MSU International Development Papers

A Simulation Study of Constraints on Traditional Farming Systems in Northern Nigeria

by

Eric W. Crawford

MSU International Development
Paper No. 2
1982

Department of Agricultural Economics
Michigan State University
East Lansing, Michigan 48824

MSU INTERNATIONAL DEVELOPMENT PAPERS

Eric W. Crawford, Carl K. Eicher and Carl Liedholm, Co-Editors

The MSU International Development Paper series is designed to further the comparative analysis of international development activities in Africa, Latin America, Asia and the Near East. The papers report research findings on historical, as well as contemporary, international development problems. The series includes papers on a wide range of topics, such as alternative rural development strategies; non-farm employment and small-scale industry; housing and construction; farming and marketing systems; food and nutrition policy analysis; economics of rice production in West Africa; technological change, employment, and income distribution; computer techniques for farm and marketing surveys; and farming systems research.

The papers are aimed at teachers, researchers, policy-makers, donor agencies, and international development practitioners. Selected papers will be translated into French, Spanish, or Arabic.

Individuals and institutions in Third World countries may receive single copies free of charge. See inside back cover for a list of available papers and their prices. For more information write to:

MSU International Development Papers
Department of Agricultural Economics
Agriculture Hall
Michigan State University
East Lansing, Michigan 48824-1039
U.S.A.

A SIMULATION STUDY OF CONSTRAINTS ON TRADITIONAL FARMING SYSTEMS IN NORTHERN NIGERIA*

by

Eric W. Crawford**

1982

*This paper was financed under a grant between the U.S. Agency for International Development (AID/afr-0929-G-SS-2011-00) and the Department of Agricultural Economics, Michigan State University, East Lansing, Michigan.

**Assistant Professor, Department of Agricultural Economics, Michigan State University, East Lansing, Michigan.

ISSN 0731-3438

Published by the Department of Agricultural Economics, Michigan State University, East Lansing, Michigan 48824 U.S.A.

TABLE OF CONTENTS

Page

CHAPTER

LIST OF TABLES

LIST OF FIGURES

Chapter I

INTRODUCTION

The central focus of this study is on the problem of small farmer development. In general, the study seeks to determine the economic constraints which affect the survival and income-earning ability of small farm households, in particular those living in ecological zones where climate and crop yields are highly variable. A stochastic simulation model of the farm household system is developed which integrates production, consumption, and investment activities. The setting of the research is northern Nigeria. Specific emphasis is placed, first, on the extent to which resource limitations and family structure constrain the growth of the farm system, and second, on examining the impact of stochastic variation in crop yields, investment returns, and major consumption expenditures on the level, variability, and rate of growth of family income and consumption. Experiments designed to address these issues are undertaken with the model for several specific farm situations. Model evaluation and design of the simulation experiments receive special attention.

A. Background to the Study

Prior to undertaking this study, the author spent several years involved in the design and implementation of development programs for small farms in Africa. A common and perplexing problem was to explain why government or donor-sponsored development initiatives of seemingly obvious benefit to farmers so frequently met with a lukewarm response. The proposed introduction of new technologies for crop or livestock production which were regarded by research scientists, planners, and field administrators as clearly feasible and profitable from the farmer's standpoint tended all too often to encounter disappointingly low adoption rates. It is fair to say that the underlying problem was the difficulty faced by Western or Western-trained development specialists in understanding just what a "profitable" agricultural improvement consisted of for a particular farming system and ecological zone.

One of the particular weaknesses of new technology evaluation by economists or farm management analysts has been the tendency to judge the profitability or acceptability of new technology on the basis of a static, one-year time horizon, and to focus on single enterprises. Gross margins or net returns calculated on an annual basis do not necessarily reveal the characteristics of a new crop or animal enterprise which are important to the farmer. This approach overlooks potential farm-level constraints which a dynamic perspective might reveal more clearly: (1) within-year requirements for minimum cash or food supplies; and (2) problems of long-run viability, especially when agricultural output is subject to weather-induced variability. Losses may critically reduce the ability of the farmer to sustain a recently-adopted new technology. Given the importance of maintaining at least a subsistence level of family consumption, one would expect that farmers who live up to the Schultzian standard of economic rationality will evaluate potential agricultural innovations in the light of these short- and long-term constraints.[1] Thus it is possible that technologies which appear desirable and profitable may in fact be too risky in terms of impact on cash or food supplies, and hence would not be adopted readily (Flinn and Lagemann, 1980).[2]

Although an interest in factors affecting the adoption of new agricultural technologies was an early impetus for the study, its focus is directed toward the broader question of constraints on the farming system, or factors affecting the farm household's income-earning capacity. Analysis of the farm household system as a whole is desirable, especially when the household's farm and off-farm activities interact, as they do in northern Nigeria. In fact, expanding the scope of analysis from single enterprises to the entire cropping system, or crop/livestock system, represents a significant advance in methods used to understand development problems faced by small farmers (Norman, 1978). As Wright (1971) notes: "The complexity of farming systems and the uncertainty associated with the decision-making process are features which indicate that a systems approach to research could be particularly useful."

---

[1]Joy (1969) suggests also that farmers may rationally decline an innovation if its returns are too low when discounted by a high rate of time preference.

[2]Given that the superiority of new enterprises or techniques offered to farmers is often not proven, the willingness of some farmers to adopt on a trial basis is surprising, and a reflection of innovativeness rather than resistance to change.

B. The Setting: Data and Farm System

The primary body of data used for the study was collected during 1974-75 by Peter Matlon, then a Ph.D. candidate in agricultural economics at Cornell University. As described in his Ph.D. dissertation (1977), Matlon's concern was to identify the determinants of income among traditional farmers in northern Nigeria. He conducted a comprehensive farm management survey in three villages of southwestern Kano State. The survey covered the farm, off-farm, and domestic activities of 140 households, including detailed information on labor use, agricultural production, and commodity and cash flows. A more complete discussion of the nature of Matlon's data as it relates to this study is contained in Chapter III.

Other survey data from similar nearby areas were also available. This includes material collected and analyzed during the 1965-67 period by Norman (1972). Yield data were supplemented by reference to studies done at the Samaru Institute for Agricultural Research, Ahmadu Bello University, located about 35 miles south of Matlon's survey area. The expectation was that combining Matlon's data with material from other sources would provide a more accurate picture of local farming systems than is usually possible in micro-level development research.[1]

The survey area was located in the semi-arid Northern Guinea Savanna zone, where annual rainfall averages about 35 inches. The unimodal rainy season covers a period of 120 days from May to September, with a severe water deficit during October-May, and a water surplus during June-September.[2] Matlon (1977: 36) also states that the Sahelian drought of 1971 to 1973 had relatively small effects in the survey area. In 1973, the year before the survey, groundnut and millet/sorghum yields were estimated to be 30-40 percent and 10-15 percent below average, respectively. As Matlon further observes (1977: 27): "High year-to-year variability with respect to total annual levels of precipitation, dates of onset and termination, and distribution within the rainy season result in substantial variation in farm production between years."

---

[1] In addition, because Matlon's stay at Cornell overlapped by a year and a half with that of the author, the problems of interpreting the raw survey data were minimized.

[2] Matlon (1977: 27) states: "During the 1974-75 cropping year which included the period of the present survey, total rainfall was very nearly equal to the 50-year mean cited above [35 inches]. The first rains arrived in late April and ended in late September for a 135-day rainy season."

Farms in the area may be described as semi-commercial family farms, with production for home consumption and for market sales. Production technology, based on hoe cultivation, is still traditional. There is little use of purchased inputs such as chemical fertilizers or insecticides, or of the few improved varieties of groundnuts or sorghum which are available. Major crops are cereals (millet and sorghum), grain legumes (groundnuts and cowpeas), onions and peppers, sugarcane, and vegetables. Groundnuts, onions and peppers, and sugarcane are the most important cash crops in terms of income earned. The relatively fertile lowland soils are used for rice cultivation during the rainy season, as well as for year-round production of high-value vegetables, root crops, and sugarcane.

Soils are heavily leached by the intense rainfall, and contain low levels of clay, organic matter, and phosphate. According to Matlon, such soils necessitate reliance on frequent bush fallow and organic manuring to maintain adequate soil fertility. However, more intensive recent forms of land use have practically eliminated fallowing; hence, soil fertility can be restored only through the use of crop rotation and the application of organic and chemical fertilizers.[1] This situation exists despite a relatively light population density in the three-village area (only 130 persons per square mile), and the availability of uncultivated land (Matlon, 1977: 36, 220).

Off-farm activities are a very important source of income, providing from 24 percent to 36 percent of total household income, depending on the village (Matlon, 1977: 34-36). Matlon identified 48 off-farm occupations, including self-employed occupations in trading, crafts, or services, as well as various types of wage employment. It is common for household members to perform wage labor on other farms; this hired labor provides an important supplement to family labor in agriculture, principally during the weeding and harvesting periods.

The area is ethnically homogeneous, with the Muslim Hausa making up 75 percent, and the settled Fulani 15 percent, of the total population. Although agricultural technology is also homogeneous, considerable diversity exists among households in terms of incomes and assets.

---

[1] Four-fifths of all fields cultivated at the time of Matlon's survey had not been fallowed since their acquisition by the farm household (Matlon, 1977: 30).

Studies by Matlon (1977), Norman (1972), and Hill (1972) have shown that these differences have an important influence on the emphasis given to farming as opposed to wage-earning or self-employed pursuits off the farm, as well as on the choice of particular agricultural production activities.

C. Objectives and Hypotheses

In general, the aim is to study the prospects for long-run growth in production and income for smallholder households in the dry savanna areas of West Africa. Despite an interest in the behavior of the farm household system over time, the study does not propose to formulate a set of optimal growth strategies for the agricultural firm, but rather to investigate the impact of various constraints on the viability of the firm over time.

The income prospects of the household are hypothesized to be a function of resource availability, the set of available production and income-earning opportunities, the objectives and management ability of the farm household, the institutional setting, and the impact of exogenous factors such as weather on crop yields and prices.[1] These factors clearly interact.[2] While the study attempts to incorporate each of these income-influencing factors to some degree, three are examined in particular:

1. Resource endowment, especially land and family labor.
2. Seasonal cash and subsistence food requirements.
3. Weather-induced variability in returns.

---

[1]This list is by no means exhaustive. Resource availability can be taken to include the supply of credit or purchased inputs. Production and income-earning opportunities depend partly on exogenous technological developments (Olsson, 1971) and partly on location-specific features of the physical and institutional environment (Perrin and Winkelmann, 1976; Norman, 1978). Household objectives encompass policies regarding the use of credit, and goals with respect to consumption, savings, and investment (Johnson, 1967). Exogenous factors other than weather would include changes in market demand (Olsson, 1971).

[2]For example, poor households may wish to accumulate assets over time, but find themselves unable to do so given their meager productive and financial resources and limited access to high-return investment opportunities. Thus a risk minimization or food security objective can be forced upon a poor farmer rather than freely chosen.

The rationale for this focus on resource endowment can be seen more easily against the background of earlier studies. Hill (1972) and Matlon (1977) de-emphasize resource endowment and stress current income as the key determinant of future incomes for households in northern Nigeria. Current incomes provide the cash necessary for the maintenance of agricultural productivity, through purchase of organic or chemical fertilizers or the timely hiring of labor, and for participation in relatively capital-intensive high-return occupations off the farm. More emphasis is given in this study to the physical resource base and to family structure because these are the fundamental determinants of the household's capacity to generate income beyond that necessary to meet its basic consumption requirements.[1] Surplus income then provides the basis for on-farm improvements or investment in remunerative off-farm activities.[2]

In addition, the relative endowment of land and labor, expressed in the land/person ratio, gives a better picture of the resource endowment than does reference to absolute resource levels. Larger farm sizes, for example, are not always associated with higher incomes. Matlon (1977: 121-134) found that the area of land cultivated was less important than the productivity of land and labor use in explaining income differences.

Which levels of the land/person ratio are most desirable will depend in part on the relative factor intensity of prevailing agricultural technology. Larger families tend to have more available workers, but also more consumers whose requirements must be satisfied.[3] It is this dual

---

[1]Hart (1978: 215) develops the concept of "proximity to subsistence," which is defined as basic expenditures minus off-farm wage income divided by the human and physical resource base. She then analyzes the level of farm labor inputs, and the allocation of family labor to on- and off-farm work and to leisure, in relation to this measure. Other studies which have stressed resource endowment include Johnson (1967) and Boussard (1971). Krishna (1969: 188) states that ". . . what keeps the peasants where they are is not so much limited aspirations but limited resource availability."

[2]Clearly, there is a circular relationship between resource availability, family commitments, and incomes earned, with intermediate links involving productivity of resource use, savings and investment (Hagen, 1975). The argument made here is that the circle begins, in a sense, with resource endowment rather than with incomes.

[3]The effect of changes in family size within simple theoretical models of the household is explored by Nakajima (1969).

aspect of family size, and the interaction between family structure and physical resource endowment, that is regarded as particularly important in this study.[1]

Before discussing the specific hypotheses of the study, it is worth commenting briefly on theoretical models of the farm household. Early microeconomic theorizing focused on narrow subsets of household behavior such as producer or consumer behavior. An exception is Chayanov's holistic theory of the peasant household, published in the U.S. in 1966 but written decades earlier. Beginning at least with Heady (1952) and Mellor (1965), efforts were then made to integrate production and consumption decisions in a household framework. Nakajima (1969) developed essentially neoclassical models for subsistence and commercial family farms which incorporated consumption and labor market participation, but not non-agricultural production or (explicitly) leisure.

In 1965, Becker introduced the concept of domestic commodity (or "Z-good") production, and treated time as a factor of production. Applications of the household production model are contained in Hart (1978) and Barnum and Squire (1979).

There are several advantages of such models in the context of research on farming systems. First, they examine the household in an integrated framework which is theoretically consistent with producer and consumer maximizing behavior. Second, their format and assumptions are by now fairly standard, hence easily interpreted by other researchers. Third, when expressed in mathematical form, their properties can be derived rigorously.

Several offsetting disadvantages should be noted. First, models of the household are generally employed in the short-run comparative statics context in which it is possible to evaluate only small changes under ceteris paribus conditions. Dynamic problems of the sort addressed in this study are difficult to treat. Second, even when simple models are examined, the direction of effects resulting from changes in parameters is often indeterminate. For example, in Nakajima's simplest model--a "pure commercial family farm without a labor market" producing a single product with only land and labor--an increase in land can be shown to

---

[1]Moscardi and de Janvry (1977) examine this question as it relates to the household's ability to bear risk.

increase money income and the marginal value product of labor, but its effect on output and labor input is indeterminate (Nakajima, 1969: 173). The problem worsens as the complexity of the model increases. When allowing for home consumption as well as sale of output, and two products but still no labor market, Nakajima himself notes that ". . . it appears exceedingly difficult to theorize on the working of subjective equilibrium . . . ." In the northern Nigerian setting of this study, however, the farm households are even more complex; they both sell and consume their output, sell their own labor and hire outside labor in the labor market, and produce multiple products using multiple inputs.

As a result, the derivation of specific hypotheses from theoretical models does not appear to be fruitful in this case, in part because the focus is specifically dynamic rather than static, and also because the complexity of the farming systems concerned is beyond the capacity of theoretical analysis. More will be said on this in Chapter II.

Specific hypotheses addressed by the study include the following:

1. Households with little land, cash, and food resources per family member will accumulate capital more slowly over time than better endowed households.[1]
2. Under conditions of climatic variability, the income and consumption levels of poorly endowed households will fluctuate more widely than those of better endowed households.[2]

The simulation model which is developed as the principal research instrument has the potential for investigating a much wider range of hypotheses than those listed above, and for operating as a tool

---

[1]Olsson (1971: 150-151), in discussing factors which promote growth, includes the amount of own capital and the proportion of income which can be saved for future investment. Both factors are incorporated in this study.

[2]Olsson (1971: 151) states that larger firms are more sensitive to "variations in the flows of incoming payments" due to uncertainty, especially when growth is financed by borrowing. It is hypothesized above that the income and consumption of poorly endowed households will be more sensitive to climatic variability than better endowed households, due not to financial considerations but to the type of farm and non-farm enterprises which their goals and resources lead them to choose.

of policy analysis. Initial consideration was given to two additional questions: (1) the effect of resource differences on ability to adopt new agricultural technologies which use purchased inputs more intensively; and (2) the effect of selected price and credit policies on the growth prospects of the poorly endowed farm households. Neither of these two questions were addressed, however, due to insufficient time and information.

D. Organization of the Report

Chapter II outlines the methodology and overall research design of the study, in relation to the principal characteristics of the farming system being modelled. A summary description of the model is presented, and its special features discussed by reference to previous research embodying similar objectives or approaches. The detailed exposition of the simulation model begins in Chapter III, where the design of the linear programming production, marketing, and basic consumption model is discussed. Selection of time periods, activities and constraints, and the estimation of coefficients and right-hand side values is also covered in Chapter III. Other components of the model are described in Chapter IV; these consist of user-written FORTRAN programs designed to determine additional household consumption, savings, and investment, as well as to link together the various components of the model within and between years. Chapter V then recounts the procedure followed to validate the model, and to evaluate the consistency of its operation in relation to the functional and factual characteristics of the real farm system. This completes the discussion of the design and evaluation of the complete simulation model.

Next, the design of the specific experiments which are carried out within the model is outlined in Chapter VI. The empirical results of these experiments are presented and interpreted in Chapter VII, which is the final chapter.

Chapter II

RESEARCH DESIGN AND METHODOLOGY

This chapter begins with a broad outline of the research design employed in the study. The suitability of the proposed methodology is then considered in relation to the objectives of the study. A summary description of the simulation model which is used in the study is presented in the following section. The chapter then closes with a detailed discussion of the principal features of the model, and the manner in which they incorporate the important characteristics of the typical farming systems found in northern Nigeria.

A. Outline of Research Design

The study develops a simulation model which covers a series of farm household situations common to the dryland savanna in northern Nigeria. The model represents a comprehensive analytical framework which is used to explore the likely behavior of the real farm system. Experiments conducted with the model make it possible to evaluate the specific research hypotheses. Analysis of the basic data obtained from Matlon's survey, though useful primarily in guiding model design, also suggested answers to the questions posed by the research.

Specific types of analysis, and the Chapter(s) in which each is discussed, include:

1. Identification of the principal crop mixtures grown in the area, and their input/output relationships. (Chapter III)
2. Calculation of family labor use and labor availability for different household types. (Chapter III)
3. Use of multiperiod linear programming to determine one-year farm plans for different household types, covering production, marketing, and subsistence consumption decisions. (Chapter V)
4. Parametric programming to investigate the relative importance of the land, labor, and cash constraints. (Chapter V)
5. Use of the full simulation model in both deterministic and stochastic modes to identify critical constraints, and to evaluate the impact of climatic variability on income and consumption. (Chapters VI and VII)

B. Suitability of the Simulation Approach

Simplification of reality is involved in all models which are used to study real systems, whether the models are purely conceptual or more quantitative. This section examines the reasons why simulation modelling was chosen over other analytical techniques. Much has been written about the advantages and disadvantages of the simulation approach, e.g., Naylor (1971), Wright (1971), Eisgruber and Lee (1971), Anderson (1974), and Johnson and Rausser (1977). A few of the relevant arguments are presented here.

First, simulation is an appropriate technique when the objective is to explore the functioning of a whole system, rather than individual economic processes such as consumption or investment. Both the experience of designing the system model, and of performing experiments with it, can yield valuable insights as to the critical variables in the system and how they interact. As noted above, this is the principal objective of the study.

Second, with the model it is possible to trace out the effects of changes in key parameters of the system, by making appropriate changes in the model and observing the resulting outcome. Such experimentation with the real system is rarely possible. In addition, when the research problem involves examining relationships over a period of time, the data required by other analytical techniques may not be available, and may be impractical to obtain by observing the real system (Anderson, 1974). A simulation model can be used to generate the necessary sequence of data on the system's behavior, which can then be analyzed with other techniques.[1] This is a particularly appropriate point in the context of this study, since only one year's data were collected by Matlon.

Third, when the system is complex, dynamic, and interactive--as, for example, when the system includes on-farm, off-farm, and household sectors--it may not be possible to derive the properties of the system or its main functional relationships analytically. For example, the allocation of farm resources to a particular activity alters the future stream of expenditure and returns. Whether or not the new configuration

---

[1]This is likely to be quicker and less costly than collection of original time series data, an advantage which may offset the greater validity of survey data.

will be consistent with the farmer's continuing objectives and resource constraints cannot always be clearly ascertained in advance. The new expenditure/returns stream will be consistent with some future consumption and investment decisions and not others; hence, a sale, storage, or investment decision in the current period affects not only future returns from that activity, but also the whole set of activities that will be feasible and optimal at various points in the future time path.

As Naylor (1971: 8) states: "Although it may be conceptually possible to formulate a mathematical model describing the behavior of a dynamic, multi-process firm operating under uncertainty, present-day mathematics is simply incapable of yielding solutions to a problem of this magnitude." Under such circumstances, it may be necessary to resort to simulation techniques in order to obtain a solution to the problem being investigated. In fact, Naylor argues that simulation permits the researcher to incorporate greater complexity and greater realism into the analysis of a particular system than is allowed by other techniques.

C. Summary Description of the Model

In order to orient the reader before proceeding further, a synopsis of the model is given here, followed by a discussion of the special features of the model. Chapters III and IV contain a more extensive discussion of the model and the important issues of model design.

Figure II.1 illustrates the basic subsectors of household activity found in the real system, and the linkages between them. It emphasizes the key exogenous factors (designated by circles) which impinge on the household, such as the institutional context, weather, and the initial physical resource endowment. In order to portray this farm system, the model integrates farm production, household consumption, off-farm wage employment, and investment on and off the farm. By altering family size and resource characteristics, a range of household types is simulated. Farm household decisions in the model are made partly in an optimizing framework, and partly by satisfying specified goals in priority sequence.

A diagrammatic representation of the simulation model is contained in Figure II.2. Optimum production/marketing decisions are simulated by solving two multiperiod linear programming (MLP) problems. Other

FIGURE II.1. FLOW CHART OF FARM-HOUSEHOLD SYSTEM.

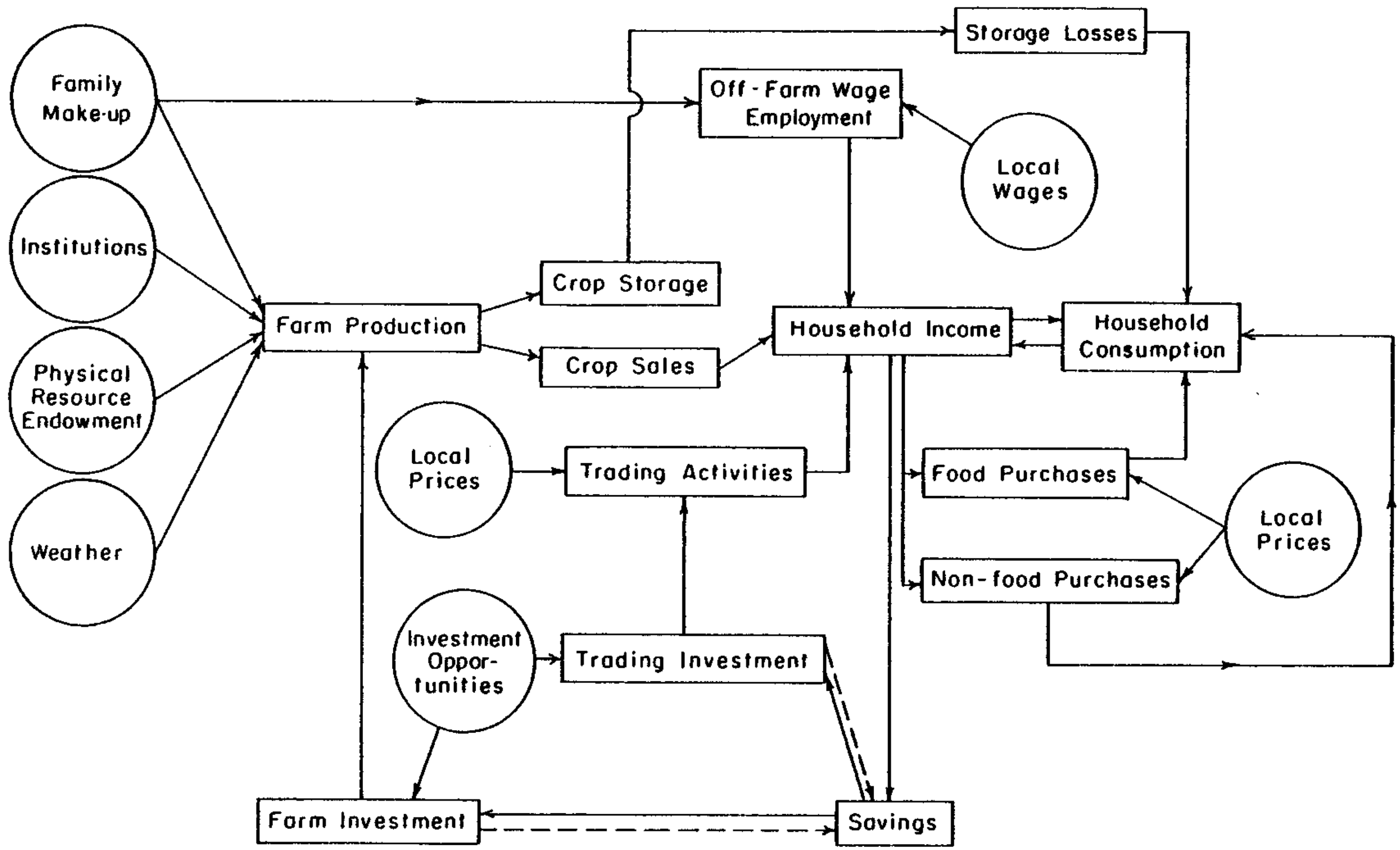
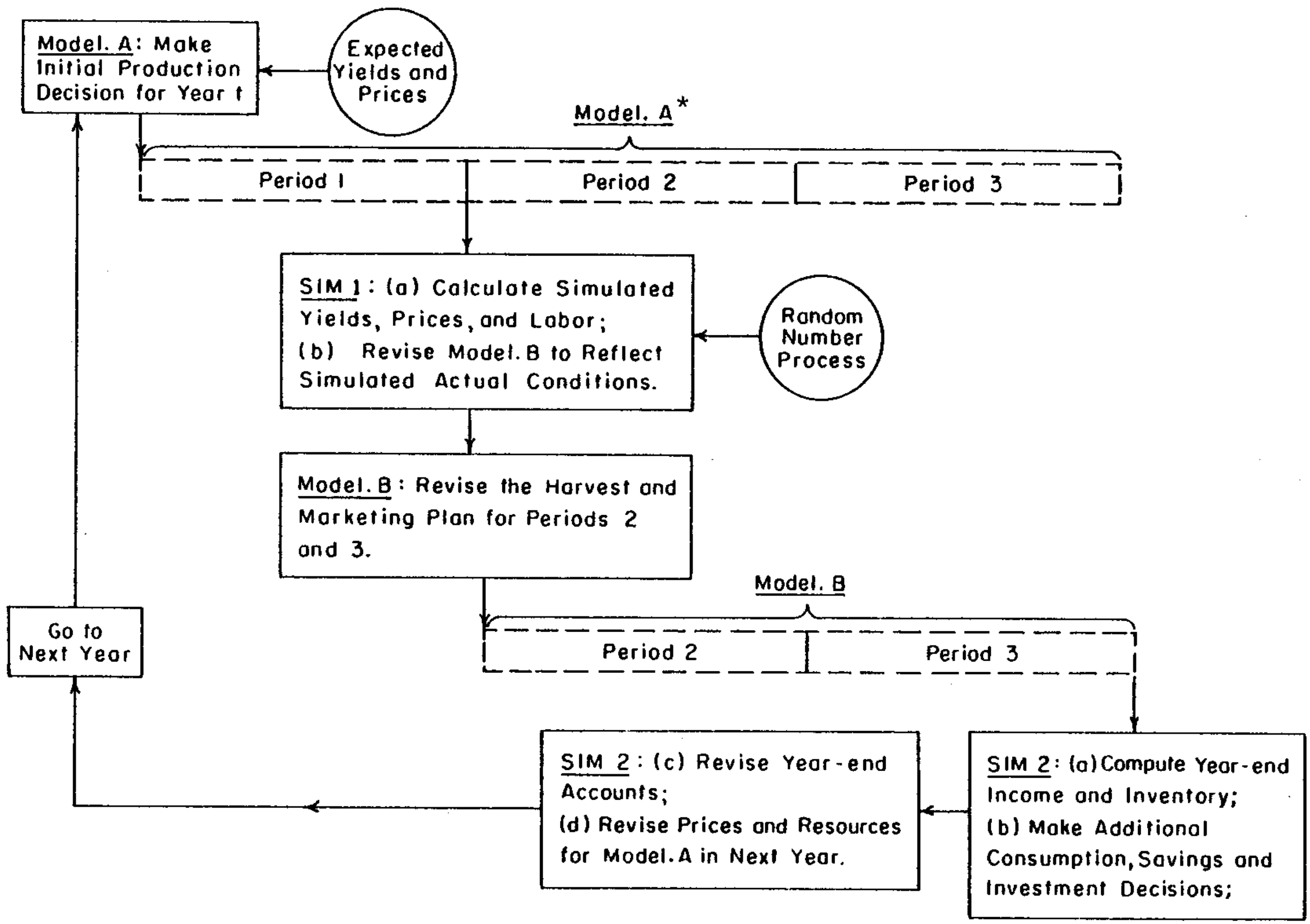


FIGURE II.2. FLOW CHART OF MODEL COMPONENTS AND DECISION POINTS.



*Period 1 = Land preparation, planting, weeding.
Period 2 = Initial harvest, marketing.
Period 3 = Later harvest, marketing, dry season activities.

activities and decisions are incorporated via two FORTRAN programs: (a) SIM1, which generates stochastic crop yields, investment returns, special consumption expenditures, and derived crop prices and harvest labor requirements;[1] and (b) SIM2, which allocates surplus income among consumption, savings, and investment, and uses the final solution for each year to update the prices, investment activity levels, and resource availabilities incorporated in the production/marketing model for the following year. The model is therefore dynamic, stochastic, and recursive.

The two stages of the multiperiod linear programming component are referred to as "Model.A" and "Model.B." Model.A is used to simulate decisions made as the growing season commences, when average-year yields and prices represent the best available information. As shown by the skeleton tableau in Figure II.3, Model.A is divided into three time periods covering the main phases of the farm operation: land preparation, planting, and weeding (Period 1); initial harvest and marketing (Period 2); and final harvest, marketing, and dry season activities (Period 3).

Model.A includes activities and restrictions for: (1) crop production;[2] (2) family labor use, labor hiring, and off-farm wage employment; (3) minimum subsistence food consumption and cash expenditures; (4) market sale and purchase of grains and groundnuts; (5) construction and maintenance of crop storage facilities; (6) cash borrowing and repayment; (7) use of surplus working capital (referred to as "investment") including crop fertilization, contract house construction, and trading; and (8) transfers of cash, crop inventories, debt, and storage capacity between periods.

Constraints are imposed on land and labor use. Inventory rows control the flows of transferrable resources. Minimum or maximum restrictions affect onion/pepper and vegetable production, labor selling, consumption, borrowing, investment, and transfers. Additional activities and constraints are included to calculate year-end balances for the key resources.

---

[1]The probability distributions of grain and groundnut yields were estimated from a 14-year sequence of field trials conducted at Samaru, near Matlon's survey area (Lombin and Abdullahi, 1977).

[2]Livestock activities were excluded partly due to data limitations, but also because for Hausa farmers in the area concerned livestock are more important as a store of wealth than as an income-earning production enterprise.

FIGURE II.3. SUMMARY DIAGRAM OF THE MULTIPERIOD LINEAR PROGRAMMING MODEL.

	Activity / Restriction	Period 1									Period 2								Period 3							
		Grow Crops	Hire Labor	Add Own Labor	Sell Labor	Con-sume	In-vest	Mar-ket	Bor-row	Trans-fer	Har-vest Crops	Hire Labor	Add Own Labor	Sell Labor	Con-sume	Mar-ket	Bor-row, Repay	Trans-fer	Hire Labor	Add Own Labor	Sell Labor	Con-sume	Mar-ket	Bor-row, Repay	Trans-fer	Net Acc'ts
		ha	man-hr	man-hr	man-hr	kg	N	kg	N	kg; N	ha	man-hr	man-hr	man-hr	kg	kg	N	kg; N	man-hr	man-hr	man-hr	kg	kg	N	kg; N	kg; N
PERIOD 1	Basic Labor	c	-1	-1	1		c	c		c																
	Add'l Labor			1																						
	Land	c																								
	Inventories	c	c		-c	±c	±c	±c	-1	1																
	Min/Max	1			1	1	1																			
PERIOD 2	Consistency	-1									1															
	Basic Labor						c				c	-1	-1	1		c		c								
	Add'l Labor												1													
	Land										c															
	Inventories						-c			-(1-c)	-c	c		-c	c	±c	±1	1								
	Min/Max													1	1											
PERIOD 3	Basic Labor						c												-1	-1	1					
	Add'l Labor																			1						
	Inventories						-c				-c							-(1-c)	c		-c	c	±c	±1	1	
	Min/Max								1								1				1	1		1	1	
	Net Acc'ts						-c																		-(1-c)	1

Note: "c" represents a coefficient not equal to zero, one, or minus one.

The second MLP component, Model.B, is simply a subset of the rows and columns of Model.A, covering only Periods 2 and 3 (harvest, marketing, and dry season activities). Model.B simulates the marketing and labor use decisions made after crop yields and early price information are known. No changes in the cropping plan can be made in Model.B. Average coefficients in the base version are replaced by randomly determined "actual" values, which become the new coefficients of Model.B for the current year. In addition, the resources available to Model.B are those available at the end of Period 1 in the prior solution of Model.A.

Figure II.2 indicates the sequence of decisions and activities in the complete model (Model.A-SIM1-Model.B-SIM2). At the beginning of Year t, a full-year production/marketing solution is obtained based on average-year yields and prices in Model.A. This represents a preliminary annual plan for the household, including the allocation of land in Period 1 to different crop enterprises, subject to the requirement that basic subsistence consumption needs be met. Next, simulated crop yields are randomly determined, reflecting in simplified form an "actual" combination of rainfall and insect or pest infestation levels. These simulated crop yields are used to calculate new price and harvest labor coefficients for the production activities. Along with simulated investment return coefficients, these are then inserted into Model.B. In addition, the cropping plan and status of the main resource inventories as of the end of Period 1 in the solution of Model.A are inserted into the right-hand side vector of Model.B.

Model.B gives revised figures for harvest value, labor allocation, marketing, and net income and inventory balances. Additional consumption,[1] savings, and investment decisions are then calculated, given the level of surplus income available from Model.B. The initial conditions for solution of Model.A in Year t+1 are then formulated, based on the final income and resource balances from Year t as well as the implications of the Year t investment decisions. Model.A is solved for Year t+1, and the process is repeated for the remaining years of the specified time period.

---

[1]Total consumption includes basic subsistence consumption plus additional consumption out of surplus income, i.e., income remaining after production expenses and basic food needs have been met.

D. Special Features of the Model which Reflect the Farm System

The model was designed to incorporate five important characteristics of the farming systems of northern Nigeria. These are described briefly here, and more extensively in Chapters III and IV.

First, the production system represented in the model is based on intercropping, since sole cropping is rarely practiced in the area. As pointed out by Norman (1973) and Andrews (1972), intercropping has several agronomic and economic advantages. Crop mixtures spread the labor demand and sequence of crop output more evenly throughout the year; they maximize the exploitation of light, water, and soil nutrients from a given area; and they promote beneficial interactions between individual crop types with respect to disease or pest resistance, and soil fertility. The timing of labor needs, other inputs, and crop outputs is directly represented in the model.

Second, the model incorporates the integrated nature of household production and consumption decisions, and the relationship between farm and non-farm activities. As Singh and Squire (1978) state:

> The household's decision to maximize utility subject to its income and time constraints is no longer independent of the firm's decision to maximize its profits subject to its resource constraints because the household income equation now depends fundamentally upon farm profits while the allocation of household time has to account not merely for trade-offs between leisure and wage incomes but also between these two and employment on the farm. This latter depends upon production technology and the firm's profit-maximizing conditions. (1978: 2)

Additional consumption out of surplus income is determined on the basis of an estimated marginal propensity to consume, a method which was adopted in several earlier studies, including Martin and Plaxico (1967) and Boehlje and White (1969), and more recently, by Hazell (personal communication).[1]

Regarding the tie between on-farm and off-farm activities, Matlon (1977) and Hill (1972) have given a clear picture of the contribution made to household income by earnings from off-farm occupations in northern Nigeria. This is especially important for households whose landholding is too small to allow all consumption requirements to be met through agricultural production.

---

[1] In an unpublished paper (1978), Peter B. R. Hazell develops a one-year linear programming model for average households in northern Nigeria, based on data collected by World Bank projects in Gusau, Funtua, and Gombe.

Third, the study embodies a dynamic framework of analysis, examining both seasonal constraints within the year as well as linkages between years resulting from the effect of current resource allocation decisions and outcomes on future opportunities and constraints. Seasonal constraints are particularly critical for the farmer whose operating resources are minimal; to survive from period to period, he must have left at the end of one period what he needs to subsist in the next. Thus the farmer's aim is not merely to achieve maximum net returns at the end of the season, but to assure domestic consumption needs and seasonal input requirements throughout the year.

Fourth, the model incorporates stochastic variability in farm production, non-agricultural trading, and major consumption requirements. Crop prices and harvest labor requirements are derived as a function of stochastic yields. Of greatest importance is weather-induced variability in agricultural production and crop prices. Matlon (1977: 26) points to "low and highly variable annual rainfall" as "one of the primary limiting factors for agricultural production in the region . . . ." The dynamic, multi-year format of the model makes it possible to explore the effects of this variability, together with investment and consumption expenditure fluctuations, on the household's financial well-being.

Fifth, the decision structure of the model involves multiple goals, sequential decision making, and a subsistence-first risk aversion constraint. In addition, there are what Olsson (1971: 144) calls "threshold goals" regarding savings and investment. These are hierarchically ordered, and act as further constraints on the optimization of net household income. Sequential decision making involves first a provisional and then a revised set of production and marketing decisions, based on simulated "actual" events.[1] Discretionary consumption, savings, and investment decisions are made later in a set order which embodies a combination of working

[1] This is superior to the "perfect knowledge" formulation used by Johnson (1967), where the farmer selects his cropping pattern with advance knowledge of actual crop yields and prices.

capital requirements, relative returns, and risk factors.[1] The decision horizon is limited to one year, the period encompassed by the multiperiod linear programming (MLP) production/marketing model.[2] Farm plans are prepared only one year in advance, since farmers in northern Nigeria at the time had practically no on-farm or off-farm investment opportunities calling for large outlays for fixed capital equipment.

As noted, the principal manifestation of risk in the decision process is the mild form of risk aversion implied by the minimum subsistence consumption constraint. The model effectively assumes that the farmer does not take yield and price variability into account in devising his crop plan, although he is affected by variability ex post. This differs from the stochastic or risk programming method of Rae (1971a,b) and Hazell (1971). The main reason for adopting this approach was lack of information on the variability of intercropped mixtures. Although conceptually rather unpalatable, this approach may be an empirically satisfactory approximation to reality. Crop mixtures commonly used by farmers probably represent optimal choices with respect to protection against yield variability (Norman, 1974), and may perform much the same in terms of minimizing risk. Hazell's results (personal communication) tend to confirm this by showing that optimal cropping plans and associated net returns were very similar whether risk information was included and worst-year net

---

[1]This draws on Nakajima's formulation (1969: 184):

> Thus, it will be reasonable to divide the decision making of the farm family into two phases. The decision making in the first phase will be made at some time before the start of production, from the standpoint of our original farm family or of a "firm-household complex," where the decisions concern both expected production and disposal (namely, consumption and/or sales). Decision making in the second phase occurs after production is completed, from the standpoint of a consumer's household having a given amount of income in kind, where the decisions do not have anything to do with production.

[2]This differs from the usual approach adopted in growth models employing multiperiod linear programming. Olsson (1971), for example, develops an MLP model in which a solution is calculated for a set of three five-year periods. Johnson (1967) specifies a decision horizon of fifteen one-year periods. Such models are appropriate in the U.S. or European setting where the problems facing the farm firm often relate to the acquisition of expensive capital equipment which must be paid off over a long period, or to other financially complex types of farm operation.

returns were maximized, or whether it was excluded and average net returns were maximized.[1]

---

[1]An earlier study in the U.S. by Merrill (1965) reached a similar conclusion, namely, that there was little difference in incomes and cropping plans between solutions based on average values (or certainty equivalents) and those which incorporated variable crop yields.

Chapter III

DESIGN OF THE PRODUCTION, MARKETING, AND BASIC CONSUMPTION MODEL

This chapter is devoted to a description of the components of Model.A, and the estimation of the numerical coefficients which it comprises. Following initial sections which set forth the algebraic formulation of the multiperiod linear programming model, and explain the basis on which the model is divided into time periods, the chapter proceeds with four sections which treat the details of the main structural elements of the model, namely the activities, constraints, numerical coefficients, and righthand side values. This follows the sequence of model design, where the first step was to decide on the activities and constraints, after which the input-output coefficients and righthand side values were estimated.

The derivation of Model.B from Model.A is discussed in Chapter IV.

A. Algebraic Formulation of Model.A

In matrix notation, the model for Year t has the following familiar form:

(1) $\text{Max } c_t x_t = y_t$ $\qquad t = 1, \ldots, n$

(2) $\text{s.t. } A_t x_t \leq b_t$

(3) $x_t \leq 0$ $\qquad$ all t

where: t = year

y_t = household income net of production expenses and the cost of minimum subsistence consumption

c_t = a row vector of cost or return coefficients

x_t = a column vector of activity levels

A_t = a matrix of input coefficients for unit levels of the activities

b_t = a column vector of righthand side values for the constraints

Each vector or matrix is partitioned into i time periods, where i = 1,2,3:

(4) $c_{it} = \begin{bmatrix} c_{1t} & c_{2t} & c_{3t} \end{bmatrix}$

(5) $x_{it} = \begin{bmatrix} x_{1t} \\ x_{2t} \\ x_{3t} \end{bmatrix}$

(6) $$A_{iit}{}^{1} = \begin{bmatrix} A_{11t} & 0 & 0 \\ A_{21t} & A_{22t} & 0 \\ A_{31t} & A_{32t} & A_{33t} \end{bmatrix}$$

(7) $$b_{it} = \begin{bmatrix} b_{1t} \\ b_{2t} \\ b_{3t} \end{bmatrix}$$

In addition, there are j sets of activities and k sets of constraints. These are shown in Figure II.3 above, which also illustrates the partitioning of the model into time periods.

The complete algebraic form of the model may therefore be written as:

(8) $\text{Max } c_{ijt}x_{ijt}$

(9) $\text{s.t. } A_{ijkt}x_{ijt} \leq b_{kt}$

(10) $x_{ijt} \leq 0$

where: i = time period within the year

j = activity type

k = constraint type

t = year

and: c is of order (1 x ij)

x is of order (ij x 1)

A is of order (ik x ij)

b is of order (ik x 1)

B. Identification of the Model Time Periods

There were two important considerations in defining the time periods for the model: first, they should split the year into agriculturally distinct seasons, and second, they should allow a proper representation of the within-year food and cash constraints. These points are explained more fully below.

Three periods were identified in light of these criteria:

1. Period 1: land preparation, planting, and weeding; covering 23 weeks from April to the end of August;

2. Period 2: harvest and initial crop sales; covering 17 weeks from September through the end of December

---

[1]The i subscript is used twice here because both the activities (columns) and the constraints (rows) are divided into three time periods. The matrix is triangular because the Period 2 activities, for example, do not have any direct connection with the Period 1 constraints.

3. Period 3: later crop sales, nonagricultural activities, investment, and preparation for the next crop season; covering 12 weeks from January to the end of March.

Table III.1 shows the timing of the cropping activities within the three periods.

The length of each time period was established by first analyzing the growth periods and labor profiles for the main crops and crop mixtures found in the area. This analysis supplements that done by Matlon (1977: 251, 324-325), and agrees closely with the crop cycles reported by Norman (1972: 72, Appendix E5) and by Delgado (1978: 74).

Second, the time periods were organized so that the cash and grain flows within each period were primarily in one direction. Because the linear programming solution algorithm treats the entire time period as a single point in time, making no distinction between the beginning and the end of the period, it is necessary not to allow expenses to be paid with income not yet received. For example, wages for labor hired to harvest early millet in September should not be payable with cash earned from sale of sorghum harvested in November/December. This is accomplished partly in the way the three periods are defined, but also by channelling cash or grain received late in Period i to the appropriate inventory in Period i+1, so that those resources are not available for use early in Period i.[1]

An important advantage of the multiple period format is that seasonal prices and interest rates can be incorporated. In the model, the cost of transferring resources from one period to the next is balanced against the possible returns from higher prices in the future. When modelling farm systems in a traditional area such as northern Nigeria where food grains play a major role in the local economy, the implications of seasonal prices and storage costs for consumption and marketing decisions are significant and should be accounted for in the model.

C. Formulation of the Activity Set

Most activities of the model occur in all three periods, but there are some exceptions which should be noted. Crops are grown in Period 1,

[1]See Section III.E below for further details. The problem could be handled by splitting the model into more periods, but adding periods rapidly increases the size of the model and hence its solution cost.

Table III.1. PRINCIPAL TIME PERIODS AND ACTIVITIES COVERED

MLP Period	Labor Period	Weeks Covered	Dates Covered 1974-1975	Principal Activities
	1	5	April 1-May 4	Plant grains
	2	2	May 6-May 19	Plant groundnuts; 1st weeding
	3	2	May 20-June 2	1st weeding, continued
	4	2	June 3-June 16	Plant vegetables; 1st weeding continued
1	5	2	June 17-June 30	Plant onions and peppers
	6	2	July 1-July 14	Plant cowpeas; 2nd weeding
	7	2	July 15-July 28	2nd weeding, continued
	8	2	July 29-Aug. 11	2nd weeding, continued
	9	2	Aug. 12-Aug. 25	Later weeding; harvest vegetables
	10	2	Aug. 26-Sept. 8	Harvest early millet
	11	4	Sept. 9-Oct. 6	Harvest groundnuts, onions/ peppers
	12	6	Oct. 7-Nov. 17	Harvest groundnuts; further weeding
2				
	13	2	Nov. 18-Dec. 1	Harvest cowpeas
	14	2	Dec. 2-Dec. 15	Harvest late millet, sorghum
	15	3	Dec. 16-Jan. 5	Harvest late millet, sorghum
3				
	16	12	Jan. 6-Mar. 30	Dry season activities; land preparation

and harvested and sold in Periods 2 and 3. The "investment" activities, which represent the allocation of working capital to special income-increasing farm and off-farm activities, are contained only in Period 1 although they act upon the labor, cash, and grain constraints in other periods.[1] Accounting activities, which total up the year-end levels of the resource inventories, are found only in Period 3. Finally, labor activities in the model have been subdivided into a total of 16 labor periods; as shown in Table III.1, ten of these lie within Period 1, five within Period 2, and one within Period 3. The exact specification of all model activities is discussed below.

1. Crop Production

Crop production activities are defined in terms of crop mixtures, since the prevalent form of production in the survey area was mixed cropping rather than sole cropping.[2] Matlon's survey of 35 households and their 204 agricultural fields indicated that of the approximate total of 225 mixtures separately identified by farmers, only 20 or less than 9 percent of these were sole crops (Matlon, 1977: 142). At the field level, only 12 out of 204 fields or 6 percent were sole cropped.

Before discussing procedures used to select crop mixtures for use as enterprises in the MLP model, it is worth reviewing the nature of Matlon's data. For each of the 204 fields, numerous input-output activities were observed, identified by the week in which they occurred. These include the use of family and hired labor, type of seeds planted and fertilizer applied, and type of crop harvested. In general both the physical quantity and monetary value of labor inputs, planting materials, and harvest are given in the data, although occasionally the quantities of planting materials and/or harvest amounts of vegetables, onions and peppers, and sugar cane are listed as unknown.

---

[1] There are five such activities: grain fertilizing, onion/pepper fertilizing, house construction on contract, trading general provisions, and trading kola nuts. The purpose and structure of these activities are explained in Chapter IV.

[2] Mixed cropping is a general term which refers to the growing of several crops on the same field at the same time, with different crops being mixed together either row by row or plant by plant within the row. "Sole cropping" refers to the planting of crops in pure stands.

Matlon's survey covered a twelve-month period from May 1974, to May 1975. Since land preparation and planting begins between mid-March and early April, the data for March-May, 1975, contain labor and input-output flows which pertain to the following (1975) agricultural season. This information was excluded when analyzing crop mixtures and calculating input-output coefficients for 1974. Information regarding activity during the mid-March to April period of 1974 was collected by Matlon using longer recall interviews, and was included in the analysis.[1]

Although field sizes were measured, Matlon did not measure the area of plots within the field nor the density of each crop planted. This of course makes it impossible to calculate inputs or outputs per hectare for individual crops, or even for crop mixtures if more than one mixture is grown on a given field, as is often the case. Each field was therefore treated as a production unit, consisting of a mixture of whatever crops were grown on the field as a whole.[2] Input and output streams were estimated for the field as a whole, with all materials planted and harvested identifiable by individual crop type. This is important from the standpoint of household consumption and resource allocation.

Identification of the most important crop mixtures for inclusion in the model proved to be a complex process. First, the 36 individual crops identified by Matlon were aggregated into ten general crop groups, which are shown in Table III.2.[3] Second, each field was analyzed to determine which of these crop groups were represented by crops planted and harvested on the field. Third, a crop mixture category was assigned to each field,

---

[1] Unfortunately, weather conditions were not comparable in the two agricultural years, 1974 and 1975. Had they been similar, it would have been possible to make a useful comparison of the recall interview data from 1974 with the more detailed and presumably accurate information obtained from the weekly interviews in 1975.

[2] As noted, most fields observed by Matlon contained more than one separately identified crop mixture. To the extent that the farmer considers the crop mixture rather than the field as the fundamental production activity, employing coefficients calculated at the field level obscures part of the farmer's decision process.

[3] Two separate grain groups were specified because early millet has a much shorter growing season than the other cereals, although it is planted concurrently. Onions and peppers are grouped apart from other vegetables because they are key cash crops. Root crops are distinguished separately because of their long growing season, e.g. 18 months for cassava.

Table III.2. CODES FOR CROP GROUPS AND CROP MIXTURES

Crop Group	Includes
A11	sorghums and millets with more than 20 percent of harvest value in early millet
A12	sorghums and millets with less than 20 percent of harvest value in early millet
A2	sorghums and late millet
B	groundnuts and bambara nuts
C	cowpeas
D	onions and peppers
E	vegetables
F	maize
G	rice
H	sugar cane
I	root crops (cassava, yams, Irish potatoes)
Mixture Type	
A1/B	sorghum, millet (inc. early millet), groundnuts
A2/B	sorghum, late millet, groundnuts
A1/C	sorghum, millet (inc. early millet), cowpeas
A1/B/C	sorghum, millets, groundnuts, cowpeas
A2/B/C	sorghum, late millet, groundnuts, cowpeas
A1/B/D/E	sorghum, millets, groundnuts, onion and pepper, and vegetables

with "crop mixture" defined to exclude individual crops representing less than 5 percent of the total harvest value on the field.[1] Using the crop codes shown in Table III.2, a mixture combining early millet, sorghum, and cowpeas would be designated as A1/C. Late millet, sorghum, onions and peppers, and vegetables would be designated A2/D/E.

Fourth, fields belonging to the same mixture type were then aggregated. A total of 25 distinct mixture types were identified as containing more than one field. These are shown in Table III.3, which suggests several initial observations: (1) the four most common mixtures are A11 and A12 (cereal grains including early millet), A1/C (the same with cowpeas added), and A1/B/C (grains, groundnuts, and cowpeas); together, these four represent about 25 percent of the total number of fields and over 40 percent of the total area cultivated; (2) a large number of fields contain mixtures which differ from the three most common ones only by the inclusion of vegetables or onions and peppers; and (3) 50 fields are unique and many of the 25 mixture categories have few fields belonging to them; in particular, fields containing maize, rice, sugar cane and root crops do not cluster into distinct categories.

The fifth step therefore aimed to amalgamate mixtures that were essentially the same despite superficial differences (e.g. A1/B/C and A2/B/C, or A1/B/C and A1/B/C/E), in order to reduce the number of mixture categories and increase the number of fields falling into each category. A variety of multivariate statistical techniques were considered for use in grouping the lesser mixture types into broader categories. Ultimately, however, none of the procedures such as factor analysis, discriminant analysis, or cluster analysis, seemed appropriate for handling the task of identifying an unknown number of groups (mixtures) containing an unknown number of variables (crops) and an unknown number of observations (fields).[2]

---

[1]Occasionally, crops representing less than 5 percent of harvest value were included in the classification either because they were significant in quantity terms and therefore were an important element of household consumption (e.g. vegetables), or because they were commonly grown as part of the mixture (e.g. cowpeas).

[2]In addition, experience with using the raw data to form mixture categories firmly underlined the value of analyzing the data by hand. This made it easier to spot data errors, and strengthened the knowledge base from which to make subjective judgments in the inevitable borderline cases.

Table III.3. CHARACTERISTICS OF THE PRINCIPAL MIXTURE TYPES

Mixture	Total Hectares	Number of Fields	Man-hrs. Per Ha.	(Naira)[a] Harvest Value Per Ha.	(Naira) Harvest Value Per Hour
* 1. A11	6.87	14	599	100	.17
* 2. A12	6.15	7	387	91	.23
3. A2	3.45	5	445	79	.18
* 4. A1/B	3.42	8	791	119	.15
* 5. A2/B	7.21	10	496	107	.22
* 6. A1/C	15.76	16	559	105	.19
7. A2/C	3.19	4	316	74	.23
* 8. A1/B/C	12.75	14	600	97	.16
* 9. A2/B/C	7.15	9	671	95	.14
10. A1/C/D	1.67	2	542	115	.21
11. A2/B/C/D	1.51	2	1,458	145	.10
12. A1/B/C/E	3.42	6	804	182	.23
13. A1/B/C/D/E	2.90	3	504	153	.30
14. A2/B/C/E	3.54	6	838	123	.15
15. A1/B/D/E	2.40	2	675	173	.26
16. A1/B/E	2.16	4	548	155	.28
17. A2/B/E	2.39	5	698	136	.20
18. A2/D/E	1.71	3	571	116	.20
19. A2/B/C/D/E/F	1.26	4	1,642	279	.17
20. A2/G	1.38	3	518	77	.15
*21. Sorghum	1.30	4	706	152	.22
22. Rice	.52	3	336	72	.21
*23. Onion/Pepper	.58	4	638	208	.33
*24. Sugar cane	2.27	7	1,109	394	.36
25. Root crops	7.26	9	805	139	.17
SUB-TOTAL	102.22	154	625[b]	114	.18
All Other	17.97	50			
GRAND TOTAL	120.19	204			
Starred Mixtures	63.46	93	594	114	.19

[a]One Naira = U.S. $1.64 (1974/75).

[b]Averages weighted by hectares.

*Mixtures identified as important and/or representative.

Accordingly, very simple data manipulations were performed to select eleven mixtures, based on the following criteria:[1]

1. importance in terms of the proportion of the total number of fields and total cultivated area represented by each mixture.

2. distinctiveness of each mixture in terms of crop composition, labor profile, and returns to land and labor.

To illustrate the information used in this selection process, Table III.4 shows the crop composition for 23 mixtures in terms of the proportion of total harvest value represented by each crop type found in the mixture. Figure III.1 compares the labor profiles of mixtures A1/B/C and A2/B/C.

Mixtures containing maize and rice were eliminated. Such mixtures cover only a small number of fields and very little cultivated area. Rice is also unattractive from the standpoint of net returns. Vegetables are shown as a separate composite enterprise, rather than as part of other mixtures.[2]

Another major issue in specifying the crop production activities for the MLP model was whether to define them in terms of average coefficients, or to base them on individual production enterprises selected from the data, or to devise synthetic or composite coefficients based on subjective evaluation of the data. The initial approach was to compute average input-output coefficients for each mixture type. Early versions of Model.A employed production activities defined in terms of these averages.

---

[1]The distribution of the 93 fields included in the eleven mixtures was analyzed by household size, income class, and village, to ascertain whether these fields were a representative subset of the total of 204 fields. The 93 fields appear to be a representative sample. Some suggestive differences by village and income class are evident, but the distribution by household size (a major focus of the study) is virtually identical to that for the 204 fields.

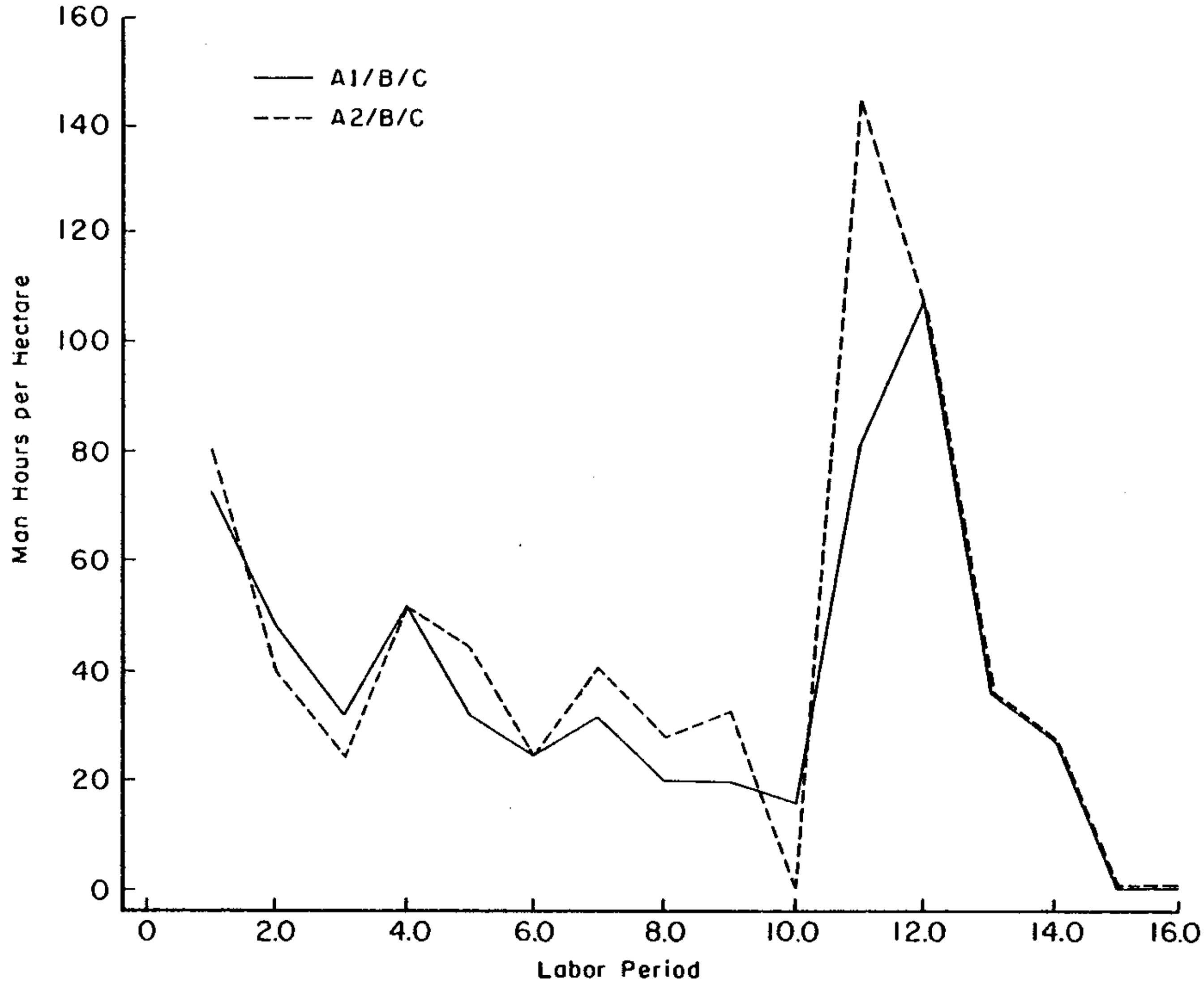
[2]This is primarily because household demand for vegetables is assumed to be essentially a fixed function of household composition rather than a function of profitability considerations. The clearest way of modelling this is to isolate the vegetable enterprise from other mixtures which are selected mainly on the basis of their net revenue and labor demand aspects.

Table III.4. PROPORTION OF TOTAL HARVEST VALUE BY CROP AND MIXTURE TYPE

Mixture Type	Total Hectares	Number of Fields	Early Millet	Other Grains	B	C	D	E	F	G	I
A1	13.13	22	.23	.76	-	-	-	.01	-	-	-
A2	3.45	5	-	.98	-	-	-	.02	-	-	-
A1/B	3.42	8	.13	.28	.58	-	-	.01	-	-	-
A2/B	7.21	10	-	.51	.48	-	-	-	-	-	-
A1/C	15.76	16	.18	.71	-	.10	-	.01	-	-	-
A2/C	3.19	4	-	.86	.01	.11	-	.02	-	-	-
A1/B/C	12.75	14	.12	.36	.44	.08	-	-	-	-	-
A2/B/C	7.15	9	-	.38	.55	.06	-	-	-	-	-
A1/C/D	1.67	2	.07	.33	.01	.05	.55	.01	-	-	-
A2/B/C/D	1.51	2	.01	.19	.49	.05	.25	-	.01	-	-
A1/B/C/E	3.42	6	.15	.49	.23	.07	-	.05	-	-	-
A1/B/C/D/E	2.90	3	.10	.25	.36	.07	.10	.10	-	-	.02
A2/B/C/E	3.54	6	-	.31	.52	.10	-	.07	-	-	-
A1/B/D/E	2.40	2	.07	.26	.31	.01	.33	.03	-	-	-
A1/B/E	2.16	4	.21	.44	.30	-	-	.05	-	-	-
A2/B/E	2.39	5	-	.34	.60	-	.01	.05	-	-	-
A2/D/E	1.71	3	-	.71	-	.01	.22	.06	-	-	-
D	.58	4	-	-	-	-	1.00	-	-	-	-
A2/G	1.38	3	-	.58	.01	-	-	-	-	.42	-
Tall Sorghum	1.30	4	-	1.00	-	-	-	-	-	-	-
Rice	.52	3	-	-	-	-	-	-	-	1.00	-
A2/B/C/D/E/F	1.26	4	-	.13	.32	.05	.34	.11	.05	-	-
Root Crops	7.26	9	.05	.34	.32	.03	.08	.04	.01	-	.13
TOTAL	100.06	148									
All Other	20.13	56									

Crop codes shown in Table III.2.

FIGURE III.1. LABOR PROFILE FOR MIXTURES A1/B/C AND A2/B/C.



Two drawbacks to this "average" specification then became apparent. First, the average labor profile, in terms of man-hours per hectare per labor period, is much smoother than the labor profile of any particular field. This effect is illustrated in Figure III.2 where the labor profiles for two individual fields are plotted against the average labor profile for Mixture A2/B/C. Because the labor peaks are obscured by the average labor profile, this formulation does not adequately portray the true pattern of labor requirements.

Second, further scrutiny of the data raised doubts about how well the average reflected production relationships within the mixture categories. It was evident that considerable variability existed within each mixture type, despite the efforts made to identify mixtures that were distinct from each other. This point may be appreciated by noting the range of values for labor input (man-hours per hectare) and harvest value per hectare or per man-hour for Mixture A2/B/C in Table III.5. A complicating factor which reduces the validity of the average is the small number of fields contained within mixture types such as pure sorghum and onion/pepper.

Despite considerable analysis, no satisfactory explanation was found for this variability by field within mixture type.[1] Several variables appear to be significant: field size; proportion of sorghum, early millet, and groundnuts in the mixture; and labor inputs per hectare. Field size is inversely related to both labor input and returns per hectare. The most likely explanation for this is that small fields tend to be close to the compound, hence are likely to receive more attention in terms of labor and manure.

Following this analysis, it was decided to base the production enterprises on individual field data rather than on averages. This allows more accurate modelling of the labor profile, and the incorporation of a range of "technologies" or production relationships reflecting the effect of field size. Nearly 30 individual fields were selected--two to three for each mixture type--by applying these criteria:

---

[1]One reason was that data on certain important determinants of crop output, e.g., soil quality and incidence of rainfall by field, were not available. The extent of enumerator or other types of measurement error is also not known, although Matlon's extremely thorough supervision procedures make it likely that his data are above-average in accuracy.

FIGURE III.2. FIELD VERSUS AVERAGE LABOR PROFILE FOR MIXTURE A2/B/C.

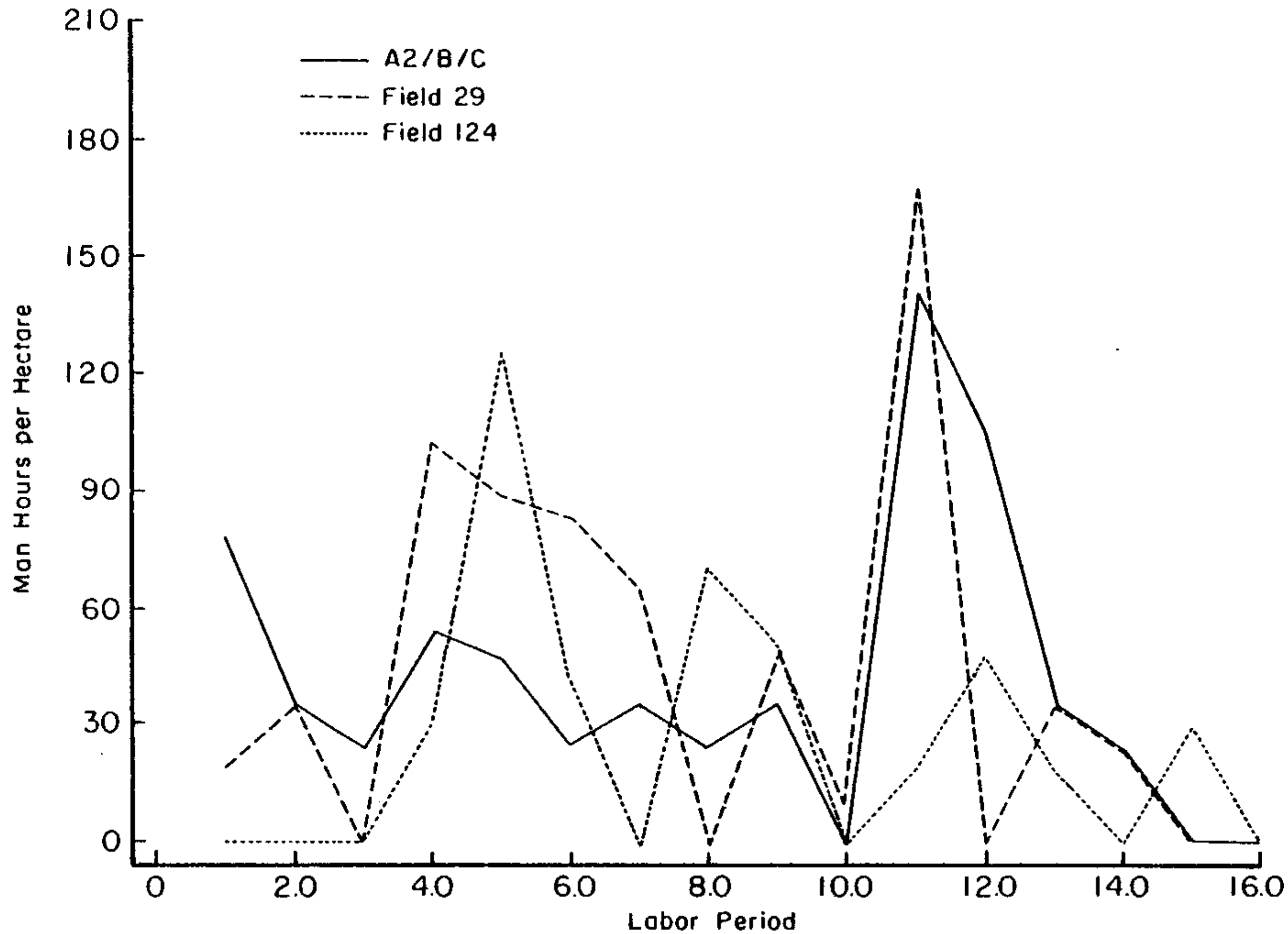


Table III.5. CHARACTERISTICS OF FIELDS BELONGING TO MIXTURE A2/B/C[a]

Item	Mixture Ave.	Field Number								
		820	6	93	124	397	29	165	263	479
Planting Costs/Ha.										
Cash (₦)[b]	.71	.48	.60	.91	.41	2.71	.32	2.54	-	-
Grain (kg.)	7.4	14.7	18.5	2.5	7.6	3.1	5.9	14.8	1.3	10.8
Groundnut (kg.)	12.4	11.5	14.8	4.0	2.0	20.7	12.1	42.3	7.3	11.7
Yield/Ha.										
Grain (kg.)	387	637	1,408	153	238	490	160	401	174	173
Groundnut (kg.)	280	166	353	266	191	527	347	631	114	492
Value/Ha.[c]										
Grain (₦)	40	61	134	13	21	47	15	33	17	16
Groundnut (₦)	51	35	67	45	29	90	66	119	22	84
Other (₦)	4	5	38	4	16	12	1	3	3	8
TOTALS										
Hectares	.79	.91	.65	1.06	.54	.42	.44	.71	2.06	.36
Man-hrs./Ha.[d]	671	468	1,146	558	431	1,852	673	1,227	291	753
Value/Ha. (₦)	95	101	239	62	56	149	83	155	42	108
Value/hr. (₦)	.14	.22	.21	.11	.13	.08	.12	.13	.14	.14

[a] A2/B/C = sorghum, millet, groundnuts, and cowpeas.

[b] ₦ = Naira. One Naira = U.S. $1.64 (1974/75).

[c] Gross harvest value.

[d] Total (family + hired) man-hour equivalents.

1. one field (if any) typifying the mixture average;

2. one large field with low input levels, tending to have high returns to labor but low returns to land;

3. one small field with high input levels, tending to have high returns to land, but low returns to labor.

4. all fields had to display labor profiles that were characteristic of their mixture type in terms of the level and timing of peak labor inputs.

Representativeness was therefore achieved by selecting individual fields which span the range of input-output relationships within each mixture type.

2. Labor Activities

Three labor activities are included in the model: labor hiring (HIRLAB), labor selling (SELLAB, reflecting the wage employment of family labor off the farm), and the allocation of additional family labor (ADDLAB) to farm activities during periods of peak demand. ADDLAB supplements the basic amount of family labor which is available in each labor period.

It is common for farmers to exhibit all three types of labor activity in the same period. Labor hiring did not occur only when a certain peak level of family labor input had been reached. Both family and hired labor inputs were observed on farms throughout the agricultural season, although the highest levels of labor hiring naturally occurred during the weeding and harvest periods. Allocation of some family labor to off-farm activities for purposes of supplementary cash earnings, even during the growing season, was also common.[1] To explain these complex patterns fully, one would have to refer to the detailed composition of individual households and to the skills possessed by each household member. This degree of detail is not found in the model, where labor is expressed in man-hour equivalents.

Based on these observed labor patterns, it is assumed in the model that families are willing to spend a certain basic number of hours per worker (e.g. 25 hours per worker per week) in either on-farm or off-farm activity. During peak agricultural periods, they are willing to work

---

[1] Hill (1972: 118) draws attention to this phenomenon, and argues that work off the farm does not conflict with the farm operation.

nearly twice as hard (e.g. 50 hours per worker per week) in on-farm activities.[1] This implies that families will engage in off-farm work only if a portion of the basic 25 hours per worker per week is not required for on-farm work, hence will not supply additional family labor hours for off-farm work if they are already working 25 hours per worker per week on the farm.[2] In effect, this allows off-farm employment to occur throughout the year except during a few two-week periods of intense on-farm activity.[3]

Given the nature of the linear programming format, the inclusion of a family labor selling activity poses a model design problem. If the household in the model is provided with enough family labor during the year to meet peak level demand, then the labor resource will rarely if ever be binding, and unrealistically high amounts of family labor will be sold by the model. If on the other hand labor supply is held to the lower nonpeak average, there will then be no provision for increasing family labor to meet peak demand, as farmers are observed to do. Specifying a basic level of family labor supply and including an activity (ADDLAB) for supplying additional family labor if necessary is a procedure which seems to reflect reality satisfactorily.

All three labor activities are specified for 16 labor periods covering the entire year (Table III.1). Periods of the year which were critical to the farm operation with respect to timeliness or peak labor requirements are represented by two-week labor periods. Longer time periods would obscure the peaks of labor demand, since labor is freely substitutable within each period. Other labor periods cover more than two weeks in cases

---

[1]These figures are purely illustrative; the exact formulation of family labor availabilities is discussed below in Section III.F.

[2] Matlon (personal communication) found some evidence that poor farmers will undertake wage employment even in peak agricultural periods if they have a pressing cash shortage. No provision is made for this behavior in the model.

[3]This of course assumes that off-farm employment is available during the slack season. Two points may be made in support of this assumption: (1) wages can be earned in nonagricultural occupations such as building, trading, and transporting; and (2) there is sufficient variability among farmers in terms of cropping patterns so that one farmer experiencing a labor demand peak may be able to hire another farmer who does not have a pressing need to weed or harvest his own fields at the same time.

where there are no farm activities which urgently require a labor input during a short span of time.

3. Marketing

The model provides for buying and selling of grain and groundnuts at seasonally appropriate prices. Grain can be bought and sold in all three periods, for trading purposes as well as for household consumption. Groundnuts can be sold in any period, but purchased only in Period 1 when seed may be required for planting. Early versions of the model allowed groundnut buying as well as selling in all periods as a representation of crop trading, which is a common form of off-farm income generation for farmers in the area. However, the model is very sensitive to the particular values used for buying and selling prices. When it is profitable, groundnut trading dominates the solution to a degree not observed in reality, possibly because having only a one-year series of prices did not allow an accurate specification of the trading margins and seasonal price movements. Groundnut trading was therefore excluded from the model by allowing groundnut purchases only in Period 1.

Buying prices for both grain and groundnuts are retail prices prevailing in the local village market.[1] Selling prices correspond to those received by farmers, and are slightly lower than the buying prices.

Onion/pepper and sugar cane--the other cash crops--are automatically sold as an integral part of the harvest activities, rather than through separate marketing activities. Eighty percent of the harvest value of these two crops is assumed to be sold, with the returns channelled into the cash reserve in Period 2.[2] The remaining 20 percent is assumed to be used for seed, given in gifts, consumed, or lost in storage.

Vegetables and cowpeas are also produced as byproducts of several mixtures included in the model. It is assumed that these are consumed by the household; hence there is no marketing activity for these crops either, nor any cash return realized. The imputed value of this unsold output is included in the objective function at harvest time, however.

---

[1]Matlon conducted monthly market price surveys in each of his three villages.

[2]Matlon's analysis (1977: 136, 476) shows that the proportion of these two crops sold was roughly 75 percent and 80 percent, respectively.

4. Consumption

Minimum subsistence consumption is included in the linear programming model as a fixed function of household composition. The principal component of consumption is grain, which can either be taken from household reserves or purchased. Each unit of grain consumed also carries a small cash charge to reflect the value of nongrain foods normally consumed, and often purchased.

5. Credit

The model allows for three cash borrowing activities, of which two represent regular borrowing which can occur in any of the three periods. The third type is an emergency borrowing activity whose function is primarily to cope with the possibility of an infeasible solution to Model.B resulting from a very bad crop year or series of bad years. Emergency borrowing (XBORROW) can occur in Period 2 or 3.

Debt from the two regular borrowing activities must be repaid before the end of the year, whereas debt resulting from emergency borrowing is automatically carried forward to the next year. Two different interest rates are used: a limited amount of credit is available at 15 percent annual interest, while larger sums can be borrowed at 1 percent per week, or 52 percent per year. Interest on emergency borrowing is also charged at 2 percent per week.[1]

6. Storage

Storage capacity is required in the model for maintenance of grain and groundnut reserves. Planting, buying, selling, and harvesting generate inflows or outflows from reserves and therefore directly affect storage

[1]Matlon states that interest charges were common, sometimes in the form of "voluntary gifts" and sometimes as in-kind payments, even though Koranic law clearly forbids levying interest. Interest rates on cash loans repaid in cash averaged 11 percent, and some borrowers (usually the poorer farmers) paid no interest at all. On cash loans repaid in-kind, however, interest rates averaged 142 percent per year when the imputed value of the in-kind payment was considered (Matlon, 1977: 354-58). This was felt to be unusually high, hence the adoption of 52 percent per year as the interest charge for the second type of borrowing.

capacity required. A storage construction activity has been included in each period of the model, at a cost of both cash and labor time. Storage losses of grains and groundnuts are embodied in the transfer activities discussed below.

7. Transfers

Transfer activities are a distinguishing feature of multiperiod linear programming models. They are required in order for resources to be carried over from one period to the next. Grain, groundnuts, cash, and storage capacity can all be transferred. When the crops are transferred, a slight deduction is made to reflect storage losses. In the case of storage capacity, the transfer activity carries a cash and labor cost meant to cover maintenance requirements. Both regular types of debt are transferrable within the year, if not repaid during the current period. Coefficients of the debt transfers add the interest charge accumulated over the current period to the amount of debt which must be repaid in the future.

8. Accounting

For each of the four transferrable resources, there is an activity in Period 3 which accumulates the net year-end inventory position, based on inflows and outflows from each resource inventory during the year. Another activity shows the total amount of emergency borrowing, if any, which occurred in Periods 2 and 3. These accounting activities are merely a convenient aid to interpreting the output of the MLP models.

D. Formulation of the Constraint Set

The following section discusses the structure of the constraints which are imposed on the production/marketing model. There are six general types of constraints: labor, land, planting/harvest acreage consistency, inventories for the transferrable resources, minimum and maximum restrictions, and accounting rows. Calculation of input-output coefficients for the A matrix, and values for the righthand side vector, are covered in later sections of this chapter.

1. Labor

There is one labor constraint for each labor period. Besides the initial amount of family labor made available in each labor period, further labor may be supplied to the labor constraint row by the HIRLAB and ADDLAB activities. Amounts of labor used in production, marketing, or off-farm wage employment, are deducted from the labor constraint row depending on the level of the activity concerned.

Ceilings are imposed on the amount of additional family labor (ADDLAB) which can be supplied in each of the 16 labor periods, and on the amount of family labor which can be sold. For labor selling, only one restriction is needed in each of the three MLP periods. No hired labor restriction is required.[1]

2. Land

Upland and lowland are the two land types specified in the model; both have constraint rows in Periods 1 and 2. With the exception of sugar cane, and vegetables in Period 2, all crop mixtures are grown on upland. Matlon's data did not include differences in soil quality from farm to farm or from village to village, apart from the upland/lowland distinction.

3. Planting/Harvest Consistency

There are constraints in Periods 1 and 2 for each crop production activity which ensure that the area harvested does not exceed the area planted. Such constraints are a typical feature of multiperiod models.

4. Resource Inventories

Separate inventory rows are specified for cash, grain, groundnuts, storage capacity, and the two types of regular borrowing. As usual, each resource has an inventory row in each of the three MLP periods. The

---

[1]Statements by Hill (1972) and Matlon make it clear that no constraint on hired labor is necessary. Matlon (1977: 232) states: "No evidence of a shortage of hired farm labor was observed in any of the villages." Observed levels of labor hire can be as high as 400 hours for a two-week period on farms of average size. Limiting labor hiring to 250 hours per period in an initial version of the model had negligible effects on the solution, hence this constraint was not used again.

inventory rows and transfer activities control the allocation of transferable resources among time periods.

5. Minima and Maxima

A minimum acreage of vegetable growing is required to satisfy home consumption needs. A maximum constraint is imposed on the area grown in onion/pepper. There is no requirement for a minimum acreage of subsistence grain production, which some models include in order to prevent specialization in high value cash crops.[1] In this model, a minimum grain consumption requirement in each of the three MLP periods is the only food-related constraint, aside from the rather unimportant minimum vegetable requirement.

For the year as a whole, there are limitations on the amount of each type of borrowing possible. In addition, the model requires the farmer to transfer small amounts of cash, grain, and groundnuts from year to year. These latter constraints are removed in some multi-year runs of the model.

6. Accounting

Accounting rows are specified for each of the four transferrable resources, and for emergency borrowing. These complement the five accounting activities that summarize the net inventory positions at the end of the year.

E. Estimation of Coefficients

It should be recognized that the process of estimating coefficients for a model involves a combination of statistical rigor and subjective judgment. Subjectivity comes into play in the major decisions, e.g., when defining the production activities or the time periods of the model, but also when deciding which price series is the most appropriate, or even whether to use weighted or unweighted averages. Since particular numerical coefficients can exert a strong influence on the model solution,

---

[1] Delgado (1978) describes a model which includes a minimum millet production requirement of 2.4 hectares. This is quite significant, since total land area in his model is only 3.85 hectares.

it therefore seems important to spell out exactly the method and assumptions used in deriving the coefficients. This section attempts to accomplish that purpose, while at the same time avoiding exhaustive detail.

Virtually all of the coefficients used in the MLP model were computed from Matlon's raw data. Information for the storage activities was also drawn from work by Hays, Jr. (1975). Studies by Norman (1972), Delgado (1978), and Hazell (personal communication) also provided a valuable cross-check on the representativeness of Matlon's data.

1. Crop Production

Input-output coefficients were estimated for each particular field chosen for inclusion as a production enterprise in the model. As noted in Section III.C.1, this approach was found to be superior to using coefficients based on averaging data for a set of fields. Table III.5 above contains enterprise budgets for fields belonging to Mixture A2/B/C (grain, groundnuts, cowpeas); Figure III.2 shows the labor profile for this mixture. Crop production activities are in hectare units, hence the coefficients are on a per-hectare basis.

Objective function coefficients. Period 1 includes a set of GROW activities for each enterprise type which encompass the land preparation, planting, and weeding operations. Objective function coefficients for the GROW activities consist of the value of seed and fertilizer applied plus the imputed value of vegetable planting materials used, if any. Seed costs for grains and groundnuts were not included in the GROW objective function values, since they are supplied by the inventories and therefore costed internally by the model. Hired labor costs are handled by the labor hire activities.

For the HARVEST activities in Period 2, the coefficient includes the value of vegetables and cowpeas harvested as part of the mixture, but not for grain and groundnuts, which are supplied to the inventories and therefore available for sale through the selling activities. The objective function coefficients for the harvest activities for sugar cane and onion/pepper include the total harvest value of all crops grown on the field concerned, of which 80 percent is channelled to the Period 2 cash inventory.

Input coefficients. The principal inputs to the production activities are grain and groundnut seed, labor, and cash. Cash expenditures cover the value of any seed, fertilizer and insecticides purchased. Hired labor payments are made from the cash inventory, and require a small payment of grain as well. Estimation of the seed requirements and nonlabor cash payments from Matlon's data was straightforward.

Labor requirements were estimated in terms of total family plus hired man-equivalent hours per hectare, in each of the 16 labor periods.[1] Man-equivalents were computed from raw data on labor inputs, which gave actual hours worked by type of activity in each of seven age-sex categories. Work productivity coefficients by age, sex, and task were then used to convert actual hours into man-equivalent hours. The conversion weights used were devised by Matlon on the basis of his experience and that of previous farm production researchers (Matlon, 1977:171). Table A.2 in Appendix A shows these weights.

The use of man-equivalents is somewhat controversial, since it assumes that there are standard tasks which are performed with unequal efficiency across age-sex categories, largely as a result of size and strength differences. This approach has been common in the past, but there is little empirical evidence of differential productivity by age-sex type. It is perhaps equally plausible to argue that differences in strength show up primarily in endurance, not efficiency (Delgado, 1978: 97). Also, persons in different age-sex categories who are engaged in harvesting, for example, are probably not all performing the identical task but rather slightly different, complementary ones to which each person is well suited. From this point of view, there is little basis for valuing the labor of a child or woman at one-third or three-quarters of a man's labor.

While the use of actual hours rather than man-equivalent hours may have somewhat greater merit, in this study the practical difference between the two approaches was very small for the following reasons:

---

[1]Not including walking time to the field. Since there is a modest tendency for small fields to be relatively close to the compound, taking account of walking time would increase the levels of labor input per hectare on larger fields to values closer to those observed for small fields. Including walking time would require additional assumptions regarding number of visits to the field, since this information was not gathered by Matlon.

1. Most families in the area are strict Muslims who practice the seclusion of women. Consequently, except for a few activities such as groundnut picking where the participation of women is socially approved, there is very little female labor input to agriculture. Females supply only 7 percent of the total on-farm family labor input, and about one-third of the hired labor input, as illustrated in Tables III.6 and III.7.

2. There is relatively little difference between actual hours and man-equivalent hours overall. Total man-equivalent hours for both family and hired labor are about 94 percent of total actual hours.[1]

3. The availability of family labor in the model is computed in terms of man-equivalent hours also; hence the discounting of non-adult-male labor which is involved in the labor demand coefficients is offset by similar discounting in labor supply.

Output coefficients. Per-hectare yields of grain and groundnuts were computed for each enterprise, broken down by period. These are considered as average-year yields in Model.A, and then modified by a random weather factor for insertion as simulated "actual" yields in Model.B. In order to prevent the model from using at the beginning of a period crops that are not actually harvested until the end of the period, only part of the yield attributable to Period 2 is made available to the Period 2 resource inventories. The following procedure is adopted:

1. For grain, the entire early millet harvest plus 40 percent of other grains harvested in Period 2 is available for use in Period 2. The remaining 60 percent of grains harvested in Period 2 plus those harvested in Period 3 are available in Period 3.

2. For groundnuts, 60 percent of the Period 2 groundnut harvest is available to the Period 2 groundnut inventory. The remaining 40 percent of the Period 2 harvest plus all of the Period 3 harvest is channelled into the Period 3 inventory.

3. For sugar cane and onion/pepper, 80 percent of the harvest value is made available to the Period 2 cash inventory. These crops are not harvested in Period 3.

---

[1]This is essentially because (a) men aged 16-49 do most of the work, and (b) the weights for other age-sex categories for planting/weeding and harvesting (the two major labor types) are generally around 0.8, i.e., only slightly less than one.

Table III.6. FAMILY LABOR HOURS WORKED PER PERSON BY AGE-SEX CATEGORY[a]

Age-Sex Category	Total Hours Worked	Percent of Total	Overall Ave. Hours Per Person
Child 0-9	1,501	2.7	21
Boy 10-15	5,830	10.6	307
Girl 10-15	372	.7	21
Man 16-49	34,258	62.5	634
Woman 16-49	3,038	5.5	42
Old Man 50+	9,377	17.1	721
Old Woman 50+	444	.8	32
TOTAL	54,780	100.0	

[a]Actual hours worked unadjusted by man-hour equivalents.

Table III.7. HIRED LABOR HOURS WORKED BY AGE-SEX CATEGORY[a]

Age-Sex Category	Total Hours Worked	Percent of Total
Child 0-9	1,376	3.6
Boy 10-15	1,415	3.7
Girl 10-15	1,868	4.8
Man 16-49	23,001	59.9
Woman 16-49	9,790	25.5
Old Man 50+	109	0.3
Old Woman 50+	872	2.2
TOTAL	38,431	100.0

[a]Actual hours worked unadjusted by man-equivalent weights.

Table III.8 shows the grain, groundnut, and cash yield of each enterprise, by period.

2. Labor

Objective function. The basic supply of family labor is not costed in the objective function. Its opportunity cost is determined by the off-farm wage rate. Hired labor costs ₦0.104 per man-hour, which is the average figure for males aged 16-49.[1] A unit of additional family labor (ADDLAB) is given an arbitrary cost of ₦0.10, and the labor selling activity (SELLAB) is priced lower at ₦0.09.[2] ADDLAB costs slightly less than hired labor and slightly more than what is earned from labor selling, so that the model will use hired labor only once ADDLAB is exhausted, and will not cause ADDLAB to enter solution merely to supply labor for off-farm wage employment. Activity levels in the MLP models were not sensitive to the absolute values of the objective function coefficients for ADDLAB and SELLAB.

Input-output coefficients. Hired labor is assumed to require an in-kind payment of 0.08 kilogram (kg) of grain per man-hour, in addition to the cash payment of ₦0.104.[3] Cash earned from the SELLAB activity during the latter half of Periods 1 and 2 is channelled into the cash reserves of the following period; other wage earnings are available to the cash reserve during the current period.

3. Marketing

Table III.9 shows the prices for crop marketing activities in the model. Grain buying and selling in period 1 is based on a three-village

---

[1]Matlon (1977: 202). During the survey period, one Nigerian naira was equal to 1.64 U.S. dollars.

[2]Off-farm employment earns hourly wages ranging from ₦0.06 to ₦0.26. Agricultural wage labor is the most common type, and earns the lowest wages. This is the main reason why a relatively low wage for SELLAB is specified in the model (Matlon, 1977: 310).

[3]Multiplying 0.08 kg times five hours per day times ₦0.12 per kg of grain gives an imputed value of the in-kind payment of about ₦0.05, which is a typical amount obtained per day by workers who are paid mainly in cash.

Table III.8. PER-HECTARE YIELDS, BY PERIOD, FOR ENTERPRISES IN THE MODEL

		Period 2			Period 3		Total	
Mixture	Type[a]	Grain kg/ha	Groundnuts kg/ha	Cash N/ha	Grain kg/ha	G'nut kg/ha	Grain kg/ha	G'nut kg/ha
A11	(a)	811			422		1,233	
	(b)	1,336			864		2,200	
	(c)	424			250		674	
A12	(a)	572			545		1,117	
	(b)	163			190		353	
	(c)	678			900		1,578	
A1/B	(a)	1,011	556		737	370	1,748	926
	(b)	355	118		136	82	491	200
	(c)	185	533		139	358	324	891
A2/B	(a)	93	365		140	243	233	608
	(b)	221	28		332	19	553	47
	(c)	200	190		299	126	499	316
A1/C	(a)	1,140			708		1,848	
	(b)	1,069			762		1,831	
	(c)	145			120		265	
A1/B/C	(a)	348	15		415	10	763	25
	(b)	289	250		379	168	668	418
	(c)	235	100		256	127	491	227
A2/B/C	(a)	-	209		159	139	159	348
	(b)	161	379		241	252	402	631
	(c)	69	68		104	46	173	214
Onion/ Pepper	(a)			412				
	(b)			178				
Sorghum	(a)	577			866		1,443	
Sugarcane	(a)			204				
	(b)			282				

[a]Type (a) high labor input and returns/ha.; often generally superior. Type (b) average. Type (c) low labor input and returns/ha.; often generally inferior.

Table III.9. CROP PRICES USED IN THE MODEL, BY PERIOD

	(Prices in Naira per kg.)[a]		
Crop/Price Type	Period 1	Period 2	Period 3
1. Grain			
a. Buying	.14	.11	.10
b. Selling	.12	.095	.085
2. Groundnuts			
a. Buying	.20	-	-
b. Selling	.18	.15	.16

[a]One Naira = $1.64 U.S. dollars (1974/75).

weighted average of prices for the four major grains.[1] Grain selling in Periods 2 and 3 was arbitrarily set slightly lower than the retail buying price, to reflect farm gate prices.[2] Returns from the selling activities are available to the cash inventory in the same period.

Matlon's market surveys showed substantial seasonal variation in groundnut prices; farm sale prices for groundnuts apparently ranged from ₦0.13 to ₦0.24 per kg (Matlon, 1977: 259, 263). It was decided that these local market prices were not representative of those usually received for farm sales, since they did not take account of the influence of the groundnut marketing board. The marketing board buying season lasts six months from November to May, corresponding roughly to Periods 2 and 3 of the model; during this period, prices are fairly stable, according to Hill (1972: 132). Groundnut selling prices were therefore revised to be: ₦0.15 in Period 2, ₦0.16 in Period 3, and ₦0.18 in Period 1.

4. Consumption

The model expresses household consumption in terms of kilograms of grain. A kilo of grain supplies 3600 calories and costs between ₦0.085 and ₦0.12, depending on the period. However, consumption surveys indicate that the total cost of 3600 calories should be ₦0.166.[3] Hence, an additional ₦0.046 to ₦0.081 should be added to the cost of a kilo of grain in order for the consumption activity to reflect total food costs accurately. The model therefore includes a nongrain food cost of ₦0.05, which is the coefficient found in both the objective function and the cash inventory row.

---

[1]Matlon (1977: 439). The four grains are early millet (gero), late millet (dauro), tall sorghum (farfara), and short sorghum (kaura). Hausa names are in parentheses. For this study, the prices were weighted 70 percent for farfara and 10 percent for each of the other three grains.

[2]This is consistent with Matlon's data (1977: 259, 263). The margin between buying and selling price is about 17 percent in the model, which is well within the observed range.

[3]A survey by Simmons, reported by Matlon (1977: 278) shows a cost per 1000 calories of ₦.0462 when adjusted for 1974/75 prices.

Recall that the value of vegetable and cowpea production generated by the crop enterprises is considered to be consumed. Also, a minimum vegetable production restriction of 0.2 hectares (ha) is imposed.

5. Credit

Borrowing activities in each period cost the objective function an amount equal to the interest charge accumulated during that period. For purposes of repayment, interest charges are accumulated in the debt inventory row by the operation of the debt transfer activity. Debts cannot be repaid in the same period they were incurred.

6. Storage

Labor and cash coefficients for storage construction and for storage maintenance (embodied in the storage capacity transfer activity) are derived from Hays, Jr. (1975: 37). Costs are ₦9.0 and 40 man-hours per 1000 kg of storage built, and ₦1.0 and 15 man-hours per 1000 kg of storage transferred from one period to the next. Storage losses of 15 percent per year for grain and groundnuts are incorporated in the grain and groundnut transfer activities.

F. Estimation of Righthand Side Values

Values for the vector of resource availabilities were estimated for the four household types studied:

1. average family size and average resource endowment (AFAR);
2. small family size and average resources (SFAR);
3. small family size and small resource endowment (SFSR);
4. average family size, small resource endowment (AFSR).

The composition of the two family types was assumed to be:

1. small family: one man, one woman, one female child aged 5, one male child aged 3;

2. average family: one man, one woman, one old man (over 50), one boy aged 10, one girl aged 11, one girl aged 6, one boy aged 3. Assumptions regarding exact ages were necessary in order to incorporate changes in family age structure through time when using the complete multi-year model.

Applying weights for adult consumer and worker equivalents gives Table III.10:[1]

Table III.10. Composition of Assumed Model Households.

Type	Residents	Consumers	Weeders	Harvesters
small family	4	2.45	1	1.6
average family	7	4.9	2.8	3.4

These categories are used in deriving values for family labor supply, and for minimum consumption requirements. "Weeder" is defined as the weighted number of boys 10-15, men 16-49, and old men 50+; "harvester" also includes the weighted number of women 16-49. Weeder is the relevant concept for Period 1; harvester is appropriate for Periods 2 and 3, and for off-farm activity.

The reason for a two-fold concept of worker equivalent can be inferred from Tables III.11 and III.12, which show total hours and hours per person worked by family members in weeding and harvesting respectively. Children below 9 years and females of all ages do not engage in weeding. Where harvesting is concerned, children continue to be unimportant, but women aged 16-49 now make a significant input. Both availability in terms of hours typically worked, and productivity in terms of efficiency of labor input, were considered in formulating the weeder and harvester weights shown in Table A.5. For example, women are assumed to have a man-hour productivity equivalent of 0.8 in harvesting, but since they work far fewer hours per person than boys, men or old men, each women is therefore counted as 0.6 harvester. On the other hand, although old men have a weeding productivity weight of 0.8 they are given a weight of 1.0 as weeders because they supply a relatively high labor input per person in weeding.

---

[1]Table A.3 in Appendix A gives the consumer weights used. Table A.5, which contains the weights used to calculate the number of weeders and harvesters, is slightly different from the set of worker equivalent weights used by Matlon, shown in Table A.4.

Table III.11. FAMILY LABOR HOURS WORKED PER PERSON IN WEEDING, BY AGE-SEX CATEGORY[a]

Age-Sex Category	Total Weeding Hours	Percent of Total	Weeding Hours Per Person
Child 0-9	280	1.8	4
Boy 10-15	1,490	9.7	78
Girl 10-15	-	-	-
Man 16-49	10,321	67.1	191
Woman 16-49	83	0.5	1
Old Man 50+	3,208	20.9	245
Old Woman 50+	-	-	-
TOTAL	15,382	100.0	

[a]Actual hours worked unadjusted by man-hour equivalents.

Table III.12. FAMILY LABOR HOURS PER PERSON IN HARVESTING, BY AGE-SEX CATEGORY[a]

Age-Sex Category	Total Harvest Hours	Percent of Total	Harvest Hours Per Person
Child 0-9	678	4.1	10
Boy 10-15	1,415	8.6	74
Girl 10-15	299	1.8	17
Man 16-49	8,527	51.9	158
Woman 16-49	2,709	16.5	37
Old Man 50+	2,440	14.8	188
Old Woman 50+	373	2.3	27
TOTAL	16,441	100.0	

[a]Actual hours worked unadjusted by man-hour equivalents.

1. Labor Supply

Several methods have been used in other studies to estimate labor supply. For a similar ecological zone in Upper Volta, Delgado (1978) fixes the labor available at the average peak level for an average family, which gives 556 hours per two-week period. Hazell (personal communication), using recent data from northern Nigeria, argues that virtually all farm work is done by adult males. He assumes a six-hour work day, 25 days per month, and an average of 1.73 adult males per household, which yields 130 hours per two-week period. As explained below, the initial approach used here gives an intermediate result: for the average family, labor available for farm work (including ADDLAB) is fixed at about 250 hours per two-week period during Period 1 of the model, and at 170 hours per two-week period during Periods 2 and 3.[1]

In the model developed here, there is first a distinction between labor supply during the planting/weeding period and the harvest and slack periods. Second, a basic amount of family labor is supplied, and then supplemented by an additional supply of family labor available at higher cost. The basic quantity of family labor may be used for any combination of farm and off-farm activity, but the higher cost ADDLAB is made available only for on-farm activity as required in periods of peak demand.[2] Labor hiring is also allowed in all labor periods.

Multiple regression equations were estimated in an attempt to predict family labor hours worked as a function of variables such as number of workers, number of consumers, farm size, etc. Unfortunately, most of these equations fit too poorly to offer a basis for estimating labor supply, given the family types in the model.[3]

---

[1]Evaluation of the MLP model led to a slight reduction of the labor supply specified in the final version of the multi-year model. See Chapter V.

[2]Storage and crop selling activities can also draw on ADDLAB if this is profitable.

[3]Estimated relationships were in the expected direction, however. For example, total family labor inputs were positively related to farm size and number of weeders; labor inputs per week per weeder increase as farm size increases. Total hired labor inputs were positively related to farm size and inversely related to number of weeders in the family.

Ultimately the following rule-of-thumb procedure was adopted; using data for the 35 households in Matlon's small sample:

1. calculate family labor input per weeder during Period 1, and per harvester during Periods 2 and 3;

2. calculate family labor input per harvester for off-farm activities as well.[1]

Typical figures were then chosen and multiplied by the number of weeders and harvesters in each of the model families to derive the basic family labor supply in each labor period. These typical figures were:

1. 25 hours/week/weeder for farm work in labor periods 1-10;
2. 15 hours/week/harvester for farm work in periods 11-16;
3. 5 hours/week/harvester for off-farm work in all periods.

With this as the basic family labor allocation, additional family labor (ADDLAB) supply was then specified as follows:

1. 20 hours/week/weeder in periods 1-10;
2. 10 hours/week/harvester in periods 11-16.

Table III.13 shows the resulting levels of available family labor for the two household types, broken down by labor period and category.

The constraint on the labor selling activity was derived from data on hours spent in agricultural wage labor by the 35 households, which ranged from zero to 1000 hours per household per year. The average of 250 hours per household per year was used in the model, divided among the three MLP periods in proportion to their length.

2. Other Resources

Important resources in the model other than family labor are land and the initial stocks of grain, groundnuts, cash, storage capacity, and borrowing ability. Land, cash, and borrowing ability are the most important resources in the model which differentiate limited endowment ("poor") farmers from farmers with average resource endowments. Values specified for resource levels in the model are summarized in Table III.14, and are discussed below.

---

[1]Harvester was used as the standard here since off-farm activities are performed by a wider range of family members than are on-farm activities.

Table III.13. LABOR SUPPLY BY PERIOD AND FAMILY TYPE: INITIAL ASSUMPTIONS[a]

		Small Family (Man-hours)				Average Family (Man-hours)			
Labor Period	No. of Weeks	Farm	Off-Farm	Basic Total	ADD-LAB	Farm	Off-Farm	Basic Total	ADD-LAB
1	5	125	40	165	100	350	85	435	280
2	2	50	16	66	40	140	34	174	112
3	2	50	16	66	40	140	34	174	112
4	2	50	16	66	40	140	34	174	112
5	2	50	16	66	40	140	34	174	112
6	2	50	16	66	40	140	34	174	112
7	2	50	16	66	40	140	34	174	112
8	2	50	16	66	40	140	34	174	112
9	2	50	16	66	40	140	34	174	112
10	2	50	16	66	40	140	34	174	112
11	4	96	32	128	64	204	68	272	136
12	6	144	48	192	96	306	102	408	204
13	2	48	16	64	32	102	34	136	68
14	2	48	16	64	32	102	34	136	68
15	3	72	24	96	48	153	51	204	102
16	12	288	96	384	192	612	204	816	408
TOTAL		1,271	416	1,687	924	3,089	884	3,973	2,274

Assumptions:

Farm: 25 hours/week/weeder for Periods 1-10.
+15 hours/week/harvester for Periods 11-16.

Off-farm: 5 hours/week/harvester for all Periods.

ADDLAB: 20 hours/week/weeder for Periods 1-10.
10 hours/week/harvester for Periods 11-16.

Small Family: 1 weeder, 1.6 harvesters.

Average Family: 2.8 weeders, 3.4 harvesters.

[a] See Chapter V for revised assumptions.

Table III.14. RESOURCE ENDOWMENT SPECIFIED IN THE MODEL[a]

	Upland (ha.)	Lowland (ha.)	Grain (kg.)	Groundnuts (kg.)	Cash (₦)	Storage Capacity (kg.)	Borrowing Type A (₦)	Borrowing Type B (₦)
Low Level								
Small Family	1.95	.15	425	50	10	1,700	5	50
Average Family	1.95	.15	750	50	10	2,000	5	50
Average Level								
Small Family	3.75	.25	450	75	20	2,200	10	100
Average Family	3.75	.25	800	75	20	2,400	10	100

[a]For revised assumptions about land availability, see Chapter V.

Land. Areas of upland and lowland are those given by Matlon (1977: 111) as the three-village average for low and middle income farmers, based on the 35-household survey. The land/person ratios implied by these assumptions are contained in Table III.15, and are compared to the ratios observed by Matlon. Except for the poor, average-size family, the levels of land per resident and per consumer initially specified in the model are above the mean values observed by Matlon. Chapter V discusses the effect of varying the land supply assumptions in the model.

Cash. Coefficients are based roughly on Matlon (1977: 118), which shows that average nonfarm operating capital per household ranged from ₦5 to ₦40.

Storage capacity. The average family has about 2100 kg of storage capacity in the form of earth and wood granaries, plus an additional 365 kg of "hut storage" (Matlon, 1977: 268). These figures are very close to those reported by Hays, Jr. (1975: 34-35). Storage availability was scaled down slightly for the poor family and small family types in the model, reflecting both limited financial capability and the smaller storage requirements resulting from fewer family members.

Borrowing ability. The limits shown in Table III.14 are based on Matlon (1977: 343-52), which implies cash borrowing of ₦5 to ₦20 per year. Larger amounts are borrowed in-kind. It is assumed that poor households have less borrowing ability than rich households.

Grain. No information was available on actual grain reserves, which Matlon found to be a closely held secret. Each family in the model was provided with enough grain to cover Period 1 consumption needs, plus a bit extra for Period 1 planting requirements. This represents the expectation that families would normally carry stores equal to at least one period's consumption and seed requirements.[1] The main difference between family types in terms of grain stocks therefore results from food consumption requirements as determined by family size. A surplus over consumption and seed requirements is not provided, since these additional grain reserves in Period 1 can simply be sold and converted into cash.

---

[1] Farmers interviewed by Hays, Jr., generally indicated that they wanted to store more than one year's consumption needs, to guard against bad weather.

Table III.15. LAND/PERSON RATIOS IN THE MODEL: INITIAL ASSUMPTIONS[a]

	Upland		Lowland		Total	
	Per Resident (ha.)	Per Consumer (ha.)	Per Resident (ha.)	Per Consumer (ha.)	Per Resident (ha.)	Per Consumer (ha.)
<u>Poor</u>						
Small Family	.49	.80	.04	.06	0.53 (0.52)	0.86 (0.64)[b]
Average Family	.28	.40	.02	.03	0.30 (0.29)	0.43 (0.43)
<u>Average</u>						
Small Family	.94	1.53	.06	.10	1.0 (0.76)	1.63 (1.02)
Average Family	.54	.77	.04	.05	0.57 (0.47)	0.82 (0.65)
Matlon 3 village Mean					(0.37)	(0.54)

[a]For the effect of revised land availability on land/person ratios, see Chapter V.

[b]Figures in parentheses are those calculated by Matlon (1977: 105).

Groundnuts. There was no information on which to base an estimate of typical groundnut stocks. The amounts provided are low, barely enough to cover demand for seed. As with grain, larger stocks would simply be sold by the model to increase cash receipts in Period 1.

3. Other Restrictions

The model requires a minimum of 0.2 ha of vegetable production, for consumption purposes. This is an arbitrary figure, and perhaps an overestimate of typical kitchen garden acreages. An upper limit of 0.2 ha is also imposed on onion-pepper production.[1]

Minimum grain consumption requirements imposed in each period are based on an annual figure of 300 kg per adult consumer equivalent. This assumes, following Matlon, a daily requirement of 2950 calories per adult consumer equivalent, and 3600 calories per kg of grain. On a per capita basis, this requirement amounts to 2010 calories per day. The total minimum grain consumption requirements in the model are therefore 735 kg for the small family and 1470 kg for the average-size family. This compares to an estimate made by Hazell (personal communication) of 1608 kg of grain for a slightly larger family size, and 1421 kg per family assumed by Eddy (1979).

---

[1]It was felt that larger acreages would be unrealistic in view of the limited size of the local market, where most of the crop is sold. The limit of 0.2 ha lies within the observed range (0.05 ha to 0.34 ha) for fields growing onion/pepper; also, 0.2 ha of onion/pepper yields a gross marketed value of about N82 in the model, which is slightly more than N75 typically earned from onion/pepper by average income households. Model evaluation showed that doubling the allowed acreage of onion/pepper to 0.4 ha changes the solution in only minor respects.

Chapter IV

DESIGN OF THE LINKAGE AND CONSUMPTION/SAVINGS/INVESTMENT MODEL

This chapter describes the second major part of the complete simulation model, the first part being the multiperiod linear programming (MLP) component. Two FORTRAN-programmed components accomplish the following purposes:

1. To set up Model.B after the solution of Model.A. The base version of Model.B is simply a subset of the rows and columns of Model.A covering Periods 2 and 3. Average-year crop yield, price, and harvest labor coefficients in the base version are replaced by simulated "actual" values, which become the new coefficients of Model.B for the current year. Cash returns to trading activities, and the value of additional production resulting from fertilizer application, are likewise adjusted for stochastic variation. In addition, resource availabilities as of the end of Period 1 of Model.A are inserted into the righthand side vector of Model.B as initial conditions for Period 2.

2. To determine the level of consumption, savings, and investment out of surplus income, as given by the solution of Model.B.

3. To calculate and print a set of yearly accounts showing the status of household income and assets, as well as the results of the consumption, savings, and investment activities.

4. To link successive years together in a recursive relationship by modifying Model.A for the next year on the basis of the previous year's investment decisions, net resource levels, and assumed trend changes in family age structure.

These functions of the FORTRAN components are discussed in the order of their occurrence in the solution procedure. For convenience, the FORTRAN program which sets up Model.B (step 1 above) will be referred to as "SIM1," while the second program dealing with steps 2 to 4 will be referred to as "SIM2." Flow charts of SIM1 and SIM2 are shown in Figures IV.1 and 2, respectively. Other terms and abbreviations used in this chapter are defined in the glossary given in Table IV.1.

FIGURE IV.1. FLOW CHART OF SIM1.

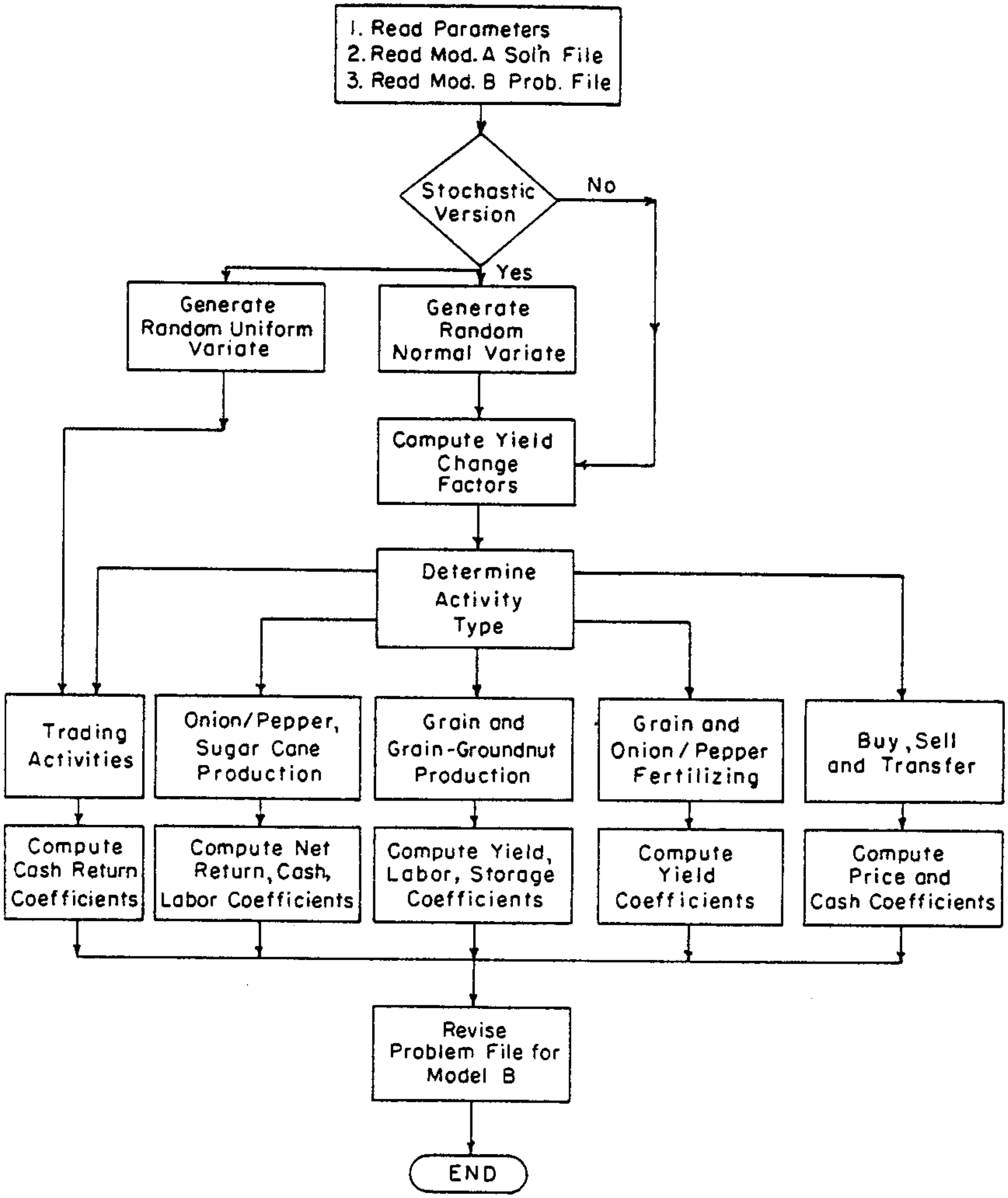


FIGURE IV.2. FLOW CHART OF SIM2

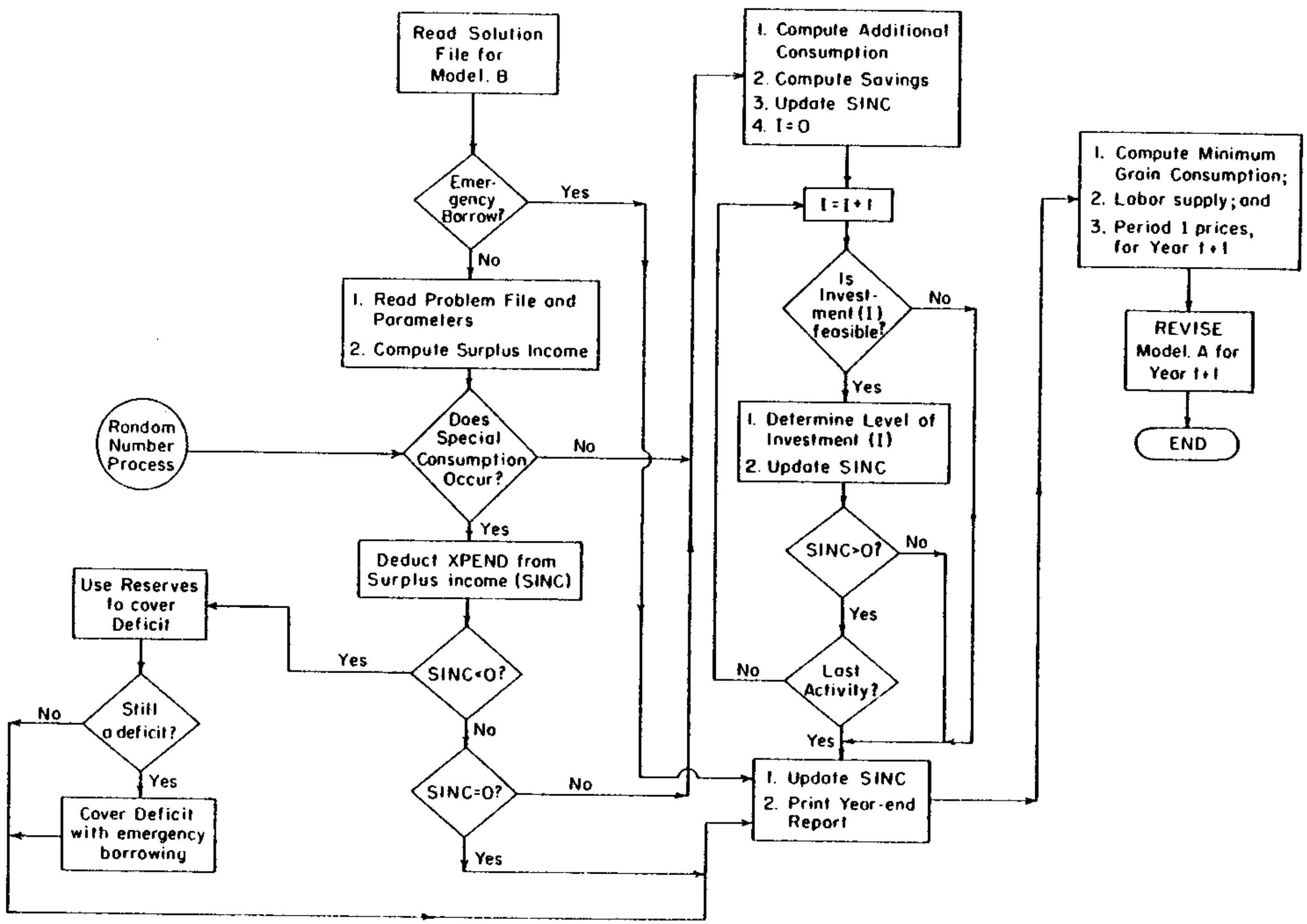


Table IV.1. GLOSSARY OF MODEL TERMS

A11	sorghums and millets with more than 20 percent of harvest value in early millet.
A12	sorghums and millets with less than 20 percent of harvest value in early millet.
A1/B	sorghum, millet (inc. early millet), groundnuts.
A2/B	sorghum, late millet, groundnuts.
A1/C	sorghum, millet (inc. early millet), cowpeas.
A1/B/C	sorghum, millets, groundnuts, cowpeas.
A2/B/C	sorghum, late millet, groundnuts, cowpeas.
ADCON	additional consumption, above subsistence level.
AVG_j	average-year yield for crop j, estimated from field trials.
$BASELAB_k$	base (average-year) harvest labor coefficient for enterprise k.
$BASEPR_{ij}$	base (average-year) price in Period i for crop j.
$BASEYLD_j$	base (average-year) yield coefficient for crop j.
CASHINV2	cash row for Period 2 in the linear programming models.
$DELTA_{tj}$	the proportional deviation of simulated yield in Year t relative to the base yield for crop j.
$DELTAB_{tk}$	the proportional deviation of total simulated yield in Year t for enterprise k relative to the average yield.
$FLEX_{ij}$	price flexibility coefficient in Period i for crop j.
FORTRAN components	part of full model; consists of the FORTRAN programs, SIM1 and SIM2.
HARLAB	harvest hours per hectare, in logarithms.
Investment	allocation of working capital to special income-increasing activities.
KGHAR	kilogram weight of harvest per hectare, in logarithms.

Table IV.1. (continued)

MLP component	multiperiod linear programming section of overall model; consists of Model.A and Model.B.
Model.A	full-year linear programming model for production, marketing, and basic consumption.
Model.B	linear programming model covering only harvest and marketing, incorporating the simulated yield, price, and labor coefficients.
MNSAV	minimum desired savings level.
MPC	marginal propensity to consume.
MPS	marginal propensity to save.
NETCASH	year-end cash reserves, from Model.B.
NETREV	value of objective function in MLP models.
Period 1	land preparation, planting and weeding, in Model.A.
Period 2	early harvest and marketing.
Period 3	late harvest, marketing, and slack period.
$RAND_t$	standard normal random deviate for Year t.
SAVE	household savings.
$SIMLAB_{tk}$	simulated harvest labor for enterprise k in Year t.
$SIMPR_{tij}$	simulated price in Year t and Period i for crop j.
$SIMYLD_{tj}$	simulated yield in Year t for crop j.
SIM1	computes simulated crop yields, prices, and labor requirements, and sets up Model.B.
SIM2	determines additional consumption, savings, and investment, and sets up Model.A for Year t + 1.
SINC	surplus income.
Surplus income	net household income minus the value of subsistence consumption plus the value of crop reserves exceeding minimum storage requirements.
STD_j	standard deviation of yield for crop j.
TRCASH1	cash transfer activity, from Period 1 to 2 in Model.A.
XPEND	special-event consumption expenditure, for marriages, funerals, etc.

A. Setting Up Model.B

1. Computing the Stochastic Coefficients

In calculating the simulated values which replace average-year coefficients in the base version of Model.B, procedures vary depending on the crop or type of activity. Crop yield adjustment factors for grain and groundnuts are derived from the probability distribution of yields in long-term fertility trials carried out by the Institute for Agricultural Research, Samaru, Nigeria, in an area very close to that surveyed by Matlon.[1] This was the only available information on the behavior of crop yields over time in that region. Means and standard deviations for the grain and groundnut producing activities in the model were computed from control plot data for the sorghum and groundnut trials, respectively. For grain yields, the mean and standard deviation used in the model were 360 and 125 kilograms per hectare, respectively; for groundnuts, the corresponding figures were 415 and 65 kilograms per hectare. The model is designed to allow either random sampling from these probability distributions, or the insertion of a predetermined sequence of yield events.

The simulated yield coefficient for crop j in Year t ($SIMYLD_{tj}$) is computed from the base (average-year) yield coefficient for crop j ($BASEYLD_j$) as follows:

(1) $SIMYLD_{tj} = BASEYLD_j\ [1 + (RAND_t)(STD_j)/AVG_j]$

where: $RAND_t$ = a standard normal random deviate for Year t[2]

STD_j = the standard deviation of yields for crop j

AVG_j = the mean yield for crop j estimated from field trials

Equation (1) can be written as:

(2) $SIMYLD_{tj} = BASEYLD_j\ (1 + DELTA_{tj})$

---

[1]The fertility trials spanned a fourteen-year period from 1954 to 1969, and were carried out on the Institute research farm at Samaru. Results are reported in Lombin and Abdullahi (1977).

[2]Note that the same random deviate is used in determining the simulated yield of each crop, based on the assumption that year-to-year changes in crop yields are correlated. The probability distributions of yields for each crop are different, however.

where: $DELTA_{tj}$ = the proportional deviation of simulated yield in Year t relative to the base yield for crop j.[1]

Yields of onion/pepper and sugar cane are expressed in the model as values rather than physical quantities. Procedures are included in SIM1 for calculating the change in harvest value as a combined effect of change in yield and change in price resulting from the random yield effect. For onion/pepper, the mean, standard deviation, and average price per kilogram (kg) are 790 kg, 260 kg, and ₦0.28/kg, respectively. The corresponding figures for sugar cane are 6100 kg, 2000 kg, and ₦0.06/kg.[2]

Prices for grain and groundnut marketing activities are a deterministic function of the stochastic yield effect in Year t. Prices are not themselves stochastically distributed with respect to yield. Buying and selling prices for Periods 2 and 3 are calculated by the model as follows:

(3) $SIMPR_{tij} = BASEPR_{ij}\ [1 + (FLEX_{ij})(DELTA_{tj})]$

where: $SIMPR_{tij}$ = simulated buying or selling price in Year t and Period i for crop j

$BASEPR_{ij}$ = base (average-year) price in Period i for crop j

$FLEX_{ij}$ = price flexibility coefficient for crop j in Period i

These price flexibility coefficients are derived from estimates of income elasticities of demand for grain and groundnuts in Nigeria, using the

---

[1] In order to avoid negative yields, $DELTA_{tj}$ is restricted to fall no lower than -1.0. In order to prevent simulated crop prices from falling to negligible levels, $DELTA_{tj}$ is restricted to rise no higher than 0.75. In both cases, these are plausible boundaries; they must be set arbitrarily because of the simplified linear nature of the yield and price functions.

[2] Mean yields and average prices were obtained from Matlon's survey data. Standard deviations are assumed to be roughly one-third of the mean.

homogeneity formula which states that the sum of own and cross-price elasticities equals the negative of the income elasticity of demand.[1]

It is further assumed that the full response of price to actual yield stretches over several periods, beginning in Period 2 and ending in Period 1 of the next year. This is intended to reflect the buffering effect of existing crop inventories held in the local market area.[2] A graduated response is accomplished by specifying flexibility coefficients which are low in absolute value in Period 2, and rise in Periods 3 and 1 toward their actual full level. For example, the overall price flexibility coefficient for grain is taken to be -1.67, while the coefficients specified in the model are -0.5, -1.2, and -1.6 in Periods 2, 3, and 1, respectively. For groundnuts, given an assumed price flexibility coefficient of -0.5, the coefficients for Periods 2, 3, and 1 are 0.0, -0.2, and -0.4, respectively. Onion/pepper and sugar cane are assumed to have unitary price elasticities, with all price changes occurring in Period 2.

Harvest labor coefficients for all crops are adjusted to reflect above or below average yields, based on estimates of the relationship between harvest labor hours and the quantity of crop harvested. For the early millet/sorghum mixture type, the relationship estimated in logarithmic form was:

---

[1]The income elasticity of demand for both grain (millet and sorghum) and groundnuts is estimated as 0.4 in: Federal Ministry of Agriculture and Natural Resources (1974: 332). Substituting this value gives: $E_{ii} + \Sigma_j E_{ij} = -0.4 = -E_{iy}$. Assuming there are more substitutes for grain than there are for groundnuts implies total cross-elasticities of 0.1 to 0.3 for grain compared to 0.0 to 0.2 for groundnuts. On this basis, the own price elasticity (E_{ii}) for grain would range from -0.5 to -0.8, implying a range in the price flexibility coefficient (approximated as $1/E_{ii}$) of -2.0 to -1.25. A figure of -1.67 is used in the model. For groundnuts, the own price elasticity would be expected to range from -0.4 to -0.6, implying price flexibility coefficients of -2.5 to -1.67. However, since prices actually increase only slightly during the official groundnut buying season, as a result of the fixed marketing board price, it is assumed in the model that the price flexibility coefficient is approximately -0.5.

[2]A more complete and theoretically satisfying model of price determination would be desirable; however, with data for only one year, this is not feasible.

(4) $$HARLAB = \underset{(-1.24)}{-1.07} + \underset{(6.61)}{0.818}\ KGHAR \qquad (\text{adjusted } R^2 = 0.77)$$

where: HARLAB = harvest hours per hectare, in logarithms

KGHAR = kilogram weight of harvest per hectare, in logarithms

t-ratios are in parentheses.

The coefficient of KGHAR can be interpreted as the elasticity of harvest labor hours per hectare with respect to weight of harvest per hectare; rounding 0.818 to 0.8 gives the proportionality factor used in calculating the revised labor coefficients:

(5) $$SIMLAB_{tk} = BASELAB_k\ [1 + 0.8\ (DELTAB_{tk})]$$

where: $SIMLAB_{tk}$ = simulated harvest labor coefficient for enterprise k in Year t

$BASELAB_k$ = base (average-year) harvest labor coefficient for enterprise k

$DELTAB_{tk}$ = proportional deviation of total simulated yield in Year t for enterprise k relative to the average-year yield

With one exception, the returns to investment are also specified as stochastic, hence the appropriate average-year grain and cash coefficients are modified by SIM1 in setting up Model.B. For the grain and onion/pepper fertilizing activities, the average-year coefficients representing additional grain yield or cash return are replaced by simulated coefficients calculated in the same manner, and following the same probability distributions, as the regular crop production enterprises. Returns to the contract house building activity do not vary. For the provisions and kola nut trading activities, the following assumptions are made:

1. In one year out of three, the level of cash returns during the year is reduced by 50 percent. The initial investment (e.g. for acquiring inventory) is recovered without loss at the end of the year, as normal.

2. In one year out of five, no cash returns are earned during the year, and, in addition, 20 percent of the initial investment is lost. In other words, there are three mutually exclusive cases: situation (1) occurs randomly with a probability of 5/15, situation (2) occurs with a probability of 3/15, and the remaining 7/15 of the time there are no losses and the average return coefficients are used.

2. Resources for Model.B

Resource levels available at the outset of Model.B are those given at the end of Period 1 of the current-year solution of Model.A. This includes cash, grain, groundnuts, storage capacity, and credit available.

B. Consumption, Savings, and Investment

Many factors are likely to affect the manner in which families in northern Nigeria dispose of their income. Among these factors are household composition, stage of life cycle, resource endowment, tastes, and preference for current versus future consumption. Some are incorporated into the MLP models, where they play a role in determining the level of income attained. The issue here is how to model the disposition of surplus income, i.e., the value of cash and crop reserves remaining after minimum subsistence consumption and storage requirements have been met. Unfortunately, there has been little study of the relevant functional relationships which might assist in model design.

The procedure adopted here allocates surplus income to additional consumption, savings, and investment. A combination of empirical estimation and subjective judgment was used to formulate the priorities and functional relationships involved. The resulting parameters (incorporated in SIM2) are then applied to all household types considered in the full simulation analysis. The model explicitly takes account of inter-household differences in age-sex composition, but not in tastes, or consumption or savings propensities. Certain broad priorities are assumed; subject to these, decisions are made sequentially on the basis of feasibility. Specifically, it is assumed that the household satisfies additional consumption goals before it makes the savings decision, and that savings are deducted before investment is considered. If emergency borrowing occurs in the solution of Model.B, this is taken as prima facie evidence of financial loss and no additional consumption, savings, or investment is allowed. In this event, SIM2 proceeds immediately to set up Model.A for the next year.

Each of these decisions is now described, following the order of their occurrence in SIM2.

1. Consumption

The year-end levels of cash and crop reserves are obtained from the solution of Model.B. A minimum cash reserve is set aside, and surplus income is computed.[1] The first consumption calculation is to establish whether there will be a "special-event" consumption expenditure ($XPEND_t$) during the current year, reflecting the cost of participating in marriages, funerals, naming ceremonies for first-borns, etc. Such expenditures typically range from ₦20 to ₦100, with richer families spending substantially greater amounts (Hill, 1972: 294, 300). The model therefore calculates $XPEND_t$ as a function of the level of surplus income ($SINC_t$):

(6) $XPEND_t = b_o + b_1 (SINC_t)$

where the values for b_o and b_1 are taken to be ₦50 and 0.1, respectively. $XPEND_t$ occurs randomly with a probability of 0.2, i.e., one year in five on average. The other four years, $XPEND_t = 0$. If surplus income is not sufficient to cover the required level of $XPEND_t$ (i.e., if $SINC_t$ was less than ₦50), then existing cash, groundnut, and grain reserves are liquidated as needed, in that order.[2] If these reserves are still insufficient, emergency borrowing is used to make up the remaining deficit. As is the case throughout the consumption/savings/investment process, if $SINC_t$ is driven to zero or emergency borrowing occurs, remaining steps are skipped and SIM2 sets up Model.A for the next year.

Once the level of $XPEND_t$ is established, SIM2 determines the value of additional consumption:

(7) $ADCON_t = MPC (SINC_t)$

where: $ADCON_t$ = additional consumption

MPC = marginal propensity to consume

---

[1]This cash reserve is ₦20 for the average resource household, and ₦10 for the limited resource household. Surplus income is then equal to remaining cash plus the value of grain and groundnut reserves exceeding the required minimum holdings.

[2]In this case, stocks would be reduced below minimum levels. Above-minimum stocks of cash, groundnuts, and grain would have already been used, since they form part of $SINC_t$.

The value of MPC was estimated from detailed household consumption data for Matlon's sample of 105 households. In order to obtain a marginal propensity to consume out of surplus income, the following consumption equation was specified.

(8) $$C = b_0 + b_1(Y_n - C_m) + b_2C_m + b_3A + b_4A^2$$

where: C = household consumption in naira

Y_n = net household income

C_m = value of minimum subsistence consumption

A = value of household assets

A^2 = assets squared

The parameter b_1 is interpreted as the marginal propensity to consume out of surplus income. Writing $(Y_n - C_m)$ as Y*, the estimated parameters of equation (9) are:

(9) $$\underset{(4.41)}{C = 107.6} + \underset{(7.02)}{.485\ Y^*} + \underset{(5.47)}{.509\ C_m} + \underset{(.98)}{.172\ A} - \underset{(-1.22)}{.0002\ A^2}$$

t-ratios are in parentheses; adjusted R^2 = .55; standard of error of estimate = 112; Durbin-Watson statistic = 2.0; N = 100.

Under different specifications of the consumption equation, the estimated values for MPC varied relatively little, ranging from 0.48 to 0.52. A round figure of 0.50 is used in the model for equation (7) above.

2. Savings

The most common forms of savings among the Hausa are crop reserves, livestock, jewelry, and cash. Which of these would be preferred by the household would depend on its current income and asset status, and on preferences. For purposes of the model, it is assumed that all forms of savings, except for crop reserves, are liquid assets and can be treated as cash. This is easily justified since in practice the conversion of livestock or even jewelry into cash would not be a difficult transaction for the household.

Consideration is given to savings after additional consumption has been computed and the level of surplus income updated. Any surplus income ($SINC_t$) up to a certain minimum (MNSAV, ₦20) is assumed to be saved. If surplus income exceeds MNSAV, then savings ($SAVE_t$) will equal MNSAV plus a marginal proportion (MPS) of the excess. That is:

(10) $SAVE_t = MNSAV + MPS (SINC_t - MNSAV)$

As might be expected, establishing a reliable value for MPS was difficult. For the 100 households, the average savings ratio (savings/net income) was slightly higher than 0.05, but the 95 percent confidence interval ranged from -0.07 to 0.18.[1] Since surplus funds are also devoted to investment, the MPS could not be derived simply as (1 - MPC), since that would completely exhaust surplus income. It was decided instead to set MPS equal to 0.10. Any funds which are not subsequently invested are also added to savings.

3. Investment

There is potential in the model for representing the diversity of factors which determine investment decisions, but too little is known about which factors to emphasize and how to incorporate them. The usual neoclassical treatment of the investment decision process involves comparing different investment options such as farming, trading, or other nonagricultural occupations on the basis of discounted net returns over time. In addition, the feasibility of a given investment must be evaluated, which depends in part on initial cash costs plus periodic outlays of cash and labor. These must be financed out of liquid assets or borrowed funds. There may also be noncapital investment requirements, such as the need to obtain formal or informal approval to engage in the activity concerned. In the traditional African setting, these noncapital investment requirements are difficult to assess. Also, there is little evidence from research, aside from the studies already cited, which would allow a very precise quantification of the initial capital requirements for investment in even the common enterprises.

Adding risk factors to the investment decision process is an obvious extension of the neoclassical approach, and one which is very relevant to the geographical area concerned. Hill (1972: 162) implies that the uncertainties associated with trading are sufficient to discourage any but the richer families from engaging in them, at least in cases where substantial (around N100) levels of working capital are required. From Matlon's data, it is clear that the entry requirements vary considerably,

[1]Five nonrandomly selected elite households were deleted from the data used for consumption and savings analysis.

and that there are many self-employed occupations including types of trading which are not above the reach of households with more modest means.

As noted in Chapter III, investment activities are included directly in Model.A and Model.B, so that the labor and cash implications of investment may be considered simultaneously with the production/marketing decision.[1] The key decisions made by SIM2 concern the type and level of investment to specify in the MLP models. Questions of profitability, feasibility, and risk are treated in the following manner: if surplus income at the end of the savings process is sufficient for any investment activity to be feasible (determined by reference to the stipulated working capital requirements), then the model will select among them according to a preset priority list which embodies a subjective combination of profitability, working capital needs, and risk aspects. The order of this priority list is: (1) fertilizing the onion/pepper crop; (2) fertilizing grain crops; (3) house construction on contract; (4) trading general provisions; and (5) trading kola nuts.

Several comments should be made about these priorities. First, allocating surplus funds first to soil fertility improvements is consistent with the common desire to secure family needs whenever possible via own farm production. The fertilizer activities included in the model are small scale, and represent observed levels of application and incremental returns. Investment in other farm improvements such as mechanization or irrigation has been extremely rare to date. Second, among the nonagricultural investment activities in the model, house building is an example of a low-capital occupation in which households of average or low incomes might participate. Its risks and returns are relative low compared to those of the trading activities, which also have much higher requirements for initial capital investment and on-going capital outlay. Third, the use of surplus funds for educating one's children or acquiring an additional wife could not be incorporated in the model, due to lack of information about the costs and returns and decision processes involved.

---

[1]Recall that the term investment is being used for convenience. These activities represent not so much true investment (although the trading activities are close) as ways in which surplus working capital is allocated to income-increasing endeavors.

As portrayed in the model, then, the farmer will use fertilizer if he has sufficient funds to do so. If he can then also engage in house building, he does so. Subsequent activities are pursued until available funds are exhausted or the farmer has invested in all five activities. The level of investment in each activity (except for building, which is fixed) may range from the initial level set by the working capital minimum up to the level imposed by the investment ceiling.[1] Both of these limits have been defined in relation to activity levels observed among the sample of 35 households for which complete labor and cash flow data exist.

Several other general aspects of the investment model should be mentioned. The labor demand of each investment category is not explicitly considered during the feasibility test, which relies only on initial cash costs. Labor requirements are met within the MLP models; no investment activity needs so much labor that the farmer would be unable to engage in it at the minimum level.[2] Borrowed funds cannot be used to finance investment, nor can minimum crop reserves be sold for this purpose. Surplus crop inventories, if any, can be used for investment since their value is included in surplus income. Except for fertilizer use, the initial cash input for investment is deducted prior to the solution of Model.A for Year t+1 and then returned at the end of the Year t+1, subject to the chance of a 20 percent loss in one year out of five. Returns on investment accrue during the year and are accumulated by the MLP models.

Table IV.2 shows the structure and coefficients of the five investment activities, the details of which are discussed in the following section.

Fertilizer use. Although farmers in the survey area applied fertilizer to nine out of the ten common mixture types, only grain and onion/

---

[1]Numerical values for minimum and ceiling levels are given below.

[2]At higher levels, investment activities do compete with crop production activities for labor. Minor changes in cropping pattern occur as a result, but not to an unrealistic degree.

Table IV.2. STRUCTURE OF THE INVESTMENT ACTIVITIES

		Period 1				
RHS[a]	Row	FERTGN[b] (ha.)	FERTOP (ha.)	BUILD (yr.)	TDPROV (₦)	TDKOLA (₦)
	OBJ	- 15	-30	15	.225	.25
	LAB1	30	30			
	⋮	c	c			c
	LAB10					.07
	CASH1	15	30	- 3		-.05
$= b_1$	MXFRT1	1				
$= b_2$	MXFRT2		1			
$= b_3$	MXBILD			1		
$= b_4$	MXPROV				1	
$= b_5$	MXKOLA					1
	LAB11					.07
	⋮					
	LAB15				.498	.25
	CASH2		-45		-.075[d]	-.10
	GRAIN2	-150				
	LAB16			115	1.87	1.15
	CASH3			-12	-.15	-.10
	GRAIN3	-100				
	YR2CASH			-30	-1[e]	-1

[a]Righthand side values for the investment activities (b_i) are determined during the investment decision.

[b]Definitions: FERTGN = fertilizing grain crops; FERTOP = fertilizing onion/pepper; BUILD = house construction on contract; TDPROV = trading provisions; TDKOLA = trading kola nuts.

[c]Investment activities may have labor requirements in periods not shown here.

[d]Returns to investment activities are stochastic; the grain or cash coefficients embodying the returns are adjusted when Model.B is set up, to reflect a loss or gain relative to the average-year return.

[e]Initial investment in the non-agricultural activities is returned to the YR2CASH row at the end of the year.

pepper fertilization is included in the model.[1] It is assumed that the farmer's first priority would be to fertilize the main cash crop (onion/pepper), and then the grain crop.

Because of the limited degree of fertilizer use in the study area, the data do not permit the estimation of a complete and reliable response surface, hence the returns to substantially higher levels of fertilizer application can only be conjectured.[2] The coefficients of the fertilizer activities used in the model reflect levels somewhat higher than the prevailing average, but not the costs and returns associated with an optimal rate of application. The value of fertilizer applied was set at ₦15 per hectare for grain and ₦30 per hectare for onion/pepper.[3] It was further assumed that fertilizing would add 20 percent to the harvest value of onion/pepper (or ₦45), for a net incremental value of ₦15 per hectare. For grain, the incremental value was estimated from the following regression equation, with data from 173 upland fields:

$$(11)\quad \underset{(-1.41)}{Y = -62.2} + \underset{(3.90)}{268.1\, X_1} - \underset{(-0.06)}{0.07\, X_2} + \underset{(1.71)}{16.8\, X_3} + \underset{(0.79)}{0.07\, X_4} + \underset{(9.06)}{37.8\, X_5}$$

Adjusted R^2 = .67

---

[1]For two main reasons, a specific activity for groundnut fertilization has not been included. First, according to Lombin and Abdullahi (1977), groundnut yields responded well to only one of several fertility treatments which they report. In addition, the conventional wisdom distilled from earlier experimental work holds that groundnuts fix all of their nitrogen requirements, and that only minor amounts of phosphorus, calcium, and sulfur may be needed if soil quality is poor (Abdullahi and Lombin, 1978). Second, analysis of the 173 upland fields from Matlon's sample of 35 households and 204 fields showed that the value of fertilizer applied is not significantly related to the groundnut yield.

[2]Studies by Lombin and Abdullahi previously cited indicate that sorghum responds well to farm-yard manure, but at application rates (2.5 to 7.5 metric tons per hectare per year) that appear to be well above those currently followed by farmers in the area, and probably higher than local supplies of manure or chemical fertilizer would permit.

[3]Matlon's data on value of fertilizer applied indicated a range of ₦1 to ₦25 per ha for grain and grain/groundnut mixtures, and ₦30 to ₦31 per ha for onion/pepper.

where: Y = kilogram harvest of grain

X_1 = field size in hectares

X_2 = minutes walking time to field, one way

X_3 = naira value of fertilizer applied

X_4 = total labor input in man-hours

X_5 = kilograms of grain seed planted

t-ratios in parentheses.

The marginal contribution of a unit (naira) of fertilizer was therefore taken to be 16.5 kg of grain. For a total fertilizer input of ₦15 per hectare, this amounts to roughly 250 kg of grain, of which 150 kg is assumed to be harvested in Period 2 and the remaining 100 kg in Period 3. These yields are subject to stochastic variation. Total labor inputs associated with fertilizing are taken to be 80 man-hours per hectare for grain and 110 man-hours per hectare for onion/pepper, distributed according to the labor profiles of the onion/pepper and sorghum mixtures.

The model will allow fertilizer application providing a minimum amount of working capital is on hand, in effect as a reserve. Fertilizer may be applied, first on the onion/pepper crop and then on the grain crop, up to a ceiling level. For onion/pepper, the working capital minimum is ₦15 and the ceiling is ₦30.[1] For grain, the minimum is ₦7.5 and the ceiling is ₦15, which corresponds to one hectare.

House construction. The coefficients for the BUILD activity, shown in Table IV.2 above, were estimated from Matlon's data. It is assumed that the minimum working capital requirement for this activity is ₦40, and that the activity may be engaged in only at the average annual level, i.e., at a level of 1. Average cash expenditures are estimated as ₦10, and average net returns as ₦5.

Trading provisions. The method of determining coefficients for the objective function and the cash rows should be explained. From Matlon's data, the average trading margin was computed to be 8 percent of sales, or ₦18 relative to sales of ₦225. The margin therefore constitutes a

---

[1]This represents the basic one hectare rate, which is then adjusted by SIM2 to take account of the onion/pepper acreage restriction in the MLP models, which is set at 0.2 ha.

22.5 percent return on the assumed investment of ₦80 in working capital.[1] This cash return on investment (subject to stochastic variation) is distributed between Periods 2 and 3 in accordance with the observed pattern of trading activity.

Since the trading activities are denominated in one-naira units, the labor coefficients were computed on the same basis. First, the observed total labor input was divided by the assumed investment of working capital to give hours worked per naira invested. Second, this figure was distributed among the 16 labor periods in proportion to the share of actual labor input expended in that period.

Trading kola nuts. A similar procedure was used to obtain the coefficients for the kola nut trading activity. Given an observed margin of 10 percent on average sales of ₦250, and assumed working capital requirements of ₦100, the return on invested funds is 25 percent. Cash flows generated from this investment accrue in Periods 1, 2, and 3, as shown in Table IV.2. Labor coefficients were computed as for the provisions trading activity.

C. Year-End Report

Before proceeding to revise Model.A in preparation for Year t+1, the SIM2 program prints a status report as of the end of the consumption/savings/investment process. Several elements are included in the report:

1. The current values of surplus income, and of the five resource inventories, namely cash, grain, groundnuts, debt, and storage capacity. The debt inventory indicates the level of emergency borrowing which occurred during the year.

2. The levels of special-event consumption, additional household consumption, and savings.

3. The levels of investment in each of the five possible activities.

---

[1]The typical pattern of cash flows in trading consists of many small inflows and outflows during the year. At any one time, therefore, a relatively small proportion of the annual sales is actually tied up in inventory. Working capital requirements given for provisions and kola nut trading overstate this to some extent, but are intended to reflect capital needs which were not quantified by Matlon, such as equipment or materials for weighing, storage, or transport. These sums might also be thought of as representing a financial reserve held to cover debts in case of losses due, for example, to unanticipated and adverse price movements.

4. The values of the random variates generated by SIM1 and SIM2 for use in computing coefficients for the stochastic variables. This information was included in order to facilitate evaluation of the model and analysis of results.

D. Revising Model.A for Year t+1

In updating Model.A for solution in Year t+1, SIM2 follows a procedure which is similar to that used by SIM1 to set up Model.B. Several types of revisions are involved. First, the final resource balances for Year t are inserted as righthand side values for the appropriate Period 1 inventory rows in Year t+1. Second, coefficients pertaining to the investment activities must be inserted. Activity levels and cash return coefficients are placed in the righthand side vector and a_{ij} matrix, respectively.

Third, the implications of the one-year time increment for the age structure of the family must be incorporated in the model. Elements affected are righthand side values, e.g., the family labor supply (LAB_i and $MXADDL_i$ rows), and the minimum grain consumption requirements expressed in the $MNCONGR_i$ rows. These coefficients are computed by SIM2 as a function of family composition, the number of weeks in each labor period, and the basic family labor supply assumptions. Lastly, price and cash coefficients for the Period 1 grain and groundnut marketing activities are inserted; they incorporate changes made on the basis of the random crop yield event occurring in Year t.

Chapter V

VERIFICATION AND VALIDATION OF THE MODEL

The topic of this chapter is the general process of evaluating the performance of the model, which encompasses both narrow and broad concerns. Individual components of the model must be tested to ascertain whether they are operating as intended from a mechanical point of view. Such components include the linkage between SIM1 and SIM2 and the linear programming package, specific elements within these programs such as the random number generator, the procedures for setting up Model.B, for calculating consumption and investment, etc. Following standard terminology, this kind of testing is referred to here as "verification" (Anderson, 1974; Johnson and Rausser, 1977).

The term "validation" refers to the broader task of determining whether the model as a whole is a believable and appropriate reflection of the system being studied. This involves assessing both the accuracy of the model's representation of the system, and also the model's ability to fulfill the objectives of the research. The term "evaluation" is also used here to connote the combined steps of verification and validation.

Model evaluation should be thought of as a continuing process rather than as an assessment which the researcher undertakes only once in the lifetime of the project. In one sense, the evaluation continuum stretches from the testing of individual components, to the checking of sub-models such as SIM1 or SIM2, to the validation of the model in its entirety. More importantly, evaluation should be seen as an <u>iterative</u> process which interacts with and supports model design and experimental design.

Evaluation is important for model design since the implications of model specifications cannot entirely be foreseen <u>a priori</u>. It is necessary to try out the model before one can be confident that it performs as desired. The earlier this can be done, the better; problems with the model can then be addressed before too much time, energy, and money are wasted.

Evaluation facilitates experimental design as well. The model may be used to provide information regarding the merit, feasibility, and cost of investigating particular research hypotheses, which allows the researcher to reorder the priorities of the study before full resources are committed. This aspect of evaluation can be particularly important for stochastic models where individual experiments must be replicated many times in order to obtain a statistically reliable distribution of results.

A. Evaluation of the MLP Components

The objectives of evaluating the MLP components were: (1) to test and refine the components; and (2) to map out the response of Model.A under alternative resource endowments. It was expected that the complete model would be expensive to run, hence it was thought desirable to identify in advance which combinations of experimental factors would be most interesting to examine in detail.

Accordingly, the evaluation consisted of three stages:

1. With the aim of improving its design, Model.A was validated in terms of the realism of the solutions with respect to cropping pattern, income levels, and labor use.

2. With the aim of screening out uninteresting experimental situations, Model.A was solved for each of the four household types. In addition, parametric programming was used to determine the sensitivity of the Model.A solutions to variations in initial cash, land, and groundnut prices.

3. With both the design and screening objectives in mind, Model.B was tested under the assumption of a fifty percent below-average crop yield, to ascertain how responsive the household income level was to a poor harvest.

These three aspects of evaluation are discussed below. The verification of the FORTRAN components (SIM1 and SIM2), and the validation of the simulation model in its entirety, are then described.

1. Validation of Model.A

Cropping pattern. Two questions are of interest: (1) how closely do the solutions to Model.A reflect actual cropping patterns, which are diversified rather than specialized; and (2) what methods are used to ensure a realistic cropping pattern? The earliest version of the model contained no minimum or maximum crop production levels. A minimum grain consumption level was stipulated as a subsistence food requirement, but this could be satisfied through grain purchase. The solution to this model showed all land devoted to sugar cane and onion/pepper.

This is unrealistic, since there is no effective market for the output which would occur if many farmers grew two or three hectares of onion/pepper. Restricting onions and peppers to a level consistent with market limitations, and retaining the minimum grain consumption constraint, leads to diversified cropping patterns containing between two and five grain, grain/groundnut, or grain/cowpea mixtures, depending on the version of the model and the household type. An example is shown in Table V.1. Each farm plan also includes small acreages of sugar cane, onion/pepper, and kitchen vegetables. The total number of crop mixtures in solution therefore ranges from four to seven, excluding vegetables (which the model artificially isolates).

This corresponds closely with cropping patterns observed on farmers' fields. Taking each farmer's landholding as a whole, the average number of mixture types grown was over seven. Counting each field as a single mixture, the number of mixtures per farmer ranges from 4.3 to 5.4 depending on income class.

Income level. As discussed in Chapter III, crop enterprises based on mixture averages were rejected in favor of those based on individual field coefficients, in order to depict the labor profile accurately and to allow a range of relative factor intensities or production technologies to be examined. One disadvantage of using field-specific enterprises is that the field model generates much higher returns than those in the average model.[1]

Four income measures were employed to compare the average and field models to each other and to observed actual levels of returns: gross harvest value per hectare and per man-hour of labor input, and net household

---

[1]For most field-enterprises, a high return to one factor of production (e.g. labor) is balanced by a low return to the other factor (e.g. land). Thus, enterprises which would be optimal from the standpoint of the land/labor endowment associated with one household type might not be optimal for household types possessing different relative factor endowments. The enterprises also differ with respect to their initial cash and seed requirements, and the distribution of necessary labor inputs across the labor periods. How these requirements might interact with the resource constraints in the model was not obvious at the outset, especially since many of the high return field-enterprises are very labor intensive.

Table V.1. CROPPING PATTERN FOR THE STANDARD AND REDUCED ENTERPRISE SET IN MODEL.A, BY HOUSEHOLD TYPE

Mixture	Harvest Value Per Ha. (N)	Standard Enterprise Set[a]				Reduced Enterprise Set[b]			
		AFAR (ha.)	SFAR (ha.)	AFSR (ha.)	SFSR (ha.)	AFAR[c] (ha.)	SFAR (ha.)	AFSR (ha.)	SFSR (ha.)
A11 (a)[d]	200	.49	.13	.49	.18	*	*	*	*
A12 (a)	141					.50	-	.54	.27
A12 (b)	102					.68	2.74	-	.47
A1/B (a)	320	.61	.06	.40	.10	*	*	*	*
A1/B (c)	185	2.20	3.16	.34	1.27	*	*	*	*
A2/B (a)	120					-	-	.17	-
A2/B (b)	101					1.88	.61	-	.76
A1/C (a)	215	.50	-	.32	-	*	*	*	*
A1/C (b)	176					.29	-	.33	.05
A2/B/C (a)	140					-	-	.38	-
Onion (b)	222	.20	.20	.20	.20	.20	.20	.20	.20
Sorghum (c)	117					-	-	.13	-
Sugar (a)	367	.15	.15	.05	.05	.15	.15	.05	.05
Vegetables	-	.20	.20	.20	.20	.20	.20	.20	.20
TOTAL HA.		3.9	3.9	2.0	2.0	3.9	3.9	2.0	2.0

[a] Only Onion (a) removed. The basic version of Model.A, incorporating field-specific input/output coefficients.

[b] Four extremely profitable enterprises removed, indicated by asterisk.

[c] AFAR = average family size, average resources.
AFSR = average family, limited resources.
SFAR = small family, average resources.
SFSR = small family, limited resources.

[d] Mixture subscripts: (see also Table III.2)
a. high labor input and returns/ha.; often generally superior.
b. average.
c. low labor input and returns/ha.; often generally inferior.

income per resident and per consumer.[1] Optimal cropping patterns in the field model imply a much higher level of gross harvest value per hectare (about ₦220) when compared to either the average model (₦124) or the observed actual figure (about ₦140). Gross harvest value per man-hour of family labor input is also higher in the field model (₦0.25 to ₦0.29, depending on household type) than in the average model (₦0.17), but lower than the observed figure (₦0.33). Returns per hour of family plus hired labor input in both the average (₦0.17) and field (₦0.21 to ₦0.24) models are very close to the observed level (₦0.19).

With respect to net income per resident, Matlon's data on 105 households show a range from ₦25 to ₦105 depending on household size and landholding. Again, the incomes generated by the field model (₦103 to ₦116) exceed these figures and those of the average model (₦65 to ₦72). The differential is even more pronounced with respect to net income per consumer.

There are three likely explanations for income being generally higher in the field model than in reality. First, the field model includes several enterprises whose returns per unit of land and labor are extremely high, as much as twice or three times the mixture average. Although these enterprises also tend to have unusually high labor and cash requirements, their returns are proportionally even higher, hence they are clearly superior.

Second, the land/person ratios embodied in the model are higher than the observed averages for certain household types.[2] For example, the small family/average resource type enjoys 1.0 ha/resident and 1.63 ha/consumer,

---

[1]Net household income (NETINC) should be distinguished from the value of the objective function (NETREV) in the model. Because the value of the objective function in the model represents net household income less: (a) minimum grain and cash consumption; and (b) the imputed value of peak family labor (ADDLAB), these two elements must be added to NETREV in order to arrive at a measure of net income which is comparable to that used by Matlon.

[2]Equal amounts of land are available in both the field and average models. However, because some of the enterprises included in the field model are superior in terms of returns to land, the field model is able to convert this relative abundance of land into a much higher income level than is the average model.

compared to the observed values of 0.76 and 1.02, respectively. For the average family/average resource type, the provision is 0.57 ha/resident and 0.82 ha/consumer, compared to the actual levels of 0.47 and 0.65, respectively.

Third, the initial provision of family labor in the righthand side vector appears overly generous. This can be seen in the discussion of labor use below.

Labor use. In evaluating labor use in Model.A, emphasis was given to the balance between family and hired labor on the farm, total farm labor inputs per hectare, and total farm and off-farm labor use. Both the average and field models generally showed higher levels of family labor use (2,543 and 3,108 man-hours, respectively) than those actually observed (1,521 man-hours), and lower levels of hired labor (10 and 498, respectively) than those observed (1,351).[1] High labor use is characteristic of the field model, which includes several very labor-intensive but high-return enterprises. The tendency of the average model to underestimate peak labor demand shows up in negligible levels of hired labor. Total farm labor inputs per hectare in the average model (655 man-hours per ha) tended to be lower than observed levels (827), while those in the field model were higher than both (902). The closest resemblance between model and reality occurs with total farm and off-farm labor use, which was 3,038, 4,325, and 3,403 man-hours for the average model, field model, and observed levels, respectively.

Revision of model design. Based on the results of the evaluation, three important changes were made to improve the model: (1) to delete the few atypically profitable enterprises from the model; (2) to lower the amount of family labor available; and (3) to reduce the supply of land to levels more typical of the normal land/person ratio for the different household types.[2] Removing five crop production enterprises drops NETREV (in the average family/average resource case) from ₦490 to ₦303 and reduces

---

[1]Figures in this section are for the average family/average resource case.

[2]Several other design changes were made, but aside from improving the descriptive accuracy of the model they had only minor effects. These included: (1) lowering the onion/pepper planting ceiling from 0.4 ha to 0.2 ha; (2) adding a second, high-interest borrowing activity; (3) reducing the initial crop inventories; and (4) increasing the margin of the crop buying prices over the selling prices in the same period.

NETINC per resident from ₦110 to ₦80. Since there was no a priori basis for determining how many enterprises could justifiably be excluded, it was eventually decided to delete only the most extreme enterprise, i.e., the Onion (a) mixture. This reduces NETREV from ₦490 to ₦422 and NETINC per resident from ₦110 to ₦101.

Basic family labor in Periods 1-10 was reduced from 25 to 20 hours per week per weeder plus 5 hours per week per harvester. For periods 11-16, the level was reduced from 20 to 15 hours per week per weeder in Periods 1-10 and from 10 to 7.5 hours per week per harvester in Periods 11-16. With this revised labor supply, the level of NETREV dropped from ₦425 to ₦383, and NETINC per resident fell from ₦100 to ₦92. As desired, the balance of family versus hired labor shifts, with proportionally more labor being hired now.

The third revision made to achieve realistic income levels was to reduce the area of land provided in the model to correspond more closely to the land/man ratios observed in Matlon's data. Table V.2 compares the initial and revised land assumptions with the observed levels for the four household types.

When both the reduced labor and reduced land assumptions are incorporated into the righthand side, NETREV becomes ₦294 and NETINC per resident declines to ₦81, for the average household case. The area grown to Mixture A1/C(a) declines and the area in Mixture A1/B(c) rises.

Evaluation by household type. Table V.3 shows how cropping patterns, labor inputs, and returns vary by household type for the standard field-specific version of Model.A. There are several points worth emphasizing.

First, of the various elements of the resource endowment, namely land, family labor, cash, crop inventories, storage capacity, and borrowing ability, it is land and family labor that appear to be most crucial in determining incomes and cropping patterns. In addition, land seems to have a somewhat greater effect on income than does labor. For a given resource bundle, the small family with its limited labor supply is able to earn nearly as much income as the average-sized family. The levels of gross harvest value and NETINC are quite similar for both family types with average resources. However, when the comparison is made between the average and limited resource endowment, NETINC differs substantially.

Table V.2. LAND/PERSON RATIOS: MODEL ASSUMPTIONS AND OBSERVED LEVELS

	Average Resources		Limited Resources	
	Ave.-size Family	Small Family	Ave.-size Family	Small Family
Initial Assumption				
1. Upland hectares	3.75	3.75	1.95	1.95
2. Lowland hectares	.25	.25	.15	.15
3. Total hectares	4.00	4.00	2.10	2.10
4. Hectares/resident	.57	1.00	.30	.53
5. Hectares/consumer	.82	1.63	.43	.86
Revised Assumption				
1. Upland hectares	3.05	2.55	no change	1.70
2. Lowland hectares	.20	.20		.15
3. Total hectares	3.25	2.75		1.85
4. Hectares/resident	.46	.69		.46
5. Hectares/consumer	.66	1.12		.76
Actual				
1. Total hectares	3.47	3.05	1.70	1.46
2. Hectares/resident	.47	.76	.29	.52
3. Hectares/consumer	.65	1.02	.43	.64

Second, for a given resource level, incomes per resident are considerably higher for small families than for average families. The small families have an equal amount of land (though less labor), but have fewer persons to feed.

Third, under the average resource assumption, a reduction in labor from average to small family size leads to heavy emphasis on Mixture Al/B(c), which has very high returns per man-hour. A similar shift in cropping pattern occurs under the limited resource assumption: the average family chooses to produce more of enterprises such as Mixtures All(a), Al/B(a), and Al/C(a) which have higher returns per hectare, but lower returns per man-hour.

Parametric programming. In addition to analyzing the effects of different broad resource categories on the model solution, parametric programming was carried out to investigate in more detail how the model responded to systematic changes in the availability of initial land and cash supplies, and to the differential between the Period 2 and 3 groundnut selling prices. The results of this exercise can be summarized as follows.

First, when the level of cash available in Period 1 is increased, there are only slight changes in crop combinations and in the value of the objective function (NETREV). For example, as Period 1 cash is increased from ₦5 to ₦31, NETREV rises from ₦55 to ₦61; there are no further changes as Period 1 cash is increased to ₦85.

Second, when the area of upland is increased for the average family case there are substantial changes in cropping pattern and income level. As the land area declines from 6.0 to 0.86 ha, the cropping pattern gives increasing emphasis to land-efficient enterprises; NETREV falls from ₦637 to ₦12. It therefore appears that land availability has a much greater effect on income and cropping pattern than does the cash resource. A sevenfold increase in land availability generates more than a fifty-fold increase in the value of the objective function, whereas a seventeen-fold increase in the level of initial cash only generates an 11 percent increase in the objective function value. This result occurs in part because of the one-year MLP format. It will be seen in later chapters that the cash constraint becomes much more powerful in the multi-year simulation model.

The third example of parametric programming focussed on the Period 2 to Period 3 groundnut price differential. The Period 3 groundnut selling price was initially set equal to the Period 2 price of ₦0.15 per kg and allowed to increase to ₦0.21 per kg. Model results were sensitive to this price differential. It was found that a price differential of less than 11 percent was sufficient to make storage and resale of groundnuts profitable. The much larger price differential initially specified (₦0.15 per kg in Period 2 and ₦0.21 in Period 3) led to unrealistic levels of crop trading, financed by extensive borrowing.

2. Test of Model.B Under the Assumption of Crop Failure

Two different experiments were conducted with Model.B to test the plausibility of its response to a shortfall in crop yields. In the first test, crop prices were not changed; in the second, they were increased on the assumption that a local crop failure would raise local market prices. Areas planted to the different crop enterprises, and available resources including debt, were taken from the previous "ex ante" solution of Model.A.

With no change in crop prices, a 50 percent decline in crop yield leads to a 60 percent reduction in NETREV (from ₦509 to ₦208) and an 80 percent fall in NETCASH (from ₦526 to ₦106). When crop prices are allowed to rise in response to crop failure and local market shortages, the solution is very similar: NETREV and NETCASH are now ₦221 and ₦118, respectively. The additional cost of grain purchases for consumption or labor payment is more than offset by higher harvest value, hence overall household income does not decline as much when prices are allowed to change as when they do not change.

The tentative and subjective conclusion drawn from these results was that Model.B performs realistically under conditions of below average crop yields. Pending evaluation of the full model, this lends support to the two-stage approach to determining the production/marketing plan, i.e., an ex ante solution with Model.A followed by an ex post solution with Model.B incorporating simulated actual yields and prices.

B. Verifying the FORTRAN Components

Several questions were addressed in checking the FORTRAN programs, SIM1 and SIM2. Special test data were used to verify whether SIM1 and SIM2 were correctly reading input information, performing calculations, and generating the proper output. Each program was then run with the relevant linear programming model to ensure that the linkages were performing as intended. Errors identified in the two programs were corrected.

C. Validation of the Complete Model

First to be checked was a one-year sequence of the complete model, consisting of four solution steps--Model.A, SIM1, Model.B, SIM2--and culminating in the printing of the year-end report. Once this was verified, a two-year sequence was tested. An extensive job control program was prepared to manage the execution of the different model steps, and to maintain the necessary computer files.

An important finding of this verification step was that both Model.A and Model.B occasionally produced infeasible solutions. In years of particularly low simulated crop yields, the year-end groundnut reserve requirements imposed in Model.B were sometimes impossible to satisfy. Also, when low yields were combined with the occurrence of special-event consumption expenditures in the previous year, the Period 1 grain consumption requirements were sometimes impossible to meet in Model.A. An emergency groundnut buying activity was therefore incorporated into Model.B, and emergency borrowing was made available in Model.A. In both cases, the value of emergency debt incurred was accumulated for use in SIM2.

To go beyond verification to a broader evaluation of the performance of the full model, it is necessary to determine how well the model acts as an experimental instrument, and how plausible the results of the simulation experiments are. For this reason, evaluation of the full model is postponed until Chapter VII.

Chapter VI

DESIGN OF THE SIMULATION EXPERIMENTS

The subject of this chapter is the design of specific experiments to be undertaken with the simulation model in order to answer the research questions. There are four main sections: (1) an overview of the experimental design; (2) design of the deterministic experiments; (3) design of the stochastic experiments; and (4) issues of data analysis.

Techniques developed for the design of biological and industrial experiments can be applied to computer simulation experiments. Montgomery (1976) states: "By the statistical design of experiments, we refer to the process of planning the experiments so that appropriate data will be collected, which may be analyzed by statistical methods resulting in valid and objective conclusions." The research instrument may be the agricultural field plot, the wind tunnel, or the simulation model. The process of formulating an experimental design early in the study can bring a variety of benefits to the researcher. Cost constraints, data limitations, or methodological difficulties may be uncovered. Low-priority research objectives can then be discarded. Careful experimental design is also a prerequisite for valid data analysis. An unplanned study may yield costly data from which no reliable conclusions may be drawn (John, 1971).

Dating at least from Zusman and Amiad (1965), the literature has included discussions of experimental design and data analysis in simulation studies, and the risks associated with neglecting them. Although not all studies call for it, nonetheless too little attention is generally given to systematic experimentation in simulation research. There is limited if any explicit treatment of experimental design in recent farm simulation studies oriented to Third World countries (Zuckerman, 1977, 1979; Low, 1974; Casey, 1974). With a growing capacity for farming systems simulation studies at national and international research institutions, these issues deserve greater attention.

A. Overview of Experimental Design

Experimentation with the full model was of two main types: (1) deterministic, where the stochastic variables were exogenously fixed; and

(2) stochastic, where these variables were randomly obtained from their respective probability distributions. Cost factors prevented the use of the model in its stochastic mode for all experiments.

Several issues relate to the formal statistical design of the experiments: (1) choice of the experimental factors and their levels; (2) choice of experimental design points; and (3) the length of the time horizon for each experiment. For the stochastic experiments, it was necessary to determine: (1) which design points to examine with the stochastic model; (2) how many replications of each point to make; and (3) the time horizon. For the deterministic experiments, it was necessary to decide how to handle the stochastic variables.

B. Deterministic Experiments

1. Experimental Factors

The four experimental factors and their levels were:

1. Household type with three levels representing different combinations of family size and resource endowment.[1]

2. Crop enterprise set with two levels: a standard set of crop production enterprises and a set in which four exceptionally profitable enterprises are deleted. These two production opportunity sets can be thought of as representing different management levels.

3. Marginal propensity to consume with two levels: a value of 0.5 (estimated from detailed consumption data) and a higher value of 0.7.

4. Stochastic sequence with four levels. Variables which normally fluctuate randomly are specified as fixed sequences of values over the full time period. These variables are: crop yield (grain and groundnuts), returns to investment in trading, and special-event consumption expenditures

---

[1]From least endowed to best endowed, these were: average family, limited resources; small family, limited resources; and small family, average resources. Average and small family sizes were seven persons (4.9 consumers) and four persons (2.45 consumers), respectively. Resource endowment ranged from 1.85 to 3.25 hectares, with varying levels of cash and crop reserves, and borrowing limits. The implied land/man ratios range from 0.43 hectares per consumer to 1.12 hectares per consumer, which is towards the lower end of the range observed by Matlon (0.10 to 1.91 hectares), where most households lie.

representing obligations for marriages, funerals, etc.[1] Table VI.1 shows the four stochastic sequences which were formulated. Three represent moderate loss, and moderate gain situations, in relation to average levels of the stochastic variables. The fourth constitutes a base-run sequence, in which crop yields and investment returns are set at their mean levels, and special consumption expenditures are assumed to occur with their average frequency of one year in five, arbitrarily located in Years 2 and 7. These sequences focus on the effects of sustained below or above average returns on overall household income.

2. Selection of Design Points

Given the above set of experimental factors, the number of experimental design points for a full factorial design would be 3 x 2 x 2 x 4 or 48. To save computing cost, a fractional factorial design was adopted. Since interactions among the factors were expected to be significant, it was not sufficient to allow for the analysis of main effects alone. At the same time, three- and four-factor interaction effects were expected to be unimportant as well as difficult to interpret. Accordingly, a design was chosen such that all main effects and two-factor interactions could be estimated.[2]

The resulting design, found in Table VI.2, comprises 25 design points.[3] While it is not a minimum variance design, it does allow estimation of the desired effects with the fewest replications and hence least cost. It is an asymmetric design, i.e., the number of levels is not equal for all factors. Since 24 effects are to be estimated using 25 observations, the design is saturated (Box and Hunter, 1961). The fraction chosen for

---

[1]Means and standard deviations for the normal crop yields are assumed to be known with certainty, hence they are fixed parameters in the model. Both investment returns and special-event consumption are characterized by discrete binomial probability distributions.

[2]The drawback of partial factorial designs is that main effects and two-factor interactions are confused with higher-order effects in the analysis of variance. However, if the higher-order effects are truly negligible, a fractional design is satisfactory (Montgomery, 1976: 240; Kleijnen, 1975: 231).

[3]The author is endebted to W. T. Federer for suggestions regarding the design.

Table VI.1. SPECIFICATION OF FIXED SEQUENCES FOR THE STOCHASTIC VARIABLES

Sequence	Year									
	1	2	3	4	5	6	7	8	9	10
Sequence 0[a]										
Crop yield[b]	0	0	0	0	0	0	0	0	0	0
Consumption[c]	0	1	0	0	0	0	1	0	0	0
Investment[d]	0	0	0	0	0	0	0	0	0	0
Sequence 1[e]										
Crop yield	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Consumption	0	1	0	1	0	0	1	0	0	0
Investment	1	0	2	0	1	0	1	0	2	1
Sequence 2[f]										
Crop yield	-1.5	-2.0	-1.5	-2.0	-1.5	-2.0	-1.5	-2.0	-1.5	-2.0
Consumption	1	1	0	0	1	0	0	1	0	0
Investment	1	2	1	2	1	2	0	1	1	0
Sequence 3[g]										
Crop yield	.5	.5	.5	.5	.5	.5	.5	.5	.5	.5
Consumption	0	1	0	0	0	1	0	0	0	0
Investment	0	0	1	0	0	1	0	0	0	0

[a]Base run, with variables at mean or typical levels.

[b]Figures represent standard deviation from the mean.

[c]Special-event consumption expenditures occur if code = 1.

[d]Zero = no loss; 1 = 50 percent below average cash returns; 2 = no cash returns, and 20 percent loss of initial investment.

[e]Moderate losses.

[f]Severe losses.

[g]Moderately above average occurrences.

Table VI.2. EXPERIMENTAL DESIGN

Design Point	Factor Levels[a] A	B	C	D	Design Point	Factor Levels A	B	C	D
1	0	0	0	0	14	1	0	0	3
2	1	0	0	0	15	0	1	1	0
3	0	1	0	0	16	0	1	2	0
4	0	0	1	0	17	0	1	0	1
5	0	0	2	0	18	0	1	0	2
6	0	0	0	1	19	0	1	0	3
7	0	0	0	2	20	0	0	1	1
8	0	0	0	3	21	0	0	1	2
9	1	1	0	0	22	0	0	1	3
10	1	0	1	0	23	0	0	2	1
11	1	0	2	0	24	0	0	2	2
12	1	0	0	1	25	0	0	2	3
13	1	0	0	2					

[a]Factor A = Enterprise set: 0 = standard; 1 = reduced.

Factor B = Marginal propensity to consume: 0 = 0.5; 1 = 0.7.

Factor C = Household type: 0 = small family, limited resources; 1 = average family, limited resources; 2 = small family, average resources.

Factor D = Stochastic sequence: 0 = base run; 1 = moderate loss; 2 = severe loss; 3 = moderate gain.

replication (25/48) is irregular. As a partial factorial, the design is unbalanced. The design matrix X is of full rank, which allows simultaneous estimation of all main effects and two-factor interactions. However, inspection of the X'X matrix indicates that the design is not orthogonal, which implies that estimates of the various effects are correlated to some degree. By redefining the experimental factors and factor levels, an orthogonal design might have been formulated, but it was considered more important to keep the structure of the problem intact.[1]

C. Stochastic Experiments

The problem of size arose again in determining the number of experiments with the stochastic model, namely which of the 25 design points covered by the deterministic model should be scrutinized in greater detail. To limit cost, only two important cases were examined: (1) Average-size family with Limited resources (AL); and (2) Small family with Average resources (SA). Household AL is regarded as relatively poorly endowed; Household SA is relatively well endowed.[2]

Final experimental design decisions concerned the identification of the time horizon over which the model should be run, and the selection of the appropriate number of replications of each stochastic experiment. In establishing the time horizon, a sequential approach was adopted in which the results of each successive two-year run of the model were

---

[1]The literature gives relatively little guidance on selection of the optimum fraction for asymmetrical factorials. The most common partial designs apply to the 2^n or 3^n factorials and involve regular fractions of the $(1/2)^n$ or $(1/3)^n$ type, rather than irregular fractions such as the 25/48 fraction used here. Exceptions to this generally involve irregular fractions of the 2^n factorial (Westlake, 1965; Addelman, 1961; Box and Hunter, 1961). Addelman (1962) discusses plans for asymmetrical factorials which allow the estimation of main effects and some two-factor interactions. Asymmetrical designs other than the common 2^n3^m type have been treated by Anderson and McLean (1974) and applied in empirical work by McQuie (1969) and Clough et al. (1965). However, the author found no example of the 2 x 2 x 3 x 4 design used in this study.

[2]One might argue that family size should be considered a positive aspect of resource endowment. However, parametric analysis with the multiperiod linear programming model indicated that changes in the family labor endowment had much smaller impact on net household income that did changes in land area. The higher consumption requirements associated with larger families tended to offset their added labor potential.

evaluated to determine whether a further two-year solution was warranted. Twenty replications of each case were found to be sufficient for the statistical analysis.[1]

The order of the experimental runs received careful attention. The deterministic experiments were undertaken first. This not only generated data for testing the basic research hypotheses, but also provided information for identifying which design points would be suitable for analysis with the stochastic version of the model.

D. Data Analysis

Analysis of variance was used to ascertain the relative impact of the experimental variables on system performance, based on the deterministic experiments. This is a common technique in simulation research (Naylor, 1971; Anderson, 1974). Primary emphasis was given to a comparison of the mean squares. Since by definition the deterministic model lacked random variation, computation of statistical significance levels was inappropriate.

The analysis focused on two measures of the household's performance or welfare. The first, called NETKAP, is the level of capital accumulated by the household at the end of the year, defined as the household's year-end cash balance plus the amount of working capital set aside for the next year's off-farm investment activities, minus the value of any emergency borrowing undertaken during the current year, minus the value of any crop reserves that were liquidated to meet special-event consumption expenditures. The second dependent variable is total household consumption per consumer (TCON), defined as the value of subsistence consumption required in the multiperiod linear programming model plus the value of additional consumption out of surplus income, this entire quantity divided by the number of adult consumer equivalents in the household concerned.

---

[1] From the standpoint of reducing the variance of the replicated outcomes for each stochastic experiment, there is a potential trade-off between the number of replications and the length of the time horizon. The use of variance reduction techniques is a refinement to which much attention is given in the literature on experimental design for simulation studies (Zusman and Amiad, 1965; Hillier and Lieberman, 1974: 635-638). Since computational resources were limited and only two sets of stochastic runs were planned, it did not appear worthwhile to implement such a technique.

Characteristics of these two variables which are examined include the mean value, rate of increase, and variability over the time horizon. Other indicators which are monitored, though not incorporated into the formal statistical analysis, are the incidence of emergency borrowing and the change in cropping pattern over time.

Chapter VII

DESCRIPTION AND INTERPRETATION OF RESULTS

The chapter begins with a discussion of the results of the deterministic and stochastic experiments conducted with the simulation model. Conclusions regarding the value of the simulation approach are then considered. Lastly, the implications of the study for further research are discussed.

A. Deterministic Results

1. Description

The aim of the deterministic use of the model was to analyze systematically how income and consumption responded to different assumptions about resource endowment, production opportunities, yield and price variability, and consumption behavior. Several conclusions emerge from the results of the deterministic experiments shown in Table VII.1. First, in the medium loss situation, only the least well endowed household (Case 3) incurs emergency debt. The best endowed household (Case 4) does quite well. Second, when losses are severe, only the best endowed household (Case 8) escapes financial loss. The other households incur substantial and increasing levels of emergency debt by the end of Year 6. Third, in the base runs and under moderately favorable conditions, none of the households experience financial loss.

Fourth, the deletion of four atypically profitable crop enterprises is sufficient to cause emergency borrowing by the poorly endowed household under medium loss conditions (Case 23). The emergency borrowing incurred by this household under severe loss conditions (Case 24) is more than double that occurring in the comparable case with standard enterprises (Case 5).

Lastly, the effect of different marginal propensities to consume (MPC) can be seen by comparing Cases 9 and 10. The household in Case 10 (MPC of 0.7) consumes more on average for the six-year period, but its level of total consumption per consumer in Year 6 is lower than that achieved given an MPC of 0.5. By consuming more, the household has less left over for saving and investment, leading to lower income and consumption by the end of the period.

Table VII.1. CHARACTERISTICS OF THE DETERMINISTIC EXPERIMENTS AND RESULTS FOR YEAR 6

Case Number[a]	Stochastic Sequence	Land/Person Ratio[b]	Marginal Propensity to Consume	Net Capital[c] (Naira)[d]	Emergency Borrowing (Naira)	Consumption per Consumer[e] (Naira)	Enterprise Set
1	Medium Loss	average	0.5	54.8	-	64.4	Standard Enterprise Set
2		average	0.7	30.4	-	65.6	
3		low	0.5	- 357.9	367.9	46.1	
4		high	0.5	148.4	-	98.5	
5	Severe Loss	average	0.5	-1,059.4	1,069.4	46.1	
6		average	0.7	-1,059.4	1,069.4	46.1	
7		low	0.5	-5,140.9	5,150.9	46.1	
8		high	0.5	45.3	-	56.4	
9	Medium Gain	average	0.5	118.5	-	90.4	
10		average	0.7	52.0	-	86.1	
11		low	0.5	116.4	-	67.8	
12		high	0.5	222.4	-	128.7	
13	Base Runs	average	0.5	142.5	-	100.2	
14		average	0.7	66.5	-	99.9	
15		low	0.5	126.6	-	69.9	
16		low	0.7	58.6	-	69.3	
17		high	0.7	120.9	-	142.2	
18		high	0.5	257.6	-	143.1	
19		high	0.5	150.1	-	99.2	Reduced Enterprise Set
20		low	0.5	29.7	-	50.1	
21		average	0.7	39.2	-	73.9	
22		average	0.5	80.2	-	74.8	
23	Medium Loss	average	0.5	1.6	8.4	46.1	
24	Severe Loss	average	0.5	-2,283.4	2,293.4	46.1	
25	Medium Loss	average	0.5	57.0	-	65.3	

[a]Case numbers do not correspond to the design point numbers in Table VI.2. To facilitate computer processing, the design points were implemented in the order shown by the case numbers.

[b]Household type, characterized primarily by land/person ratio. Average = four persons, limited resources; low = seven persons, limited resources; high = four persons, average resources.

[c]Net capital is the year-end value of cash reserves plus working capital minus emergency borrowing incurred that year.

[d]One Nigerian Naira = U.S. $1.64 in 1974-75.

[e]Total household consumption per adult consumer equivalent.

2. Analysis of Variance

Based on a partial sum of squares for each effect (correcting for all other effects), mean squares were computed to indicate the size and relative magnitude of the main effects and two-factor interactions. Table VII.2 gives the analysis of variance for the two dependent variables, NETKAP and TCON.

The two most important determinants of the household's financial performance are: (1) exogenous circumstances affecting crop yields, investment returns, and special consumption requirements, embodied in the stochastic sequence factor; and (2) family size and resource endowment, embodied in the household type factor.[1] The set of available production enterprises was of lesser importance, and marginal propensity to consume appeared to be insignificant. It was found that the size and relative magnitudes of the various effects remained generally the same even when alternative computational procedures and computer packages were used.[2] Additional interaction terms, e.g., between enterprise set and stochastic sequence, were sometimes sizeable.

Although the ranking of these factors derives in part from the specific magnitudes chosen for each in the experimental design, the results do suggest that the household's financial success depends critically on its ability to cope with and adjust to adverse environmental conditions. Both management skills and resource availability would contribute importantly to the household's adjustment capacity and to its ability to take advantage of off-farm income-earning opportunities.

It is worth illustrating the effect of family size and resource endowment on income. Figure VII.1 shows that the level of net income per resident or consumer is an increasing function of the amount of land per resident

---

[1]The interaction between these two factors (HST x STO) also has a large effect since high levels of emergency borrowing by moderately and poorly endowed households occur in unfavorable years.

[2]Figures in Table VII.2 were computed with the Michigan State University STAT package. The SAS GLM procedure (Barr et al., 1976) and the Cornell University ECON package (Snipper and Tomek, 1977) were also used. For unbalanced designs including interaction effects (the design required by this study), the results for the partial sum of squares will depend on the computational algorithm followed (Barr et al., 1976: 131), and hence on the computer package used (Searle, 1979).

Table VII.2. ANALYSIS OF VARIANCE FOR THE DETERMINISTIC EXPERIMENTS

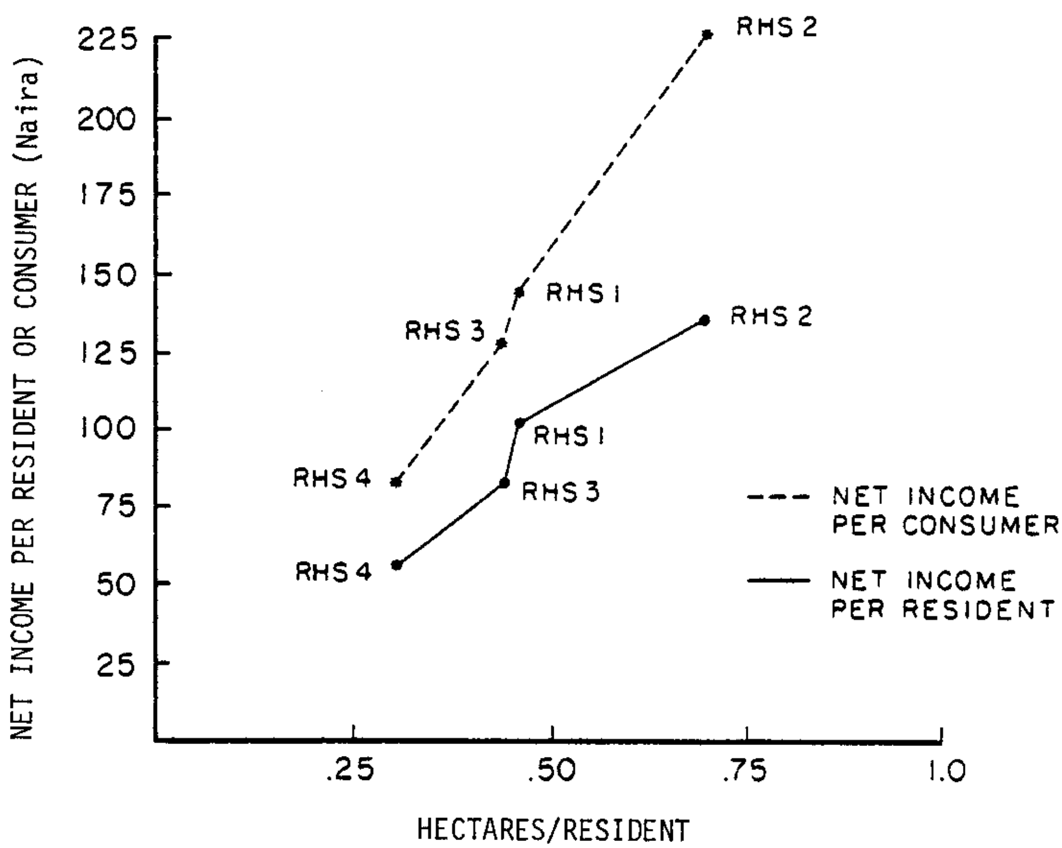
		Net Capital[b]		Consumption per Consumer[c]	
Effect[a]	Degrees of Freedom	Mean Square	Rank	Mean Square	Rank
ENT	1	43,044	5	158	4
MPC	1	582		0	
HST	2	463,328	3	277	2
STO	3	1,567,165	2	308	1
ENT x MPC	1	306		0	
ENT x HST	2	279		80	5
ENT x STO	3	169,662	4	71	
MPC x HST	2	706		0	
MPC x STO	3	638		3	
HST x STO	6	1,715,660	1	187	3

[a]ENT = enterprise set; MPC = marginal propensity to consume; HST = household type; STO = stochastic sequence.

[b]Year-end accumulated capital.

[c]Total household consumption per consumer.

FIGURE VII.1. RELATIONSHIP BETWEEN NET INCOME PER RESIDENT AND HECTARES PER RESIDENT.



RHS1 = Average family size, average resources
RHS2 = Small family, average resources
RHS3 = Small family, limited resources
RHS4 = Average family, limited resources

available to the household. Figure VII.2 shows that net income per resident or consumer is inversely related to the availability of family labor in man-hours per hectare per year. This inverse relationship indicates that, at least in the model, the value of a larger family as a productive labor resource is outweighed by the negative effect associated with the concomitant rise in the number of consumers.

B. Stochastic Experiments

The two experimental cases chosen for analysis with the full stochastic model were: (1) Household AL: the Average-size (seven persons) family with Limited resources, representing the least favorable land/person ratio; and (2) Household SA: the Small family (four persons) with Average resource endowment, corresponding to the most favorable land/person ratio. In both cases, the standard enterprise set and a marginal propensity to consume of 0.5 were specified. The time horizon was six years and each case was replicated twenty times. Table VII.3 summarizes the results of the stochastic experiments, indicating the values for net capital (NETKAP) and total household consumption per consumer (TCON) achieved in Year 6 by households AL and SA.

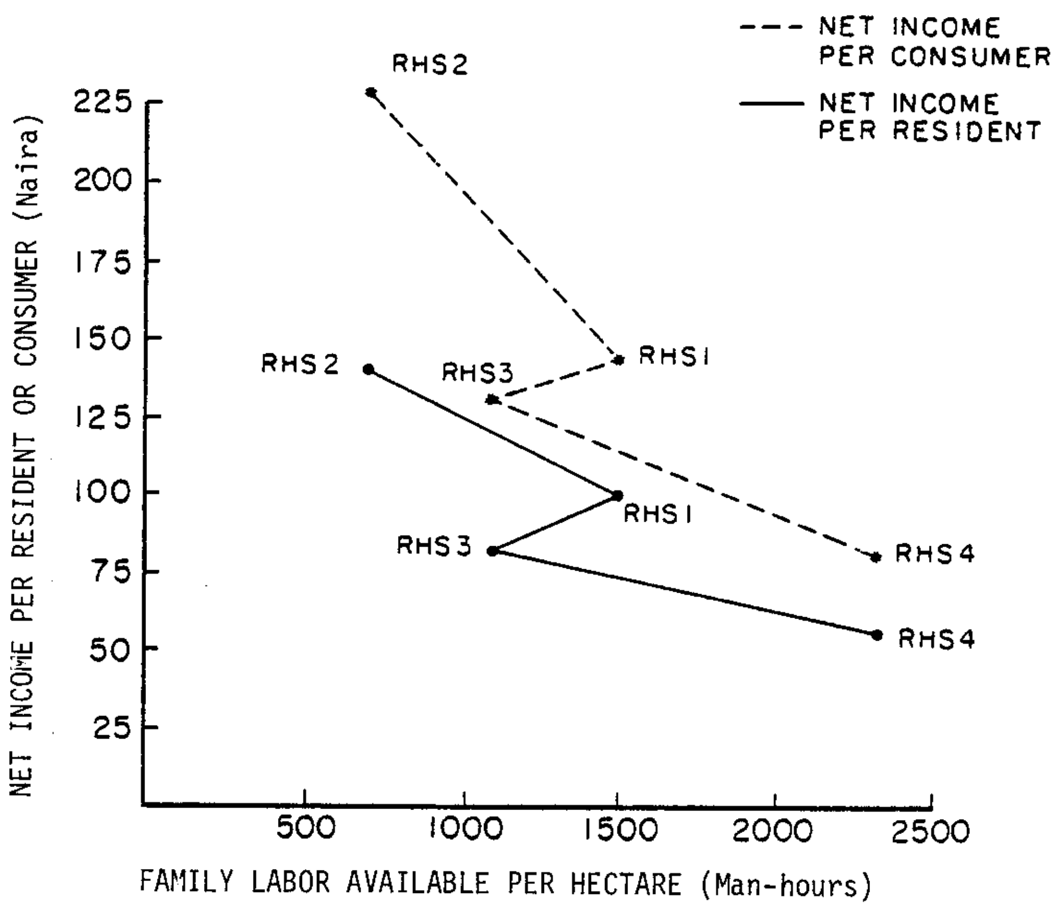
Results of the stochastic experimentation have implications for the research hypotheses concerning the impact of stochastic events on the level, variability, and rate of growth of NETKAP and TCON. Findings regarding each of these impacts are considered in turn.

1. Impact on Level of Returns

Both the overall mean and Year 6 mean levels of NETKAP and TCON were lower in the stochastic experiments than in the deterministic base runs.[1] The difference between stochastic and base run values is statistically significant at the .05 level (except for TCON in experiment SA), depending

[1]See the notes to Table VII.3 for a definition of terms. The "base run" values are those obtained when all three stochastic variables were maintained at their average or typical levels throughout the experimental period. Cases 15 and 18 in Table VII.1 constitute the base runs for stochastic experiments AL and SA, respectively.

FIGURE VII.2. RELATIONSHIP BETWEEN NET INCOME PER RESIDENT AND FAMILY LABOR AVAILABLE PER HECTARE.



RHS1 = Average family size, average resources
RHS2 = Small family, average resources
RHS3 = Small family, limited resources
RHS4 = Average family, limited resources

Table VII.3. SELECTED RESULTS OF THE STOCHASTIC EXPERIMENTS

Statistical Results	Accumulated Net Capital		Household Consumption per Consumer	
	AL: 7 Persons Limited Resources	SA: 4 Persons Average Resources	AL: 7 Persons Limited Resources	SA: 4 Persons Average Resources
			(Naira)[a]	
1. Overall mean[b]	88.1	200.9	62.1	122.7
2. Standard deviation	44.8	36.3	8.0	18.0
3. Base run, mean over six years	106.4	215.4	65.8	125.9
4. t ratio, overall mean vs. base run mean[c]	1.73 (.05)	1.79 (.05)	2.07 (.05)	0.80 (.3)
5. Year 6 mean[d]	104.6	229.5	63.6	132.5
6. Year 6 std. dev.	41.7	59.4	9.9	24.7
7. Range of Year 6 values	30.2 - 173.7	83.9 - 305.1	46.1 - 79.5	72.2 - 162.5
8. Base run, Year 6 value	126.6	257.6	69.9	143.1
9. t ratio, Year 6 mean vs. base run Year 6 value	2.24 (.025)	2.12 (.025)	2.85 (.01)	1.92 (.05)
10. Emergency borrowing (cases)	8 of 20	none	8 of 20	none

[a] One Nigerian Naira = U.S. $1.64 in 1974-75.

[b] Let x_{ij} = value of dependent variable in Year i and replication j:

$$\text{Replicate mean} = \bar{x}_j = \left(\sum_{i=1}^{m} x_{ij}\right) / m$$

$$\text{Overall mean} = \bar{X} = \left(\sum_{j=1}^{n} \bar{x}_j\right) / n$$

$m = 6$
$j = 1, \ldots, n$
n = 18 for net capital (AL), 20 otherwise

[c] Significance level in parentheses.

[d] $$\text{Year 6 mean} = \bar{x}_6 = \left(\sum_{j=1}^{n} x_{6j}\right) / n$$

on household type. This is shown in Table VII.3, lines 4 and 9. The gap between stochastic and base run overall means (18.3 and 14.5 for AL and SA, respectively) is lower than that for the Year 6 means (22.0 and 28.1), which suggests a widening of the gap as time progresses.

Two factors contributed to the lower returns under stochastic conditions.[1] First, there is what might be called an efficiency loss which occurs in Model.B as a result of the two-stage decision process. The cropping pattern which was formulated ex ante in Model.A cannot be changed in Model.B, although labor use, marketing, borrowing, and resource transfer plans can be altered. A cropping plan which is optimal for the average-year yields and prices of Model.A is unlikely to be optimal given the particular set of simulated "actual" yields and prices incorporated into Model.B. The resulting ex post suboptimality involves a cost in terms of net farm revenue which can be substantial.[2]

Second, in the model as in reality, a threshold amount of surplus working capital must be accumulated before self-employed off-farm occupations or soil fertility improvements can be undertaken.[3] (Off-farm wage

---

[1] A check was made to confirm that the random number generator had produced variates with the expected probability distribution. The mean of the 120 normal variates (of expected mean zero and standard deviation one) used to obtain crop yields for household AL was computed to be .0690 with a standard deviation of .9676. These values are not significantly different from the expected ones. The observed frequency of special-event consumption expenditure (25/120 = .208) is not significantly different from the expected value of .20.

[2] To illustrate, evaluation of the model showed a loss of ₦50 resulting from inability to adjust completely to actual production conditions once they are known. This is the difference between ex post earnings of ₦92 from Model.B and earnings of ₦142 from a fully adjusted "perfect knowledge" model, i.e., Model.A with average-year coefficients replaced by simulated "actual" ones. In reality farmers may employ a variety of methods for adjusting their farm plan during the season as additional information about growing conditions is gained. Nonetheless, some such losses are inevitable as at least some events happen upon the farmer too quickly for any effective adjustment to be made.

[3] Matlon (1977: 422) mentioned other factors which might link cash shortages to low incomes: (1) choice of crop mix; (2) timing of crop sales; and (3) demand for and cost of credit. These factors are incorporated into the model. In general, Matlon did not find that these factors explained to any significant degree the differences in income among households in his survey (1977: 165, 285).

employment is not limited in this way.) Other studies in northern Nigeria (Matlon, 1977; Hill, 1972) indicate that the more profitable off-farm activities also have higher working capital requirements (as well as higher risks). Accordingly, if working capital can be accumulated steadily, the household will be able to engage in off-farm occupations of increasing profitability. On the other hand, if surplus capital is reduced or wiped out by stochastic crop failures, investment losses, or special consumption obligations, the household must operate in the following year with fewer if any growth-inducing activities. The impact of stochastic variability is not symmetric, however. When a poor year occurs, minimum family needs must still be met. In a good year, proportionally larger amounts are allocated to additional household consumption and savings before investments are made.

The cash constraint, whose importance is emphasized by Matlon (1977) and Hill (1972), thus exerts a strong influence in the complete model. By contrast, differences in initial cash reserves had little effect on incomes achieved in the linear programming component. This illustrates an advantage of the more complete model.

2. Impact on Variability of Returns

The household with the relatively unfavorable land/person ratio (AL) experienced greater variability of year-end accumulated capital (NETKAP) than did the better endowed household (SA). Over all replicates, the average coefficient of variation of NETKAP was .51 for experiment AL, compared to .18 for experiment SA.[1] The ratio of high to low values of NETKAP was 5.75 to 1 for AL and 3.64 to 1 for SA.

The principal explanation for this finding is differences in cropping pattern, in turn a function of family size and resources. The poorly endowed household with a lower land/person ratio has more abundant family labor relative to its farm size than does the better endowed household. At the same time, it has more consumers and thus higher subsistence grain

---

[1]The poorly endowed household experiences slightly but not significantly lower variability in total household consumption per consumer (TCON). The coefficients of variation are .13 for household AL and .15 for household SA. A likely explanation is that for the poorly endowed household the variable component of TCON (additional consumption out of surplus income) is smaller than the fixed component (required minimum subsistence consumption).

consumption requirements. The poorly endowed household therefore selects crop mixtures which are productive of grain although labor intensive. The better endowed household favors crop mixtures which are less labor-intensive and contain a larger proportion of groundnuts (a valuable cash crop) than grain. Since the estimated year to year variance of yields was greater for grain than for groundnuts, the cropping pattern adopted by the poorly endowed household has a higher weighted average coefficient of variation (.33) than the cropping pattern of the better endowed household (.22).[1] Idachaba's (1980) data on relative yield variance confirm that this result would apply in at least four states including Kano, but not in all areas of Nigeria.[2]

3. Impact on Rate of Growth of Returns

The poorly endowed household accumulated net capital at a slower rate than that achieved by the better endowed household. Slope coefficients for the regression trend line of NETKAP against time from Year 1 to Year 6 were 6.5 ($t = 1.94$) for the poorly endowed household and 17.8 ($t = 5.99$) for the better endowed household.

Poorly endowed households were also more prone to financial stress. In both the linear programming component as well as in the complete simulation model, the extent of grain purchase for consumption was greater for the limited resource households than for the average resource households. In the complete simulation model, emergency borrowing was more frequent and severe for the less well endowed household types. When particularly unfavorable events were incorporated, levels of emergency debt incurred by the poorly endowed households accumulated faster than they could be repaid,

---

[1]The coefficients of variation are (175 /350=0.50) for grain, and (65/410=0.16) for groundnuts. When these coefficients are weighted by the proportions of harvest value made up by grain and groundnuts in the two cropping plans, the above figures are obtained. This is a very rough measure, since the variability of a given crop mixture is not necessarily the average of the variabilities of the individual crop types included in the mixture. One would expect that beneficial interactions between crops within the mixture would reduce the overall variability.

[2]Tables 9 and 11 in Idachaba (1980: 24-5) show that for Kano State the normalized coefficient of variation of groundnut yields from 1968/69 to 1974/75 is .53, which is the same for millet (.53) and substantially lower than for sorghum (.72). (NB: Idachaba's figures have been expressed as decimals rather than percentages to facilitate comparison).

resulting in a steady decline into debt. When the key variables were randomly determined in the stochastic version of the model, emergency borrowing occurred in eight out of the twenty replications for the poorly endowed household, but not at all for the better endowed household.[1]

The results of the stochastic experiments indicate that poorly endowed households experience lower, slower growing, and more variable incomes than better endowed households, as well as more frequent financial difficulties. Limited land and initial cash and crop reserves relative to family size are clearly a disadvantage under the conditions of traditional production technology prevailing during the 1974/75 period from which data for the model were taken. The relatively abundant family labor possessed by poorly endowed households has to date not had the productive outlet which labor intensive high-yielding biochemical technology provides in the Asian setting.[2] In addition, the more family members, the higher the subsistence consumption requirements, which must be met before income is allocated for other purposes.

With improved production technology, together with hard work and good management, poorly endowed households would have the opportunity to earn satisfactory incomes and accumulate capital over time, although perhaps no more so than better endowed households. To the extent that improved production technology is cash-intensive, poorly endowed households would again be placed at a disadvantage, however. Results of the stochastic model indicate the extent to which shortage of working capital constrains income growth by limiting ability to engage in higher-return

---

[1]Total emergency borrowing ranged from N5 to N378, averaging N111 over the eight replications concerned. In three out of four cases, emergency borrowing was caused by unfavorable crop yields alone; in the remaining cases, poor crop yields combined with the incidence of special-event consumption expenditures to push emergency borrowing to levels 65 percent higher (N102 versus N60, on average). There were no cases of emergency borrowing caused solely by the need to meet special-event consumption expenditures.

[2]Improved maize and sorghum have been introduced in recent World Bank projects in the Funtua, Gusau, and Gombe areas of northern Nigeria (World Bank, 1981: 53). Adoption of improved maize has been particularly rapid, partly in response to heavy subsidies on fertilizer.

enterprises and by causing more frequent use of high-cost borrowing. Thus, measures will be needed to ensure that poorly endowed households can gain access to the resources necessary to successfully adopt new technology.

C. Assessment of the Simulation Approach

An implicit assumption underlying the study was that formal modelling is a useful complement to descriptive statistical analysis of farm level data. Studies such as those by Matlon (1977), Hill (1972), and Norman (1972) provide essential insights regarding the critical activities, constraints, and functional relationships of the farming systems concerned. However, as noted in Chapter II, critical system properties can also be investigated with a simulation model, by tracing out the effects of changes in key parameters. The flexibility of the simulation approach makes it possible to incorporate complexities such as multiple goals and sequential decision-making, and the interaction between family size and resource endowment.

One strength of this study is its use of a multi-year model. Earlier modelling work by Zuckerman (1977, 1979), Low (1974), and Hazell (personal communication), analyzed the farming system only over a one-year period. With a dynamic, multi-year model, the relative importance of variables which are hypothesized to determine long-run economic success can be systematically and directly examined. This study has suggested how careful experimental design can facilitate the acquisition and interpretation of relevant information from such modelling research.

The importance of a multi-year perspective, demonstrated here for farming systems using relatively low-capital production technology, is even greater when evaluating farm improvements which involve major capital investment. An example is the adoption of animal-powered cultivation techniques. As shown by Barrett et al. (1981) and Sargent et al. (1981), the substantial capital requirements of animal traction in West Africa lead to major cash flow problems in the early years following adoption. While animal traction technology may be profitable over the long-run, these initial cash flow problems reduce its acceptability to farmers and thus pose an obstacle to adoption.

A multi-year stochastic model of the type developed in this study provides a tool for evaluating major farm investments taking into account the year-by-year timing of revenues and expenditures and the effect of climatic variability. Extending the analysis over a five- to ten-year period guards against the possibility that the modified farm system might be subject to unacceptable cumulative, seasonal, or bad-year losses. Such losses are unlikely to be picked up in a single-year analysis employing average returns to assess profitability. The improved evaluation of a technology's dependability which the simulation approach can afford would be particularly helpful where there are many marginal farmers, and/or where weather conditions are highly variable.

The cost-effectiveness of quantitative modelling has been questioned by Collinson (1979, 1982) and Bernsten and Herdt (1981). They argue that the payoff from modelling in terms of improved understanding of farming systems is not high enough to justify the cost, especially in countries where skilled manpower is scarce. Clearly, the cost effectiveness of modelling depends on the purpose for which it is used. When the objective is quick identification of practices and constraints pertaining to a major crop enterprise, and the selection of factors for field experiments, modelling seems less appropriate than informal surveys as a means of gaining the necessary information.

While the benefits of modelling may be debated, its costs can be examined. They should not be over-estimated. In terms of time, manpower requirements, and computer resources, micro-level modelling tends to be much less costly than macro modelling.[1] Its costs should also be balanced against the cost of research conducted on the experiment station or in farmers' fields, both of which can be quite expensive.

---

[1]This study involved two years of professional manpower and approximately $4,000 in computer and programmer costs. It was explicitly designed to take advantage of data already collected by an earlier research project whose total cost for field work and Ph.D. dissertation was approximately $25,000. The model developed here included a small multiperiod linear programming component (150 activities by 100 constraints) and two FORTRAN programs of 500 lines each. The training and resources for such a model are well within the capacity of many institutions in the Third World. By contrast, macro modelling projects tend to involve large teams, years of work, broad expertise requirements, and costs ranging in some cases as high as one million dollars. For a critique of agricultural sector models, see Egbert (1978).

Bernsten and Herdt (1981) argue that farming systems research should be seen as only one component of an overall agricultural research program which includes basic scientific and commodity-oriented research. Modelling research should be seen as complementing these other research activities as well. It is a potentially useful technique for assessing prototype technology since it permits the analyst to evaluate the sensitivity of new technology under different assumptions regarding household type and environmental conditions (Crawford, 1980).

D. Implications for Future Research

The results of the study have several implications for future research. First, the model includes no mechanism for acquiring additional land, partly because of the difficulties of modelling land acquisition accurately. Opportunities to expand land-holding would substantially strengthen the income-earning prospects of richer households. Unused bush land exists, but bringing it into production is not costless. Matlon (1977: 114) found that fields cleared from unclaimed bush land were only 3 percent of total cultivated area for the three villages he surveyed; 58 percent was inherited, 20 percent purchased, 16 percent rented, and 3 percent pledged as loan collateral. While land-short poor households would have the option of land rental, their access to good quality bush land, or to fertile lowland, would inevitably be more limited than for better endowed households with more investible resources. Further study of the land market in this area would be valuable.

Second, non-monetary barriers to investment are not incorporated in the model. This means that preferential access to resources on social, ethnic, or political grounds is not treated. These factors no doubt affect who undertakes the more prestigious and remunerative trading activities, for example. However, since status is influenced importantly by income and asset levels, incorporating non-monetary barriers to investment in the model would likely reinforce the income growth disparities reported above. To the poorly endowed household's unfavorable economic position would be added non-monetary restrictions on access to opportunities for income expansion, resulting in even less economic success by comparison to the better endowed households.

The results of the study underscore the drawbacks of using averages in farm level research, an issue raised by Upton and Casey (1974). First, the realism of labor use in the multiperiod linear programming component was much improved by replacing average input-output coefficients with those computed from individual farms and fields. Because it removes the typical peaks and valleys in the labor profile, averaging gives coefficients which underestimate peak labor demands.

Second, coefficients based on data from individual fields also allowed the incorporation of a range of technologies reflecting different relative factor and product combinations for a given enterprise type. Matlon's data showed a wide range in field level input-output relationships even within a given crop mixture type. This accords with the findings of other studies, e.g., Norman et al. (1976: 19), which showed that yields from sorghum trials based on farmers' fields varied from five- to ten-fold within a given year. The variability observed in Matlon's data could be explained partially but not completely by field size, crop mixture composition, and labor inputs per hectare. Smaller fields had higher labor inputs and higher returns per hectare than larger fields, perhaps because small fields tended to be close to the compound and therefore likely to receive more attention.

Third, Matlon's data made it possible to incorporate several household types in the model, rather than utilizing "representative" categories. Although his study area was ecologically homogeneous and technologically traditional, with few ethnic or social distinctions, there was still considerable variability among households in terms of land/labor ratios, family and hired labor use, proportion of income earned from off-farm sources, etc. Reflecting this inter-household variation in the model was considered important.

Fourth, and perhaps most important, the results suggest that models based on average-year yields and prices may overestimate the potential for income growth, at least for poorer households. Incomes in the stochastic versions of the model fell below those obtained when crop yield, investment, and expenditure variables were fixed at average-year levels. This illustrates the need to incorporate stochastic variability into the analysis of long-term growth prospects, and to examine a range of farm household situations rather than a representative "average" household type.

The study also suggests the importance of further empirical and theoretical research on the household's allocation of surplus funds, i.e., those remaining after subsistence requirements are met. Allocation of funds to additional consumption, education, marriage, acquisition of land or livestock, or to self-employed non-agricultural occupations, are among the logical alternatives. Understanding the processes involved here is particularly crucial in any analysis which attempts to forecast the household's response to new technology.

The need for agronomic data in microeconomic research is also becoming increasingly evident. Although unusually comprehensive and accurate, Matlon's survey did not include field-level information on soil type, rainfall, and disease or pest infestation, which would have allowed more detailed analysis of production processes, and hence improved model coefficients. Data over a series of years would have improved the dynamic specification of the model, by revealing how farmers respond to changing climatic and economic conditions. Information on the differential response of the common crop mixtures to weather events over time would have provided the basis for expanding the treatment of risk and testing its importance in the production decision. Lastly, information on village- or region-level market processes would have strengthened the specification of the price determination process in the model.

APPENDIX A

Selected Tables

Table A.1. COMPARATIVE DATA ON CROP YIELDS AND LABOR REQUIREMENTS

Mixture Type	1974/75 Matlon	1966/67 Norman	1976 Hazell
1. Pure Sorghum			
a. Hours/ha.	706	232	397
b. Grain/ha. (kg.)	1,610	787	750
c. Grain/hour (kg.)	2.3	3.4	1.9
2. Sorghum + Millet[a]			
a. Hours/ha.	499	509	450
b. Grain/ha. (kg.)	1,040	1,140	1,342
c. Grain/hours (kg.)	2.1	2.2	3.0
3. Millet, Sorghum, Groundnuts			
a. Hours/ha.	791	526	382
b. Grain/ha. (kg.)	441	737	306
c. Groundnuts/ha. (kg.)	382	390	300
d. ₦/ha.[b]	119	143	85
e. ₦/hour	.15	.24	.22
4. Millet, Sorghum, Cowpeas			
a. Hours/ha.	559	598	659
b. Grain/ha. (kg.)	1,010	1,116	1,150
c. Cowpeas/ha. (kg.)	44	167	120
d. ₦/ha.	105	142	135
e. ₦/hour	.19	.24	.20
5. Millet, Sorghum, Cowpeas, Groundnuts			
a. Hours/ha.	600	608	821
b. Grain/ha. (kg.)	491	741	361
c. Cowpeas/ha. (kg.)	30	139	116
d. Groundnuts/ha. (kg.)	227	430	496
e. ₦/ha.	97	182	153
f. ₦/hour	.16	.30	.19

[a]In this table, millet means early millet. For Matlon, sorghum may include late millet.

[b]One Naira (₦) = U.S. $1.64 (1974/75). Naira values for Norman and Hazell are computed using the following average prices obtained from Matlon:

grain	₦	.094/kg.
groundnuts	₦	.189/kg.
cowpeas	₦	.22/kg.

Sources: Matlon (1977), Norman (1972: 80-84), and Hazell (personal communication).

Table A.2. CONVERSION COEFFICIENTS USED IN COMPUTING MAN-EQUIVALENT LABOR HOURS BY AGE, SEX, AND FARM TASK

	Child	Male			Female		
Activity	0-9	10-15	16-49	50+	10-15	16-49	50+
Clearing	.5	1.0	1.0	1.0	a	.8	a
Early ridging	a	.75	1.0	.8	a	a	a
Carrying manure	.5	.8	1.0	1.0	a	.75	a
Spreading manure	.5	1.0	1.0	1.0	a	a	a
Spreading inorg. fert.	a	1.0	1.0	1.0	a	a	a
Planting	.75	1.0	1.0	1.0	.8	1.0	.8
Supplying	a	1.0	1.0	1.0	a	1.0	a
Transplanting	.5	1.0	1.0	1.0	a	1.0	a
Weeding	.25	.8	1.0	.8	a	.6	a
Late ridging	a	.75	1.0	.8	a	.5	a
Irrigating	.5	.75	1.0	1.0	a	a	a
Fencing	.5	1.0	1.0	1.0	a	a	a
Cutting stalks	.25	.8	1.0	1.0	a	.75	a
Lifting groundnuts	.25	.75	1.0	.8	.5	.75	a
Cutting heads	.5	1.0	1.0	1.0	.8	.8	.8
Picking	.5	1.0	1.0	1.0	1.0	1.0	.75
Transporting crop	.5	.8	1.0	1.0	.5	.75	.5
Trans. crop residues	a	.8	1.0	1.0	.5	.75	a

[a]Not observed

Source: Matlon (1977: 171).

Table A.3. COEFFICIENTS USED TO ESTIMATE THE NUMBER OF CONSUMER-EQUIVALENTS PER HOUSEHOLD

	Age			
Sex	0-4	5-9	10-15	16+
Male	.2	.5	.75	1.0
Female	.2	.5	.75	.75

Source: Matlon (1977: 61).

Table A.4. WORKER EQUIVALENT WEIGHTS BY AGE AND SEX (MATLON)

Sex	5-9 Years	10-15 Years	16+ Years
Male	.25	.8	1.0
Female	.25	.5	.6

Source: Matlon (1977: 98).

Table A.5. WEIGHTS FOR CALCULATION OF WEEDERS AND HARVESTERS (CRAWFORD)

	0-9 Years		10-15 Years		16-49 Years		50+ Years	
Sex	Weed	Harvest	Weed	Harvest	Weed	Harvest	Weed	Harvest
Male	-	-	.8	.8	1.0	1.0	1.0	1.0
Female	-	-	-	-	-	.6	-	-

BIBLIOGRAPHY

Abdullahi, A., and G. Lombin. "Comparative Effectiveness of Separate and Combined Applications of Mineral Fertilizers and Farmyard Manure in Maintaining Soil Productivity Under Continuous Cultivation in the Savannah." Institute for Agricultural Research, Samaru, Nigeria, Miscellaneous Paper 75, 1978.

Addelman, Sidney. "Irregular Fractions of the 2^n Factorial Experiments." Technometrics. 3(1961): 479-496.

________. "Symmetrical and Asymmetrical Fractional Factorial Plans." Technometrics. 4(1962): 47-58.

Anderson, Jock R. "Simulation: Methodology and Application in Agricultural Economics." Review of Marketing and Agricultural Economics. 42(1974): 3-55.

Anderson, V. L., and R. A. McLean. Design of Experiments: A Realistic Approach. New York: Marcel Dekker, 1974.

Andrews, D. J. "Intercropping with Sorghum in Nigeria." Experimental Agriculture. 8(1972): 139-150.

Barnum, Howard N., and Lyn Squire. A Model of an Agricultural Household: Theory and Evidence. World Bank Staff Occasional Papers No. 27. Baltimore: Johns Hopkins University Press, 1979.

Barr, Anthony J., James H. Goodnight, John P. Sall, and Jane T. Helwig. A User's Guide to SAS 1976. Raleigh, N.C.: SAS Institute, Inc., 1976.

Barrett, Vincent, Gregory C. Lassiter, David Wilcock, Doyle Baker, and Eric W. Crawford. Animal Traction in Eastern Upper Volta: A Technical, Economic and Institutional Analysis. MSU African Rural Economy Paper No. 24. East Lansing, Michigan: Department of Agricultural Economics, Michigan State University, 1981.

Becker, Gary S. "A Theory of the Allocation of Time." Economic Journal. 75(1965): 493-517.

Bernsten, Richard H., and Robert W. Herdt. "Farm Management's Role in Farming Systems Research to Increase Productivity in Small Farms." Paper for the Seventh Session of the FAO Regional Commission on Farm Management for Asia and the Far East, Jogyakarta, Indonesia, 24-29 August, 1981.

Boehlje, M. D. and T. K. White. "A Production Investment Decision Model of Farm Firm Growth." American Journal of Agricultural Economics. 51(1969): 546-563.

Boussard, Jean-Marc. "Time Horizon, Objective Function, and Uncertainty in a Multiperiod Model of Firm Growth." American Journal of Agricultural Economics. 53(1971): 467-477.

Box, G. E. P., and J. S. Hunter. "The 2^{k-p} Fractional Factorial Designs Part I." Technometrics. 3(1961): 311-315.

Casey, H. "Dynamic Programming in Agricultural Production." Planning Agriculture in Low Income Countries: A Symposium, Department of Agricultural Economics and Management, University of Reading, England, Development Study No. 14, pp. 101-115, 1974.

Chayanov, A. V. On the Theory of Peasant Economics. Eds. Daniel Thorner, Basil Kerblay, and R. E. F. Smith. Homewood, Ill.: Richard D. Irwin, Inc., 1966.

Clough, D. J., J. B. Levine, G. Mowbray, and J. R. Walker. "A Simulation Model for Subsidy Policy Determination in the Canadian Uranium Mining Industry." Canadian Operations Research Society Journal. 3(1965): 115-128.

Collinson, Michael. "Micro-Level Accomplishment and Challenges for the Less Developed World." Paper presented at the XVII Conference of the International Association of Agricultural Economics, Banff, Canada, September 3-12, 1979.

_______. Farming Systems Research in Eastern Africa: The Experience of CIMMYT and Some National Agricultural Research Services, 1976-81. Forthcoming. MSU Rural Development Paper No. 7. East Lansing, Michigan: Department of Agricultural Economics, Michigan State University, 1982.

Crawford, Eric W. "Understanding, Quantification, and Modelling in Farming Systems Research: Results of a Simulation Study in Northern Nigeria." Department of Agricultural Economics Staff Paper No. 80-19, Michigan State University, East Lansing, Michigan, March, 1980.

Delgado, Christopher L. "Livestock Versus Food Grain Production in Southeastern Upper Volta: A Resource Allocation Analysis." Ph.D. thesis, Cornell University, 1978.

Eddy, Edward Danforth, III. "Labor and Land Use on Mixed Farms in the Pastoral Zone of Niger." M.S. thesis, Cornell University, 1979.

Egbert, A. C. "Agricultural Sector Planning Models: A Selected Summary and Critique." World Bank Staff Working Paper No. 297. Washington, D.C.: World Bank, October, 1978.

Eisgruber, L. M., and G. E. Lee. "A Systems Approach to Studying the Growth of the Farm Firm." Systems Analysis in Agricultural Management, eds. J. B. Dent and J. R. Anderson, pp. 330-347. Sydney: John Wiley and Sons Australasia Pty. Ltd., 1971.

Federal Ministry of Agriculture and Natural Resources. Agricultural Development in Nigeria 1973-1985. Lagos: Joint Planning Committee, 1974.

Flinn, J. C., and J. Lagemann. "Evaluating Technical Innovations Under Low-Resource Farmer Conditions." Experimental Agriculture. 16(1980): 91-101.

Hagen, Everett E. The Economics of Development. Homewood, Ill.: Richard D. Irwin, Inc., Revised Edition, 1975.

Hart, Gillian P. "Labor Allocation Strategies in Rural Javanese House-Holds." Ph.D. thesis, Cornell University, 1978.

Hays, H. M., Jr. "The Marketing and Storage of Food Grains in Northern Nigeria." Institute for Agricultural Research, Samaru, Nigeria, Miscellaneous Paper 50, 1975.

Hazell, Peter B. R. "A Linear Alternative to Quadratic and Semivariance Programming for Farm Planning under Uncertainty." American Journal of Agricultural Economics. 53(1971): 53-62.

Heady, E. O. Economics of Agricultural Production and Resource Use. New York: Prentice-Hall, Inc., 1952.

Hill, Polly. Rural Hausa--A Village and a Setting. London: Cambridge University Press, 1972.

Hillier, Frederick S., and Gerald J. Lieberman. Operations Research. San Francisco: Holden-Day, Inc., Second Edition, 1974.

Idachaba, Francis Sulemanu. Agricultural Research Policy in Nigeria. Research Report 17. Washington, D.C.: International Food Policy Research Institute, August, 1980.

John, Peter W. M. Statistical Design and Analysis of Experiments. New York: Macmillan, 1971.

Johnson, Stanley R. "A Multi-Period Stochastic Model of Firm Growth." South Dakota State University Agricultural Experiment Station Bulletin 541, 1967.

Johnson, S. R., and Gordon C. Rausser. "Systems Analysis and Simulation: A Survey of Applications in Agricultural and Resource Economics." A Survey of Agricultural Economics Literature, Vol. 2, Judge et al. (eds.), pp. 157-304. Minneapolis: University of Minnesota Press, 1977.

Joy, J. Leonard. "Diagnosis, Prediction, and Policy Formulation." Subsistence Agriculture and Economic Development, ed. Clifton R. Wharton, Jr., pp. 376-381. Chicago: Aldine Publishing Co., 1969.

Kleijnen, Jack P. C. Statistical Techniques in Simulation, Part II. New York: Marcel Dekker, 1975.

Krishna, Raj. "Comment: Models of the Family Farm." Subsistence Agriculture and Economic Development, ed. Clifton R. Wharton, Jr. pp. 185-190. Chicago: Aldine Publishing Co., 1969.

Lombin, G., and A. Abdullahi. "Long Term Fertility Studies at Samaru--Nigeria: II. Effect of Farm-yard Manure on Monocropped Cotton, Sorghum and Groundnuts and a Rotation of the Three Crops Under Continuous Cultivation." Institute for Agricultural Research, Samaru, Nigeria, Miscellaneous Paper 72, 1977.

Low, A. R. C. "Linear Programming as a Tool in Innovation Selection for Farms in South East Ghana." Planning Agriculture in Low Income Countries: A Symposium, Department of Agricultural Economics and Management, University of Reading, England, Development Study No. 14, pp. 64-86, 1974.

McQuie, Robert. "Experimental Design and Simulation in Unloading Ships By Helicopter." Operations Research. 17(1969): 785-799.

Martin, J. R., and J. S. Plaxico. "Polyperiod Analysis of Growth and Capital Accumulation of Farms in the Rolling Plains of Oklahoma and Texas." U.S.D.A. Technical Bulletin No. 1381, 1967.

Matlon, Peter J. "The Size Distribution, Structure, and Determinants of Personal Income among Farmers in the North of Nigeria." Ph.D. thesis, Cornell University, 1977.

Mellor, John W. "The Subsistence Farmer in Traditional Economies." Paper presented at the ADC Seminar on Subsistence and Peasant Economies, East-West Center, Honolulu, Hawaii, February-March, 1965.

Merrill, William C. "Alternative Programming Models Involving Uncertainty." Journal of Farm Economics. 47(1965): 595-610.

Montgomery, Douglas C. Design and Analysis of Experiments. New York: John Wiley and Sons, 1976.

Moscardi, Edgardo, and Alain de Janvry. "Attitudes Towards Risk among Peasants: An Econometric Approach." American Journal of Agricultural Economics. 59(1977): 710-716.

Nakajima, Chihiro. "Subsistence and Commercial Family Farms: Some Theoretical Models of Subjective Equilibrium." Subsistence Agriculture and Economic Development, ed. Clifton R. Wharton, Jr., pp. 165-185. Chicago: Aldine Publishing Co., 1969.

Naylor, Thomas H. Computer Simulation Experiments with Models of Economic Systems. New York: John Wiley and Sons, Inc., 1971.

Norman, D. W. "An Economic Survey of Three Villages in Zaria Province. Vol. i-Text." Institute for Agricultural Research, Samaru, Nigeria, Miscellaneous Paper 37, 1972.

________. "Crop Mixtures under Indigenous Conditions in the Northern Part of Nigeria." Factors of Agricultural Growth in West Africa, ed. I. M. Ofori. Legon, Ghana: Institute of Statistical, Social and Economic Research, University of Ghana, 1973.

________. "Rationalising Mixed Cropping under Indigenous Conditions: The Example of Northern Nigeria." Journal of Development Studies. 11(1974): 3-21.

________. "Farming Systems Research to Improve the Livelihood of Small Farmers." American Journal of Agricultural Economics. 60(1978): 813-818.

Norman, D. W., P. Beeden, W. J. Kroeker, D. H. Pryor, B. Huizinga, and H. M. Hays. "The Feasibility of Improved Sole Crop Sorghum Production Technology for the small-scale [sic] Farmer in the Northern Guinea Savanna Zone of Nigeria." Institute for Agricultural Research, Samaru, Nigeria, Miscellaneous Paper 60, 1976.

Olsson, Rolf. "A Multiperiod Linear Programming Model for Studies of the Growth Problems of the Agricultural Firm." Swedish Journal of Agricultural Research. 1(1971): 139-177.

Perrin, Richard, and Don Winkelmann. "Impediments to Technical Progress on Small versus Large Farms." American Journal of Agricultural Economics. 58(1976): 888-894.

Rae, Allan N. "Stochastic Programming, Utility, and Sequential Decision Problems in Farm Management." American Journal of Agricultural Economics. 53(1971a): 448-460.

________. "An Empirical Application and Evaluation of Discrete Stochastic Programming in Farm Management." American Journal of Agricultural Economics. 53(1971b): 625-638.

Sargent, Merritt W., John A. Lichte, Peter J. Matlon, and Roger Bloom. An Assessment of Animal Traction in Francophone West Africa. MSU African Rural Economy Program Working Paper No. 34. East Lansing, Michigan: Department of Agricultural Economics, Michigan State University, March, 1981.

Searle, S. R. "Annotated Computer Output for Analysis of Variance of Unequal-Subclass-Numbers Data." American Statistician. 33(1979): 222-223.

Singh, Inderjit, and Lyn Squire. "A Model of the Agricultural Household: Some Implications for Nutrition Policies in Rural Areas." Preliminary draft, mimeo. Studies in Employment and Rural Development No. 49. Washington, D.C.: World Bank, September, 1978.

Snipper, Reuben, and William G. Tomek. "Documentation for ECØN (Version 2.1)." Mimeo. Department of Agricultural Economics, Cornell University, August, 1977.

Upton, M., and H. Casey. "Risk and Some Pitfalls in the Use of Averages in Farm Planning." Journal of Agricultural Economics. 25(1974): 147-152.

Westlake, W. J. "Composite Designs Based on Irregular Fractions of Factorials." Biometrics. 21(1965): 324-336.

World Bank. Accelerated Development in Sub-Saharan Africa: An Agenda for Action. Washington, D.C.: The World Bank, 1981.

Wright, A. "Farming Systems, Models and Simulation." Systems Analysis in Agricultural Management, eds. J. B. Dent and J. R. Anderson, pp. 17-33. Sydney: John Wiley and Sons Australasia Pty. Ltd., 1971.

Zuckerman, Paul S. "Different Smallholder Types and Their Development Needs." Journal of Agricultural Economics. 28(1977): 119-127.

________. "Simulating the Decision Making Process of a Nigerian Smallholder." Canadian Journal of Agricultural Economics. 27(1979): 17-16.

Zusman, Pinhas, and Amotz Amiad. "Simulation: A Tool for Farm Planning Under Conditions of Weather Uncertainty." Journal of Farm Economics. 47(1965): 574-594.

ERRATA SHEET

MICHIGAN STATE UNIVERSITY INTERNATIONAL DEVELOPMENT PAPER NO. 2

"A Simulation Study of Constraints on Traditional

Farming Systems in Northern Nigeria"

by Eric W. Crawford

TEXT

Page	Line	Incorrect	Correct
22	18	$x_t \leq 0$	$x_t \geq 0$
23	13	$x_{ijt} \leq 0$	$x_{ijt} \geq 0$