen use and yields of maize from each village for the different and the combined years are also shown in Table 4.12. The mean nitrogen use for each village was at 150 kg/ha while the mean yield was 3191 kg/ha for Samaru, 2441 kg/ha for Daudawa and 3332 kg/ha for Maigana. The mean response was 23 kg maize per kg N at Maigana, 21 kg maize per Kg N at Samaru and 16 kg maize per kg N at Daudawa. The mean response was therefore highest at Maigana. Soil nitrogen is lost more rapidly at Daudawa through erosion and sinking down because of the soils.

The predicted yields using the predicted equations for each year and the combined years are shown in Table 4.12. The predicted yields showed that the 1990 yields were better than those of 1991 at each site. The pattern of response shown in Fig. 1 clearly shows that for each site the yields for the different years were different. The 1990 yields were consistently higher than the 1991 yields. At the village level, in 1990, the Maigana yields were higher than the Samaru yields while the Samaru yields were higher than the Daudawa yields. In 1991, Samaru yields were better than Maigana yields while Daudawa yields were the least.

Technical optimum of N-usage

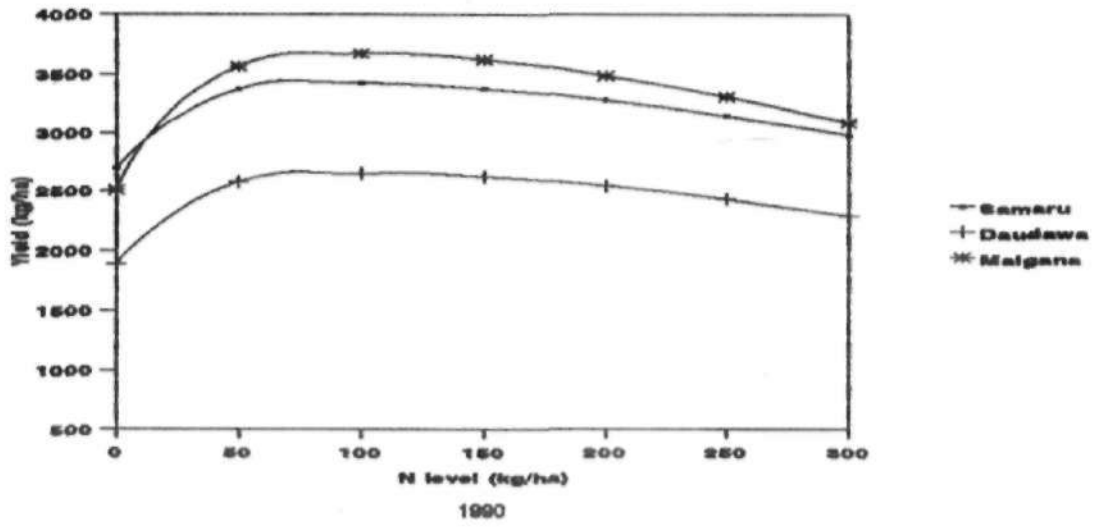
The technical optimum level use of N correspond to the level at which the yield of maize is highest. This cannot be determined from Table 4.13 since the N-levels were increasing by 50 units. The first derivative of the predictive equation for each village was taken and equated to zero and thereafter, the value of N in each equation were determined. At the optimum level, the marginal physical product is zero. Thus, for;

Samaru; $\frac{\delta y}{\delta N} = -0.0077 + 0.0752N^{-0.5} = 0$; N = 95.25 kg

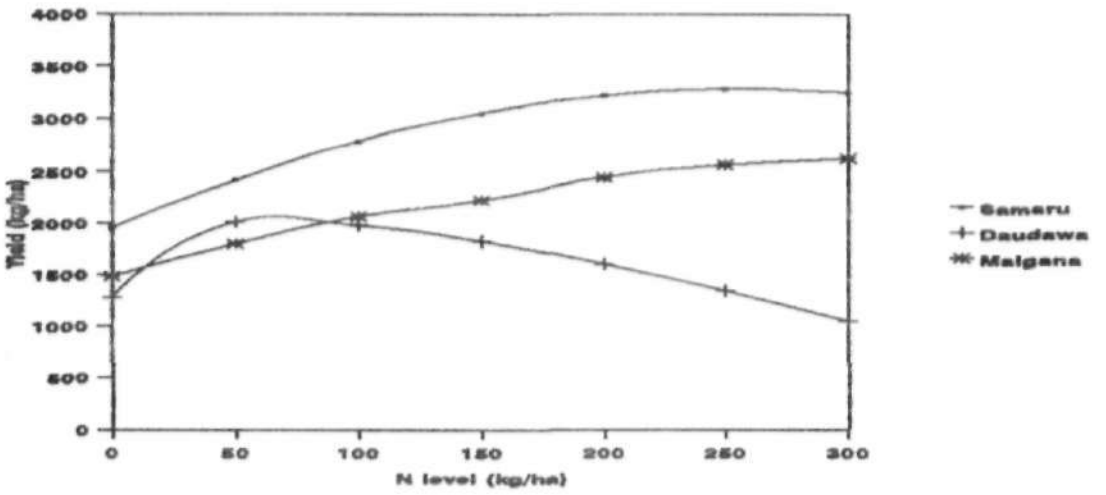
Daudawa; $\frac{\delta y}{\delta N} = -0.0071 + 0.0733N^{-0.5} = 0$; N = 106.58 kg

Maigana; $\frac{\delta y}{\delta N} = -0.0113 + 0.1146N^{-0.5} = 0$; N = 102.85 kg

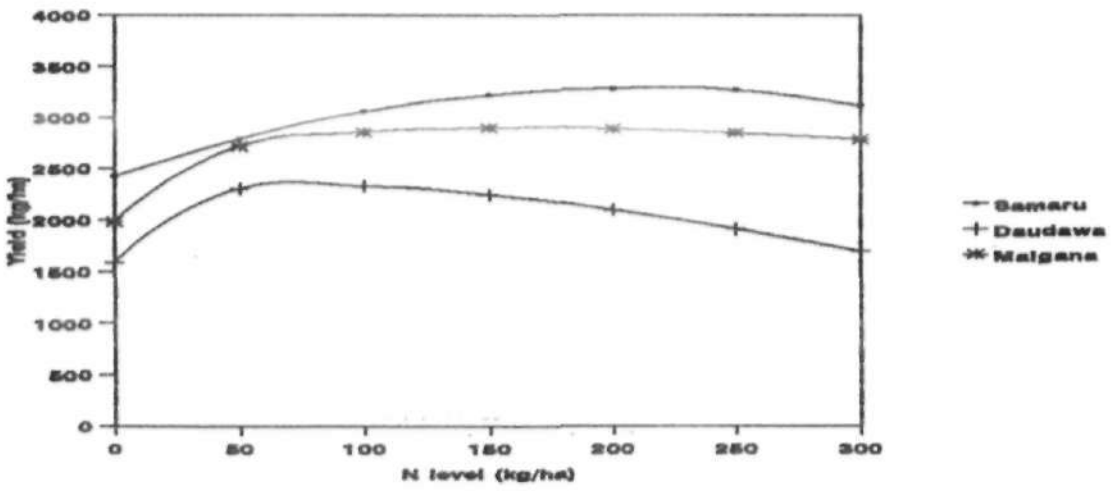
Fig. 1: The predicted response curve of maize to nitrogen fertilization in three villages in NGS, 1990-1991.



1990



1991



1990 & 1991 combined

Table 4.13: The predicted yield response of maize to N-fertilization in Samaru, Daudawa and Maigana, NGS, Nigeria, 1990 and 1991 (kg/ha).

N-Level (kg/ha)	Samaru			Daudawa			Maigana		
	1990	1991	1990-91 Pooled	1990	1991	1990-91 Pooled	1990	1991	1990-91 Pooled
0	2695	1955	2423	1889	1280	1582	2512	1485	1981
50	3373	2420	2788	2581	2013	2302	3568	1800	2715
100	3428	2785	3053	2655	1983	2328	3674	2065	2855
150	3381	3050	3218	2630	1823	2240	3624	2280	2897
200	3281	3215	3283	2552	1603	2092	3493	2445	2889
250	3149	3280	3268	2442	1344	1907	3311	2560	2848
300	2988	3245	3113	2299	1052	1695	3090	2625	2785

The technical optimum N-requirements were 95 kg/ha, 107 kg/ha and 103 kg/ha of fixed levels of 40kg P ha^{-1} respectively for Samaru, Daudawa and Maigana. The corresponding yields of maize were 3429 kg/ha, 2655 kg/ha and 3674 kg/ha at Samaru, Daudawa and Maigana respectively. In all the villages, the technical optimum N-level obtained was below the 120 kg N/ha recommended by the Institute for Agricultural Research (IAR) Samaru for maize in the zone. This suggests that the recommended rate was on the high side. At these rates, the mean response of maize to N-fertilization at Samaru was 36 kg, at Daudawa, it was 25 kg while at Maigana it was 36 kg maize per kg of N nutrient. Samaru and Maigana have the same mean response while Daudawa had the least response. Although these values differ from the mean values obtained in Table 4.12 they are however similar in pattern. Samaru and Maigana have similar responses to N-fertilization which are higher than at Daudawa.

Economic optimum level of N-usage

The economic optimum level of fertilizer is often different from the technical optimum level of fertilizer use. While the technical optimum emphasised the level at which the obtained yield is highest, the economic optimum emphasises the level at which the marginal revenue from the extra use of fertilizer equates the cost of the fertilizer used.

One approach is to equate the marginal value product of the crop with the unit price of the fertilizer nutrient. Another is simply to compare the marginal revenue at each level of fertilizer use to the marginal cost. In this study, since for each variable level of N, there is a fixed level of P and K-nutrients, the marginal value approach cannot be used because there is no single price for the nutrients. Consequently, the second approach was used and the result is shown in Table 4.14. The table clearly shows that at the level of 100 kg N/ha for Samaru and Daudawa and the fixed level of 40 kg P/ha and 60 kg K/ha, the marginal cost of the fertilizer (₦3.60) exceeded the marginal returns of ₦2.08 and ₦2.80 respectively. At this level, for Maigana, the marginal returns of ₦4 exceeded the marginal cost of ₦3.60. The profit level for each fertilizer level is also shown in the table.

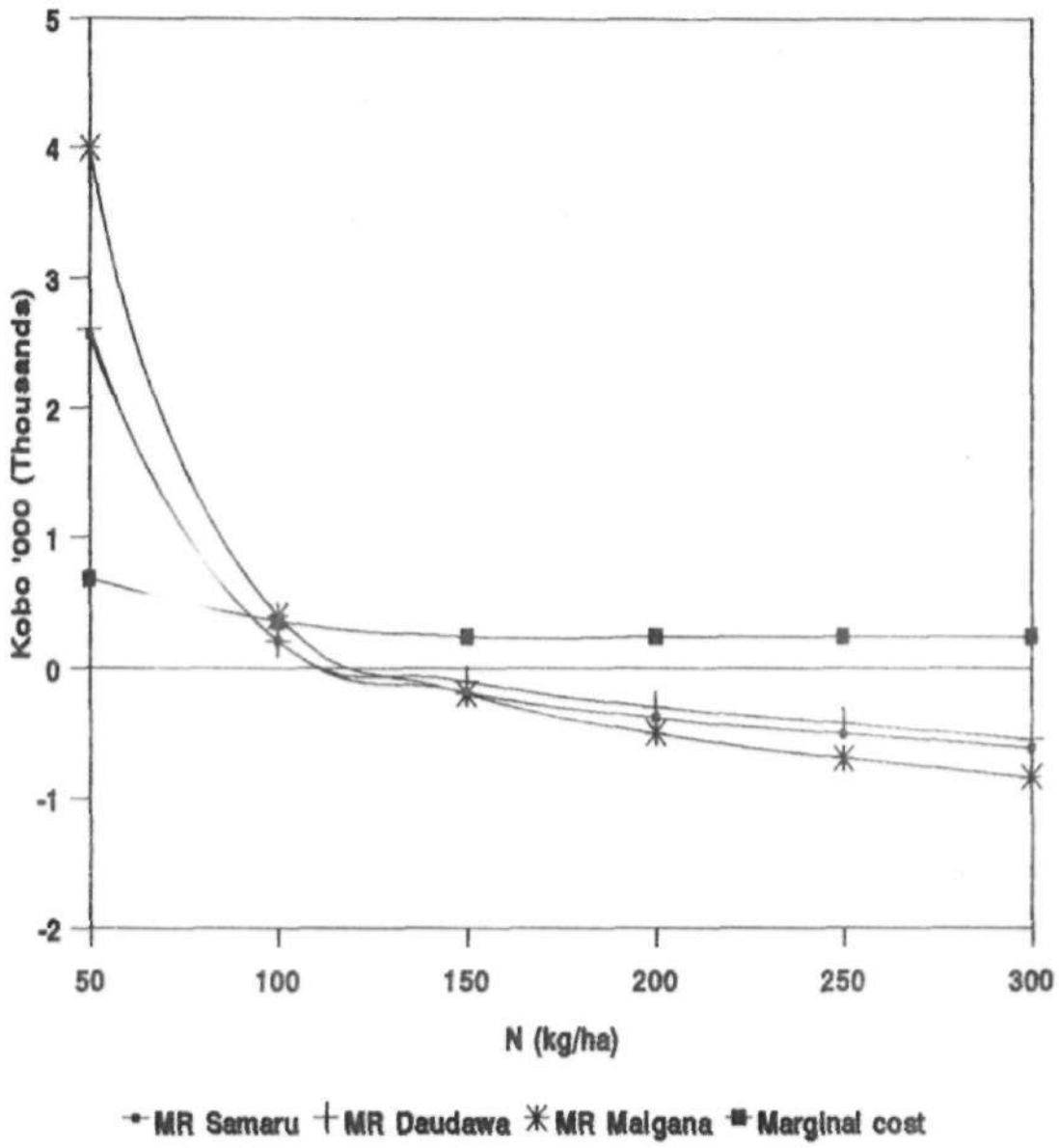
The price level of N-for which the marginal returns (MR) equals the marginal cost (MC) is given in Fig. 2. From the figure, the economic levels of N for Samaru was 110 kg/ha, 114 kg/ha for Daudawa and 120 kg/ha for Maigana and their corresponding yields were 3424 kg/ha for Samaru, 2655 kg/ha for Daudawa and 3667 kg/ha for Maigana. In all the villages, the levels of N obtained using both technical and economic optimum criteria fall within the recommendation of 120 kg/ha N by IAR, Samaru. The mean responses were 31 kg, 23 kg and 31 kg per kg N at Samaru, Daudawa and Maigana respectively.

Table 4.14: The total yield, returns, and cost parameters for maize production at various levels of N-fertilization in three villages in the Northern Guinea Savanna, Nigeria, 1990.

N-Level (kg/ha)	Total Yield (kg/ha)			Total Returns (N/ha)			Marginal Returns (N/kg)			Direct Total Cost of Fertilizer*	Direct Marginal Cost of Fertilizer	Profit (N/ha)		
	Samaru	Daudawa	Maigana	Samaru	Daudawa	Maigana	Samaru	Daudawa	Maigana			Samaru	Daudawa	Maigana
0	2695	1889	2512	5094	3570	4748	-	-	-	0	-	5094	3570	4748
50	3373	2581	3568	6375	4878	6744	25.62	26.16	39.92	340	6.80	6035	4538	6404
100	3428	2655	3674	6479	5018	6944	2.08	2.80	4.00	520	3.60	5959	4498	6424
150	3381	2630	3624	6390	4971	6849	-1.78	-0.94	-1.90	640	2.40	5750	6331	6209
200	3281	2552	3493	6201	4823	6602	-3.78	-2.96	-4.94	760	2.40	5441	4063	5842
250	3149	2442	3311	5952	4615	6258	-4.98	-4.16	-6.88	880	2.40	5072	3735	5378
300	2988	2299	3090	5647	4345	5840	-6.10	-5.40	-8.36	1000	2.40	4647	3345	4840

N.B. Maize is valued at N1.89/kg.
* Refers to the costs of nutrients only.

Fig.2: The marginal returns and marginal cost from nitrogen fertilization of maize in three villages in NGS, 1990.



4.4.2.2 Phosphorus response

The yield data was fitted to the response models specified in equations 3.10 to 3.12 for 1990, 1991 and the two years combined. For each year and the combined years, the best fitted function is reported in Table 4.15. An analysis of variance was performed to test the equality of the variances of the two year data in each village (Appendix B1 to B3). In Samaru and Maigana, the tests were statistically significant at 1% level of probability while in Daudawa, it was not. This means that the two years' data in Samaru and Maigana cannot be said to come from the same population and thus, cannot be combined in a pooled regression and the result used to represent either of the two years. The reason is attributed to the variations in the rainfall amount and distributions for the two years as shown in Table 4.11. Therefore, like the N-response data, the 1990 data and response curves were used to determine the response levels of maize to P-fertilization.

The response functions for each village was given by:

Samaru; $Y = 2.998 - 0.0084P + 0.1347P^{0.5}$ ..... (4.4)

Daudawa; $Y = 2.081 + 0.0091P - 0.00008P^{2}$ ..... (4.5)

Maigana; $Y = 2.407 - 0.0311P + 0.4299P^{0.5}$ ..... (4.6)

In Samaru and Daudawa, the responses were not significant. The amount of variability in maize yield accounted for

Table 4.15: The parameters of the selected functions of maize response to P-fertilization in three villages in the Northern Guinea Savanna, Nigeria, 1990-1991.

Village	Year	Function	No. of Obs.	Coefficient						Mean Level of P- (kg/ha)	Mean Yield of Maize (tonne/ha)	Mean Response
				Constant	P	$P^{0.5}$	P^2	R^2	F-Values			
	1990	Square root	18	2.998* (0.408)	-0.0084 (0.015)	0.1347 (0.169)		0.08	0.62^{NS}	63	3.411	54.14
Samaru	1991	Quadratic	18	1.598* (0.274)	0.048 (0.011)		-0.0004* (0.00009)	0.56	9.57*	63	2.357	37.41
	1990-91	Quadratic	36	2.341* (0.305)	0.0303** (0.013)		-0.00024** (0.00001)	0.15	2.98^{NS}	63	2.884	45.78
	1990	Quadratic	18	2.081* (0.187)	0.0091 (0.008)		-0.00008 (0.00006)	0.09	0.74^{NS}	63	2.216	35.18
Daudawa	1991	Quadratic	18	1.206* (0.357)	0.0112 (0.015)		-0.000004* (0.0009)	0.33	3.72**	63	1.893	30.05
	1990-91	Quadratic	36	1.644* (0.219)	0.010 (0.008)		-0.00004 (0.00007)	0.14	2.71^{NS}	63	2.054	32.60
	1990	Square root	18	2.407* (0.398)	-0.0311** (0.015)		0.4299** (0.165)	0.37	4.46**	63	3.456	54.86
Maigana	1991	Quadratic	18	2.167* (0.311)	0.0319** (0.013)		-0.0003** (0.0001)	0.33	3.66**	63	2.566	40.73
	1990-91	Quadratic	36	2.415* (0.290)	0.0344* (0.012)		-0.0003* (0.0001)	0.21	4.24*	63	3.011	47.79

NB: * Parameter is significant at 1% level of probability
** Parameter is significant at 5% level of probability
Value in bracket is the standard error of parameter.

$t_{0.05, 17} = 1.740$ $F_{0.05, 2, 17} = 3.59$
$t_{0.01, 17} = 2.567$ $F_{0.01, 2, 17} = 6.11$
$t_{0.05, 35} = 1.697$ $F_{0.05, 1, 34} = 4.17$
$t_{0.01, 35} = 2.457$ $F_{0.01, 1, 34} = 7.56$

by variation in P-level was only 8% in Samaru and 9% in Daudawa. In Maigana the response level was statistically significant at 1% level of probability while 37% of the variability in yield of maize was attributed to variability in P-levels. It should be noted that while the P-levels were varied, N and K-levels were fixed at 100 kg/ha and 60 kg/ha respectively. At the used rates, the mean responses were 54 kg, 35 kg and 55 kg maize per kg P_2O_5 for Samaru, Daudawa and Maigana respectively.

The corresponding predicted yields for each level of P_2O_5 in each village for each year are shown in Table 4.16. For 1990, there is a response in yield of maize up to 60 kg/ha of P_2O_5 in each village (Fig. 3). For 1991 and the combined years (Fig. 3) there were similar responses in Samaru and Maigana while Daudawa seemed to have exhibited a linear response function.

Technical Optimum Level of P_2O_5 Usage

The technical optimum P_2O_5 requirement for each village was calculated by taking the first derivative of each predictive equation with respect to P. Thus:

Samaru; $\frac{\delta y}{\delta P} = -0.0084 + 0.0674P^{-0.5}$; P = 64.4 kg/ha

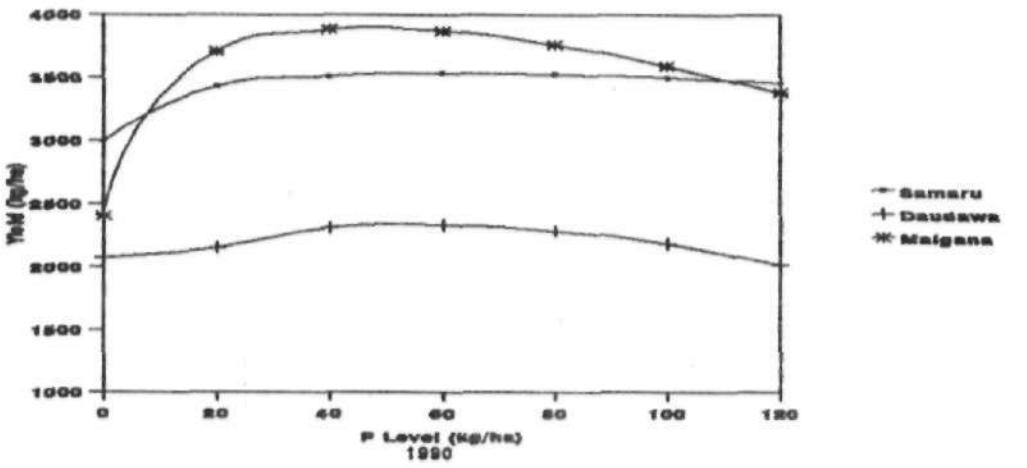
Daudawa; $\frac{\delta y}{\delta P} = 0.0091 - 0.00016P$; P = 56.9 kg/ha

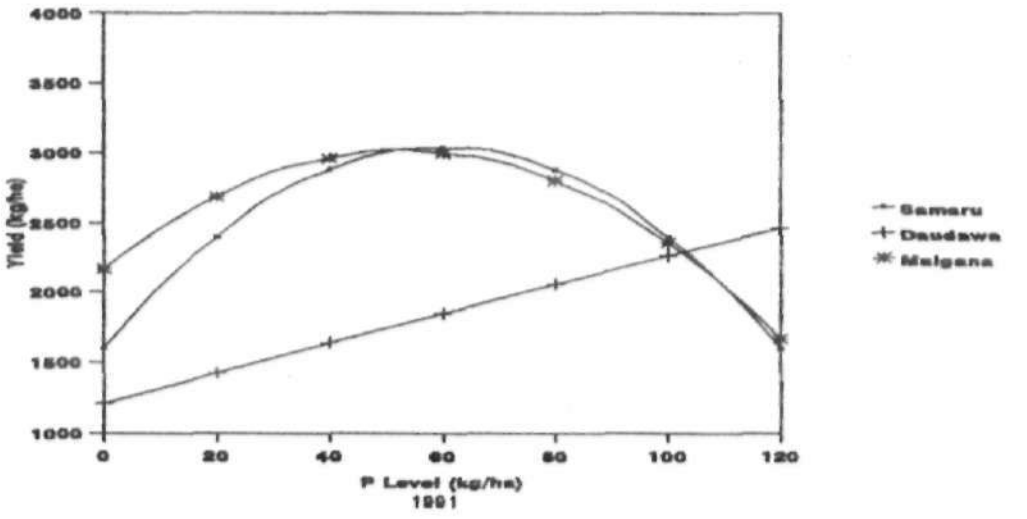
Maigana; $\frac{\delta y}{\delta P} = -0.0311 + 0.2150P^{-0.5}$; P = 47.8 kg/ha.

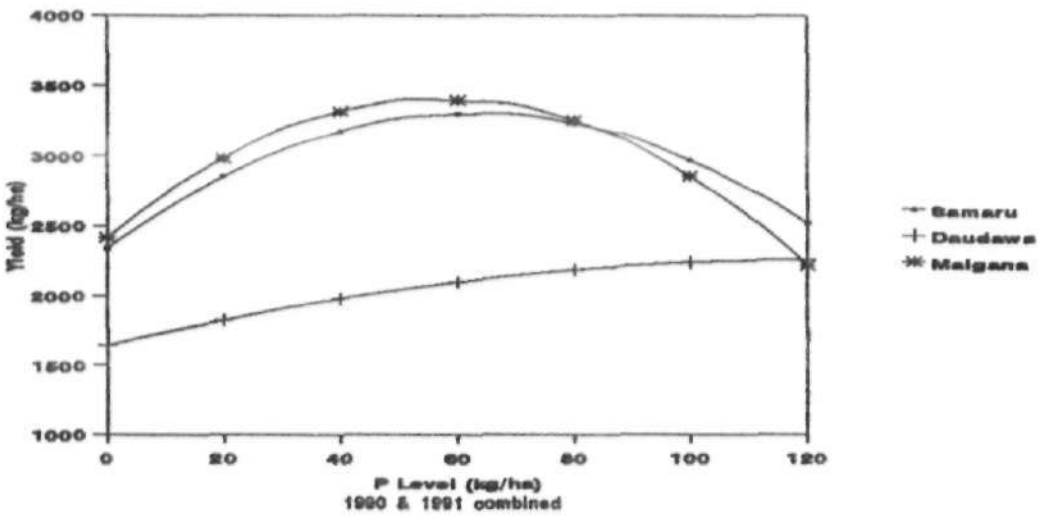
Table 4.16: The predicted yield response of maize to P-fertilization in Samaru, Daudawa and Maigana, NGS, Nigeria, 1990 and 1991 (kg/ha).

P_2O_5 Level (kg/ha)	Samaru			Daudawa			Maigana		
	1990	1991	1990-91 Pooled	1990	1991	1990-91 Pooled	1990	1991	1990-91 Pooled
0	2998	1598	2341	2081	1206	1643	2407	2167	2415
20	3432	2398	2851	2160	1424	1827	3708	2685	2983
40	3514	2878	3169	2315	1639	1979	3882	2963	3311
60	3537	3038	3295	2339	1851	2099	3871	3001	3399
80	3531	2878	3229	2292	2059	2187	3764	2799	3247
100	3505	2398	2971	2191	2264	2243	3596	2357	2855
120	3466	1598	2521	2021	2466	2267	3384	1671	2223

Fig.3: The predicted response curve of maize to phosphorus fertilization in three villages in NGS, 1990-1991.







The optimum yields when these values are used in the predictive equations are 3538 kg/ha at Samaru, 2340 kg/ha in Daudawa and 3892 kg/ha at Maigana. In all the villages, the technical optimum rates were close to 60 kg/ha P_2O_5 recommended by IAR for maize in the zone. The study however shows that yield response was obtained up to 64 kg P_2O_5/ha. Given the above rates and yields, the mean responses to P_2O_5 in Samaru, Daudawa and Maigana were 55kg, 32kg and 81kg of maize yield per kg of P_2O_5 nutrient applied respectively.

Economic Optimum Level of P_2O_5 Usage

The marginal returns at each level of P_2O_5 usage was compared with the direct marginal cost of the fertilizer (Table 4.17). The result shows that in all the villages, and up to 40 kg P_2O_5/ha, the marginal returns exceeded the marginal cost of the fertilizers. At 60 kg/ha P_2O_5, the marginal cost exceeded the marginal returns in all the villages which shows that the economic optimum level lies between 40 kg/ha and 60 kg/ha.

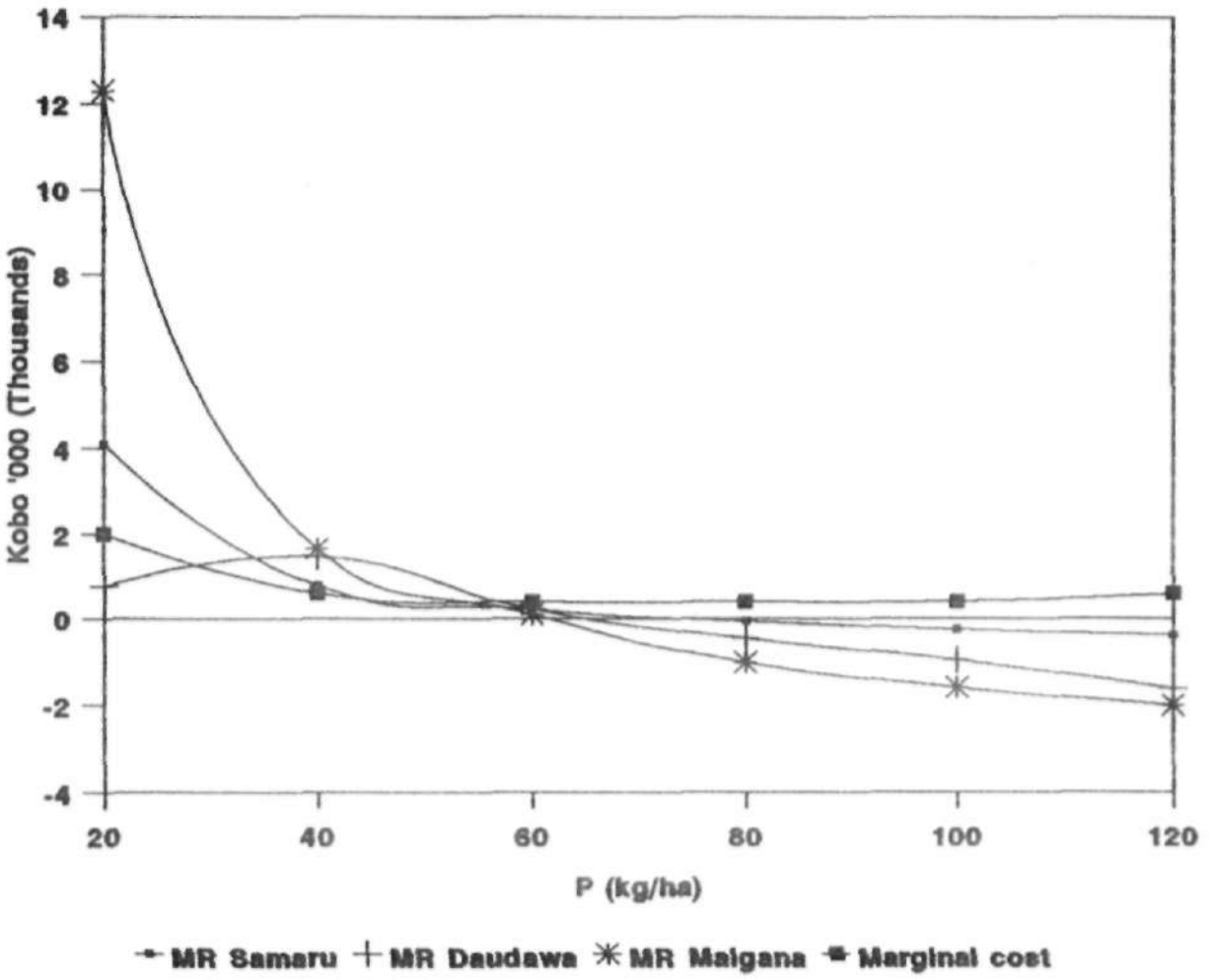
The precise point was obtained by using the marginal return and marginal cost curves in Fig. 4. The precise point is that point where the falling marginal return curve cuts the marginal cost curve. From the curves, the economic optimum level of P_2O_5 was obtained at 42 kg/ha at Samaru, 56 kg/ha at Daudawa and 50 kg/ha at Maigana. In all these cases, the levels were closed to the recommended rate of 60 kg/ha

Table 4.17: The total yield, returns, and cost parameters for maize production at various levels of P-fertilization in three villages in the Northern Guinea Savanna, Nigeria, 1990.

P-Level (kg/ha)	Total Yield (kg/ha)			Total Returns (N/ha)			Marginal Returns (N/kg)			Direct Total Cost of Fertilizer*	Direct Marginal Cost of Fertilizer	Profit (N/ha)		
	Samaru	Daudawa	Maigana	Samaru	Daudawa	Maigana	Samaru	Daudawa	Maigana			Samaru	Daudawa	Maigana
0	2998	2081	2407	5666	3933	4549	-	-	-	0	-	5666	3933	4549
20	3432	2160	3708	6486	4082	7008	41.00	7.45	122.95	400	20.00	6086	3682	6608
40	3514	2315	3882	6641	4375	7337	7.75	14.65	16.45	520	6.00	6121	3855	6817
60	3537	2339	3871	6685	4421	7316	2.20	2.30	-1.05	600	4.00	6085	3821	6716
80	3531	2292	3764	6674	4332	7114	-0.55	-4.45	-10.10	680	4.00	5994	3652	6434
100	3505	2191	3596	6625	4141	6796	-2.45	-9.55	-15.90	760	4.00	5865	3381	6036
120	3466	2021	3384	6551	3820	6396	-3.70	-16.05	-20.00	880	6.00	5671	2940	5516

N.B. Maize is valued at N1.89/kg.
* Refers to the costs of nutrients only.

Fig.4: The marginal returns and marginal cost from phosphorus fertilization of maize in three villages in NGS, 1990.



of P_2O_5 for maize. The corresponding yields were 3518 kg/ha at Samaru, 2340 kg/ha at Daudawa and 3892 kg/ha at Maigana. The economic optimum level yields for Samaru was lower than the technical optimum yield while in Daudawa and Maigana, the yields were the same. The mean responses were 84 kg at Samaru, 42 kg at Daudawa and 78 kg at Maigana per kg P_2O_5.

4.4.2.3 Potassium response

The data were fitted with the equation specified in models 3.13 to 3.15 for the years 1990, 1991 and the combined years. The parameters of the best fitted equation in each year and the combined years are shown in Table 4.18. The result of an analysis of variance performed to test the equality of the variances of the two years data is shown in Appendix C1 - C3. The results show that for Samaru and Maigana, the variances were statistically significant at the 1% level of probability. For Daudawa however, it was not statistically significant. This result was similar to that obtained for phosphorus data analysis and as such, the 1990 data will be used for subsequent analysis for consistency in analysis and for the fact that the year was a better reflection of the normal years in terms of rainfall.

The overall equations for Samaru and Maigana in 1990 were not statistically significant at 5% level of probability. The R^2 in both cases were very low. For instance, in Samaru only 7% in the variability of maize was attributable

Table 4.18: The parameters of the selected functions of maize response to K-fertilization in three villages in Northern Guinea Savanna, Nigeria. 1990 - 1991.

Village	Year	Function	No. of Obs.	Coefficient of						Mean K-Level	Mean Maize yield (tons/ha)	Mean Response
				Const.	K(lnk)	$K^{0.5}$	K^2	R^2	F-values			
	1990	Square Root	18	3.090* (0.405)	-0.0092 (0.010)	0.1406 (0.137)		0.07	0.56^{NS}	95	3.424	36.04
Samaru	1991	Quadratic	18	2.062* (0.311)	0.0155 (0.009)		-0.00009 (0.00005)	0.21	1.95^{NS}	95	2.351	24.75
	1990-91	Quadratic	36	2.638* (0.306)	0.0117 (0.008)		-0.00007 (0.00005)	0.06	1.06^{NS}	95	2.888	30.40
	1990	Double Log	18	0.514* (0.082)	0.0447* (0.018)			0.28	6.08**	95	1.927	20.28
Dandawa	1991	Quadratic	18	1.873* (0.202)	0.0041 (0.006)		-0.000032 (0.00003)	0.12	1.06^{NS}	95	1.849	19.46
	1990-91	Square Root	36	1.685* (0.259)	-0.0026 (0.006)	0.0515 (0.088)		0.05	0.88^{NS}	95	2.001	21.06
	1990	Square Root	18	3.031* (0.259)	-0.0064 (0.006)	0.1018 (0.088)		0.09	0.76^{NS}	95	3.316	34.91
Maigana	1991	Quadratic	18	2.130* (0.410)	0.0014 (0.011)		-0.000006 (0.00006)	0.04	0.33^{NS}	95	2.338	24.61
	1990-91	Quadratic	36	2.642* (0.292)	0.0034 (0.008)		-0.00001 (0.00004)	0.02	0.29^{NS}	95	2.827	30.39

NB: *. Significant at 1% level of probability
**. Significant at 5% level of probability
NS. Not significant at 5% level of Probability
( ). Standard error of parameter.

$t_{0.05,\ 17} = 1.740$ $F_{0.05,\ 2,\ 17} = 3.59$
$t_{0.01,\ 17} = 2.567$ $F_{0.01,\ 2,\ 17} = 6.11$
$t_{0.05,\ 35} = 1.697$ $F_{0.05,\ 1,\ 34} = 4.17$
$t_{0.01,\ 35} = 2.457$ $F_{0.01,\ 1,\ 34} = 7.56.$

to variations in K_2O level while in Maigana the variability in yield was attributed to only 9% variations in K_2O levels. In Daudawa, the response was significant at the 5% level with 28% of the variability in maize yield being caused by variation in K_2O level. Except in the case of Daudawa, the coefficient of K in all the equations were not statistically significant at the 5% level. However, the signs were consistent and correct.

The predicted response functions were:

Samaru $Y = 3.090 - 0.0092K + 0.1406K^{0.5}$ ..... (4.7)

Daudawa $Y = 1.672K^{0.05}$ ..... (4.8)

Maigana $Y = 3.051 - 0.0064K + 0.1018K^{0.5}$ ..... (4.9)

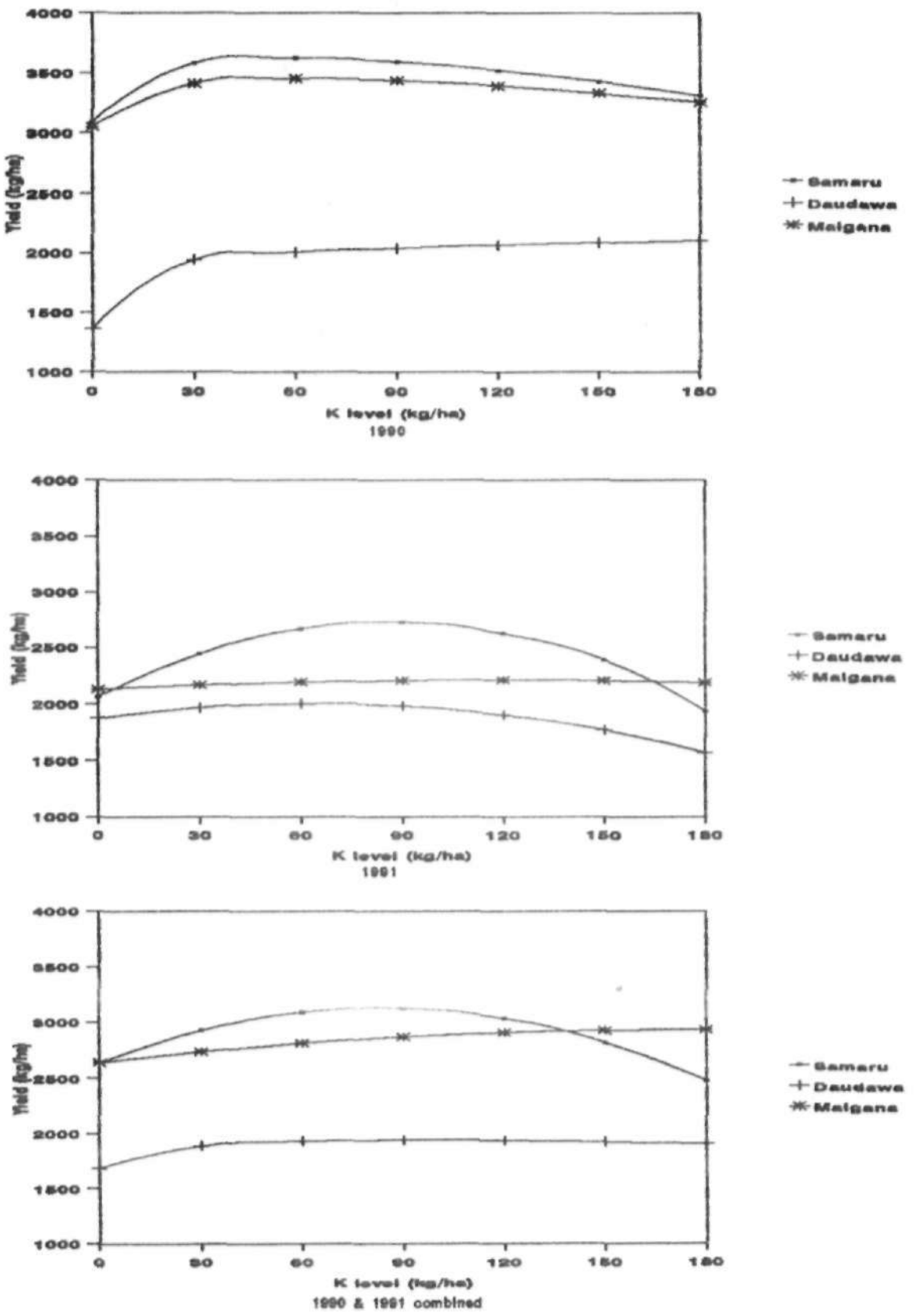
In deriving these functions, N- and P- were kept fixed at 100 kg/ha and 40 kg/ha respectively. The mean response to K-fertilization at Samaru was 36 kg, at Daudawa it was 21 kg and at Maigana it was 35 kg yield per kg nutrient.

The predicted yields using the function for each village are given in Table 4.19. In Samaru and Maigana there were responses of up to 60 kg k/ha in 1990 while in Daudawa it was not possible to determine the level due to the asymptotic nature of the Cobb-Douglas Production function used. The square root and the quadratic functions which could have been used to predict the optimum yield did not show the correct signs. The response curves for the various years in each village are shown in Fig. 5. In 1991, responses to K_2O were

Table 4.19: The predicted yield response of maize to K-fertilization in Samaru, Daudawa and Maigana, Nigeria, 1990 and 1991 (kg/ha).

K-Level (kg/ha)	Samaru			Daudawa			Maigana		
	1990	1991	Pooled 1990-91	1990	1991	Pooled 1990-91	1990	1991	Pooled 1990-91
0	3090	2062	2638	1361	1874	1685	3051	2130	2642
30	3585	2446	2926	1947	1967	1889	3417	2167	2735
60	3627	2668	3088	2008	2004	1929	3453	2192	2810
90	3596	2728	3124	2045	1983	1940	3441	2207	2867
120	3526	2626	3034	2071	1904	1937	3398	2212	2906
150	3432	2392	2816	2092	1768	1926	3338	2205	2927
180	3320	1936	2476	2109	1574	1908	3265	2188	2930

Fig.5: The predicted reeponse curve of maize to potassium fertilization in three villages in NGS, 1990-1991.



obtained up to 120 kg/ha at Maigana. The mean responses for 1990 were 36 kg at Samaru, 20 kg at Daudawa and 35 kg at Maigana per kg of K_2O. The mean K-usage was 95 kg/ha.

Technical Optimum Level of K_2O Usage

The 1990 predictive equations were used to determine the technical optimum level of K_2O for each village by taking the first derivative of each equation. It should be noted that as explained earlier, the technial optimum for Daudawa cannot be determined because of the function which does not exhibit maximum yield. For Samaru the technical optimum is given by;

$$\frac{\delta y}{\delta k} = -0.0092 + 0.0703K^{-0.5} = 0;\ k = 58.4 \text{ kg/ha}$$

and for Maigana it is given by:

$$\frac{\delta y}{\delta k} = -0.0064 + 0.0509K^{-0.5} = 0;\ k = 63.3 \text{ kg/ha}$$

Thus, Samaru required 58 kg/ha while Maigana required 63 kg/ha K_2O. Their predictive yields were 3627 kg/ha for Samaru and 3456 kg/ha for Maigana. At these rates of K_2O application and yield responses, the mean responses were 63 kg for Samaru and 55 kg for Maigana per kg of K_2O applied. This suggests that the response to K-Fertilization is higher at Samaru than Maigana.

The Economic Optimum Level of K_2O Usage

In order to determine the economic optimum level of K-fertilization, the Marginal returns from each level of fertilization was computed and compared with the direct marginal cost of the fertilizer used (Table 4.20). The Table shows that for each village, the marginal returns was positive up to the 60 kg K_2O/ha level. However, to determine precisely the levels at which economic optimum is reached, Fig. 6 was used. In using the figure, the economic optimum level correspond to the level at which the marginal return curve (MR) intersect the marginal cost (MC) curve. From the Figure, the economic optimum level was obtained in Samaru at 78 kg/ha, in Daudawa at 86 kg/ha and in Maigana at 82 kg/ha. At these rates, the economic optimum yields were 4614 kg/ha in Samaru, 2089 kg/ha in Daudawa and 3438 kg/ha in Maigana. The corresponding mean responses were 46 kg at Samaru, 24 kg at Daudawa and 42 kg at Maigana per kg K_2O applied. Thus, Samaru has the highest response to K_2O, followed by Maigana and the least was Daudawa. These results suggest that the present recommendation of 60 kg k_2O/ha for maize is small and should be increased to 90 kg/ha.

In summary, the 1990 response of maize to single nutrient fertilization show that the recommended rate for nitrogen in maize production is still valid (Table 4.21). The table shows that although the technical levels are much lower

Table 4.20: The total yield, returns, and cost parameters for maize production at various levels of K-fertilization in three villages in the Northern Guinea Savanna Nigeria, 1990.

N-Level (kg/ha)	Total Yield (kg/ha)			Total Returns (N/ha)			Marginal Returns (N/kg)			Direct Total Cost of Fertilizer*	Direct Marginal Cost of Fertilizer	Profit (N/ha)		
	Samaru	Daudawa	Maigana	Samaru	Daudawa	Maigana	Samaru	Daudawa	Maigana			Samaru	Daudawa	Maigana
0	3090	1361	3051	5840	2572	3876	-	-	-	0	-	5940	2572	3876
30	3585	1947	3417	6776	3680	6458	31.20	36.93	86.07	460	15.33	6316	3220	5998
60	3627	2008	3453	6855	3795	6526	2.63	3.83	2.27	500	5.33	6355	3295	6026
90	3596	2045	3441	6796	3865	6503	-1.97	2.38	-0.77	540	1.33	6256	3325	5963
120	3526	2071	3398	6664	3914	6422	-4.40	1.63	-2.70	580	1.33	6084	3334	5842
150	3432	2092	3338	6487	3954	6309	-5.90	1.33	-3.77	620	1.33	5867	3334	5689
180	3320	2109	3265	6275	3986	6171	-7.07	1.07	-4.60	660	1.33	5615	3326	5511

N.B. Maize is valued at N1.89/kg.
* Refers to the costs of nutrients only.

Fig.6: The marginal returns and marginal cost from potassium fertilization of maize in three villages in NGS, 1990.

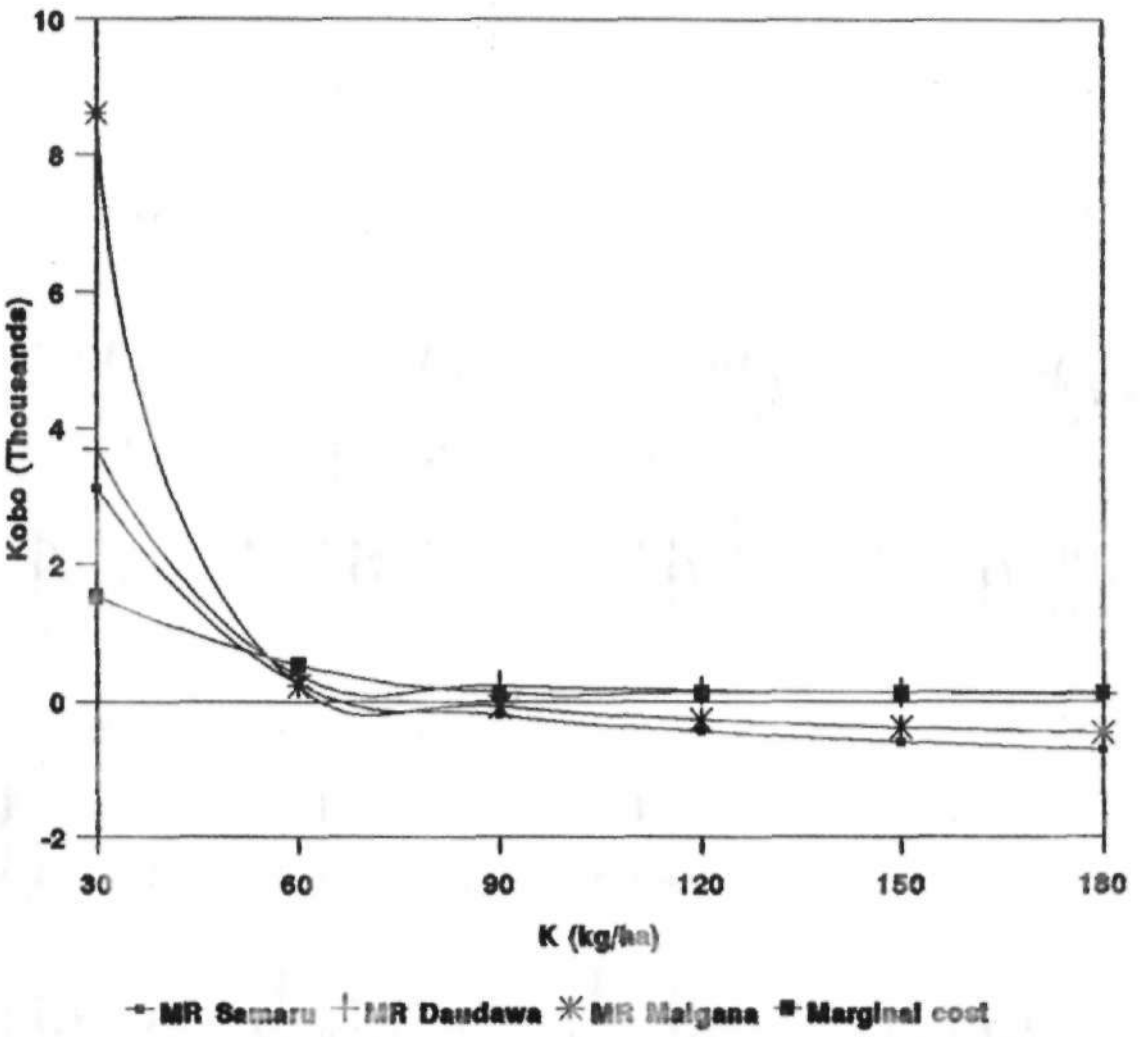


Table 4.21: Recommended N,P and K rates, the obtained technical and economic levels of N, P and K and their corresponding yields in three villages in Northern Guinea Savanna, Nigeria, 1990.

Village	Recommended Rates of N,P and K (kg/ha)			Technical Optimum (1990)				Economic Optimum (1990)			
				Nutrient Level (kg/ha)			Yield (kg/ha)	Nutrient Level (kg/ha)			Yield (kg/ha)
N-				**N**	**P**	**K**					
Samaru	120	60	60	95	60	60	3429	110	60	60	3434
Daudawa	120	60	60	107	60	60	2655	114	60	60	2655
Maigana	120	60	60	107	60	60	3674	120	60	60	3667
P-				**N**	**P**	**K**					
Samaru	120	60	60	100	64	60	3538	100	42	60	3518
Daudawa	120	60	60	100	54	60	2340	100	56	60	2340
Maigana	120	60	60	100	48	60	3892	100	50	38	3892
K-				**N**	**P**	**K**					
Samaru	120	60	60	100	60	58	3627	100	60	78	3614
Daudawa	120	60	60					100	60	86	2089
Maigana	120	60	60	100	60	63	3456	100	60	82	3448

than the economic levels, they are close to within the recommended rate of 120 kg N/ha. Similarly, in the case of phosphorus, both the technical and economic rates were close to the recommended rate of 60 kg P_2O_5 ha. The rate therefore, is also still valid. The potassium recommendation rate is 60 kg K_2O/ha. While the technical optimum levels were close to this rate, the economic optimum levels were far above it and close to 90 kg/ha. The recommendation should therefore be increased to 90 kg K_2O/ha.

For a comparison with 1990, the predicted equations for 1991 were used to predict the technical optimum levels of each nutrient for each village. In the case of N- response, the technical optima were 340 kg/ha, 258 kg/ha and 65 kg/ha for Maigana, Samaru and Daudawa respectively. There was an abnormal response in each village in 1991. For phosphorus response, the technical optimum levels were 53 kg/ha, 60 kg/ha and 1400 kg/ha at Maigana, Samaru and Daudawa respectively. The Daudawa response was abnormal. With respect to potassium response, the optimum levels were 116 kg/ha, 86 kg/ha and 64 kg/ha at Maigana, Samaru and Daudawa respectively. Again the response at Maigana was abnormal. The abnormality in 1991 was caused by irregular rainfall which led to replanting of maize and application of fertilizers many times leading to over fertilization. Thus, 1990 data was used for the response analyses in the study.

4.4.3 Response to multiple nutrients (NPK)

The multiple nutrient response models specified in equations 3.16 to 3.18 were fitted with the data for each year and the two years combined. As was done for the single nutrient data, an analysis of variance was done to determine the equality of the variances of the two year data (Appendix D1-D3). The results show that for each village tested , the variances were statistically different at the 1% probability level. This suggests that the pooled data cannot be used as a good representation of every year response behaviour for each village. A correlation analysis was also performed on the data to determine the nature of relationships between the nutrients, the villages and between the nutrients and villages (Table 4.22). The table shows that the Pearson correlation coefficient (r) in all the cases was positive and statistically significant at the 5% level of probability. In terms of nutrient, the degree of association between N and P is 44.2%, between N- and K- is 43.6% and between P- and K- is 43.7%. In terms of nutrient and yield in each village, the degree of association between N and yields in Samaru was 25.6%, between N and yields in Daudawa was 32.2%, and between N and yields in Maigana was 27.4%. The response to N at Samaru and Maigana was similar and less than Daudawa. The degree of association on the other hand between P and yields at Samaru was 36.3%, between P and yields in Daudawa was 26.2% and between P and yields in Maigana was 37.5%. This

Table 4.22: Pearson correlation coefficients (r) between yields and villages, between nutrients and villages, and between nutrients in three villages in Northern Guinea Savanna, Nigeria, 1990.

	Samaru	Daudawa	Maigana	N	P	K
Samaru	r = 1.0000	r = 0.4621 P = 0.000	r = 0.5282 P = 0.000	r = 0.2538 P = 0.013	r = 0.3633 P = 0.001	r = 0.2952 P = 0.005
Daudawa	r = 0.4621 P = 0.000	r = 1.0000	r = 0.4220 P = 0.000	r = 0.3224 P = 0.000	r = 2622 P = 0.012	r = 0.3101 P = 0.003
Maigana	r = 0.5282 P = 0.000	r = 0.4220 P = 0.000	r = 1.000	r = 0.2736 P = 0.009	r = 3752 P = 0.000	r = 0.2346 P = 0.021
N-	r = 0.2558 P = 0.013	r = 3224 P = 0.002	r = 0.2736 P = 0.009	r = 1.0000	r = 0.4419 P = 0.000	r = 0.4355 P = 0.000
P-	r = 0.3633 P = 0.001	r = 0.2622 P = 0.012	r = 0.3752 P = 0.000	r = 0.4419 P = 0.000	r = 1.000	r = 0.4369 P = 0.000
K-	r = 0.2952 P = 0.005	r = 0.3101 P = 0.003	r = 2346 P = 0.021	r = 0.4356 P = 0.000	r = 0.4369 P = 0.009	r = 1.0000

P = Probability level; No. of observation = 75.

suggest a similar but higher responses of maize to P in Samaru and Maigana than Daudawa. For potassium, the degree of association between it and yields in Samaru was 30%, between it and yields at Daudawa was 31% and between it and yields in Maigana was 23%. Thus, Samaru and Daudawa have similar response to potassium.

In terms of the relationship between the yields in the villages, the study shows that the degree of association between yields in Samaru and Daudawa was 46%, between Samaru and Maigana was 53% while that between Daudawa and Maigana was 42%.

In using models 3.16 and 3.17, multicolinearity problems were discovered. This arose, first, because of the high degree of association between the nutrients and secondly, because some of the variables in the models were simply multiples of the variables already in the model. To overcome the multicolinearity problems, those variables that were highly correlated were dropped from the models. Consequently, the NP, NK and PK interactions did not appear in the functions (Tables 4.23 and 4.24). The best fitted quadratic and double logarithm functions for each year was reported in the Table 4.23 while that of the best fitted square root function for each year was reported in Table 4.24. The predicted equations for 1990 are given by:

Table 4.23: The parameters of the selected quadratic and double logarithm functions for maize response to N,P and K-fertilisation in the Northern Guinea Savanna, Nigeria, 1990-1991.

Village	Year	Function	No. of Obs.	Coefficient								R^2	F-Value	Mean Yield (kg/ha)
				Const.	N (lnN)	P (lnP)	K (lnK)	N^2	P^2	K^2	NPK			
Samaru	1991	Quadratic	75	1.321* (0.532)	$5.5x10^{-3}$ (0.005)	$15.6x10^{-3}$ (0.012)	$-3.7x10^{-4}$ (0.008)	$-7.8x10^{-6}$ ($1.0x10^{-5}$)	$-1.2x10^{-4}$ ($9.7x10^{-5}$)	$-2.6x10^{-4}$ ($4.4x10^{-5}$)	$2.5x10^{-7}$ ($1.9x10^{-7}$)	0.31	4.38*	2355
	1990-91	Quadratic	150	0.964* (0.283)	$3.2x10^{-3}$ (0.004)	$12.1x10^{-3}$ (0.010)	$4.5x10^{-3}$** (0.007)	$-6.8x10^{-6}$ ($6.7x10^{-5}$)	$9.0x10^{-5}$ ($8.0x10^{-5}$)	$7.0x10^{-5}$ ($4.0x10^{-5}$)	$8.0x10^{-6}$ ($1.6x10^{-7}$)	0.23	5.90*	2952
Daudawa	1990	Quadratic	75	0.964* (0.283)	$3.2x10^{-3}$ (0.004)	$12.1x10^{-3}$ (0.010)	$4.5x10^{-4}$ (0.007)	$-6.8x10^{-6}$ ($6.7x10^{-5}$)	$9.0x10^{-5}$ ($8.0x10^{-5}$)	$7.0x10^{-5}$ ($4.0x10^{-5}$)	$8.0x10^{-6}$ ($1.6x10^{-7}$)	0.25	3.11*	2140
	1991	Quadratic	75	9.976* (0.233)	0.0028 (0.003)	0.0186 (0.008)	0.0016 (0.005)	$-1.0x10^{-5}$ ($1.0x10^{-5}$)	$-6.0x10^{-5}$ ($6.0x10^{-5}$)	$-9.0x10^{-6}$ ($3.0x10^{-5}$)	$-1.0x10^{-7}$ ($1.0x10^{-7}$)	0.33	4.67*	1722
Maigana	1991	Double Logarithm	75	0.520* (0.088)	0.0420* (0.020)	0.00616 (0.022)	0.0140 (0.021)							

NB: 1. *The parameter is significant at 1% level of probability.
2. **The parameter is significant at 5% level of probability.
3. The value and bracket is the standard error of the parameter.
4. $t_{0.05,\ 74} = 1.684$
5. $t_{0.01,\ 74} = 2.390$
6. $t_{0.05,\ 149} = 1.649$
7. $t_{0.01,\ 149} = 2.326$
8. $F_{0.05,\ 7,67} = 2.17$
9. $F_{0.01,\ 7,67} = 2.95$
10. $F_{0.05,\ 3,146} = 2.60$
11. $F_{0.01,\ 3,146} = 3.78$

Table 4.24:The parameters of the selected aquare root functions for maize response to N,P and K fertilizationin three villages in the Northern Guinea Savanna of Nigeria, 1990-1991.

Village	Year	No. of Obs.	Coefficient								R^2	F-Value	Mean Yield (kg/ha)
			Const.	N	P	K	$N^{0.5}$	$P^{0.5}$	$K^{0.5}$	$N^{1.5}P^{-2}K^{-3}$			
Samaru	1990	75	1.713* (0.004)	$-9.1x10^{-3}$ (0.004)	$-7.2x10^{-3**}$ (0.01)	$-6.3x10^{-3}$ (0.006)	0.1675* (0.061)	0.1173 (0.097)		$5.0x10^{-4}$ (0.0005)	0.32	4.54**	3322
Dandawa	1990-91	150	0.583* (0.235)	-0.0057 (0.003)	-0.0033 (0.007)	-0.0072** (0.004)	0.1075* (0.041)	0.1048 (0.65)	0.1147** (0.053)	$6.0x10^{-5}$ (0.0004)	0.23	6.14*	1935
	1990	75	1.260* (0.260)	-0.0113* (0.003)	-0.2221* (0.007)	-0.0132* (0.005)	0.1956* (0.045)	0.2841* (0.072)	0.1412* (0.058)	$9.0x10^{-4**}$ (0.004)	0.58	13.16*	3361
Maigana	1990-91	75	1.366* (0.326)	-0.0085** (0.004)	-0.0106 (0.009)	-0.006 (0.006)	0.1605* (0.057)	0.1376 (0.090)	0.0727 (0.073)	0.006 (0.006)	0.17	4.12*	2805

NB: 1. *The parameter is significant at 1% level of probability.
2. **The parameter is significant at 5% level of probability.
3. The value and bracket is the standard error of the parameter.
4. $t_{0.05,\ 74} = 1.684$
5. $t_{0.01,\ 74} = 2.390$
6. $t_{0.05,\ 149} = 1.649$
7. $t_{0.01,\ 149} = 2.326$
8. $F_{0.05,\ 7,67} = 2.17$
9. $F_{0.01,\ 7,67} = 2.95$
10. $F_{0.05,\ 3,146} = 2.60$
11. $F_{0.01,\ 3,146} = 3.78$

$$\text{Samaru } Y = 1.713 - 0.0091N - 0.0072P - 0.0063K + 0.1674N^{0.5} + 0.1173P^{0.5} + 0.0879K^{0.5} + 0.0005N^{0.5}P^{0.5}K^{0.5} \quad \text{.....(4.10)}$$

$$\text{Daudawa } Y = 0.964 + 0.0032N + 0.0121P + 0.0045K - 0.0000068N^{2} + 0.00009P^{2} + 0.00007K^{2} + 0.00000008NPK \quad \text{..... (4.11)}$$

$$\text{Maigana } Y = 1.264 - 0.0113N - 0.2221P - 0.0132K + 0.1956N^{0.5} + 0.2841P^{0.5} + 0.1412K^{0.5} + 0.0009N^{0.5}P^{0.5}K^{0.5} \quad \text{..... (4.12)}$$

In each village, the overall equation was statistically significant at the 5% probability level and the signs of the coefficients were correct. However, not all the coefficients were statistically significant in Daudawa and Samaru. In Samaru only K- was statistically significant at 5% level. The R^2 was 0.32 which meant that only 32% of the variability in the yield of maize is attributed to variability in NPK nutrients. In Daudawa, the R^2 was 0.25 which was an indication that only 25% of the variability in the yield of maize was attributed to application of the NPK fertilizers. In addition, only the coefficient of K in the model was statistically significant at 5% level of probability. In Maigana, the coefficients of all the parameters in the equations were statistically significant at the 5% level of probability while the R^2 of 0.58 shows that 58% of the variability in yield of maize was caused by the application of NPK fertilizers.

These results suggest that in addition to the application of NPK fertilizers, other factors such as the soil properties, crop management practices, rainfall, etc. were also responsible for the variability in the yield of

maize in the zone. These other factor effects seems stronger in Daudawa and Samaru than in Maigana.

The predicted yields for the various and combined years from equations 4.10 - 4.12 are given in Table 4.25. The table shows that for 1990, there was response in yield up to the 250-100-150 NPK application in Samaru while in Daudawa there was response up to the 200-80-120 NPK. In Maigana, there was response of maize yield to NPK fertilization only up to the 150-60-90 levels.

Technical Optimum Level of N-P-K Usage

It is difficult to determine the technical optimum level under the multi-nutrient combination as shown in Fig. 7. However, up to the 150-60-90 kg/ha N-P-K, it was observed that the yield was increasing at a decreasing rate which suggest that the technical optimum was somewhere around that combination.

Economic Optimum Level of N-P-K Usage

Table 4.26 shows the total yield, total returns, additional returns, direct total and marginal costs and the profit for each level of combined NPK fertilizers. When the additional returns were compared with the additional cost, the economic optimum combination for Samaru was at 150-60-90, which was the point at which the marginal return (₦210) was just above the marginal cost (₦180). For Daudawa, it was

Table 4.25: The predicted yield response of maize to N,P and K fertilization in Samaru, Daudawa and Maigana, NGS, Nigeria,1990-1991 (kg/ha).

Nutrient Level	Kg/ha		Samaru			Daudawa			Maigana		
N	P	K	1990	1991	Pooled	1990	1991	Pooled	1990	1991	Pooled
0	0	0	1713	1321	1708	964	976	583	1264	1275	1366
50	20	30	3202	1833	2552	1689	1476	1885	3444	2137	2553
100	40	60	3479	2250	3100	2201	1844	2105	3773	2228	3025
150	60	90	3590	2617	3403	2514	2061	2153	3804	2286	3128
200	80	120	3632	2980	3524	2640	2110	2111	3750	2327	3152
250	100	150	3638	3383	3508	2597	1707	2017	3653	2359	3154
300	120	180	3621	3870	3412	2397	1632	1880	3537	2384	3096

Fig.7: The predicted response curve of maize to NPK fertilization in three villages in NGS, 1990.

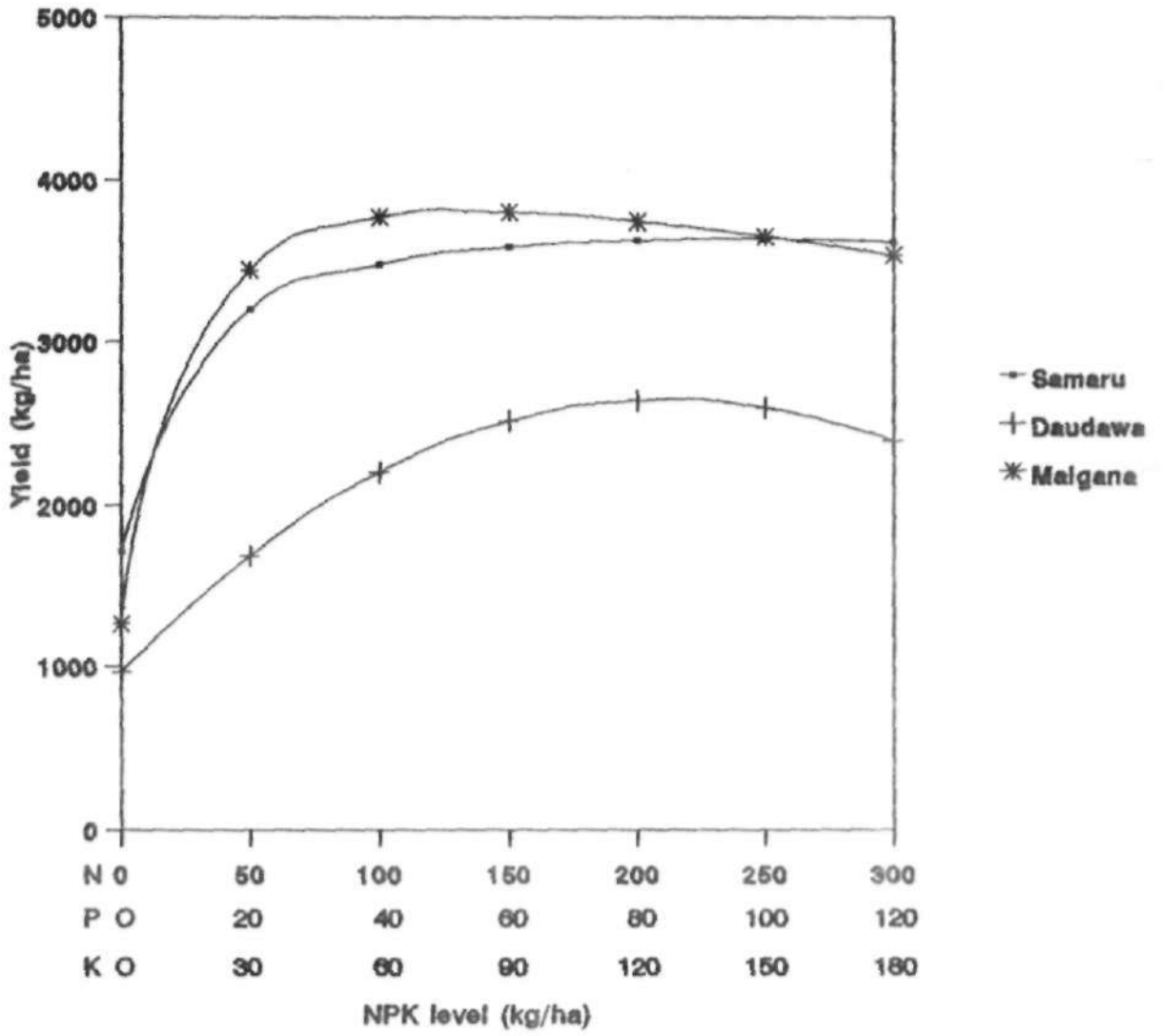


Table 4.26: The total yield, returns and cost parameters for maize production at various levels of N-P-K fertilization in three villages in the Northern Guinea Savanna, Nigeria, 1990.

N-P-K Levels (kg/ha)			Total Yield (kg/ha)			Total Returns (N/ha)			Additional Returns (N/ha)			Direct Total Cost of Fertilizers (N/ha)	Direct Additional Cost of the Combination (N/ha)	Profit (N/ha)		
			Samaru	Daudawa	Maigana	Samaru	Daudawa	Maigana	Samaru	Daudawa	Maigana			Samaru	Daudawa	Maigana
0	0	0	1713	964	1264	3238	1822	2389	-	-	-	0	-	3238	1822	2389
50	20	30	3202	1689	3444	6052	3192	6509	2814	1370	4120	260	260	5792	2932	6249
100	40	60	3479	2201	3773	6575	4160	7131	523	968	622	520	260	6055	3640	6611
150	60	90	3590	2514	3804	6785	4751	7190	210	591	59	700	180	6085	4051	6490
200	80	120	3632	2640	3750	6864	4990	7088	79	239	-102	1000	300	5864	3990	6088
250	100	150	3638	2597	3653	6876	4908	6904	12	-82	-184	1280	280	5596	3620	5624
300	120	180	3621	2397	3537	6844	4530	6685	-32	-378	-219	1520	240	5324	3010	5165

N.B. Maize is valued at N1.89/kg.
* Refers to the cost of nutrients only.

at 200-80-120 and for Maigana it was be at the 150-40-60 kg/ha N-P-K levels. Thus, the precise level or combination was difficult to determine. Consequently, the profit level for each combination was determined and the combination at which profit is maximum was chosen. Using the profit criterion, the combination of 150-60-90 will be used for Samaru and Daudawa where profits of ₦6,085 and ₦4,051, respectively were made per ha. For Maigana, the combination with the highest profit was the 100-40-60 and at this combination a profit of ₦6,611 was made per ha. Thus, a combination of between 100-40-60 to 150-60-90 kg N-P-K/ha was suitable for the zone. The profit level shows that profit was maximized in each village at 150-60-90 kg NPK/ha.

In general, the cost of fertilizer in this study has been restricted to the actual price of fertilizers used. The cost could be much higher if the cost of procurement like transportation cost, cost of extra labour required to apply the fertilizer, extra labour required to weed the weeds induced by the fertilizer and the extra labour required to harvest and process the extra yields have been included. In these cases, the economic rate which is a function of the marginal cost might be lower than has been indicated in the study. It was not possible in this study to estimate economic rates because these information was not available as the data used were from on-station research work.

4.5 Analysis of the Linear Programming Model

The linear programming model was specified in equation 3.19. The model was expected to provide information on the value of the objective function (net receipts in this case), optimum enterprise combinations, the resources used with their respective marginal value products (shadow prices), the non-optimal activities with the cost of forcing each of such resources into the solution and the range of values over which the optimum plan holds.

The validity of the optimum plan usually is a function of the assumption made about the prices, technical coefficients and constraints. Where realistic assumptions are made, the optimum farm plan obtained will be valid as the representative farm.

4.5.1 Optimum farm plan of the representative farm

The features of the optimum farm plan of the representative farm is shown in Table 4.27. The value of the objective function was ₦25,571.62 as against the ₦17,780 in the unplanned farm. It represents the net farm income since it was assumed earlier that the farmers did not possess much depreciable fixed inputs used on the farm. Out of the seven crop enterprises specified in the model, five were feasible and included in the model. These include sole maize, sole sorghum, sole cowpea, maize/sorghum mixture and sorghum/

Table 4.27: Optimum organization of the representative farm and the existing activity levels.

Objective function/ Real activity	Existing Activity Level
Objective function	
Total Net Income (₦)	25,571.62
Real Activities - Crop (ha)	
Sole maize	5.282
Sole sorghum	0.101
Sole cowpea	0.264
Maize/sorghum mixture	0.823
Sorghum/groundnut mixture	0.000
Human labour hiring (hrs)	
July	283.07
August	42.29
November	247.98
Fertilizer Purchase (kg)	
NPK 15:15:15	2581.04
SSP (Supa)	29.38
Urea	830.15
Seed buying (kg)	
Cotton seed	0.00
Use of Farmer's owned seed (kg)	
Maize seed	141.93
Sorghum seed	7.27
Cowpea seed	6.61
Groundnut seed	0
Crop selling (kg)	
Maize	17224.97
Cotton	0
Crop consumption (kg)	
Maize	830
Sorghum	1096
Cowpea	216

groundnut mixtures. However, the sorghum/groundnut mixture entered the optimum plan at zero levels. The exclusion of maize/cotton mixtures and maize/sorghum/cowpea mixtures from

the plan implies that although they were grown by the farmers, they were not competitive enough given the resources available to the farmers. Farm planning results in improved net income from less enterprises. The dominant enterprise was sole maize which accounted for 81.7% of the land area cultivated. This was followed by maize/sorghum mixture which accounted for 12.7% of the cultivated land. Before the farm plan, sole maize was second after maize/sorghum mixtures in terms of plot devoted to each enterprise (Table 4.7).

In terms of fertilizer purchases, the optimum farm plan derived its N,P and K nutrients by purchasing 2581.04 kg of 15-15-15 NPK compound fertilizer, 29.38 kg of single superphosphate (supa) fertilizer and 830.15 kg of urea fertilizers. Even though calcium ammonium nitrate (CAN) fertilizer was specified as one of the sources of N, it did not enter the optimum plan. This means that it was not as economical as the other sources (1 kg of N is ₦2.6 in urea, ₦2.67 in NPK 15-15-15 and ₦3.08 in CAN). The survey showed that 76% of the sources of fertilizer used was NPK, 6% was urea and 2% was SSP. The total cost of the fertilizer was estimated to be ₦4,116.93. This excludes transportation and other handling charges.

Although seed buying activities were specified for all the crops grown, only cotton seed buying was feasible. However, because cotton production activities did not enter

the optimum plan, the cotton seed buying activity entered the plan at zero level. All the farmers therefore used their own seeds of maize, sorghum, cowpea and groundnut. This practice is consistent with the practices among farmers in the area. The farm survey shows that for maize, sorghum, cowpea and groundnut crops, between 80 - 100% of the seeds planted were from the previous year's harvest of the farmers. They rarely buy seeds from the market unless when such a crop is new to them.

In the model, all produced crops were offered for sale although in the cases of maize, sorghum and cowpea sales were allowed only after the minimum family consumptions were satisfied. Of the crops that entered the optimum plan, only maize was sold. A total of 17,224.97 kg of maize was sold yielding a total revenue of ₦32,555.19. The sale of seed cotton was feasible but since its production did not enter the plan, the level of sale was zero. Thus, the goal of farmer's production for cash generation was met by the production of maize only in the representative farm.

The consumption requirements specified for maize, sorghum and cowpea were satisfied. All the sorghum and cowpea produced were consumed (1096 kg and 216 kg respectively) while in the case of maize, only 830 kg of the 18,054.97 kg produced was consumed. In practice, some farmers sold their sorlghum and cowpea in the market in order to obtain cash

necessary to buy other non-farm goods even where the quantities produced were not sufficient to feed the household for the year. The farmer who obtained the optimum farm plan was thus, able to satisfy the food security as well as the cash security goals of his production.

The labour profile of the optimum farm plan (Table 4.28) shows that a total of 4,489.30 man-hour, were used on the farm. This was made up of 3,915.56 man-hour of family labour representing about 87% of the total labour used and 573.36 man-hours of hired labour which represented about 13% of the total labour used on the farm. At the N5/per hour wage rate used in the model, the cost of the hired labour for 1990 was N2,866.70 while the opportunity cost of the family labour amounted to N19,579.80.

Table 4.28: Resource use levels in the optimum farm plan.

Resource	Unit	Resource Level
Land	ha	6.47
Labour:		
Family	hr	3915.96
Hired	hr	573.34
Total labour	hr	4489.30
Revenue from maize sale	N	32,571.62
Net farm income	N	25,571.62
Cost of fertilizers	N	4,116.93
Cost of hired labour	N	2,866.70
Cost of family labour	N	19,579.80
Operating capital	N	14,248.56

Labour was a constraint to production in the months of July, August and November. The family labour supply was not able to cope with the demand for labour during these periods and so the family labour had to be augmented by hiring labour. The July-August months correspond to one period of peak demand for labour needed for weeding of maize and sorghum fields and planting of cowpea while the November month correspond to the peak labour demand for harvesting maize, cowpea and sorghum.

The objective function value of ₦25,571.62 represents the difference between the revenue from the sale of maize (₦32,555.19) and the total variable cost consisting of the cost of fertilizers (₦4,116.93) and the cost of the hired labour (₦2,866.70). The amount was the return to owner's land, labour, management and operating capital in excess of satisfying the family food needs.

The operating capital in the optimum plan was ₦14,248.56. The return to farmers land, labour and management was ₦11,323.06. This is much lower than the cost of family labour of ₦19,579.80. Since most of the household members do not offer themselves for wage labour, this return is still reasonable in the sense that the cost of the food crops used in the home have not been included.

The maximum available land of 6.47 ha was used up in producing four crop enterprises defined earlier.

4.5.2 Resource Use Efficiencies

The efficiencies of the farm resources were evaluated by comparing their marginal value products with their unit costs where possible (Table 4.29).

Table 4.29 Marginal value products (MVP) and unit cost of the resources in the optimum farm plan.

Row	Resource	Unit	Marginal Value Product (₦)	Unit Cost (₦)
1	Land	Ha	2969.41	0
2	FL Jan-Apr	Ha	0	5
3	FL May	Ha	0	5
4	FL Jun	Hr	4.12	5
5	FL Jul	Hr	5	5
6	FL Aug	Hr	5	5
7	FL Sept	Hr	0	5
8	FL Oct	Hr	0	5
9	FL Nov	Hr	5	5
10	FL Dec	Hr	0	5
11	Operating Capital	₦	0	0.30
12	N-	kg	2.61	
13	P-	kg	4.44	
14	K-	kg	0.95	
15	MZ-Balance	kg	1.89	0
16	SG-Balance	kg	2.55	0
17	CP-Balance	kg	6.11	0
18	CT-Balance	kg	3.35	0
19	GN-Balance	kg	8.43	0
20	MZ-Cons	kg	-1.89	0
21	SG-Cons	kg	-2.55	0
22	CP-Cons	kg	-6.11	0
23	MZ-Seed	kg	1.89	0
24	SG-Seed	kg	2.55	2.05
25	CP-Seed	kg	6.11	4.93
26	CT-Seed	kg	5.00	3.35
27	GN-Seed	kg	3.35	5.33

The marginal value products of the resources which were also the dual values of the solution were the same as the shadow prices on the disposal activities of the linear

programming model. The shadow prices of the disposal activities show the resources that could best be expanded in order to increase the income from the farm. The shadow prices show the productivity of each resource and thus, how the total income can be expanded by utilizing an additional unit of the resource. The values were zero for excess (slack) resources and positive for the limiting or constraining resources. According to Etuk (1979), the more limiting a resource is, the higher is the marginal value product.

Land resource in Table 4.29 had a very high marginal value product of ₦2,969 which meant that land was a limiting factor in production. It also shows that an additional use of 1 ha of land would increase farm income by ₦2,969. Land rentage as a means of acquiring an additional land was not a common practice in the zone and therefore, it was difficult to compare the marginal value product of land with its unit cost in the study area.

The marginal value product of labour for June, July, August and November were positive meaning that labour was a constraint in these months. For June, the marginal value product (₦4.12) was less than the unit cost of labour (₦5) while for the months of July, August and November, they were equal in each case. In these months, labour was a constraining factor and an additional use of labour by hiring would add ₦5/hr to the total income of the farmer. The months

of January-April, May, September and October were the months when farmers have excess family labour (labour was under-valued in such months).

The marginal value product of capital in the area was zero whereas the interest on borrowed capital was 30%. This shows that there is no market for agricultural capital in the zone. Indeed, there was no capital borrowing from formal credit institution observed in the area. Where borrowing occurred, it was usually from relations and no interest was paid on such loans. The implication of this on farm credit policy is that more farmer education is needed to change this attitude which has its foundation on religion.

The use of additional unit of nitrogen fertilizer would increase farm income by ₦2.61 while the use of additional phosphorus fertilizer would increase the income by ₦4.44. On the other hand an additional unit of K-fertilizer would increase the income by ₦0.95. These show that all the nutrients (N, P and K) were limiting factors to crop production in the zone. The P-nutrient was more limiting than N-nutrient while the K-nutrient was the least limiting. This result was consistent with previous fertilizer response studies which show that the unit response to K was highest in most of the sites. However, it was difficult to compare the marginal value product of the nutrients with their unit costs since the unit costs would depend on the type of fertilizer used as the source of the given nutrient.

4.5.3 Penalties for forcing into the optimum plan excluded activities

The crop enterprises excluded from the optimum plan include those designated as non-basis in the primal solution. They included maize/cotton mixture and maize/sorghum/cowpea mixture. These enterprises were the least profitable and forcing them means a penalty on the objective function in form of a reduction in the net income. The penalty for forcing a unit of maize/cotton mixture on the plan was that the net income would be reduced by ₦661.90 (net return value in the primal solution values) while forcing a unit of maize/sorghum/cowpea mixture would have reduced the net income by ₦1,562.22. If labour was hired in April-May, September, October and December, the income would have reduced by ₦5 per hour while in June it would have reduced by ₦0.88 per man-hour.

Borrowing of a unit of capital would have lowered the net income by 30% or ₦0.3 per Naira borrowed. Purchasing of Calcium Ammonium Nitrate would have reduced the net income by ₦0.12 per unit.

If buying of maize seeds were included, the objective function value would be reduced by ₦3.11 per kg while the inclusions of buying sorghum seeds, cowpea seeds, and groundnut seeds would have reduced the net income by ₦2.45, ₦8.89 and ₦16.65 respectively.

If a unit of sorghum produced was sold, the net income would have increased by ₦0.50 while a unit of cowpea sold would have increased the net income by ₦1.18. On the other hand, a unit of groundnut sold would have increased income by ₦3.10. The purchasing of maize for consumption from the market would have reduced the net income by ₦0.70 per unit while that of sorghum would have reduced net income by ₦0.60 per unit.

4.6 Sensitivity Analysis

The initial farm plan was subjected to four parametric models as described in Table 4.30. The results of the analyses are presented as follows:

Model 3.5.3.1

In this model, the prices of urea, NPK (15:15:15), CAN and SSP were each raised by 150%. That raised the prices of NPK and urea from the initial ₦60/bag each to ₦150/bag each while the prices of SSP and CAN rose from ₦40/bag to ₦100/bag. The price at which maize grains was sold was also increased by 68.8% from ₦189/bag to ₦319/bag.

The optimum plan under this model showed a reorganization of the farm activities and resource use levels. The new plan (Table 4.31) showed that the net farm income increased from ₦25,571.62 to ₦43,664.98. This represented about 71% increase in the net farm income.

Table 4.30 Sensitivity models and the levels of price changes in fertilizers and maize used.

Models	Fertilizer Prices (₦/kg)			Maize selling Price (₦/kg)	% increase
	NPK & Urea	SSP & CAN	% Increase		
Initial Plan	1.2	0.8		1.89	
3.5.3.1	3.0	2.0	150	3.19	68.8
3.5.3.2	4.8	3.2	300	3.19	68.8
3.5.3.3	6.0	4.0	400	3.19	68.8
3.5.4.4	6.0	4.0	400	4.0	111.6

The new plan contained three feasible crop enterprises namely sole maize, sole cowpea and sorghum/groundnut mixtures instead of the five in the initial plan. The level of maize production was increased from 5.282 ha to 6.206 ha. The level of sole cowpea production remained at the same level of 0.264 ha. Although the cultivation of sorghum/groundnut mixture was feasible, no sorghum and groundnut were produced. Sorghum was a mandatory crop for food consumption and it was allowed in the plan to be produced and/or bought using the income derived from the farm. The plan showed that the family had to purchase all the sorghum required for consumption (1,096 kg) at the rate of ₦315/bag of 100 kg. The logic here was since maize command higher price and higher yield per ha, it was economically wiser to produce maize, sell it and use the revenue from the sale to buy sorghum grains.

Table 4.31: Optimum farm organization and existing activity levels when the prices of fertilizers were increased by 150% and that of maize by 68.8%.

Objective function/ Real activity	Existing Activity Level
Objective function	
Total Net Income (₦)	43,664.98
Real Activities - Crop (ha)	
Sole maize	6.206
Sole cowpea	0.264
Sorghum/groundnut mixture	0
Human labour hiring (hrs)	
June	42.07
July	345.11
August	50.69
November	315.65
December	6.43
Fertilizer Purchase (kg)	
NPK 15:15:15	2517.50
SSP (Supa)	29.38
Urea	809.43
Seed buying (kg)	
Cotton seed	0.00
Use of Farmer's owned seed (kg)	
Maize seed	155.00
Sorghum seed	0.00
Cowpea seed	6.61
Groundnut seed	0.00
Crop selling (kg)	
Maize	19,108.65
Cotton	0.00
Crop consumption (kg)	
Maize	830
Sorghum	1096
Cowpea	216
Crop buying (kg)	
Sorghum	1096

The new plan however shows that the increase in maize production would introduce more labour bottleneck to the household labour. Instead of hiring labour in June, July and

August as in the initial plan, labour would be hired in June, July, August, November and December. This means more operating expenses on the part of the farmers. For instance, the cost of hired labour would increase by 32.6% from ₦2,866.70 to ₦3,800 per farm plan. The total labour use would be 4,645.5 man-hours consisting of 3885.5 hrs of family labour and 760 hours of hired labour (Table 4.32).

The same table also shows that the total variable cost would be ₦13,839.40. This would be made up of ₦10,039.4 spent on fertilizer purchases and ₦3,800 spent on hiring labour. In addition, a total of ₦3,452.4 would be spent in buying sorghum grains for family consumption. This would reduce the net farm income since the money spent would be part of the income earned from the farm.

The marginal value product of the land in the model increased from ₦2,969.40 to ₦5598.17. Similarly, the marginal value product of N, P and K increased from ₦2.61/kg, ₦4.44/kg and ₦0.95/kg to ₦6.52/kg, ₦11.1/kg and ₦2.37/kg respectively. The marginal value products of these resource being positive, shows that they are limiting factors in production.

Model 3.5.3.2

In this model, the prices of fertilizer were allowed to increase by 300% from the initial plan prices while maize price remained constant at ₦319/bag. That brought the prices

of NPK and Urea to N300/bag each and that of CAN and SSP to N200/bag each.

Table 4.32: Resource use levels when fertilizer prices were increased by 150% and maize by 68.8%.

Resource	Unit	Level of Usage
Land	ha	6.47
Labour:		
Family	hr	3885.5
Hired	hr	760.0
Total labour	hr	4645.5
Revenue	₦	60,956.60
Cost of fertilizer	₦	10,039.40
Cost of hired labour	₦	3,800.00
Operating capital	₦	14,852.62
Net Farm Income	₦	43,664.98

The resulting optimum farm plan (Table 4.33) is similar to that obtained in model 3.5.3.1. The feasible crop enterprises are the same and they are at the same level of production. All other activities are similar and at the same levels. In terms of resource usage (Table 4.34), the resources and their levels remained the same except expenditure on fertilizer which increased from ₦10,039 to ₦16,057. This represented about 44% increase in the total variable cost over model 3.5.3.1. The net farm income declined from the previous year value to ₦37,647.

Table 4.33: Optimum farm organization and existing activity levels when the prices of fertilizers were increased by 300% and maize remained constant at N319/bag.

Objective function/ Real activity	Existing Activity Level
Objective function	
Total Net Farm Income (N)	43,664.98
Real Activities - Crop (ha)	
Sole maize	6.206
Sole cowpea	0.264
Sorghum/groundnut mixture	0.00
Human labour hiring (hrs)	
June	42.03
July	345.11
August	50.69
November	[illegible]
December	6.43
Fertilizer Purchase (kg)	
NPK 15:15:15	2517.50
SSP (Supa)	[illegible]
Urea	809.4
Seed buying (kg)	
Cotton seed	0.00
Use of Farmer's owned seed (kg)	
Maize seed	155.14
Sorghum seed	0.00
Cowpea seed	6.61
Groundnut seed	0.00
Crop selling (kg)	
Maize	19,108.65
Cotton	0.00
Crop consumption (kg)	
Maize	630
Sorghum	1096
Cowpea	216
Grain buying (kg)	
Sorghum	1096

Table 4.34: Resource use levels when the prices of fertilizer were increased by 300% and maize remained at N319/bag.

Resource	Unit	Resource Use Level
Land	Ha	6.47
Labour:		
Family	hr	3885.5
Hired	hr	760.0
Total labour	hr	4645.46
Revenue from maize	N	60,956.60
Cost of fertilizer	N	16,057.32
Cost of hired labour	N	3,800.00
Operating capital	N	14,857.32
Net Farm Income	N	33,647.14

The increase in cost brought about by the increase in the prices of fertilizer resulted in a lower net farm income of N33,647.14 i.e.,8% lesser. The non-optimal effect of an increase in the prices of fertilizers without a corresponding increase in the price of maize will result in lower net farm income even though the level of real activities and resource use remained the same.

Model 3.5.3.3

In this model, the prices of fertilizers were increased by 300% from the initial plan prices while that of maize sales remained constant. That meant that urea and NPK were sold at N240/bag, CAN and SSP were each sold at N160/bag while maize was sold at N319/bag.

The resulting optimum farm plan (Table 4.35) is similar in all respect to that obtained in models 3.5.3.1 and 3.5.3.2. However, the net farm income would be decreased further as a result of the further increase in the prices of fertilizers. The net farm income would be ₦33,625.45 instead of the ₦37,647.14 in model 3.5.3.2.

There was 11% reduction in the net farm income over model 3.5.3.2 as a result of the 25% increase in the total cost of fertilizers from ₦16,057 to ₦20,079 (Table 4.36).

The marginal value product of land fell from ₦4,643 to ₦4007 while that of potassium dropped from ₦4.90/kg to ₦3.05/kg. On the other hand, the marginal value products of N and P increased from ₦10.43 to ₦13.04/kg and from ₦16.67 to ₦22.22/kg respectively.

The marginal value product of labour remained the same at ₦5/man-hour. The factors of production that were limiting production in the last model were also limiting production in this model.

Model 4.5.3.4

In this model, the price of fertilizer remained at ₦300/bag each for NPK and Urea and ₦200/bag for CAN and SSP while the price of maize was increased from ₦319/bag to ₦400/bag. This increase was 112% over the initial plan prices and 25.4% over the last model price.

Table 4.35: Optimum farm organization and existing activity levels when the prices of fertilizers were increased by 400% and maize remained constant at ₦319/bag.

Objective function/ Real activity	Existing Activity Level
Objective function	
Total Net Farm Income (₦)	33,625.45
Real Activities - Crop (ha)	
Sole maize	6.206
Sole cowpea	0.264
Sorghum/groundnut mixture	0.00
Human labour hiring (hrs)	
June	42.07
July	345.11
August	50.69
November	315.65
December	6.43
Fertilizer Purchase (kg)	
NPK 15:15:15	2517.50
SSP (Supa)	29.4
Urea	809.4
Seed buying (kg)	
Cotton seed	0.00
Use of Farmer's owned seed (kg)	
Maize seed	155.14
Sorghum seed	0.00
Cowpea seed	6.61
Groundnut seed	0.00
Crop selling (kg)	
Maize	19,108.65
Groundnut	0.00
Crop consumption (kg)	
Maize	830
Sorghum	1096
Cowpea	216
Grain buying (kg)	
Sorghum	1096

Table 4.36: Resource use levels when the prices of fertilizer were increased by 400% and maize remained at ₦319/bag.

Resource	Unit	Resource Use Level
Land	Ha	6.47
Labour:		
Family	hr	3885.5
Hired	hr	760.0
Total labour	hr	4645.5
Revenue	₦	60,956.60
Cost of fertilizer	₦	20,079.00
Cost of hired labour	₦	3,800.00
Operating capital	₦	14,854.39
Net Farm Income	₦	33,625.45

The new optimum farm plan (Table 4.37) is similar in all respect to the last model optimum plan. The enterprises and other real activities remained the same while the resource usage was also the same (Table 4.38).

However, the net farm income would increase from ₦33,625.45 to ₦49,103.46. The revenue would increase by 25% from ₦60,956.60 to ₦76,434.60 while the net farm income would increase by 46% over the last model. The marginal value product of land would increase from ₦4,006.86 per ha to ₦6,609.39 per ha.

The same factors of production that limited production in the last model were also limiting production in this model.

Table 4.37:Optimum farm organization and existing activity levels when the prices of maize was increased by 111.6% while fertilizers remained at ₦300/ bag for NPK and urea and ₦200 for CAN and SSP.

Objective function/ Real activity	Existing Activity Level
Objective function	
Total Net Farm Income (₦)	49,103.46
Real Activities - Crop (ha)	
Sole maize	6.206
Sole cowpea	0.264
Sorghum/cotton mixture	0.00
Human labour hiring (hrs)	
June	42.07
July	345.11
August	50.69
November	315.65
December	6.43
Fertilizer Purchase (kg)	
NPK 15:15:15	2517.50
SSP (Supa)	50.69
Urea	315.65
Seed buying (kg)	
Cotton	0.00
Use of owned seed (kg)	
Maize	155.14
Sorghum	0.00
Cowpea	6.61
Groundnut	0.00
Crop selling (kg)	
Maize	19,108.65
Groundnut	0.00
Crop consumption (kg)	
Maize	830
Sorghum	1096
Cowpea	216
Grain buying (kg)	
Sorghum	1096

Table 4.38:Resource use levels when the prices of maize was increased by 111.6% while that of fertilizers remained at ₦300/bag for NPK and Urea and ₦200/bag for CAN and SSP.

Resource	Unit	Use Level
Land	Ha	6.47
Labour:		
Family	hr	3885.5
Hired	hr	760.0
Total labour	hr	4645.5
Revenue	₦	76,434.60
Cost of fertilizer	₦	20,079.00
Cost of hired labour	₦	3,800.00
Operating capital	₦	507.07
Net Farm Income	₦	49,103.46

Under an assumption of limited available farm land for production, the total mean hectarage of all the enterprises in Table 4.7 which is 2.76 ha was used for the initial plan. The results of the optimum farm organization (Table 4.39) show that the net income of the farmer was reduced from the ₦25,571 to ₦8,783. The feasible enterprises were reduced from five to four. There was no labour limitation as family labour provided all the needed labour force on the farm (Table 4.40). In terms of the available land, all was used up.

This result shows that under a land constraint, labour is not a constraint to production, in a small holder

agriculture however because of low capital input, the net farm income is always very low?

Table 4.39: Optimum organization of the representative farm and existing activity levels under a land constraint, NGS, Nigeria, 1990.

Objective function/real activity	Existing activity
Objective function	
Total Net Income (₦)	₦8,782.56
Real Activities	
Crop (h)	
Sole sorghum	1.950
Sole cowpea	0.545
Sorghum/groundnut mixture	0.264
	0.0
Fertilizer purchased (kg)	
NPK 15:15:15	
SSP (Supa)	931.71
Urea	29.38
	292.32
Real Buying (kg)	
Cotton seed	
	0.00
Use of Farmer's owned seed (kg)	
Maize seed	48.76
Sorghum seed	8.18
Cowpea seed	6.61
Groundnut seed	0.00
Crop selling (kg)	
Maize	5436.46
Cotton	0.00
Crop consumption (kg)	
Maize	831
Sorghum	1096
Cowpea	216

Table 4.40: Resource use levels under a limited land *constraint, NGS, Nigeria, 1990.*

Resource	Unit	Use Level
Land	Ha	2.76
Labour:		
Family	hr	1864.15
Hired	hr	0.00
Total labour	hr	1864.15
Revenue	₦	10,274.90
Cost of fertilizer	₦	1,492.34
Cost of hired labour	₦	0.00
Total operating capital	₦	6,177.40*

**include cost of spraying, handling and transportation charges on fertilizer and seed treatment.*

The results from the linear programming analysis show that a farmer who plans his farm properly would utilise his resources better in terms of income and operating expenses. Thus, through farm planning, the farmer's income was more than when it was unplanned. His operating expenses was also lower because resources were more efficiently used. The sensitivity analysis also showed that, the farmers' net income is highly dependent on the prices of fertilizer and cash crops. Thus, a substantial increase in the price of fertilizers would reduce farmers income drastically while an increase in the price of the produce will increase it. There is therefore, a need to balance the issue of fertilizer subsidy removal with the market prices of the major cash crops.

Chapter 5

SUMMARY, POLICY IMPLICATIONS, LIMITATIONS AND SUGGESTIONS FOR FURTHER STUDY

5.1 Summary

The average size of the farm household in the study area was nine people and the farm labour force was provided mainly by the farm family.

The main form of land ownership among the respondents was by inheritance. However, some land borrowing from relations and very little purchase was practised. The implication of this finding is that commercial production will be rare, since farm expansion through land acquisition by purchase is almost impossible. This is aggravated by the customary tenure system prevalent in the area and the highly fragmented and scattered holdings which results in waste of time spent travelling between farms and the homes.

It was observed that not all farms cultivated were owned by the cultivator/operator. This was attributed to the *gandu* system in which *gandu* members other than the head may not operate farms of their own unless they are adults and married. The maximum land devoted to any crop enterprise in the study area was 6.47 ha while the minimum was 0.01 ha. However, the total mean hectare devoted to all the crop crop enterprises was 2.76 ha.

Seventeen crops were grown in the study area in 98 crop enterprises and out of the crop enterprises, twenty-six (26) were maize-based while sixteen were sorghum-based. The crop enterprises which were common to at least four of the five study villages were sole maize, sole sorghum, sole cowpea, maize/sorghum, sorghum/groundnut and maize/sorghum/cowpea mixtures while maize/cotton mixture was very important in three of the five study villages.

The physical factors which determine the type of crops grown were rainfall pattern and distribution, the type of soil in terms of physical properties and fertility, and the availability of fertilizers. The rainfall pattern was only important for short season crops like cereals, legumes and vegetables such that in bad years (drought) sorghum was always preferred as the alternative crop to maize by farmers because of its relative drought tolerance. The dominant soil types are loamy and sandy loam soils which are suitable to the crops grown. The relatively more fertile soils were devoted to the production of maize in the absence of fertilizers to apply while the relatively poor soils were used to grow millet and sorghum which were found to be less demanding in nutrient requirement.

The social factors which determined crop choice was the need to be self-sufficient in feeding one's household. Towards this goal, all the farmers grew their own food crops

mainly sorghum, maize and some cowpea. Sorghum meals were preferred over maize meals (especially tuwo) for ease of preparation, better taste, more energy, better storage and more flour. However, maize was said to have more usage in terms of meal types and also better appeal. In addition, maize was regarded as the crop that 'quench hunger' since those grown early in the season is the main source of food between the months of July and November when the old sorghum stock would have been exhausted. Cowpea was grown mainly to supplement protein requirement of the households since meat, egg and milk were consumed occasionally, usually at festival and ceremonial times and when special visitors arrived.

Political considerations did not feature much on the crop choice decisions in the study area. However, when the campaign for wheat programme was on, a few of the farmers participated in order to get fertilizers for their use on other crops.

The main economic factors which affected crop choice was availability and prices of inputs and the products. For the seeds, most of the farmers used improved varieties (over 50%). However, most of them used previous year's harvest for the next season and therefore rarely buy seeds for which they have stock. Labour was hired only at peak periods when family labour could not cope with the competing demands for farm work. The ever increasing cost of hired labour (wage) has

made farmers to drop highly labour intensive crops like groundnut and cotton. Fertilizer was bought and used by all farmers in the study area. However, the level of usage was hampered by non-availability rather than by the prices. Although crop price was an economic factor that determined crops to be grown, it was the unanimous view of the farmers in the study area that for food crops like sorghum and maize that price factor was not important because if the crops produced were not sold, they would be kept for consumption in the following year. However, the prices of cash crops like cotton, pepper, sugarcane etc. in the previous season determine whether or not and how much of the crop to produce the following year. Credit availability determined crop choice in the area only to the extent of financing immediate farm operations. Most farmers relied on the sale of last season's harvest either in piecemeal or in whole to finance farm operation when the need arises. There was hardly any borrowing of funds which involved interest payment among the farmers. Where the need became inevitable, farmers have sold one or two domestic animals especially bulls, sheep and goats and used such money or offered themselves for wage labour (*gandu* members and small-scale farmers) or borrowed from relatives at no interest charge to finance farm operations.

Agronomic characteristics of crops was one of the main determinants of fertilizer requirements of a crop. Farmers believed that shallow rooted crops like cereals, vegetables

and legumes require more fertilizers than deep rooted crops like tubers because the nutrient level of the surface soil was lower than that of the sub-surface soils. Not only that, they also believed some crops cannot do well without the application of fertilizers. For this reason, they always applied fertilizer to maize in form of organic, inorganic or both.

The fertility status of the soil which was mostly judged by its colour was often considered in determining the amount and type of fertilizer to apply. Black and red soils were said to be more fertile than stony and white soils. The supposedly more fertile soils received less fertilizers per crop and often in the form of organic fertilizer than the poorer soils. However, the farmers were found not to bother about the recommended rates of nutrients applied. They relied on the observed performance of the growing crop based on past experience with the crop to know whether or not sufficient quantity of fertilizer has been applied. This situation, often lead to over or under application of fertilizers in crop production among farmers. Economic consideration in fertilizer use by farmers in the zone was concerned more with availability than the unit prices. Farmer accorded the highest priority to the problem of availability at the right time. This was followed by the problem of capital to purchase them while the least problem identified by the farmers was the price per unit. It was argued that since they have to

farm, they must use fertilizers and they can only use them if they are available for sale. If they must farm therefore, they must find the money to buy them. However, they all agreed that high prices would reduce the scale of fertilizer application and consequently, the type of crop grown and the size of land cultivated.

The supplementary relationship between organic and inorganic fertilizers was fully utilized by farmers in the zone to cut down cost of fertilization and to reduce the problem of scarcity of inorganic fertilizer. Towards this end, all farmers used organic fertilizer in the form of farm yard manure consisting of cow dung, house sweeps and other animal droppings on small or nearby sorghum, millet and sugarcane fields. On maize fields where they were used, inorganic fertilizers were often used in addition which suggest that the sustainability of maize production in the zone depends solely on the continued availability and use of inorganic fertilizers.

The physico-chemical properties of the study villages showed that all of the sites fell into the low nitrogen level status using the total N. For phosphorus status, Daudawa and Samaru fell into the medium fertility while Maigana fell into the low fertility status when the Bray-I-P was used as the measure. In terms of potassium status, the exchangeable cation measure indicated that all sites fell into the low

status. Consequently, reasonable responses to N, P and K were expected for maize in all the sites.

For nitrogen response, the mean N-level used for each village was 150 kg/ha. However, the technical optimum level were 95 kg/ha for Samaru, 103 kg/ha for Maigana and 107 kg/ha for Daudawa while the economic optimum levels were 110 kg/ha for Samaru, 120 kg/ha for Maigana and 114 kg/ha for Daudawa. In the case of phosphorus response, the mean level of usage was 64 kg/ha for all sites although the technical optimum usage were 64 kg/ha for Samaru, 57 kg/ha for Daudawa and 48 kg/ha for Maigana while the economic optimum levels were 42 kg/ha for Samaru, 56 kg/ha for Daudawa and 50 kg/ha for Maigana. In all cases, the rates obtained were close to the 60 kg/ha recommended for maize by IAR. The mean level of potassium usage was 95 kg/ha for all the sites. However, the technical optimum level was 58 kg/ha for Samaru, and 63 kg/ha for Maigana while the economic optimum levels were 78 kg/ha for Samaru, 66 kg/ha for Daudawa and 82 kg/ha for Maigana. In the case when all the three elements, N,P and K were varied simultaneously the technical optimum was found to be between 100-40-60 and 150-60-90 kg/ha but the economic analysis showed that the profit was maximized for each village at 150-60-90 kg/ha of N,P and K respectively.

The linear programming solution of the farm model shows that the average farmers who had 6.47 hectare of land could

grow sole maize, sole sorghum, sole cowpea, and maize/sorghum mixtures and obtain a net farm income of ₦25,572.00. However, where he has only 2.76 hectare, he would cultivate the same sole maize, sole sorlghum and sole millet and obtain a net farm income of ₦8,782.56.

The sources of N, P and K fertilizers used by farmers in the model were NPK 15-15-15, single superphosphate and urea most of which were bought from the open market. Farmers used seeds preserved from previous year's harvest for all the crops grown. Maize was the only crop sold and therefore the cash crop of the farm households. The food requirements of the farm households consisting of seven consumption unit were met by consuming 830 kg of maize (8 bags), 1096 kg of sorghum (11 bags) and 216 kg of cowpea (2 bags) per year which were all produced from the farms.

The farm household relied mainly on family labour (87%) for farm activities and only augment by hiring labour (13%) at the peak of labour needs in the months of July, August and November.

The initial operating capital is often small. However, as the farming season progresses, revenue from maize sales of previous year is injected into the capital base of the farm.

The limiting resources to crop production in the zone

were land which has high shadow prices, and June, July, August and November labours. Fertilizer nutrients were also limiting factors to crop production especially for maize. The marginal value products of N, P and K were ₦2.61, ₦4.44 and ₦0.95 respectively compared with the unit price of maize which was ₦1.89. This gave nutrient crop price ratios of 1.4:1, 2.35:1 and 0.50:1 for N, P and K respectively which except for *P* was far lower than the ratio of greater than 2:1 suggested by Vachhrajani (1990). An increase in the prices of N, P and K sources through an increase in the prices of all brands of fertilizers and an increase in the price of maize grains would result in a lower net farm income and higher nutrients-crop price ratios. Increasing the prices of fertilizers would result in the production of sole maize and sole cowpea enterprises while sorghum would no longer be produced by the farmer but purchased from the market for household consumption. More maize would be produced which would increase the net farm income of the household. However, the increase in maize production would introduce additional labour constraint in the months of June, and December. Thus, to improve the net farm income substantially calls for reorganization of farms along sole cropping line, a situation which is different from existing practices.

For instance, with 400% rise in the prices of the fertilizers and 112% rise in the price of maize grain the net farm income increased to ₦49,104 while the nutrient crop

price-ratios declined slightly to 3.26:1 for N, 5.56:1 for P and 1.18:1 for *K*.

5.2 Policy Implications of the Study

There are many findings from the study which have policy implications.

1. The finding that the average household size was nine and that 54 per cent of the respondents were dependent have implications for farm technology usage and the orientation for production. The basic goal of the farm household has to be how to produce enough food crops to feed the household members. Since the working population is low, improved production technologies must be used to produce over and above what is required in the home. In addition, policies which will reduce family size, train and create skills among household members will reduce dependency ratio. It was not therefore surprising that the seventeen crops grown in the area were grown in as much as ninety-eight different crop enterprises in order to provide a wider choice of food varieties. While maize and sorghum crops formed the basis for the food crops, maize was the dominant cash crop in the zone. Economic considerations, especially crop prices were hardly considered by farmers when it comes to the choice of food crops. This implies that specialization of crop production among farmers which

is being advocated by government will continue to suffer setbacks because price which is normally the driving force behind specialization is ignored by the farmers for their own food crops.

2. The finding that farm ownership through inheritance and borrowing from the family members accounted for 97 per cent of land transactions implies that land fragmentation and small size of holdings are still much practised in the zone. This is out of tune with the land use act of 1976 which allowed land ownership through lease within the customary land tenure system (which is the dominant form of land tenure in the area). The farmers are not utilizing the opportunities for increase in farm size and farm consolidation offered in the act by leasing or buying farm lands. In deed, there was neither market for farm land nor any form arrangement for land consolidation such as cooperative farming in the study area.

3. Farm credit borrowing from commercial sources to finance farm operations was rare among the farmers in the zone because of religious rather than economic reasons. This has implication for farm size and investments in that only farmers who are already rich can probably expand their farm and carry out new investments and initiatives. The poor farmers, for lack of enough investment capital, and the unwilling-ness to

borrow credit on interest payment basis, would continue to operate small farms basically for subsistence and make little income for other family needs from the farm i.e. they will remain in the vicious cycle of poverty and Nigeria will continue to face food problems as a nation. Thus, for these categories of farmers to benefit from credit policies, their production goals and religious orientation towards investment credit must be changed or in the alternative establish an interest-free Islamic banking - a profit sharing arrangement.

4. The findings that continuous land cultivation was a major practice in the zone and that the practice has been sustained through soil fertility maintenance by using organic and inorganic fertilizers have implications. The first implication is that both organic and inorganic fertilizers must be made available for production to be sustained. In the case of organic fertilizers in form of farm yard manure, compost and animal droppings, the scale of usage is limited to small farms, usually to those near homes because of their bulkiness and by the fact that they are slow to act due to the time taken to decompose and release the nutrients into the soil. In the case of inorganic fertilizers, its availability is the main constraint to its usage and the farmers were willing to use it

irrespective of the prices especially on maize, for which they know they will sell and make money to cover their cost. The second implication is that the on-station recommendation for fertilizer rates currently in use for maize in the zone needed re-validation. The result shows that the current economic levels of N and P were satisfactory at 120 kg/ha and 60 kg/ha respectively given site location differences in the zone. However, the economic rate for K, needs to be increased from 60 kg/ha to 90 kg/ha. The technical rates for N, however was lower than the recommended rate.

5. The low nutrient fertilizer-crop price ratios in use by farmers in Nigeria was confirmed by the result of the solution to the initial LP model in which the nutrient-crop price ratios for maize were 1.38:1 for N, 2.35:1 for P and 0.50:1 for K which except for P were all lower than the recommended ratio of greater than 2:1 for any crop. The implication is that the prices of the fertilizers needed to be increased which is why the subsidy on them is being suggested to be reduced. The sensitivity analyses showed that this suggestion might have some merit in that raising the ratios up to 3.25:1 for N, 5.56:1 for P and 1.18:1 for K by selling NPK and Urea at ₦300/bag each, CAN and SSP at ₦200/bag each and maize grain at ₦400/bag, the farmers can still make a net farm income of ₦49,104 from using 6.47 ha (or

₦17,030 from 2.76 ha). The farmer, in spite of this high net farm income would have been able to feed the household members of nine people with the minimum requirements of maize and cowpea produced on the farm and would also have purchased with the income earned enough sorghum from the market for the family consumption throughout the year.

5.3 Conclusion

The conclusions from the study are that food and cash needs were the main determinants of crop choice among farmers in the area. To this extent, food crops were grown without consideration of their market prices while cash crops were grown based on the performance of their prices in the markets. Inorganic fertilizer use was and would remain the main driving force behind maize production in the zone. The present nutrient-crop price ratios for maize were low and shows that they are inefficiently used. This calls for a reduction in the subsidy level on fertilizers. However, because this study was based on a year's data, it cannot recommend the level of subsidy to be maintained by government. Farms were not efficiently organized presently and reorganization would result in lesser enterprises but higher income as a result of more efficient utilization of the farm resources.

5.4 Limitations of the Study and Suggestions for Further Studies

The validity of the results of a study depend much on the accuracies of the data used and the assumptions made about them. In this study, many hands, some whom have to depend on interpreters were used in collecting the various data. This may introduce individual biases arising from interpretation and measurement errors into the data. These biases were assumed to be randomly distributed and the effects cancelled out one another. Similarly, the farmers sampled cut across different categories of farmers with their own biases. Again, these biases were assumed to be random and cancelled out one another such that in the end, the data were as accurate and as representative as possible.

The fertilizer response data were based on a two year experimental trials. However, for climatic reason, the second year data were not used because it differed significantly from the first year data and the results were quite different as shown. The limitation therefore is that this analysis cannot adequately describe the response of maize to fertilization in the zone as average response over the years would have been preferred. Besides, farm level response was not determined since farm level fertilizer use data were not available. There is need to do this in the future.

The linear programming model was based on the representative farm which in reality is non-existent. The interpretation of the results and their applications on a wider basis would have to be done with caution. For instance, some of the technical coefficients were adjusted to reflect average input-output coefficients obtained in the zone from previous studies rather than using what was obtained in this study. The initial linear programming analysis was based on a static equilibrium analysis whereas in practice or in the real world, the farmer is faced with a dynamic situation in which many economic and non-economic variables are changing. For instance, the sensitivity analyses were based on the assumptions that it is either the price of maize or fertilizers or both that change at once while the other prices remained the same. This assumption ignores the competitive, complementary and supplementary relationships between the crops and other inputs involved. These relationships need to be investigated in a future study. In spite of all these limitations, the results from the study have provided useful insights into the crop choice and crop fertilizer use decisions of the farmers, the importance of maize in the cropping system as well as the role of inorganic fertilizers in sustaining maize production in the northern guinea savanna of Nigeria.

Fertilizer response studies are continuous for the sake of updating information available on soils and therefore it

is suggested that further work should be done on it. The data for one season cannot accurately show the impact of subsidy on a crop production because of the continuous price changes in both input and output. Therefore, a research covering several years may be needed to reach a conclusion on the impact of subsidy removal.

BIBLIOGRAPHY

Ahmed, B. 1985. "Scale economies in maize production: A case study of Daudawa farms in Kaduna State". Unpublished M.Sc Thesis, Department of Agricultural Economics and Rural Sociology, Ahmadu Bello University, Zaria, Nigeria.

Andre Guinard. 1982. Economic optimization of fertilizer application: A method for field staff based on response curves and surfaces. *Trop. Agric* (Trinidad) Vol. 59 No.3.

Baker, E.F.I. 1975. "Effects and interactions of package deal input on yields and labour demand of maize. *Expl. Agric.* 11pp, 295-304.

Balasubramanian, V., L.A. Nnadi and A.U. Mokwunye. 1978. Fertilizing sole crop maize for high yields. *Samaru Miscellaneous Paper* 76. I.A.R., A.B.U., Zaria, Nigeria.

Balcet Jean-Claude and W. Candler. 1982. Farm technology adoption in Northern Nigeria, Department of Agricultural Economics, Cornell University.

Beneke R.R. and R. Winterboer. 1973. *Linear programming applications to agriculture.* The Iowa State University Press, Ames.

Cooke, G.W. 1982. *Fertilizing for maximum yield.* Granada Publishing, London.

Enwezor, W.O., E.J. Udo, N.J. Usoroh, K.A. Ayotade, J.A. Adepetu, V.O. Chude and C.I. Udegbe (editors). 1989. *Fertilizer use and management practices for crops in Nigeria.* Series No. 2, Fertilizer Procurement and Distribution Division, Federal Ministry of Agriculture, Water Resources and Rural Development, Lagos.

Etuk, E.G. 1979. Micro-economic effects of technological change on smallholder agriculture in Northern Nigeria: A linear programming analysis. Unpublished Ph.D Dissertation submitted to the Department of Agricultural Economics, Michigan State University.

Falusi, A.O. 1973. Economics of fertilizer distribution and use in Nigeria. Unpublished Ph.D Thesis. Cornell University.

Federal Office of Statistics. 1983. Survey of modern holdings of agriculture 1981/82. Agricultural Survey Unit, Lagos.

Food and Agricultural Organization (FAO) and World Health Organization (WHO). 1973. "Energy and protein requirements". Report of joint FAO and WHO ad-hoc Committee, Rome.

Hazel, P.B.R. and R.O. Norton. 1986. *Mathematical programming for economic analysis in agriculture*, Macmillan Publishing Company, New York.

Heady, E.O. and W. Candler. 1973. *Linear programming methods.* Iowa State University Press, Ames, Iowa.

Heady, E.O. and J.L. Dillon. 1961. Agricultural production functions. Iowa State University Press, Iowa.

Hopper, W.D. 1965. Allocation efficiency in a traditional Indian agriculture. *Journal of Farm Economics*, 47(3).

Idachaba, F.S. 1987. "State-Federal relations in Nigerian agriculture". MADIA Working Paper. The World Bank, Washington D.C.

Institute for Agricultural Research Samaru and International Institute of Tropical Agriculture. 1989. "Some characteristics of different representative villages in Northern Guinea Savanna of Nigeria.

Kassam, A.H., J.K. Kowal, M. Dagg and M.N. Harrison. 1975. "Maize in West Africa and its potential in savanna areas". *World Crops*, March-April.

Khan, A.S. 1974. "Derivation of fertilizer-crop response and optimum levels of fertilization for various crops/areas." Department of Agricultural Economics, University of Agriculture, Lyallpur.

Lombin, G., V.O. Chude, E.N.O. Iwuafor and A.D. Barau. 1989. "NPK calibration studies on maize". Summary Report, IAR, ABU, Zaria.

Low, A.R.C. 1974. Linear programming as a tool in innova-tion selection for farm in S.E. Ghana in planning in low income countries: A Symposium Development Study No.14, Reading.

Millers, W.L. and D.M. Byers. 1976. Development and display of multiple objective project impacts. *Water Resources Research* 9(1).

Mudahar, M.S. 1974. Dynamic analysis of direct and indirect implications of technological change in agriculture: The case of Punjab, India. Occasional Paper No.79, Department of Agricultural Economics, Cornell University.

Norman, D.W. 1972. "An economic survey of three villages in Zaria Province. 2. Input-output study Vol.1. Text". *Samaru Miscellaneous Paper 37*, I.A.R., A.B.U., Samaru.

Norman, D.W. 1973. Economic analysis of agricultural production and labour utilization among the Hausa in the North of Nigeria. African Rural Employment Paper 4. Michigan State University.

Norman, D.W., P. Beeden, W.j. Krocker, D.H. Pryor, H.M. Hays and B. Huizinga. 1976. "The feasibility of improved sole maize production technology for small scale farmers in Northern Guinea Savanna".

Ogunfowora, Bisi. 1992. Derived resource demand, product supply, and farm policy in the North Central State of Nigeria. Unpublished Ph.D Dissertation. Iowa State University.

Ogunfowora, Bisi. 1993. "Analysis of fertilizer supply and demand in Nigeria." Paper presented at the symposium on alternative pricing and distribution systems for fertilizer in Nigeria.

Ogungbile, A.O. and O.O. Ologunde. 1986. Economic analysis of fertilizer research on maize in two locations in the Southern Guinea Savanna of Nigeria. *Samaru J. Agric. Res.* 4 (1&2).

Okon, Sunday. 1989. An economic analysis of small-scale mixed farming system: The case of farm crop/livestock enterprises in Giwa District of Kaduna State. Unpublished Ph.D Thesis, Department of Agricultural Economics and Rural Sociology, Ahmadu Bello University, Zaria.

Ologunde, O.O. 1987. "Two decades of agronomic research on yield improvement of sole crop maize (*Zea mays L.*) in the savanna ecological zone of Northern Nigeria - A review". *Samaru Miscellaneous Paper* 118.

Paschal, J.L. and B.L. French. 1956. A method of economic analysis applied to nitrogen fertilizer rate-experiments on irrigated corn. *Technical Bulletin No. 1141.* U.S.A. Department of Agriculture, Washington, D.C.

Rastogi, B.K. 1980. Cropping patterns, farming practices, and economics of major crops in selected dryland farming regions of India. In *Socio-economic constraints to development of semi-arid tropical agriculture.* A proceedings of International workshop held at ICRISAT, Patancheru, India.

Sankhayan, P.L. and H.S. Cheema. 1991. "Using linear programming models for generating optimum farm plans: An expository analysis". *Ind. Jn. of Agric. Economics* Vol. 46 No.4.

Sodangi, S.T. 1981. "Fertilizer distribution and use in Nigeria: Problems in the development of increased consumption". An invited paper presented at the ISMA Conference held in Rome, Italy.

Thampapillai, D.J. 1978. Methods of multiple objective planning: A review. *World Agricultural Economics and Rural Sociology Abstract* 20(12).

Uma Lele, R.E. Christiansen and K. Kadiresan. 1989. "Fertilizer policy in Africa: Lessons from development programs and adjustment lending, 1970-87". *Managing Agricultural Development in Africa* (MADIA) *Discussion Paper* 5. The World Bank, Washington D.C.

Upton, M. 1974. Some of the problems in using planning techniques. Development study No. 14. Reading.

Vachhrajani, N. 1990. "Fertilizer subsidy management scheme for Nigeria". Mimeograph, World Bank, Washington, D.C.

Wedderburn, S., J.Bamidele and C. Okonjo. 1988. "Crop yield response to fertilizer use at selected ADPs". Agricultural Projects Monitoring, Evaluation and Planning Unit, Federal Department of Rural Development, Kaduna.

Wolf, E.R. 1966. *Peasants.* Prentice Hall Inc.

Zalla, T., R.B. Diamond and M.S. Mudahar. 1977. Economic and technical aspects of fertilizer production and use in Africa. *African Rural Economy Program Working Paper No.22.* Department of Agricultural Economics, Michigan State University, East Lansing, Michigan.

APPENDICES

The appendices in this study are concerned with test of variances between the 1990 and 1991 fertilizer response data for the N,P,K and NPK treatments respectively. In this test, we tried to establish if there was a uniformity between the data sets of 1990 and 1991 for each village and treatments. The test of equal variance is given by

$$U_1 - U_2 = d_o$$

and

$$t = \frac{(\bar{x}_1 - \bar{x}_2) - d_o}{S_p\sqrt{(\frac{1}{n_1}) + (\frac{1}{n_2})}}$$

$$V = n_1 + n_2 - 2$$

and

$$S_p^2 = \frac{(n_1-1)S_1^2+(n_2-1)S_2^2}{(n_1+n_2)-2}$$

where

U_1 and U_2 are the means for the two populations 1 and 2.

d_o is the variance

t = is the appropriate student t at a chosen probability level(s) and a given degree of freedom (V). ∞ is either 5% or 1%.

$\bar{x}_1$ and $\bar{x}_2$ are sample means for sample 1 and 2 respectively.

n_1 = the sample size of the 1st population

n_2 = the sample size of the 2nd population

S_1^2 = variance of the 1st sample

S_2^2 = variance of the 2nd sample.

P = the pooled data.

Ho : $U_1 - U_2 = 0$ (null hypothesis)

Ha : $U_1 - U_2 = d_o$ (alternative hypothesis).

Decision Rule: Reject Ho if $t_c \infty V < t$

where t_c = calculated t

t = table value.

Let the maize yields in Samaru in the 1st year be C11 and Samaru in the 2nd year be C12. Also let the maize yield in Daudawa in the 1st year be C21 and in the 2nd year be C22 while the yields in Maigana in the first year be C31 and in the 2nd year be C32.

t 0.05, 40 = 2.021
t 0.01, 40 = 2.704

* = Significant at 1% level of probability.
** = Significant at 5% level of probability.

APPENDIX A. This represents the variances in nitrogen data.

Appendix A1 (Samaru).

$$C_{11} - C_{12} \quad t_{c11} - C_{12} = \frac{3.191-2.784}{S_p\sqrt{(\frac{1}{21}) + (\frac{1}{21})}} = \frac{0.407}{S_p 0.309}$$

$$S_p^2 = \frac{20(0.732)^2 + 20(0.736)^2}{40} = 0.539$$

$$t_c = \frac{0.407}{0.734 \; x \; 0.309} = 1.793$$

Decision Rule: Accepts Ho and Reject Ha.

Appendix A2 (Daudawa)

$$C_{21} - C_{22}, \quad t_c = \frac{2.441 - 1.591}{S_p\sqrt{0.095}} = \frac{0.85}{S_p \; x \; 0.309}$$

$$S_p^2 = \frac{20(0.583)^2 + 20(1.591)^2}{40} = \frac{6.798 + 50.63}{40}$$

$$S_p^2 = 1.436$$

$$S_p = \sqrt{1.436} = 1.198$$

$$t_{C_{21-22}} = \frac{0.85}{1.198 \times 0.309} = 2.296^{**}$$

Decision Rule: Reject Ho and Accept Ha.

Appendix A3 (Maigana)

$$t_{C_{31-32}} = \frac{3.332 - 2.076}{S_p\ 0.309} = \frac{1.256}{S_p\ 0.309}$$

$$S_p^2 = \frac{20(0.511)^2 + 20\ (0.992)^2}{40} = \frac{5.222 + 19.68}{40}$$

$$S_p^2 = 0.623$$

$$S_p = \sqrt{0.623} = 0.789$$

$$t_{C_{31-32}} = \frac{1.256}{0.789 \times 0.309} = \frac{1.256}{0.244} = 5.148^{*}$$

Decision Rule: Reject Ho and Accept Ha.

APPENDIX B. This represents the variances in the phosphorus data.

$$t_{0.05,\ 34} = 2.04$$

$$t_{0.01,\ 34} = 2.75$$

Appendix B1 (Samaru)

$$t_{c11-c12} = \frac{3.411 - 2.357}{S_p\sqrt{(\frac{1}{18}) + (\frac{1}{18})}} = \frac{1.054}{S_p\sqrt{\frac{2}{18}}} = \frac{1.054}{S_p\sqrt{0.333}}$$

$$S_p^2 = \frac{17(0.702)^2 + 17(0.766)^2}{34} = 0.54$$

$$S_p = \sqrt{0.54} = 0.73$$

$$t_c = \frac{1.054}{0.73 \times 0.333} = 4.34^*$$

Decision Rule: Reject Ho and Accept Ha.

Appendix B2 (Daudawa)

$$t_{c21-c22} = \frac{2.216 - 1.893}{S_p\ 0.333} = \frac{0.323}{S_p\ 0.333}$$

$$S_p^2 = \frac{17(0.363)^2 + 17(0.811)^2}{34} = 0.395$$

$$S_p = \sqrt{0.395} = 0.63$$

$$t_c = \frac{0.322}{0.63 \times 0.333} = 1.54$$

Decision Rule: Accept Ho and Reject Ha.

Appendix B3 (Maigana)

$$t_{c31-c32} = \frac{3.456 - 2.566}{S_p\ 0.333} = \frac{0.89}{S_p\ 0.333}$$

$$S_p^2 = \frac{17(0.831)^2 + 17(0.704)^2}{34} = 0.593$$

$$S_p = \sqrt{0.593} = 0.770$$

$$t_c = \frac{0.89}{0.770 \times 0.333} = 3.47^{*}$$

Decision Rule: Reject Ho and Accept Ha.

APPENDIX C: This represents the variances in the potassium data.

$$t_{0.05,\ 34} = 2.04$$

$$t_{0.01,\ 34} = 2.95$$

Appendix C1 (Samaru)

$$t_{c11 - c12} = \frac{3.424 - 12.351}{S_p\sqrt{(\frac{1}{18}) + (\frac{1}{18})}} = \frac{1.075}{S_p.0.333}$$

$$S_p^2 = \frac{17(0.693)^2 + 17(0.647)^2}{34} = 0.449$$

$$S_p = \sqrt{0.449} = 0.67$$

$$t_c = \frac{1.075}{0.67 \times 0.333} = 4.818^{*}$$

Decision Rule: Reject Ho and Accept Ha.

Appendix C2 (Daudawa)

$$t_{c21 - c22} = \frac{2.001 - 1.849}{S_p\sqrt{(\frac{2}{18})}} = \frac{0.161}{S_p \times 0.333}$$

$$S_p^2 = \frac{17(0.581)^2 + 17(0.407)^2}{34} = 0.256$$

$$S_p = \sqrt{0}.256 = 0.506$$

$$t_c = \frac{0.161}{0.506 \times 0.333} = 0.955$$

Decision Rule: Reject Ho and Accept Ha.

APPENDIX D: This measures the variances in the yield data for N,P and K combined.

$$t_{0.05,148} = 1.96$$

$$t_{0.01,148} = 2.58$$

Appendix D1 (Samaru)

$$t_{c11 - c12} = \frac{3.322 - 2.352}{S_p\sqrt{(\frac{1}{75}) + (\frac{1}{75})}} = \frac{0.967}{S_p 0.163}$$

$$S_p^2 = \frac{74(0.781)^2+74(0.930)^2}{148} = 0.74$$

$$S_p = \sqrt{0}-74 = 0.624$$

$$t_o = \frac{0.967}{0.624 \times 0.163} = 9.48*$$

Appendix D2

$$t_{c21 - c22} = \frac{2.140 - 1.722}{S_p \times 0.163} = \frac{0.418}{S_p \times 0.161}$$

$$S_p^2 = \frac{74(0.714)^2 + 74(0.622)^2}{148} = 0.45$$

$$S_p = \sqrt{0}.45 = 0.67$$

$$t_c = \frac{0.418}{0.67 \times 0.163} = 3.83^*$$

Decision Rule: Reject Ho and Accept Ha.

Appendix D3 (Maigana)

$$t_{c31-c32} = \frac{3.361 - 2.166}{S_p \times 0.163} = \frac{1.195}{Sp \times 0.163}$$

$$S_p^2 = \frac{74(0.733)^2 + 74(0.353)^2}{148} = 0.33$$

$$S_p = \sqrt{0.33} = 0.58$$

$$t_c = \frac{1.195}{0.58 \times 0.163} = 12.64^*$$

Decision Rule: Reject Ho and Accept Ha.

APPENDIX E

LIST OF ABBREVIATIONS IN THE LP MODEL

FL	-	Family labour
HL	-	Hired labour
MZ	-	Maize
SG	-	Sorghum
CP	-	Cowpea
CT	-	Cotton
GN	-	Groundnut
N	-	Nitrogen nutrient
P	-	Phosphorus nutrient
K	-	Potassium nutrient
MZ cons	-	Maize consumption
SG cons	-	Sorghum consumption
CP cons	-	Cowpea consumption
BN	-	Buy nitrogen nutrient
BP	-	Buy phosphorus nutrient
BK	-	Buy potassium nutrient
B-NPK	-	Buy NPK fertilizer
B-SUPA	-	Buy single superphosphate fertilizer
B-CAN	-	Buy calcium ammonium nitrate fertilizer
B-UREA	-	Buy urea fertilizer
B-MZS	-	Buy maize seeds
B-SGS	-	Buy sorghum seeds
B-CPS	-	Buy cowpea seeds
B-CTS	-	Buy cotton seeds
B-GNS	-	Buy groundnut seeds
U-MZS	-	Use own maize seeds
U-SGS	-	Use own sorghum seeds
U-CPS	-	Use own cowpea seeds
U-GNS	-	Use own groundnut seeds
MZ BL	-	Maize balance
SG BL	-	Sorghum balance
CP BL	-	Cowpea balance
CT BL	-	Cotton balance
GN BL	-	Groundnut balance
MZS BL	-	Maize seed balance
SGS BL	-	Sorghum seed balance
CPS BL	-	Cowpea seed balance
CTS BL	-	Cotton seed balance
GNS BL	-	Groundnut seed balance
SMZ	-	Sell maize grains
SSG	-	Sell sorghum grains
SCP	-	Sell cowpea grains
SCT	-	Sell seed cotton
SGN	-	Sell groundnuts
CMZ	-	Consume maize grains
CSG	-	Consume sorghum grains
CCP	-	Consume cowpea grains
BMZ	-	Buy maize grains
BSG	-	Buy sorghum grains.