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AGROECOSYSTEM ANALYSIS IN A SEMI-ARID, SMALLSCALE FARMING SYSTEM OF ZIMBABWE: A SYSTEMS APPROACH

By

Timothy Jan Philip Lynam

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

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1993

ABSTRACT

Effective agroecosystem analysis is made difficult by the lack of suitable philosophical and methodological approaches and the difficulty of applying performance criteria, such as sustainability, to agroecosystem behavior. A research methodology for the analysis of agroecosystem behavior in data scarce environments was described. The approach was used to examine an agroecosystem in the mid-Zambezi Valley.

A questionnaire survey and RRA techniques were used to develop a general understanding of the needs, resources and constraints households faced in satisfying their needs. Thereafter an extended analysis was conducted with the objective of developing a computer simulation model of the agroecosystem. Five male villagers were elected and three women volunteered to act as village representatives (VRs) in the analysis. Data collection methods were developed and then used with the VRs to identify, and weight, by relative importance, major household needs and the production enterprises used to satisfy those needs as well as all inputs to and outputs from each production enterprise.

Household needs and yield probability density functions derived from the VRs were used to develop a computer simulation model of the agroecosystem. Up to 300 households were randomly placed on a raster based GIS image of the

Masoka agroecosystem. Each cell of the landscape represented one acre. Households were allocated cells (fields) around their house sites and on soils adjacent to the Angwa River. The model simulated the productive activities of up to 300 households, updating variables in each cell and for each household once a season. Households could be allocated to one of four production strategies which determined the crops as well as the proportion of household land that was planted to each crop each year. Households could employ labor from other households to make up for deficits failing which their yields were reduced. A partial budget format was used to estimate returns to land, labor and initial investment. Soil erosion was modeled using the SLEMSA erosion model.

The effects of changing important model inputs and parameters on model response variables were examined. Factors that had notable effects on the proportion of deficit households, yields and returns to land, labor and initial investment were rainfall, the land area available and the cash needs required by households.

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Timothy Jan Philip Lynam

1994

To Limited, who never got to see a rhino

and

to the spirit of CAMPFIRE.

ACKNOWLEDGEMENTS

In a study spanning two continents and of considerable breadth I have had to rely on the goodwill and assistance of many people and organizations. I am especially grateful to the WWF Multispecies Project, for providing me with the institutional and financial support for this research and to the Project Leader, Dr. D.H.M Cumming, whose enthusiasm, mentorship and unfailing support were crucial to every aspect of my research. I would like to thank the Rotary Foundation for the generous scholarship which made it possible for me to attend MSU. I would like to thank Dr. J.T. Ritchie, my advisor, who provided the impetus that brought me to MSU, the institutional support while I was at MSU and for leaving me to go my own way. My committee members Dr. Campbell, Dr. Crawford, Dr. Manetsch, Dr. Robertson, Dr. Paustian proved invaluable as teachers, advisors and friends. I am very grateful to them all. Like so many Zimbabwean colleagues I am indebted to Peter Frost. His remarkable stream of ideas, criticisms, support and friendship have enriched my work and my abilities. Working with Gift Chisunga, George Kanoderuka, Mai Kajengo, Mai Tekenyeka, Mai Kowe, Albert Fero, Saraoga Mbisvi and Inocent Fakero was both a delight and a pleasure. Without their enthusiasm and dedication I could not have achieved a fraction of what we did. I am grateful to Henry Elwell for his invaluable help with erosion modeling, for doing the erodibility tests for me and for the many ideas and thoughts he has so generously provided. All errors and omissions in the erosion model used here are however, my responsibility! Sarah Funkhouser made a great difference to my life and to my work, I am grateful. Bill Verboem and Katherine Verbeek were invaluable in helping with soil mapping and classifications. I am particularly grateful to Stanford Mushiri of the Chemistry and Soil Research Institute for the tremendous assistance he gave in having my soil samples analyzed. Bill Derman, Stuart Gage, Sharlene Rhines, Karen Potter-Witter, Brian Baer and Ivan Bond provided invaluable support and help over the years. I would like to thank the staff at WWF MAPS Project Office Harare, for all they have done and continue to do. To all those I have inadvertently missed, thank you.

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ABBREVIATIONS

AGRITEX ...... Department of Agricultural Technical and Extension Services

CA ...... Communal Areas

DMS ...... Department of Meteorological Services

FSRU ...... Farming Systems Research Unit

GOZ ...... Government of Zimbabwe

MAPS ...... Multispecies Animal Production Systems Project

MLARR ...... Ministry of Lands, Agriculture and Rural Resettlement

MZVRDP ...... Mid-Zambezi Valley Rural Development Project

VR ...... Village Representative

WWF ...... World Wide Fund for Nature

Chapter 1.

Background and justification

INTRODUCTION

Two problems need to be overcome in analyzing the behavior of agroecosystems[1]. The first of these is the lack of a suitable and philosophically and methodologically coherent approach to the analysis of agroecosystems. The second is the problem of meaningfully applying performance criteria such as sustainabilty or stability in real world decision making.

Generally speaking science is ill-prepared, both methodologically and philosophically, to solve real world problems of agroecosystems where the performance criteria are sustainability, stability or similar measures requiring a predictive understanding of agroecosystem behavior. MacRae *et al.* (1989) review several scientific barriers to achieving sustainable food production. They discuss the failings of the reductionist approach to scientific investigation, question

1 Agroecosystems are defined as ecosystems in which basic biological processes are managed to obtain food and fibre as well as other goods and services. They include social, managerial or decision making and economic as well as bio-physical components. In Zimbabwe Communal Areas and at the scale of this analysis they incorporate a number of households. They include therefore, a political component as well.

scientific objectivity, particularly in fields of research such as agriculture, and the common belief that quantifying is an essential precursor to rational evaluation of facts.

There can be little doubt that reductionist science has been a powerful problem solving paradigm. It is limited, however, in its ability to deal with problems associated with systems and especially where multiple performance criteria are to be used (Bawden, 1991; MacRae *et al.*, 1989). The perception of science as an objective and value free search for the truth has not been substantiated by research (MacRae *et al.*, 1989; Busch and Lacey, 1983; Mahoney, 1979). The perception of some agricultural scientists that it is possible to remain objectively detached from social and economic processes is a dubious assumption at best. Values influence what problems are addressed and which solutions are considered acceptable (or considered at all). These decisions have political, social and economic consequences that should be recognized. Failure to explicitly define values in agricultural research could result in the introduction of sources of bias not accounted for in subsequent analyses.

Agricultural scientists rely on quantitative data to support or refute their assertions and are more likely to believe quantitative arguments (MacRae *et al.*, 1989; Mahoney, 1976). Quantifying states and outputs in agroecosystems, with their tightly coupled bio-physical, social and economic sub-systems, is difficult. Reliance on quantified relationships could lead to emphases that would not be supported by giving equal weight to those system attributes that are difficult to quantify and for which there might only be qualitative relationships. By quantifying relationships and states analysts also stand the risk of expressing a precision that is not a true reflection of their knowledge of the world.

Philosophically, much of contemporary science uses the hypothetico-deductive approach in establishing whether or not assertions are false. For the most part scientists are concerned with the probability of making a Type I error (rejecting a true null hypothesis) but rarely examine the likelihood of making a Type II error (accepting a false null hypothesis). Yet, in the world of decisions, costs and benefits, these errors may have equally expensive consequences (MacRae *et al.*, 1989; Officer and Dillon, 1968). Aversion to making Type I errors is a strong incentive to reduce problems to single variables to ensure that observed effects are due to factor changes. The assumptions imposed on observation, in order to use classical inferential statistics, constrain our ability to react to "scientific complexity" (Box and Tiao, 1992). The hypothetico-deductive methodology, as formulated by Popper (1968), also makes the assumption that, *a priori*, we know nothing whatsoever about the subject matter of interest (Stove, 1982). In basing decisions on this view a tremendous body of knowledge and previous experience are discarded. Given the complexity of the performance criteria used in comparing agroecosystems or agroecosystem outputs as well as the sometimes high costs of making either Type I or Type II errors, this seems a wasteful practice; in essence the tools used are dictating the nature of the problems that are addressed.

The systems approach is one that offers promise for dealing with the complex requirements of design and analysis in agricultural systems (Bawden, 1991). The soft systems approach of Checkland (Checkland, 1981; Checkland and Scholes, 1990) was specifically developed to deal with problems where neither the objectives nor the system boundaries are clearly defined, or perhaps even clearly definable. This may often be the case with agricultural systems. The soft systems approach does not stress the value of computer modeling as is the case in conventional or "hard" systems approaches. The systems approach is not without its critics however; Belinski (1976) is scathing in his attacks on the misuse of logic, mathematics and statistics in systems science and particularly when these methods have been applied to social and biological systems. Hoos (1972) is critical of the ability of the systems approach to adequately deal with public policy issues. She is even more damming of attempts to predict the future of social systems (Hoos, 1974). These criticisms are often valid and should not be ignored. Criticism is a necessary but, not sufficient, condition for change and improvement. Change also requires trying new techniques or taking what is deficient and improving it. So, whilst the systems approach is clearly not perfect it is a useful approach with which to start and from which to develop new approaches to agroecosystem analysis. The well developed and tested approaches to analysis, including the large body of knowledge on many aspects of modeling dynamic systems, offers a rich tool box with which to undertake the analysis of agroecosystem behavior.

Perhaps the most widely advocated approach to the analysis of agricultural systems in the developing world is the agroecosystem analysis approach of Conway (Conway, 1987, 1986, 1985). Agroecosystem analysis (after Conway) uses four system properties to describe system behavior. These are productivity, stability, sustainability and equitability. Grimm *et al.* (1992) provide a checklist of factors that should be explicitly defined when discussing ecosystem stability concepts; a checklist that appears equally appropriate for use with sustainability, productivity and equitability as it does with stability. These factors are: a) the level of description (whether individual, population or ecosystem for example); b) the variable of interest; c) the referential behavior of the variable of interest; d) the nature of the disturbance; e) the spatial scale; and f) the temporal scale.

In the view of many systems' theorists, systems exhibit what are called emergent properties; these are properties that are not deducible from observations of the individual parts of the system (Bawden and Ison, 1992). If we accept these assertions then the selection of the level of analysis as well as the spatial and temporal scales of analysis are made very much more complex. Changes in factors at one level of analysis could lead to unexpected changes at others or an agroecosystem could be stable at one scale but not at another.

Data suitable for a quantitative description of both the current state of the agroecosystem as well as those describing the behavior of the agroecosystem over space and in time are seldom likely to be available and particularly so in developing countries.

These problems are compounded in practical decision making by issues of whose values need be considered and the large number of variables and performance criteria that need to be considered simultaneously. Policy makers and individual heads of household are unlikely to share the same set of values. Theoretically at least, the policy maker could be expected to act in the best interests of society whilst the household head could be expected to act in the best interests of the household. As analysts we are faced with the dilemma of selecting which set of values are to be used in the analysis. There do not seem to be any clear cut criteria for selecting one view of the world as opposed to another.

In Conway's approach (Conway, 1985, 1987) these issues are not addressed. The approach is orientated toward the analyst's world view. Techniques that include local farmer participation are used for data collection and the farmers in the target agroecosystem appear to participate only as passive sources of data rather than active participants in an client orientated analysis. Conway (1985) admits that the properties he defines are more easily defined than measured and that "satisfactory methods of measuring sustainability still need to be found." In more recent applications of the methodology (Conway, 1987) a team of experts is used in a workshop format, to subjectively select patterns of space, time, flow and decisions, that are likely to reveal the key functional relationships that determine system properties.

The agroecosystem analysis approach of Conway (1986, 1985) does not advocate predictive modeling. Evaluations of sustainability, stability and equitability appear to be made subjectively by the team of experts. With scarcely any data at all, let alone time series data, this may be the only approach that is possible, yet it can lend itself to biased and erroneous interpretations. Under Zimbabwean communal area conditions, farmers and analysts are often from different cultures and backgrounds and share very different futures. Few of the analysts are likely to have spent more than a few weeks, let alone months, in a communal area farming system. Fewer still of the analysts will have futures that are more than cursorily linked to the outcome of the analysis. Given that the analysts and communal area farmers have neither values nor objectives in common and the analysts are not accountable to households for their decisions it appears unlikely that a team of professionals can reliably predict the sustainability, stability and equitability performances of an agroecosystem.

It is undeniable, that there are a number of philosophical and methodological tools available, which could be gainfully used to develop insights appropriate to the analysis of complex agricultural systems, particularly those in the developing world. There does not, however, appear to be a philosophically and methodologically coherent approach to agroecosystem analysis for use with performance criteria such as sustainability, stability, resilience or equitability, and in particular where there are no data except local or indigenous knowledge.

The World Wildlife Fund Multispecies Animal Production Project (WWF MAPS) was established in 1988 with one of its major objectives being to critically examine the ecological and economic implications of multispecies and single species animal production systems in Zimbabwe (Cumming, 1991). A number of the hypotheses to be tested by the project used sustainability, stability and resilience as performance criteria. As a research fellow working on the WWF MAPS project, I developed a research program designed to examine the sustainability of Masoka, an agroecosystem located in the mid-Zambezi Valley.

The following chapters describe the research I conducted as part of the WWF MAPS Project. My original objective was to examine the sustainability of Masoka. The result is a first, and admittedly rather crude, methodology for conducting agroecosystem analyses where the local people were seen as equal, if not major participants in the analysis.

I have not been able to address any of the philosophical problems associated with research of this kind. I have also failed to address any of the difficulties of statistically analyzing the data collected in the field as well as the simulated results from the model. Despite the obvious importance of resolving these philosphical and analytical issues I have not had the time, in this study, to do more than recognize their existence.

In Chapter 2 I briefly present background data on the Masoka agroecosystem. In Chapter 3, material that was used to develop a general understanding of the agroecosystem and the constraints household face in satisfying needs are presented. Chapter 4 is a description and evaluation of the methods used for field data collection; summaries of these data are included. In Chapter 5, development of the Masoka agroecosystem model is described and the results of preliminary sensitivity analyses of the model are presented. In the final chapter, major features of the research are reviewed and I make a few suggestions about key issues for future research.

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Chapter 2.

Background data on the Masoka agroecosystem

INTRODUCTION

In this chapter I present background data on Kanyurira ward. Kanyurira ward was selected as a study site because: a) it was one of the first CAMPFIRE projects in the Zambezi Valley; b) it has a small and relatively discrete human population; c) studies by the Centre for Applied Social Sciences (CASS) at the University of Zimbabwe (Cutshall, 1989) as well as those by the WWF Multispecies Animal Production Systems project (Taylor, 1993) provide useful background resources; d) the community has been living in the area for, at least, several generations and thus could be expected to exhibit traditional, as well as the more modern, technologies that are spreading through the mid-Zambezi valley area; e) the absence of cattle considerably simplified analysis of the agroecosystem; f) Masoka is still relatively undeveloped. The community has therefore, a large set of development options that it could follow.

Study site description

Administratively, Zimbabwe is divided into provinces, districts, wards and villages. Kanyurira Ward (Masoka[2]) is situated in Guruve District, Mashonaland Central Province, Zimbabwe, between 30^{o} 10' E and 16^{o} 15' S (Figure 2.1). Nearly 170 km^2 (40%), of the 400 km^2, lie above the Zambezi escarpment (Taylor, in preparation). The altitude of the ward ranges from 1120 meters at the top of the escarpment to about 400 meters where the Angwa river leaves the ward in the north east (Figure 2.2). The topography of the ward ranges from steeply dissected slopes on the escarpment to gently sloping alluvial terraces along the major rivers.

The geological formations of the area are largely recent to Pleistocene alluvial sands and gravel, Triassic sandstone (upper Karoo group) and micaceous sandstone, the upper portion of the latter alternating with mudstone (Broderick, 1989; Oesterlen, 1989). There is little likelihood of useable shallow aquifers in the ward (Owen, personal communication, 1991; Owen, 1989).

In general, the river systems of the ward drain north and south into the Angwa River which rises about 120km to the south, above the escarpment (Figure 2.1). All rivers flow seasonally. The Angwa River is dry for most of the year (May to October), floods after the onset of the rains (November or December) and has peak flows in January and February.

Masoka has a long dry season from April to November and a wet season

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2 The name Kanyurira is derived from the sub-Chief of the Ward, Headman C. Kanyurira. Masoka is the name of the royal spirit, (*Mhondoro*) of the area and is the name in common usage. It is not used for the whole ward but is used to refer to the area of present habitation. I shall use Masoka when describing the area of current habitation and Kanyurira to refer to the Ward.

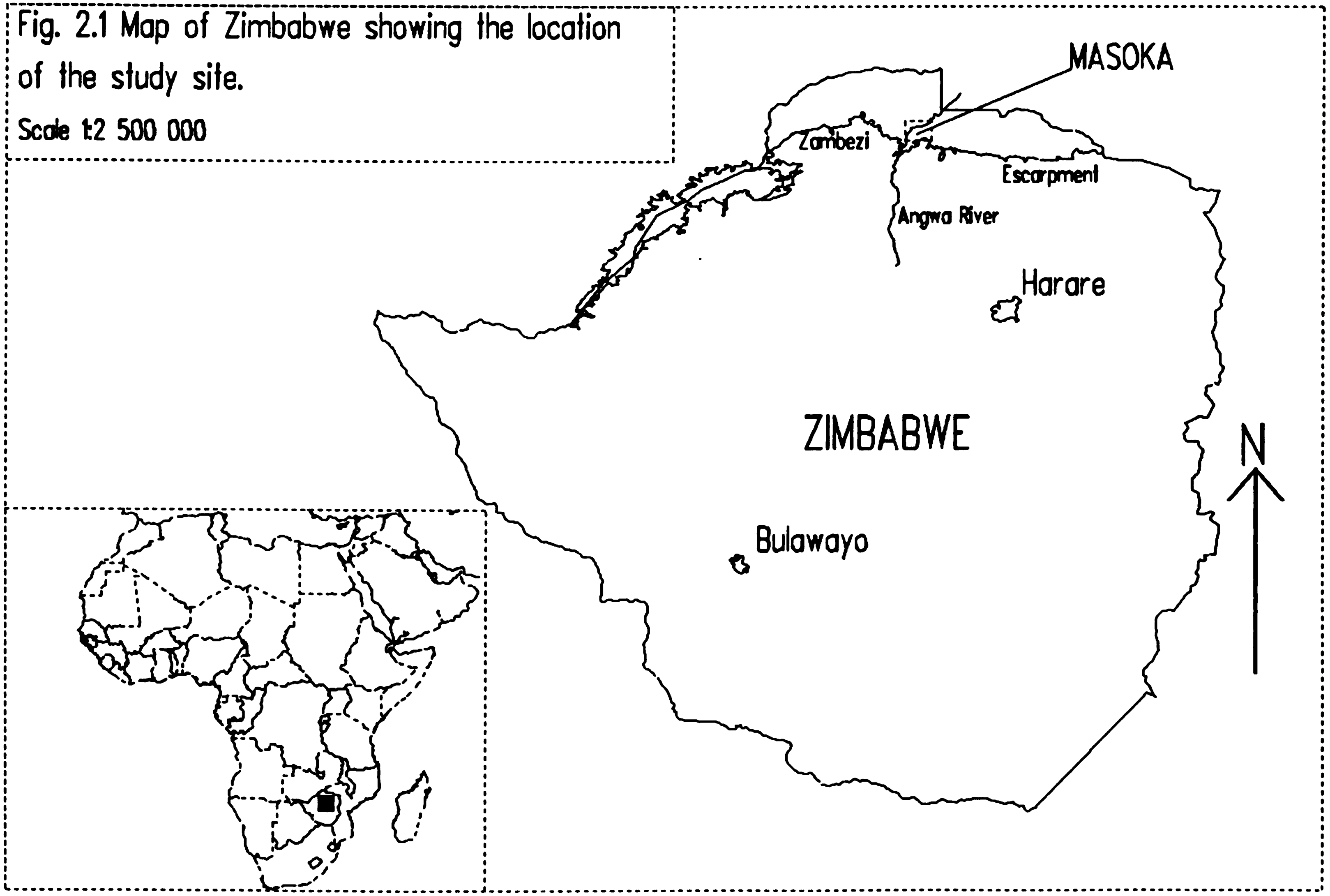

Fig. 2.1 Map of Zimbabwe showing the location of the study site.
Scale 1:2 500 000

from December to March. Mean annual rainfall (725mm, n=15, CV=34%) was recorded at Angwa Bridge, some 15km north east of Masoka. Mean annual evaporation (2050mm, n=6, CV=11%) was measured at Muzarabani, approximately 90km south east of Masoka (Figure 2.2). Mean monthly rainfall values and mean monthly pan evaporation are shown in Figure 2.3. Mean monthly precipitation seldom exceeds mean monthly evaporation. The Zimbabwe Department of Meteorological Services, (Department of Meteorological Services, 1981) report increasing evaporation northward from the Zambezi escarpment. Evaporation at Masoka is therefore, likely to be somewhat higher than that measured at Muzarabani. The rainfall of the area is highly erosive with annual energy values estimated by Stocking and Elwell (1976) to be between 11000 and 13000 J $mm^{-1}m^{-2}h^{-1}$.

Anderson (1987) identified three major soil types at a 1:250 000 scale (Table 2.1). The soils were described and classified following Thompson and Purves

Table 2.1 Major soil types of Kanyurira Ward, mapped at 1:250 000 (Anderson, 1987).

Zimbabwe soil name	Classification		
	Zimbabwe	USDA	FAO
Sialitic	4S	Typic ustorthent	Calcaric regosol
Strongly sodic	8N	Typic naturastalf	Orthic solonetz
Alluvial vertisols	3S	Typic pellustert	Pellic vertisol

(1978) and Thompson, (1965). The soils of this part of the Zambezi Valley are

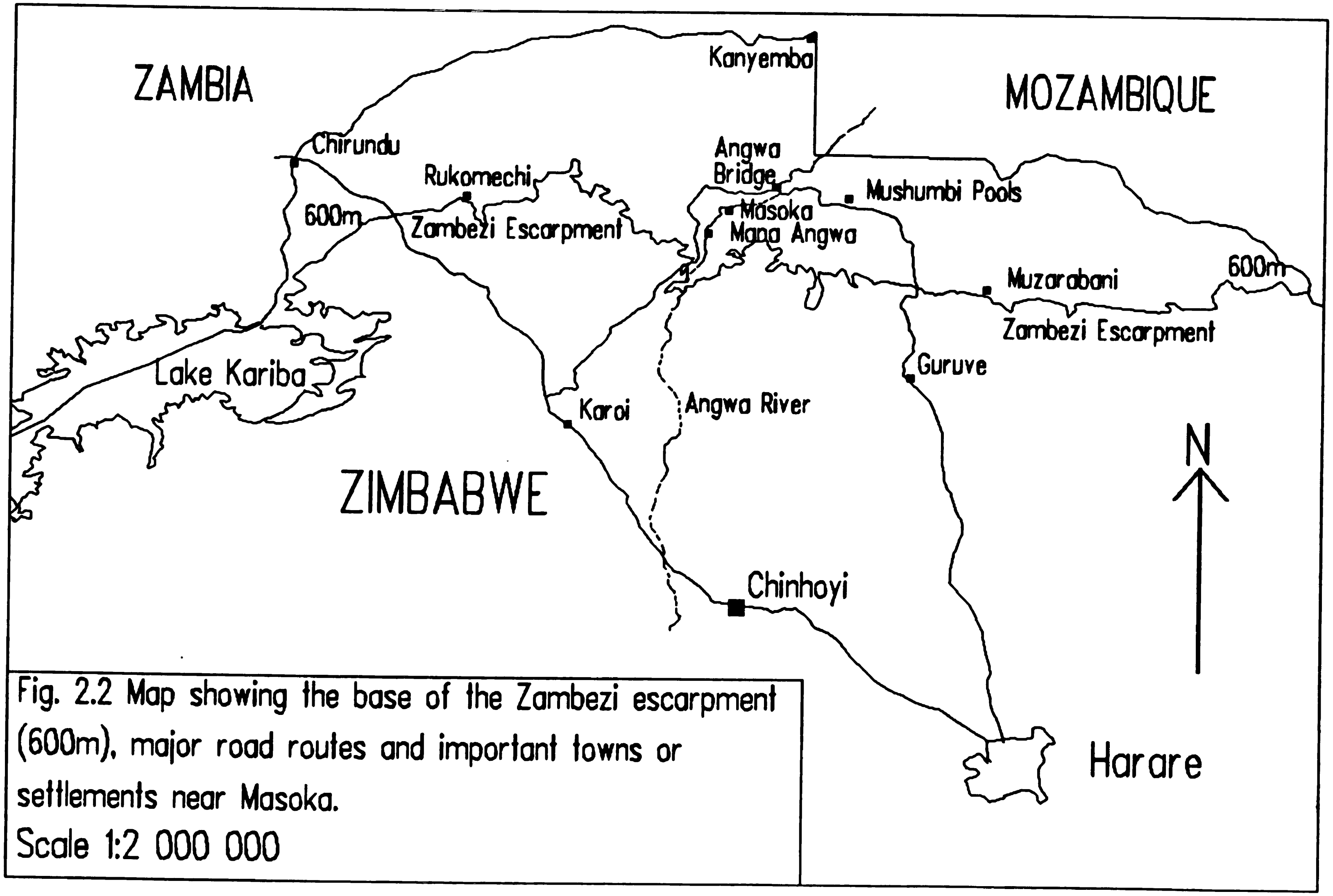

Fig. 2.2 Map showing the base of the Zambezi escarpment (600m), major road routes and important towns or settlements near Masoka.
Scale 1:2 000 000

considered to be moderately erodible; low vegetation cover and high soil erodibility being the major factors contributing to this erodibility (Madhiri and Manyanza, 1989).

The vegetation of Kanyurira has been described at scales of 1:250 000 (Anderson, 1987) and 1:50 000 (Taylor, 1993). Taylor describes 14 different vegetation types, broadly grouped into i) riverine and alluvial vegetation; ii) dry deciduous forest; iii) *Colophospermum mopane* communities; iv) miombo communities; v) *Terminalia* communities; and vi) mixed mopane-miombo communities. Taylor suggested a close association between these vegetation types and the soils of the area.

Most residents of Masoka claim to have lived at Mana Angwa, 10km south west of the present centre of habitation (Figure 2.2), prior to 1965 and to have lived in the general area of Masoka for several generations. In 1979, all households[3] were moved into a "protected village" at Angwa Bridge as part of the Rhodesian government's attempts to isolate nationalist guerrillas from the population. The households moved back to their current centre of habitation, Masoka, in 1980. By the end of 1992 there were about 143 households in the ward, an almost 140% increase since 1988, when Cutshall (1989) surveyed the community and counted 60 households. Part of this rapid growth can be attributed to the arrival of between 30 and 35 households of VaDema people who settled on

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3 The definition of what constitutes a household is somewhat difficult (Hammel, 1984; Guyer, 1981). Throughout this study I use the definition supplied by key informants. A household is defined by one of the following: a married couple; a widow or widower; or a couple who have lived together all their lives.

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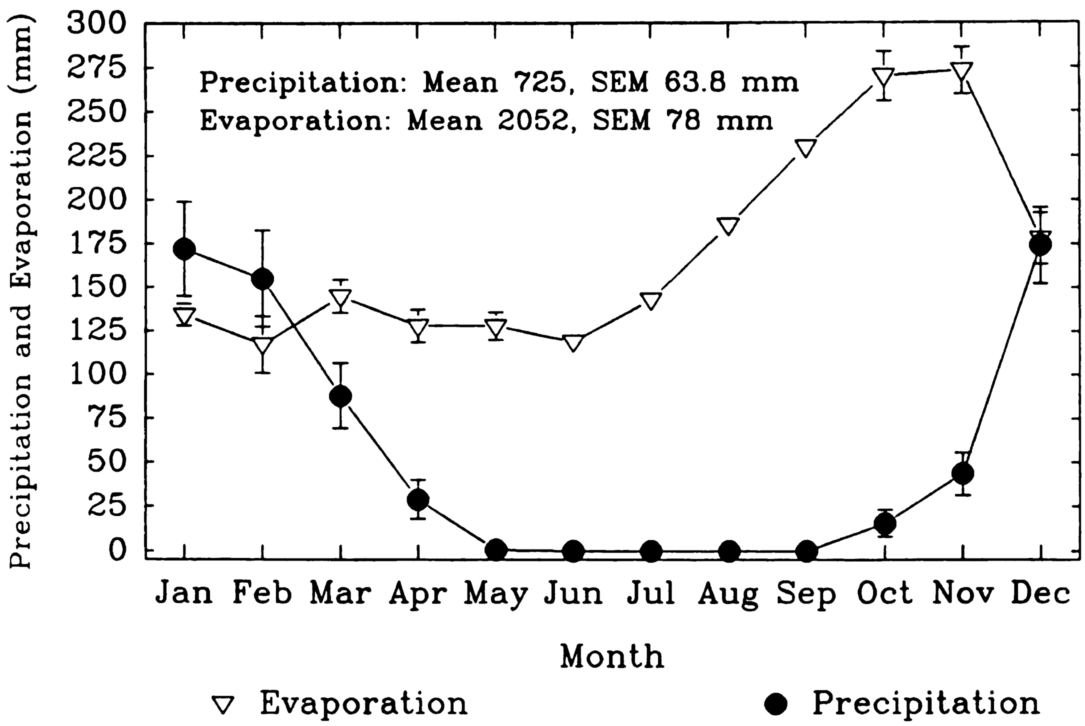

Figure 2.3 Precipitation (mm), from Angwa Bridge (n=15) and evaporation (mm) from Muzarabani (n=6). Data are monthly means with bars showing SEM.

the northern banks of the Angwa River sometime in 1990/1991. Excluding this immigration the growth rate in the number of households in the ward is still about 10% per year. Ethnically, the community is dominated by Korekore (Cutshall, 1989) but has a large population of VaDema, as well as a few Chikunda and Malawian households. In late 1992, ten households from Masvingo Province were allowed to settle in the ward.

Politically, Kanyurira Ward is divided into three Village Development Committees (VIDCOS). A ward councillor, who represents ward interests in meetings of the district council, is elected by popular vote of all households in the Ward. These political institutions were initiated after independence in 1980. Traditional leadership is vested in the Chief (in this case sub-chief Kanyurira), the spirit medium and village headmen. In Kanyurira these traditional leaders still play a major role in directing community affairs. Important organizations that influence community planning and decision making are the Department of Agricultural, Technical and Extension Services, (AGRITEX) which has a representative at Angwa Bridge, the Department of National Parks and Wild Life Management (DNPWLM) which has a large station at Mkanga Bridge, 11km north west of Masoka, and the Tsetse Control Branch of the Department of Veterinary Services which has a base at Mana Angwa.

In 1988, Guruve was one of the first districts in Zimbabwe to begin exercising authority over its wildlife resources. This was formalized in 1991 when Appropriate Authority status was granted by the central government in terms of the

1975 Parks and Wild Life Act. With Appropriate Authority status, district councils have control over the use of their wildlife resources, with any income generated by wildlife utilization projects being available to the district council (Cumming, 1991; Peterson, 1991). During 1989 the Kanyurira community developed a wildlife land use plan (Kanyurira Wildlife Committee, 1989). Based on this plan, the community chose to fence slightly more than 14km^2 along the south bank of the Angwa River, and to limit settlement and cultivation to within this area (Figure 2.4). All of the households except those of the VaDema and one of the original Korekore households live and carry out most of their cultivation within this fenced area. A number of households in the community (n=42), however, have fields on the recent alluvium outside of the fenced area.

Wildlife in the ward generate revenues in the form of trophy and accommodation fees paid to the professional safari hunter who leases the ward hunting concession from the district council[4]. The professional hunters pay the district council trophy fees and a lease or concession fee for use of the ward. The district council deducts a district council levy, a budget allocation for resource management and a levy for the Campfire Association; the remainder of wildlife revenues belong to the ward. Theoretically, each ward should decide what to do with these revenues but in practice the Guruve district council makes these decisions (Peterson, 1991). Each household in Masoka received direct payments

[4] For the first three years the District Council managed the safari operation. More recently the wildlife enterprise is managed by a professional safari operator with contracts being awarded, by the District Council, on consideration of submitted tenders.

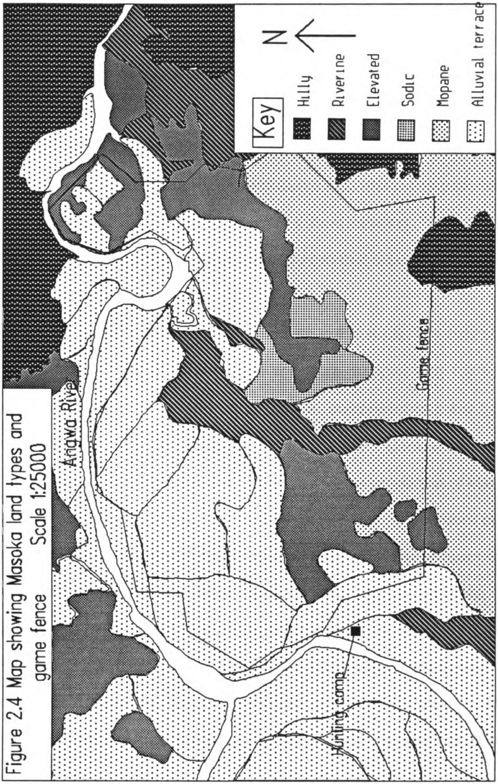

Figure 2.4 Map showing Masoka land types and game fence Scale 1:25000

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(dividends) from ward wildlife revenues three times since 1989 (Table 2.2). These dividends are equivalent to between 9 and 2800% of the annual income that Cutshall (1989) has reported households derive from cotton production. The wide range of areas that households reported planting to cotton is likely to have resulted in the variability in total returns to cotton reported by Cutshall.

Wild animal populations in Masoka have been estimated regularly since 1989 (Mackie, 1993; Taylor, 1991; Taylor and Cumming, 1989). The populations of the major herbivores show considerable inter-annual variation (Table 2.3), indicating that these populations are using resources that expand over an area greater than that of the ward.

The $14km^2$ fenced area is of primary concern in this study. The soils of this are mostly alluvial deposits of varying ages and were mapped with 1:9750 air photography (Figure 2.4). Four major land classes, comprising four soil types, were identified (Table 2.4). Two additional land types were identified (hilly and riverine) but were not investigated as they comprise a small proportion of Masoka and are not important agriculturally. The mopane woodland area comprises deep, medium textured sandy loams with small, localized patches of fine textured sodic soils. The alluvial or river terraces slope away from the original river bank. Soil texture on these terraces grades from medium textured sands near the historical river bank to fine textured sandy clays on the down-slope edge of the terrace. The river terraces have been the focus of traditional agriculture in Masoka. More recently however, settlers have been moving into areas of elevated old alluvium

Table 2.2 Total revenues generated by wildlife in Masoka in each year since 1989, dividends paid per household and total revenues paid to households in Zimbabwe dollars (Z$).

YEAR	Total Wildlife Revenues (Z$)	Dividend per Household (Z$)	Total Revenues paid to Households (Z$)
1989	47,310	200	17,200
1990	78,170	NIL	NIL
1991	89,293	NIL	NIL
1992	276,746	400	56,000
TOTAL	491,519	600	73,200

and even onto some sodic areas.

Traditionally, households satisfy their food and cash needs largely from rainfed crop production and illegal hunting[5]. Crop production is based on grain crops, primarily maize (*Zea mays L.*) and sorghum (*Sorghum bicolor L.*) inter-cropped with cucubits such as watermellon, pumpkin and cucumber. Less commonly grown are small plots of groundnuts (*Arachis hypogaea*) and sweet potatoes (*Ipomoea batatas*). Mean total areas cultivated for small, medium and large households are about 1.3, 1.8 and 2.2 ha (this study, Chapter 3). Dry season production is limited to vegetable crops grown in small gardens along the banks of the Angwa River that are irrigated from shallow wells dug into the sand of the river bed.

5 Wildlife in Zimbabwe belongs to the state. Hunting is strictly controlled by the DNPWM. Poachers in the Zambezi Valley face jail sentences if caught. In the war against rhino and elephant poaching, poachers are often shot.

Table 2.3 Census population estimates of large herbivores in Kanyurira Ward, 1988 to 1992[1].

Valley floor ($290km^2$)	1988	1989	1990	1992
	Numbers of animals			
Elephant		209		412
Buffalo	1824		28	149
Rhino	24		9	
Impala	459	380	9	82
Sable		74	9	15
Kudu		12		29
Escarpment ($182km^2$)				
Elephant	NOT SURVEYED		70	116
Buffalo	NOT SURVEYED		23	
Rhino	NOT SURVEYED		23	
Impala	NOT SURVEYED		14	
Sable	NOT SURVEYED		5	42
Kudu	NOT SURVEYED		5	8

1. Source: Mackie, 1993; Taylor, 1991; Taylor and Cumming, 1989

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Table 2.4 Land types within the Masoka fenced area with Zimbabwean and USDA soil classifications.

Land type Local soil description	Soil classification Zimbabwe	 USDA
River terraces		
Jecha	Calcimorphic 4U	Typic rhodustalf
Bepe	3U	Fluventic ustochrept
Elevated old alluvium		
Jecha	Calcimorphic 4U	Typic haplustalf
Mopane woodland	Calcimorphic	
	4U	Typic haplustalf
	Natric order	Typic natrustalf
	8NU	
Sodic soils		
Shapi	Natric order 8NU	Typic natrustalf

Cotton (*Gossypium hirsutum*) was introduced into Masoka in the mid-1970s and it is now a major cash crop with 73% of the households growing it in 1988 (Cutshall, 1989) but only 57% growing it in 1991 (this study, Chapter 3). Fewer than 7% of the households reported using inorganic fertilizers in the 1990/1991 growing season. Soil fertility in the older alluvial terraces is restored with a tree fallow dominated by *Acacia tortilis* (subsp. *heterocantha*). In the recent alluvium outside the fenced area, field fertility is restored by the periodic flooding of the Angwa River.

Obtaining reliable estimates of the contribution of wildlife meat to household incomes is difficult owing to the technical illegality of hunting in Masoka. Village informants suggest that wild meat was always in plentiful supply. This source of food has dropped to much smaller amounts since Masoka was fenced in 1989.

Masoka is not on a major transport or bus route. The nearest bus route is on the road from Mkanga Bridge to Angwa Bridge. These buses stop on the north bank of the Angwa but the river is not crossable during periods of heavy rainfall. Most farm and household inputs are purchased in Guruve, about 140km south east of Masoka (Figure 2.2), and then transported by bus to Angwa Bridge or to the north bank crossing point. There is no public transport that goes directly to Masoka. Cotton harvests are taken by tractor to the Cotton Marketing Board (CMB) depot at Mushumbi Pools. Although a clinic is scheduled to be built using revenues derived from wildlife, Masoka does not yet have either a clinic or a bank (although the Agricultural Finance Corporation has a local agent who helps villagers complete applications for credit). There is no electricity or piped water in the community. Households obtain all drinking water from the Angwa river or from shallow wells dug into the river bed during the dry season. The AGRITEX agricultural extension agent visits the community less than once per season.

Summary

Despite having constrained household production activities to an area of 14km^2, the Masoka community is growing very rapidly, both within and outside of the fenced area. Household needs are satisfied from a diversity of rainfed crop production activities, from cash earned from local agricultural or external (i.e. not within the ward) wage labor and from the revenues generated by the ward wildlife project. The rainfall is however, low and variable with evaporation exceeding precipitation over most of the season. Crop yields are consequently poor. Transporting inputs to Masoka and harvests to markets is difficult and expensive.

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Chapter 3.

Towards a general understanding of the Masoka agroecosystem

INTRODUCTION

The ability to predict the behavior or future state of an agroecosystem, such as Masoka, is constrained by the difficulty of dealing with complexity. Masoka is socially, politically, economically and bio-physically complex. To predict the future behavior or state of this agroecosystem the major components and behavioral trends need to be identified from among the plethora of system components and behaviors. This will: a) enable one to establish whether or not to proceed with the analysis and b) facilitate a more focused and therefore, efficient analysis. Preliminary investigations of the agroecosystem had four main objectives. These were firstly, to obtain a general understanding of the agroecosystem. The second objective was to identify the needs the agroecosystem is to satisfy. Identification of major trends and patterns in the structure and functioning of the agroecosystem was the third objective and the fourth was to identify important environmental[6]

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6 The term "environment" is used here in the systems theoretic sense, where environment implies everything external to the system of interest.

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variables and their trends. It is important, at this general level of analysis, to keep the investigation as broad as possible.

The purpose of this chapter is to describe the methods and results of the coarse level analysis of the Masoka agroecosystem and to discuss the results with regard to the satisfaction of household needs. The analysis is also aimed at identifying issues that will focus the intermediate level analysis.

Viewed from outside the agroecosystem Masoka can be seen as one element in a biophysical, social, economic and political matrix. The smallest unit of resolution is the household whilst the extent of the analysis depends on the criteria being evaluated; economically and politically it is the national system, socially it is the area of Chief Chisunga and bio-physically it is a part of the Angwa and Zambezi River catchments.

For the remainder of this introductory section I review pertinent literature to provide an overview of the environment in which Masoka exists and changes. Thereafter, I present the methods used in this level of analysis; describe and discuss the results of the analysis; and end by discussing the implications of these findings to the necessity for further analysis and to the ability of households in Masoka to continue to satisfy their needs.

Zimbabwean communal area (CA) farmers manage their agroecosystems to satisfy their food and cash needs[7] (Shumba, 1989; Reh, 1986; FSRU, 1985).

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7 The considerable debate on what constitutes "basic needs" and the measurement thereof, is beyond the scope of this study. Streeten (1986) provides a useful discussion of the issues. Hopkins and Van Der Hoeven (1983) discuss the main concepts.

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Societal needs are reflected in the development objectives of the Zimbabwe Government's First Five-Year National Development Plan (GOZ, 1986); "...raising the standards of living of the population, enlargement of employment opportunities and manpower development and maintenance of a correct balance between development and the environment."

The major components that households manage or use to satisfy these needs are: 1) cropping systems (Stack and Chopak, 1990; Campbell and Swift, 1989; Jackson and Collier, 1988; Murindagomo, 1988; Stilz and Weyl, 1986); 2) livestock systems (Cumming and Bond, 1991; Stack and Chopak, 1990; Ndlovu, 1990; Murindagomo, 1988; Scoones and Wilson, 1988; Stilz and Weyl, 1986); 3) wildlife systems (Cumming, 1991; Cumming and Bond, 1991); 4) woodland systems (Lynam *et al.*, 1993; Swift *et al.*, 1989) and 5) systems providing paid employment (Jackson and Collier, 1988; Stilz and Weyl, 1986). Development of livestock production systems in most of the mid-Zambezi Valley area has been constrained by the disease trypanosomiasis that is fatal for many livestock species, including cattle (Jordan, 1986). The vector of this disease, the tsetse fly *Glossina morsitans*, is present throughout much of this area. The satisfaction of needs in the Zambezi Valley therefore, largely depends on rainfed crop production, wildlife and woodland use and the acceptance of paid employment off-farm. The European Economic Community (EEC) initiative to eradicate tsetse fly from the mid-Zambezi Valley area could, however, result in livestock becoming an important component of household and community production systems.

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There are few data on the extent to which Zambezi Valley households satisfy their needs. A number of indicators from national statistics as well as from studies in other areas of the country indicate, that for a large number of communal area farmers, household needs for cash and food are not being satisfied. Illife (1990) found famine to have been a regular phenomenon in Zimbabwe between 1890 and 1960. Rukuni and Wyekoff (1991) report that even in normal rainfall years, about 40% of rural households do not produce sufficient food to last them through the dry season. During periods of drought the government feeds as much as 8.5% of the population (Rukuni *et al.*, 1990). The Zimbabwe Central Statistics Office (CSO, 1989) reports that thirty percent of Zimbabwe's children under five are chronically malnourished. Malnutrition is the highest cause of mortality in children between the ages of one and four (Mason, 1990). Households in semi-arid areas, such as Masoka, are among the most vulnerable groups (Jayne *et al.*, 1990; CSO, 1989).

Factors that are both internal and external to the agroecosystem can increase the vulnerability of households to failure to meet their needs. Internal factors are often related to high population density and subsequent inefficient or poor use of resources (Campbell and Swift, 1989; Whitlow and Campbell, 1989; Stilz and Weyl, 1986). External factors that impact the ability of households to satisfy needs include soil type, rainfall, technology, markets and social or political stability. Most communal area soils are infertile sands (Grant, 1981) as is the case with Kanyurira Ward where shallow, infertile sands cover most of the area

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(Anderson, 1987). Rainfall in much of the mid-Zambezi Valley area is low and highly variable (Anderson, 1987; Vincent and Thomas, 1965).

Drinkwater (1991) discusses how variable and inconsistent the extension advice to communal area (CA) farmers has been since the early 1900s. The long-term political environment has also shown itself to be variable and uncertain because, within 15 years, CA farmers have faced a violent war, Marxist development policies and then market-oriented development policies (Drinkwater, 1991).

Many of these variables show increasingly unfavorable trends when viewed from the perspective of the CA farmer. Land has become a scarce commodity in Zimbabwe to the extent that "...it must be acknowledged that it is no longer possible to honor every citizen's claim to land rights." (World Bank, 1991). Elwell (1992) suggests a downward trend in mean annual rainfall across the country. Producer prices for maize and cotton have declined by 15 to 20% in the period 1985 to 1990 (Jansen and Rukovo, 1992). Government expenditure on agriculture has declined from an average 9.8% of gross domestic product (GDP) in the early seventies to 6.4% of GDP in the period 1986 to 1990 (Jansen and Rukovo, 1992). Government expenditure on agricultural research and extension has also declined since 1984 (Rukovo *et al.*, 1991).

These facts create an image of an uncertain and variable bio-physical, social, economic and political environment in which CA householders have had and will continue to have difficulty satisfying their basic needs for cash and food.

This situation is likely to be exacerbated if declining government expenditure on agricultural research limits the development and dissemination of technologies appropriate to the conditions and needs of CA farmers in the Zambezi Valley.

METHODS

Secondary data of relevance to the study area were reviewed. Thereafter, academics and professionals from several university departments, non-governmental organizations (NGOs) and government departments, were brought together for a one day workshop with the objective of developing a conceptual model of a Zambezi Valley farming system. After a few paper presentations, participants split up into small groups to develop conceptual models of components of a Zambezi Valley farming system. In a final session, the whole group attempted to bring these components together into a farming system model.

In a 1991 reconnaissance trip to Masoka, a local informant, Mr. Gift Chisunga, arranged meetings with community leaders and individuals. I used semi-structured interviews to identify components of the agroecosystem, constraints or problems faced in attempting to satisfy household needs, and key individuals or social groups in the community. To obtain a general understanding of the layout of the community, the distribution of soils, cropping practices, and land ownership I mapped these factors along four transects through the area; from the Angwa river to the southern most edge of the cultivated area. Transects were placed to

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cut through the major areas of habitation and crop production as well as through areas that were more recently being opened for cultivation. Transect starting points and routings were identified from air photographs. These routings were followed as far as was convenient and appropriate. If farmers were encountered during this exercise they were asked questions about their fields, their period of residency in the area, how they had been allocated land, their yields, and their production practices.

During this reconnaissance field trip it seemed that a number of households, and especially the poorer households, could not produce enough to satisfy their household needs from their crop production system. It seemed that access to good quality soils, access to labor, and the mix of crops planted by households, were key constraints to households being able to satisfy needs. A more detailed survey was planned to examine these ideas as well as to provide information that would be used to focus the next level of the analysis.

A questionnaire was developed, and administered in September 1991, in which respondents were asked to state which crops they planted and on what soil type; what acreage they planted; and the yields they harvested for the 1990/91 growing season (i.e. the season for which harvesting had just ended). These latter data provided estimates of actual yields. To obtain estimates of perceived yield (i.e. the yields farmers believed could be obtained), respondents were presented with scenarios of crop, soil type, hand or tractor tillage and good or poor rainfall season, and were asked what yields they would expect to get under these condi

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conditions. Respondents were also asked how many bags of maize and sorghum and how many bales of cotton their household required to meet basic household needs for one year. Data were collected on the number of adults and juveniles (< 16 years old) in the household and the number of years that the household head had been resident in the community. Soils were classified according to local soil classification practices as shapi (sandy loam), bepe (sandy clay) and jecha (sand) (see Table 2.1, for FAO and USDA classifications). Respondents were asked to state how many acres of the different soil types their household could manage using traditional hand cultivation and how many acres of the different soil types they could manage using a tractor. Finally respondents were asked to class the previous three seasons (1988/89, 1989/90, 1990/91) as being either good, average or poor rainfall seasons.

The questionnaire was translated into Shona and then retranslated into English, by independent translators, to ensure translation accuracy. Three enumerators were employed from within the community and were trained for one day. Training included questionnaire translation, detailed discussions of each question, group and individual practice with administering the questionnaire and finally, supervised field administration. I attempted to survey the entire community (n=80 households[8]) but sampled only 74 households.

Prior to analysis, data that did not conform to a normal distribution were

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8 This is the number of households reputed to be in the community at the time of the survey. It excludes a group 30 to 40 households of VaDoma who settled on the north bank of the Angwa river at about this time.

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transformed using natural logarithms ($x = \ln(x+1)$) and, in one case, the square root transformation. All data were converted to SI units. For the purposes of data analysis, households were classified as small, medium or large using the following rules:

if # adults + 0.5 * # children <= 4 then household = small

if # adults + 0.5 * # children > 4 and <= 7 then household = medium

if # adults + 0.5 * # children > 7 then household = large

Selection of these cutoff values was based on discussions with the three field assistants.

A simple linear programming model was used to establish the optimal configuration of crops grown on each of the three soil types that would meet the needs of each household size class. The model was expected to roughly identify whether or not households, in each size class, were likely to satisfy needs for cash and food. If it were possible to satisfy needs with the available resources then the LP model should find solutions that could achieve the objective. The solutions identified by the LP model were not expected to be ideal solutions for households classes but only indicators as to whether or not households could satisfy needs in any one year.

The objective function of this model was the maximization of gross household income subject to the household satisfying its needs for maize, cotton and sorghum. Households were constrained in the number of hectares they could manage. All data used in the model were derived from the questionnaire survey. Two fifths of the cropping area available to each household was allocated as shapi,

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shapi, two fifths as jecha and one fifth as bepe soils. These proportions were thought to represent the probable distribution of the different soils currently cropped in the community. To evaluate the ability of households to satisfy needs in the long run, the optimal crop and soil mixes derived from the linear programming model were used for each season from 1977/78 to 1991/92 (i.e. 15 years). Rainfall data from Angwa Bridge were used and the season was considered good if rainfall exceeded the 15 year mean less 20% (i.e. IF rainfall > (mean-20%) THEN season = "good"). Otherwise, the season was considered bad. Crop production that was surplus or deficit to household needs was converted to Zimbabwe dollars (Z$) using 1990/91 season producer prices; Z$264.40 ton^{-1} for maize, Z$1660 ton^{-1} for cotton and Z$213.35 ton^{-1} for sorghum.

The potential of households to generate income was calculated using crop producer prices for 1978 to 1991, converted to 1991 dollars. The 1978 to 1991 Angwa Bridge rainfall data were used to determine whether a season was good or bad as described above. Yields were set as functions of soil type and season. The land allocations derived from the linear programming models were used for the optimal scenario. For the average scenario no cotton was planted. Of the average areas that different households in each size class claimed they were able to manage, one quarter was planted to sorghum and the rest to maize. Sorghum was always planted on shapi soils.

The analyzed results of the survey were presented to the community using graphic techniques: colored cardboard cutouts were made of three sizes of hous

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household to represent large, medium and small household classes. A number of cutouts were also made to represent bales of cotton, bags of maize and tins[9] of sorghum. Other cutouts of a tractor, a man and woman hoeing, different colored squares and different sizes of cloud were used to represent the two forms of traction discussed, different soil types and whether a rainfall season was good, average or poor. These cards or icons were stuck on a large board to illustrate the results of the survey. For example, yields on each soil type in each rainfall season type could be discussed by pinning maize bag or cotton bale shaped cards on the board to represent the average number of bags or bales reported in the survey.

RESULTS AND DISCUSSION

The attempt during the workshop to develop a conceptual model of a farming system was inconclusive, in the sense that participants failed to agree on a conceptual model of the agroecosystem and were unable to agree on the appropriate scales of analysis. Much of this uncertainty could be attributed to the ambitiousness of the objective as well as lack of clarity in defining what was actually needed. In another sense however, this result was conclusive in that it illustrated that, as a group, the workshop participants did not have a sufficiently clear understanding of a typical farming system to derive a model or to derive

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9 Most households reported sorghum yields in twenty kilogram tins or buckets.

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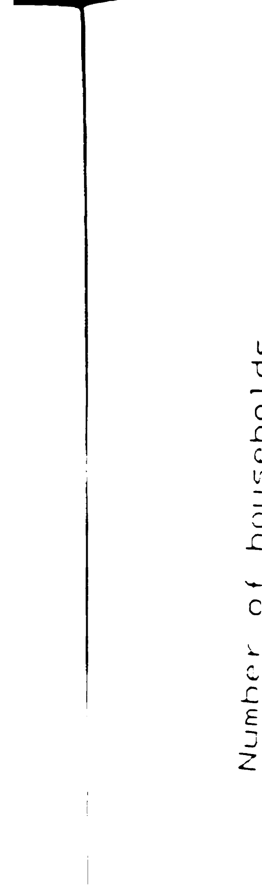
Estimated numbers of households in the community between 1985 and 1992 were provided by the village informant. These data show the average annual increase in household numbers to be ten percent (Figure 3.1). A linear regression model (population=-16291.4+8.23*year; df=6, r^2=.94) and an exponential model ($population_{(t+1)} = population_t * exp^{(.1)}$) were used to extrapolate household numbers to the year 2010 (Figure 3.1).

Questionnaire survey results are presented and discussed in six sections. In the first, household needs for food and cash crops are described. In the second, the areas of land that households claimed to be able to manage are presented. Production and production potential of the different soil types in the village area are presented in the third section. The fourth section deals with the gross income generating potential of households and in the fifth section, areas of cropland that households require to satisfy their needs are presented. In the last section, the implications of these results for satisfying household and societal needs are discussed.

Household needs for food and cash crops

The requirements for maize (n=72; r^2 = 0.915; p<.001), cotton (n=56; r^2 = 0.87; p<.001) and sorghum (n=13; r^2 = 0.907; p<.001) increased with family size (Table 3.1). These values were derived by linear regression of kilograms of cotton, maize or sorghum (dependent variable) against the total number of adult



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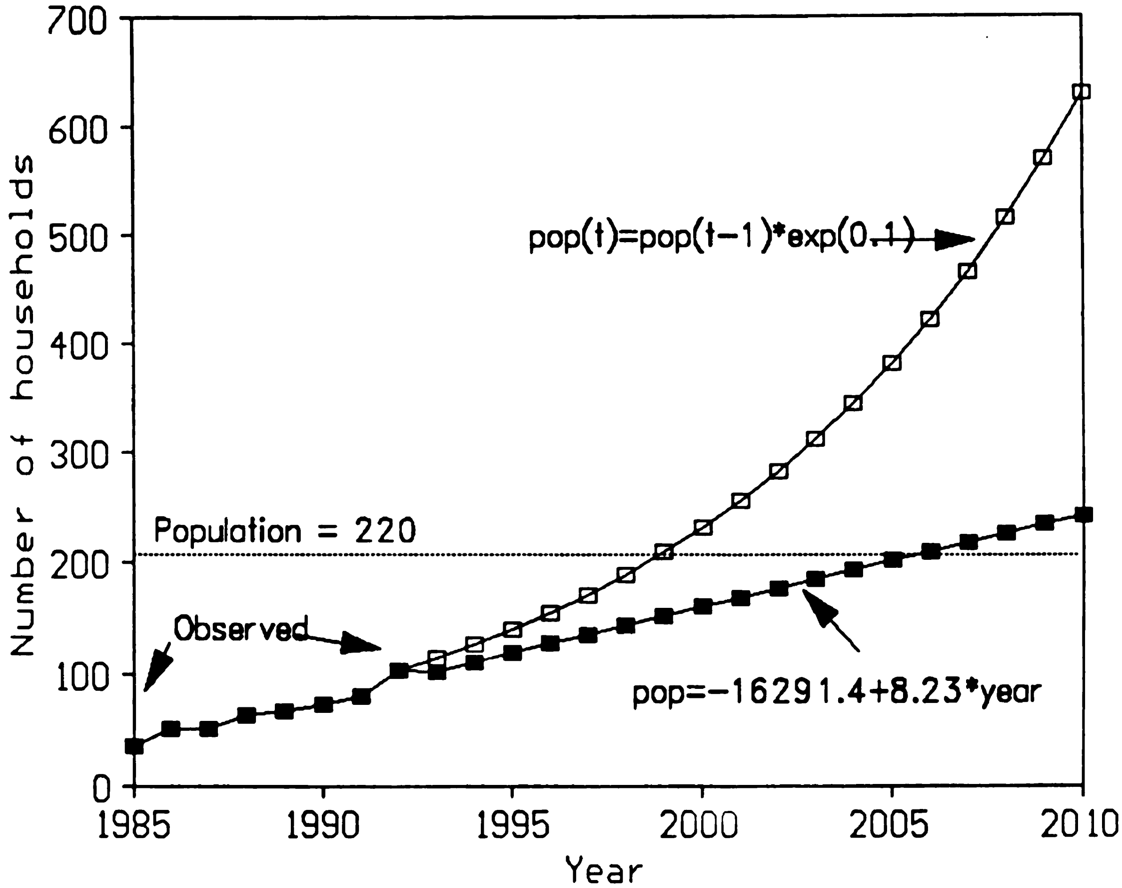

Figure 3.1 Estimated numbers of households in Masoka, 1985 to 1992 and predicted numbers of households through 2010 based on a linear and an exponential projection model.

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Table 3.1 Household needs for maize, cotton and sorghum, by household size class. Data are mean $\pm$ SEM, with n in parentheses.

NEED Household size	MAIZE (kg)	COTTON (kg)	SORGHUM (kg)
Small	720 $\pm$ 8 (19)	1620 $\pm$ 32 (13)	170 $\pm$ 14 (4)
Medium	1270 $\pm$ 9 (24)	2840 $\pm$ 36 (21)	230 $\pm$ 40 (3)
Large	1610 $\pm$ 8 (29)	3020 $\pm$ 34 (22)	470 $\pm$ 42 (6)

equivalents (two children = one adult) in each household (independent variable). Maize requirements were about 180 kg per adult equivalent, cash requirements were about Z$400 per adult equivalent for small and medium households and Z$350 per adult equivalent for large households. Sorghum requirements per adult equivalent were 45, 35 and 50 kg for small, medium and large households.

Acreage that households can manage

Respondents indicated that they would be able to manage greater areas if they had tractors for ploughing than they could manage by hand, suggesting that labor for land preparation is an important constraint. The mean areas that small households claimed to be able to manage were 1.34 ha by hand and 2 ha with a tractor ($t=6.26$, $df=18$, $p<.001$). For medium households these means were 1.8 ha by hand and 3 ha with a tractor ($t=7.29$, $df=22$, $p<.001$) and for large households the means were 2.2 ha by hand and 3.4 ha with a tractor ($t=6.48$, $df=24$, $p<.001$).

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Seventy two percent of farmers believed the 1990/91 season was a bad one. The very low rainfall measured at Angwa Bridge (480mm) supports this belief. Yields for maize, cotton and sorghum that were obtained by farmers for this season are shown in Table 3.2. Yields were low but did not differ among soil types for any of the three crops investigated. The cotton and sorghum yields were considerably lower than the poor season (1983/84) yields for cotton (950kg ha^{-1}) and sorghum (450kg ha^{-1}) but considerably higher than the maize yields of the same season (180kg ha^{-1}) reported by Harizi (1985) for the Muzarabani area. Harizi used Agritex crop yield data to estimate these yields as well as average yields (maize, 720kg ha^{-1}, cotton, 1200kg ha^{-1}, and sorghum 900kg ha^{-1}) and best yields (maize, 1800kg ha^{-1}, cotton 1600kg ha^{-1} and sorghum, 1600kg ha^{-1}). Brunt et. al. (1986) report yields for the mid-Zambezi Valley area of 700kg ha^{-1} for maize and cotton and 600kg ha^{-1} for sorghum which are similar to the yields reported in Table 3.2.

Farmers who ploughed with a tractor (n=14) had yields no greater than those that used hand cultivation, nor did those who used fertilizer (n=5) achieve higher yields than those who did not. The sample size is, however, too small to make definitive conclusions about the effects of tractors or fertilizer on yields. Only 7 (10%) of the respondents had used credit facilities in the last growing season whilst 13 (18%) intended doing so in the forthcoming growing season.

In general the yields that farmers stated they were likely to get on a given

Table 3.2 Maize, cotton and sorghum yields obtained by respondents for the 1990/91 season on three soil types. Data are mean ± SEM, with *n* in parentheses.

SOIL	MAIZE	COTTON	SORGHUM
	<---------------	kg ha^{-1}	--------------->
SHAPI	670 ± .18 (28)	673 ± .19 (12)	No data
BEPE	540 ± .34 (11)	476 ± .29 (4)	490 (1)
JECHA	482 ± .19 (24)	600 ± .12 (26)	198 ± .64 (6)
Mean	570 ± .12 (63)	600 ± .1 (41)	225 ± .55 (7)

soil with a bad season (Table 3.3) were slightly higher than the yields they actually achieved (Table 3.2). Acceptance of the anticipated yield figures presented in Table 3.3 assumes; a) that farmers have had some experience in growing the crop and b) that they can predict the yields they are likely to obtain under a given set of conditions. To satisfy the first assumption respondents were asked only to respond to crops they had grown. As for their ability to predict yields under given conditions, a fair assumption to make is that farmers, whose families depend on their ability to produce sufficient food and cash, would be able to estimate potential yields and plant sufficient areas to meet their needs. One would in fact expect these estimates to be slightly conservative because mistakes could have serious implications for the well being of the farmer's household. Comparisons of the yields in Tables 3.2 and 3.3 suggest that farmers tended to overestimate their poor season maize and cotton yields, on bepe soils in particular, and underestimate their sorghum yields. The anticipated yields presented in Table 3.3, however, compare favorably with the yield figures reported by Harizi (1985). The

Table 3.3 Anticipated yields for hand cultivated maize, cotton and sorghum on three soils in good and bad rainfall seasons. Data are mean[1] ± SEM, with *n* in parentheses.

SOIL CROP Season	SHAPI	BEPE	JECHA	AVERAGE
	<--------------------	kg ha^{-1}	-------------------->	
MAIZE				
Good	1650_{ab} ± 20 (52)	2330_{cde} + 18 (56)	1610_{fg} + 24 (39)	1870 + 12 (147)
Poor	760_{bcg} + 22 (52)	1080_{d} ± 22 (56)	760_{aef} ± 24 (39)	870 ± 13 (147)
COTTON				
Good	1780_{h} ± 42 (37)	2510_{ij} ± 62 (28)	1970_{h} ± 50 (16)	2050 ± 31 (81)
Poor	900_{i} ± 47 (38)	1150 ± 56 (27)	610_{j} ± 62 (16)	910 ± 32 (81)
SORGHUM				
Good	1260_{knm} ± 148 (8)	810 ± 113 (6)	470_{k} ± 58 (5)	860 ± 11 (19)
Poor	540 ± 128 (8)	160n ± 43 (5)	170_{m} ± 58 (5)	300 ± 56 (18)

1. Means followed by the same letter are significantly different at *a* = 0.05.

major differences are that Masoka farmers anticipated much higher poor season maize and good season cotton yields whereas Harizi reported much higher good season sorghum yields. In general, the anticipated yields appear to be adequate estimates for use in the current analysis.

Respondents clearly perceived that yields, for all crops, on tractor cultivated fields would be higher than those on hand cultivated fields (Table 3.4; Cotton, n=324, df=323, p<.001; maize, n=585, df=585, p<.001; sorghum, n=72, df=71, p<.001). Since few households had actually used tractors in production of these crops, these yield data are to be treated with some caution.

Table 3.4 Perceived yields for tractor cultivated maize, cotton and sorghum on three soils in good and bad rainfall seasons. Data are mean[1] ± SEM, with *n* in parentheses.

SOIL / CROP / Season	SHAPI	BEPE	JECHA	AVERAGE
	<----------	kg ha^{-1}	---------->	
MAIZE				
Good	3090_{ab} ± 22 (52)	4620_{cdef} ± 19 (56)	2540_{d} ± 25 (39)	3430 ± 13 (147)
Poor	1390_{bc} ± 23 (51)	2320_{f} ± 21 (55)	1380_{ae} ± 28 (38)	1690 ± 14 (144)
COTTON				
Good	2930_{i} ± 55 (37)	4430_{gh} ± 64 (28)	3230 ± 82 (16)	3452 ± 37 (81)
Poor	1380_{hi} ± 51 (37)	1860_{g} ± 67 (28)	1330 ± 74 (16)	1521 ± 35 (81)
SORGHUM				
Good	1130_{jk} ± 124 (8)	1760 ± 133 (6)	920_{j} ± 55 (5)	1236 ± 60 (19)
Poor	1020 ± 164 (7)	970 ± 138 (5)	470_{k} ± 86 (4)	838 ± 74 (16)

1. Means followed by the same letter are significantly different at *a* = 0.05.

Income generating potential

The gross annual incomes that households could earn from the production of rainfed, hand cultivated maize, cotton and sorghum were Z$430 (CV = 46%) under the average scenario and Z$1400 (CV = 52%) under the optimal scenario for large households. For small households these values were Z$260 (CV = 46%) under the average and Z$1015 (CV = 52%) under the optimal scenario. The mean values for each year 1978 to 1991 are shown for large households (Figure 3.2) and for small households (Figure 3.3). These data highlight a) how far from being able to satisfy their needs most households are likely to be; and b) the potential impo

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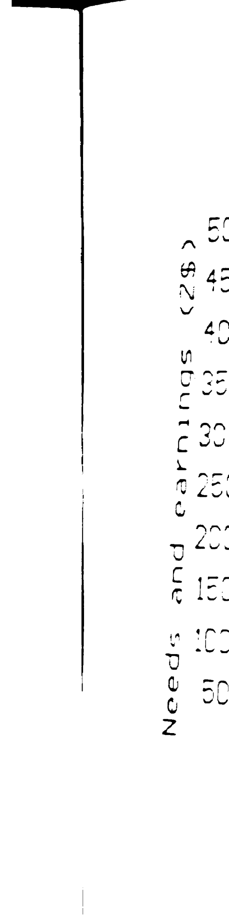
importance of wildlife revenues (Table 2.2) in assisting households to satisfy their needs. Average annual household income from wildlife dividends (Z$150 pa, Table 2.2) could be equivalent to between 15 and 88% of incomes derived from crop production for small households and between 11 to 35% for large households. Some implications of these earning potentials are discussed later in this chapter.

Cropland areas required by households to meet needs

The areas required by each household class to satisfy their perceived needs were calculated by dividing the household needs for food and cash crops by the yields achieved for that crop on any of the three soil types where the crop was grown (Table 3.5).

Linear programming analyses based on the acreage that households indicated that they could manage and the yield figures from Table 3.3, indicate that none of the household size classes could produce anywhere near enough to meet their basic needs in bad rainfall seasons. To do so, households of all sizes would have to increase their yields or acreage by well over 100% (Table 3.5).

These figures are daunting to say the least. Even in good rainfall years it is not at all clear that production from crops is sufficient to meet basic household needs. Using the yield figures of Table 3.3 only small households could produce enough to meet their basic needs given the land areas they claimed they could manage by hand (and the allocation of soil types assumed in this analysis). Medium and large households would need to increase the areas cultivated in good



Figure

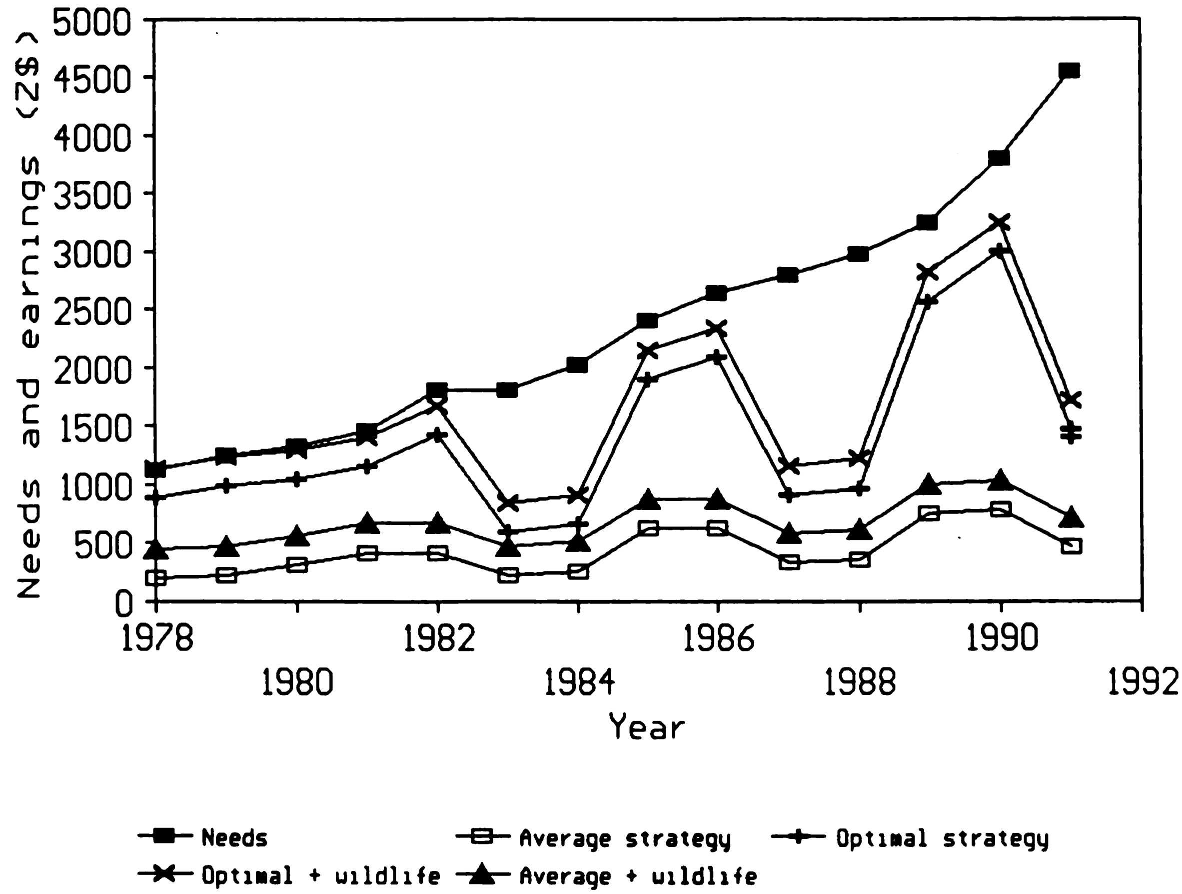


Figure 3.2 Household needs (Z$) and earning potential for large households over the period 1978 to 1992.

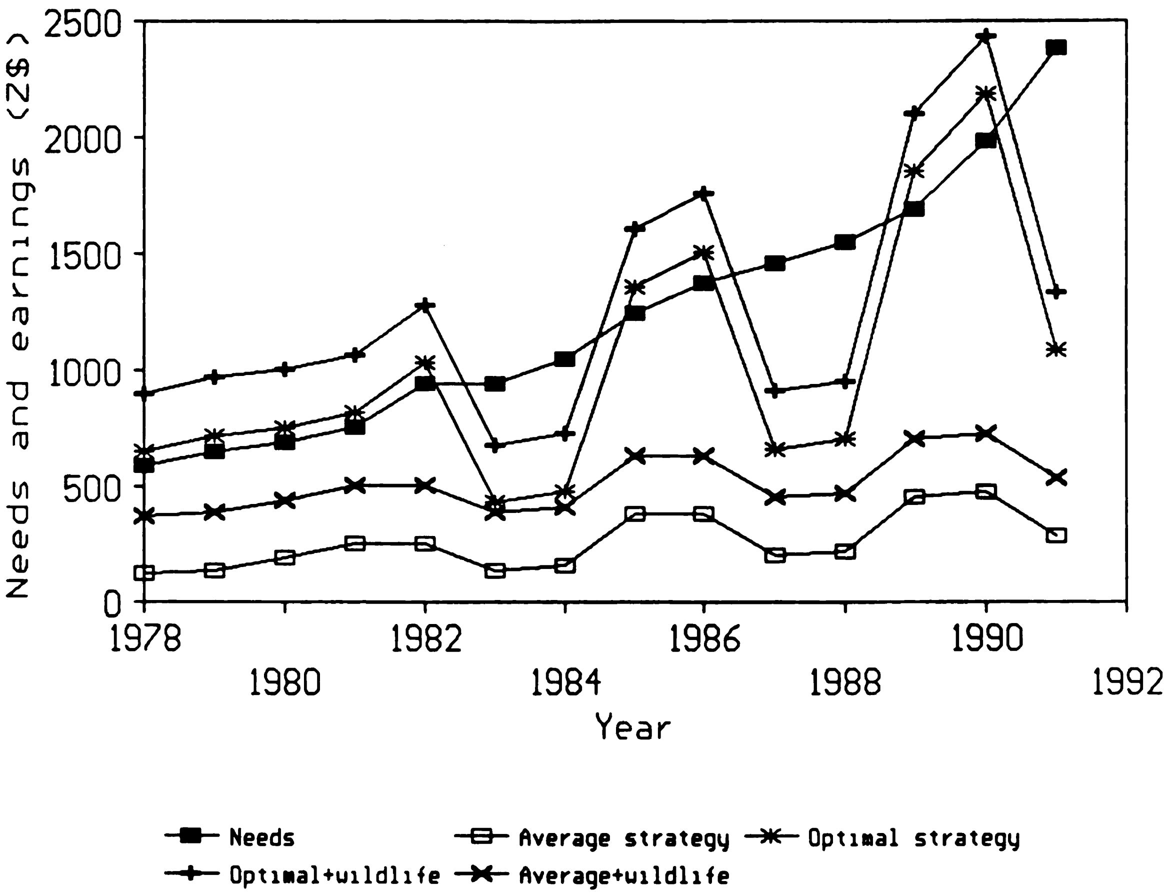


Figure 3.3 **Household needs (Z$) and earning potential for small households over the period 1978 to 1992.**

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Table 3.5 Cropland areas (ha) required to satisfy household needs[1]. Data are total area for household size class with the area per adult equivalent for each size class in parentheses.

HOUSEHOLD SIZE	SMALL	MEDIUM	LARGE
Manageable (ha)	1.3 (.33)	1.8 (.26)	2.2 (.24)
Good season (ha)	1.3 (.33)	2.3 (.33)	2.9 (.32)
Change	0%	+30%	+30%
Poor season (ha)	3.0 (.75)	5.2 (.74)	6.2 (.70)
Change	+125%	+190%	+180%
Weighted Total (ha)	2.0 (.5)	3.5 (.5)	3.8 (.4)

1. The total areas required during good and bad seasons are obtained by weighing the areas required in those seasons by the proportion of good (0.6) and bad (0.4) seasons at Angwa Bridge.

years by up to 30% (Table 3.5). Solutions from the linear programming model were sensitive to reductions in areas of soil types and the price of maize. Using the areas that households reported as being manageable with tractor tillage, all household classes could produce enough to meet their basic needs in good rainfall seasons, but still not in poor rainfall seasons.

If we accept that the yields of Table 3.3 are conservative and add 40% to the maize and sorghum yields and 50% to the cotton yields, then all household size classes are theoretically capable of meeting their needs in good rainfall years, with notable cotton surpluses. If, however, we take the long-term view and use the rainfall data from Angwa Bridge for the past 15 years, and the 1990/91 season producer prices for C grade crops, a different picture emerges. Large and medium households could show gross deficits of between Z$4000 and Z$6000 over the 15 year period whilst small households could show gross surpluses of Z$10000. These figures assume everything else being held constant and optimal allocation of land to crops. The surpluses of the small household are attributable to their lower grain needs and therefore, the relatively larger areas they are able to plant to cotton.

Implications

When presented to members of the community there was general agreement with the results of this analysis. In seeking an answer to the question, "Why do households not grow more cotton and use the higher returns to purchase their maize and sorghum needs?" community members responded that they wished to ensure their maize supplies - their staple food crop - and could not rely on their ability to purchase and get transport for maize supplies from Guruve. In the 1992/93 season these farmers were proved correct; the drought resulted in national maize shortages and households were unable to purchase sufficient amounts to meet their needs.

A number of patterns are evident from the coarse level analysis. First, large and medium sized households are unlikely to be able to satisfy their basic needs for food and cash over the long term. They are constrained by their need to produce sufficient grain to meet household food needs. Second, households that concentrate their productive activities on cotton production appear more likely to be able to satisfy household food and cash needs than those who attempt to

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satisfy food needs from local grain production. Third, the ability of households to satisfy needs is partially attributable to the areas of each soil type to which they have access. Fourth, households would need to double the average annual wildlife dividends they received between 1989 and 1992 (i.e. Z$400 pa) to offset the deficits the large and medium sized households could be accruing.

One way for households to improve their overall yields in bad seasons is to increase the areas they cultivate so that they always plant sufficient area to satisfy household needs even in a bad season. The recent calls for a tractor are clear indicators that, in the eyes of many households, this is perhaps a more viable option than trying to improve yields by 130% or more. If this is a route that the community chooses, the choice has important implications for the carrying capacity of the arable lands in Masoka and needs to be carefully evaluated. The fine soil tilth and larger field sizes that result from tractor cultivation practices could increase the erosion risks on the erodible soils of Masoka. The jump from hand cultivated technologies to tractor technologies is not always advisable (Pingali *et al.*, 1987). The poor fence management performance of the Masoka community is illustrative of the need for caution in introducing relatively sophisticated technologies.

I have not dealt with the need to allow fields to go to fallow. Discussions with farmers indicate that fertility declines significantly after three to five years of continuous cropping. With the high risks of crop failure due to low rainfall, low levels of fertilizer seems the rational choice. This means however, that the community needs to plan for twice as much land for each household (assuming five years of continuous cropping and five years of fallow).

Based on the hand cultivation figures households claimed to be able to manage and assuming (i) technology remains constant at current levels; (ii) the proportions of large, medium and small households within the community remain constant; (iii) two fifths of the land area is in each of shapi and jecha soil types and one fifth is bepe and (iv) all land within the fenced area is arable, then the number of households supportable within the fenced area is about 220. Given current household population growth rates the community could reach this number of households within six years (Figures 3.1, 3.4).

Rapid population growth is a rational response where large families provide labor in a labor constrained environment. Population increases, the need to expand cropped areas to satisfy needs and the tendency of labor constrained households to use existing fields rather than to open new fields (as well as looming land shortages) imply the biophysical resources of Masoka will come under increasing pressure. Wildlife revenues, by buffering households from the variability in needs satisfaction that is a result of the climate, could also undermine the resilience of the agroecosystem by capitalizing the expansion of cropland areas without improving the underlying technology.

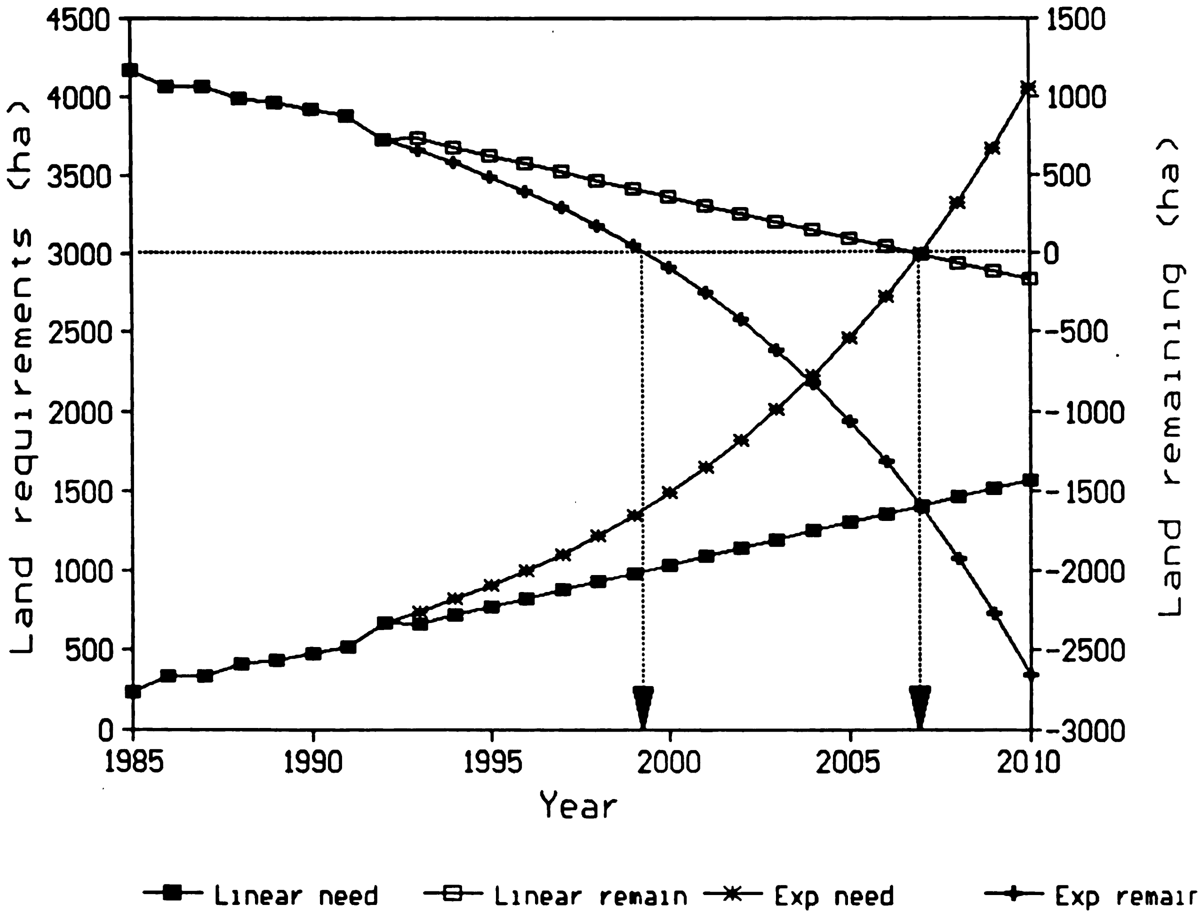

Figure 3.4 Arable land required and remaining under the population growth scenarios presented in Figure 3.1 and the land requirements presented in Table 3.5.

CONCLUSIONS

The majority of households in the community are unlikely to be able to produce enough to meet their basic needs from their crop production system, using current technology. Low and unreliable rainfall, a shortage of labor or traction, and inadequate information on optimal cropping patterns and technology appear major constraints to this agroecosystem being able to satisfy household needs. Smaller households and households with greater access to resources have better chances of satisfying their needs. The use of a tractor to improve tillage and the areas households can manage is one possible solution, but one that needs to be evaluated with caution. The calls from the community for a tractor have important implications both for assisting households to stabilize their needs satisfaction and also for increasing the erosion hazard in Masoka. These implications need to be more fully investigated. Average wildlife dividend payments would have to be more than doubled to ensure continuous needs satisfaction, for large and medium households, under the conditions presented in this analysis. Declining national (and global) cotton prices as well as the failure of the GMB to provide adequate food in drought years suggest the common practice of managing a portfolio of productive activities in Masoka is well advised.

The fact that households have been living in the area for several generations suggests that the agroecosystem is more resilient than this coarse level analysis would have us believe. We need therefore, to investigate more completely the productive practices of households in different resource access classes.

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Chapter 4.

Needs analysis, system identification and problem formulation in the Masoka agroecosystem

INTRODUCTION

To successfully improve a system's performance we need to first identify the system and second define what constitutes an improvement. What is not as clear is whose perspective we are to adopt in making these decisions (Bawden, 1992; Bawden and Ison, 1992). A large number of actors (individuals and organizations), with an equally large set of motivations, have varying degrees of influence on a part or, the whole of, the Masoka agroecosystem. These perspectives and motivations carry with them value systems that the actors use to weight the inputs, components or outputs of the agroecosystem: the National Government, for example, might emphasize cotton production activities to maximize its foreign currency earnings. Whereas individuals might place greater weight on activities that minimize the risk of their household going without food that year. Development plans or projects that use values other than those of the target community have failed so often the credibility of this "top-down" development model has been ur

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undermined (Bawden and Ison, 1992; Chambers 1983; Redclift, 1987). These failures often arise from inadequate understanding of household needs, household resources, household objectives and the constraints that households face and suggest that, for the purposes of this analysis, we stand a greater chance of being effective if we adopt the perspective of Masoka households. The value of incorporating local knowledge and perspectives into development planning has been receiving increasing attention (Brokensha *et al.*, 1980; Warren, 1991).

Whilst using local knowledge may be a necessary condition for successful analysis of the Masoka agro-ecosystem, assuming that adopting a household perspective would be a sufficient condition for a successful analysis is naive. Local knowledge is often restricted to what farmers can see and what is within their experience (Richards, 1980) and may be unevenly distributed in a community (IDS Workshop, 1983). If either the agroecosystem or its environment are likely to change faster than household adaptive capabilities, or in ways that are radically different from local experience or perception, then we are compelled to incorporate alternative perspectives into our analysis. The obvious source for these alternative perspectives is the large body of empirical knowledge that has been built up in Zimbabwe on many aspects of household resource use (Campbell *et al.*, 1989; Campbell and Du Toit, 1988), crop production practices (FSRU, 1985; Reh *et al.*, 1989; Shumba, 1984a, 1985, 1986a,b), crop yields (Akwabi-Ameyaw, 1990; FSRU, 1985; Shumba, 1984b), soils (Anderson, 1986; Grant, 1981; Thompson, 1965; Thompson and Purves, 1978), household labor use (Reynolds, 1991), household economics (FSRU, 1985; Shumba, 1985; Stanning, 1987a,b; Chopak, 1991; Mudimu *et al.*, 1988) and soil erosion (Elwell, 1980, 1985; Elwell and Stocking, 1984, 1988). Much of this information is, unfortunately, inadequate to develop the predictive capabilities we require in our analysis. Few of these authors provide the kind of data (statistics of population distributions) needed for stochastic simulation. With the exception of the detailed study on child labor in the Zambezi valley by Reynolds (1991) and Elwell's erosion model (Elwell, 1980), little of this information is directly relevant to the mid-Zambezi Valley.

A further problem with using indigenous knowledge as the basis for an extensive analysis is the difficulty in evaluating the degree to which the information presented by local informants is an unbiased representation of the populations of interest. With few exceptions (Farrington and Martin, 1987; Gil, 1991; Swift, 1979) this issue has received little attention in the literature on indigenous knowledge or RRA. The literature on potential biases in human responses to questions is large and has been examined from several perspectives: Alreck and Settle (1985) discuss sources of bias from a survey perspective and Tversky and Kahneman (1974, 1981) discuss the subject from a psychological perspective. Adelman, in describing the problems of biases in expert knowledge suggests, "At the very least, knowledge engineers and evaluators should be aware of their existence and look out for instances where elicited judgements may reflect a bias," (Adleman, 1992) which is hardly a rigorous strategy for establishing the accuracy and precision of a set of knowledge! Of particular relevance to this study is the extensive treatment of bias and measurement validity by Mitchell and Carson (1989).

There are two issues of concern here. The first is knowing whether one has measured that which was set out to be measured. Mitchell and Carson, (1989, p190) call this the validity of a measure and identify three indicators of a valid measure - content, criterion related, and construct. Content validity concerns establishing whether the method used to measure the parameter of interest constrains or biases the elicited response. A measurement is valid if it does not bias or constrain the response. Criterion validity concerns the degree to which other measures of the population of interest can be used as criteria to establish the validity of the elicited measure. The ideal measure here would be actual measures of the population under consideration. For example, measures of actual maize yields would be an ideal criterion to establish the validity of the yields farmers say they obtain. Direct measures are unlikely to be available (otherwise we would not be using an indirect method) but other measures that are "unequivocally closer to the theoretical construct than the measure whose validity is being assessed" (Mitchell and Carson, 1989, p192) are necessary to assess this type of validity. Construct validity concerns the degree to which other measures of the same population either converge towards the same result or are consistent with what we would predict from theory.

A second issue of concern is the accuracy and precision of the measurements one makes. In evaluating sources of bias in respondent responses, Mitchell and Carson (1989) note four major sources of systematic bias. The first is the use of scenarios that contain strong incentives for respondents to misrepresent their true beliefs either because they think they can influence some result of the study or because they wish to comply with the interviewer's beliefs to please either the interviewer or the study sponsor. The second source of bias arises when respondents, unsure of their responses, rely on the information relayed to them through study questions to formulate their responses. The third and fourth of these sources of systematic bias involves the incorrect specification of the scenario about which the interviewer seeks information. This may occur either because the scenario is incorrectly specified from a theoretical perspective or the scenario is correctly specified but communicated in such a way that the respondent does not perceive it the way the researcher intended.

To my knowledge no predictive analyses of community level production with differentiated households has been undertaken in Zimbabwe. There can be no doubt that analyses at the scale of the household are difficult: Households are structurally heterogenous (Cutshall, 1989); they have different labor, land and capital resource bases (Coudere and Marijse, 1991; Reynolds, 1991; Shumba, 1984b, 1985); they exhibit different production objectives (Stanning, 1987) and they engage in a diverse set of productive activities (Jackson and Collier, 1991), not all of which are agriculturally based (Helmsing, 1991). The importance of inter-household sharing, hire and employment (Shumba, 1985; Stanning, 1987; Zinyama *et al.*, 1987) as well as the major role of women and children in household production (Adams, 1991; Mehretu and Mutambirwa, 1992; Reynolds, 1991) exacerbate the difficulty of analyzing agroecosystem performance from a household perspective.

From this daunting complexity we must construct a model that we believe incorporates the essential elements (properties) of the agroecosystem and is capable of accurately simulating agroecosystem functions and of predicting future states and outputs of the agroecosystem. We quite obviously have to simplify the system considerably. In this simplification process we are faced with two major methodological problems. First, how do we identify major actors, their needs and key agroecosystem components? Second, how do we collect the data we require to develop and test our predictive model? These problems are particularly difficult firstly because, Masoka household decision makers are, for the most part, illiterate and inumerate and therefore keep no records of production inputs, areas or outputs. Second, time and money constraints allow us only a single cropping season for data collection.

There is little in the scientific literature to guide our search for appropriate methods. Most household analyses rely on household questionnaire surveys (Campbell *et al.*, 1989; Jackson and Collier, 1991; MLARR, 1989; Stanning, 1987), which are questionably useful for the rapid and flexible learning recording required when no *a priori* model exists to guide data collection. The long term immersion approach of anthropologists often lacks the quantitative information required to predict changes and to compare alternative development or production strategies over long time periods (Hasler, 1992; Reynolds, 1991). The more informal open-ended interview techniques commonly used by social anthropologists (Derman, 1990, 1992) yield qualitative information on many aspects of a production system but lack temporal breadth and are not likely to yield the general functions required for predictive simulation analyses. Recent developments in techniques classed as rapid rural appraisal (RRA) or participatory rural appraisal (PRA) show great promise in terms of their flexibility and the range of both quantitative as well as qualitative data they are able to record (Khon Kaen University, 1987; Mascarenhas *et al.*, 1991). The depth and breadth of data that are required for predictive simulation analyses require, however, far more than the single short visit with a multi-disciplinary team of investigators, that is standard practice in RRA. Where RRA techniques have been used in Zimbabwe (Carter *et al.*, 1993), there has been little attempt on the part of the researchers to test the validity of the methods used or the accuracy and precision of the information collected.

The nature of the analysis required to develop a predictive model of the Masoka agroecosystem, from a household perspective, demands some hybrid of the in-depth, qualitative analysis of anthropologists, with the rapid and multi-disciplinary approach of RRA as well as the more formal methods of agricultural research. For the most part appropriate data collection methods have not been developed.

In this chapter, the field data collection methods developed for the analysis of the Masoka agroecosystem are described. The results of applying these m

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methods to the Masoka agro-ecosystem are described and discussed with regard to: a) identifying major actors and client groups influencing agro-ecosystem behavior; b) establishing the needs and objectives client groups expect the agroecosystem to satisfy; c) identifying the major components of the agro-ecosystem and their relationships and; d) identifying the criteria client groups use to evaluate the performance of the agroecosystem. The focus of the data collection is on developing the ability to predict the state or behavior of the agroecosystem as a function of controls that Masoka households can impose on their resources.

METHODS

Having a multi-disciplinary team carry out the Masoka agro-ecosystem analysis for the period required by this analysis was not possible. Expecting large numbers of Masoka residents to give as much of their time as this analysis required was also not feasible. I decided therefore, that the most appropriate approach to knowledge collection would be to have the community elect a group of villagers to represent the community perspective. This group provided most of the community level knowledge presented in this chapter.

Selection of community representatives

At an open meeting held on February 2, 1992, Masoka community members were informed of the objectives of my research. Community members were informed that I would need to work intensively with a small group of people from the community. No reward or bench fees for the members of the group with whom I would work were mentioned. The community members were explicitly asked if they wanted me to proceed with the analysis. Upon receiving the community's approval, people at the meeting were asked to identify classes of household in Masoka and to proportionately weight these classes according to the number of households in each class. Community members at the meeting were asked to elect representatives from each of these classes to form the team of village or community representatives (VRs) who would work with me. The community was specifically requested to include women in this elected group but this request was refused on the grounds that the men in the community did not wish their wives or daughters to interact with unknown men. Six of the men present at the meeting were elected. All except one were young and either recently married or unmarried.

At the first meeting with the VRs, in early March 1992, I was informed that the eldest VR had withdrawn. The village informant who assisted me during earlier survey work (described in Chapter 3) was elected by the remaining VRs to replace the missing man. The ward councillor was approached to have women included in the VR team. He subsequently sent three women who had agreed to join the VR team. One of these women was the councillor's wife, one a widow and one the wife of a locally respected farmer. The women VRs were aged between 38 and 58, had between three and eight children each, and none of them had been to school. The male VRs were younger, between 22 and 26 years old and had between nine and 11 years of schooling each. Two of the men had one child each, the others had none. Each of the men spoke at least some English but none of the women did. All except two of the VRs were born in Masoka and had lived there for most of their lives.

In discussing the work that we were to do together, I broadly explained my objectives and the methods I would attempt to use. I volunteered to pay the VRs and to provide food for the group while we worked. A daily wage and a meal schedule were agreed upon. In this, as in all such discussions, my approach was to develop a sense of equal participation in a team effort. Each member of the team was encouraged to express his or her views and decisions were reached by consensus. In this visit I had brought with me a field assistant and translator, Mr. Limited Mukusanya, a permanent staff member of the WWF Multispecies Project. For this first visit, the VRs were split into two groups, one comprising the men and the other the women. In all other visits the VRs worked as mixed male and female groups.

Altogether eight visits were made to Masoka over the period March to December 1992. Each visit lasted from seven to 14 days. After March 1992 translation during interviews and all VR activities was carried out by two of the VRs; Mr. Gift Chisunga and Mr. George Kanoderuka.

General approach to recording local knowledge

Field trips were generally structured as follows: I arrived in the early afternoon and used the remainder of the day to send messages to the VRs that

I wanted to meet the following morning. One of the VRs would find someone from the community to prepare food for the team for the duration of my visit. A morning and midday meal were prepared for all VRs by the hired cook. By tradition men and women ate separately. I shared all meals with the VRs. The issue of food and meals requires some clarification. Zimbabwe, at this time, was in the middle of the worst drought in memory. Many of the people in Masoka were living on drought-relief food supplied by the government. Expecting hungry people to work the long and intense hours that the VRs worked was neither realistic nor ethical. I therefore undertook to feed the VR team whilst we were working together. The sharing of meals is also an important social process in the rural areas of Zimbabwe, and facilitated an open and trusting relationship among the VRs and me.

At the first meeting the VRs were asked to describe events and issues that had occurred or were being debated in the community since my previous visit. Thereafter, the objectives of the visit were outlined and work schedules were proposed, discussed and arranged. All work times and arrangements were arranged to suit VR needs.

New concepts and techniques were illustrated with simple, and locally relevant examples. VRs would then carry out a task using the new technique or concept. Once a task was complete the entire group would collect to discuss and seek consensus on the outcome of the task.

When the basic data collection procedures and methods had been used for several field trips, VRs were asked to prepare projects that they would like to see developed in Masoka. The VRs were asked to do this in my absence with the objective of evaluating whether the techniques that had been developed were likely to be useful outside of the framework of my own research.

Identification of key individuals and groups within the community

Perhaps the most important data collection method developed during this analysis was what is called a spidergram: a graph with a central node and arms or branches leading off this node. Each branch may end in a sub-node which may also have branches leading from it to further sub-sub-nodes and so on (Figure 4.1). Three points are allocated for each branch emanating from a node. These points are allocated to each branch of a node to weight the relative importance (RIW) of that branch. The central node is designated as the main concept or question about which we are seeking information. For example, Figure 4.1 shows the spidergram developed to answer the question "Which individuals or groups in Masoka have most influence on agricultural production?" Each branch emanating from the core node represents an individual or a group. The numeric values are the weights attached to these individuals or groups in terms of their degree of influence on agricultural production. RIWs were normalized by dividing each branch score by the total number of points allocated to that node (i.e., three times the number of branches).

VRs drew these spidergrams in the sand and used stones or sticks to indicate the RIW of each branch. VRs were encouraged to use appropriate symbols to represent each node so that even those VRs who could not read could understand the representation. When a spidergram was complete the group would gather around it and the VRs who had drawn the diagram would carefully explain what each node and branch represented and then have to defend, to the entire group, the branches they had included or left out and the RIWs they had allocated to each branch. After consensus was reached that all relevant branches were present and that the RIWs were correct, the spidergram was copied into a field notebook. Exceptions to the consensus rule were the actors and needs spidergrams developed separately by male and female VRs. Consensus was reached within these groups but not among the entire VR team.

Identification of household needs

VRs were asked to develop spidergrams to express the needs that households required to live a basic, but adequate life. During a subsequent field trip the identification of these needs was developed in greater detail using needs calendars or matrices. VRs were asked to draw columns in the soil to represent each month of the year. Then, for each of their major needs they made a row and filled in the amount of that need required for each month. Separate matrices were developed for the needs of an average man, an average woman and an average child. In a thirteenth column the VRs were asked to allocate a number of points between one and five to indicate the degree to which they could not live without that need (five points) or if it was more of a luxury than a necessity (one point). A row was added to the matrix and once again the VRs were asked to allocate points between one and five, but this time to indicate the degree to which they experienced needs shortages (five being none and zero being extreme) in each month of the year. When a group of VRs had completed a matrix the whole team gathered around it and the authors were asked to explain the matrix and defend their inclusion or exclusion of items, the amounts they claimed were required in each month and the relative weights they gave to each need and to each month. Once consensus was reached by the VRs on the diagram and its content, it was copied into a field notebook.

Inputs to, outputs from and measures of performance of, the Masoka agroecosystem

Identification of the major inputs and outputs from the agroecosystem built upon the spidergrams developed for needs identification. Once the needs nodes were identified, they became central nodes for more detailed input/output spidergrams. The question posed in the central node then became, for example, "What is needed in order to produce a good yield of maize?" Branches from this node indicated the major inputs to, and losses from, the production of maize. These branches were weighted and sub-branches were added where necessary. All spidergrams were discussed and defended before final acceptance.

A third major tool for recording local knowledge was the possibility diagram. The objective of these diagrams was to enable VRs or other village informants to express the probabilities that they believed described the relationships under consideration. A possibility diagram for maize yields is described for illustrative purposes. Specific maize production scenarios were identified from the production spidergrams and from discussion with VRs. Soil type and rainfall, for example, might be identified as key determinants of maize yields. For each soil type and rainfall season combination a possibility diagram was developed. A single stick or stone, representing a maize yield of one 91kg bag acre^{-1}, was placed at the base of a column drawn in the sand. VRs were then asked to indicate the possibility of obtaining at least that yield, under the specified conditions, by placing between zero and 10 sticks or stones in the column above the symbol representing the single bag maize yield. A score of 10 indicated that households could definitely obtain at least that yield whilst a score of zero indicated they would definitely not be able to achieve that yield. Scores between 10 and zero indicated the probability that a household could achieve at least the yield specified at the base of the column, under the given circumstances. A column was then added with stones representing the number of bags yielded incremented by one. The scoring process was repeated as before. Columns were added (and possible yields steadily increased) until a score of zero was given to a particular yield to indicate that it could definitely not be achieved.

Possibility diagrams were developed for maize, cotton and sorghum yields on each of the soil types on which they were cultivated (bepe, jecha and river lands) and for a good, an average and a poor season. Possibility diagrams were also developed for maize, cotton and sorghum in each season and grown on virgin jecha (i.e., never cultivated) and jecha that had been continuously cultivated for five years. The need for this differentiation was realized following discussions with VRs and other community members as yields on the jecha soils decline with continuous cultivation. Possibility scores were normalized to lie in the range of zero to one. These diagrams represent the cumulative probability function of achieving at least a given yield. The probability of achieving a given yield can be calculated by subtracting the normalized probability of achieving a particular yield from the probability of achieving the next highest yield. The mean of a yield distribution (E[x]) was calculated as:

$$E[x] = \sum P(x_i) x_i$$

The variance of a yield distribution (V[x]) was calculated as:

$$V[x] = \sum (P(x_i) x_i^2) - E[x]^2$$

Where:

$P(x_i)$ = the probability of achieving yield level x_i

x_i = the ith yield level.

Where weighted means and variances were used they were calculated according to the following:

$$Weighted\ E[x] = \sum Wt_i\ (E[x_i])$$

$$\text{Weighted } V[x] = \sum (Wt_i (V[x_i]^2) + Wt_i (E[x_i]^2)) - E[x]^2$$

Where:

Wt_i = the probability of a particular event occurring, such as the probability of a particular season or soil type.

Possibility scores were also used to analyze the rainfall of Masoka. VRs were asked to identify the types of rainfall that occurred in Masoka. For each of these rainfall types possibility scores were developed to indicate a) the probability of a rainfall event of each type occurring in any week of the rainy season; b) the probability of a given number of these rainfall events occurring in any two week period of the rainy season; and c) the probability of a rainfall type lasting for a given period of time.

VRs were asked to map the soils of Masoka, map the placement of households in Masoka, as well as the areas that were unsuitable for crop production due to soil, slope or cultural reasons. These maps were drawn in the sand or on canvas, using locally available materials for differentiation. The maps were described and defended by their authors and then copied onto paper. A paper map was also drawn by two of the VRs to indicate the historical distribution and movement of households within the Ward.

To elicit information on cropping decisions, yields and farmer perceptions of soil condition, a combination of field mapping and semi-structured interviews was used. When used with VRs as respondents these were combined with what were called field interviews. A hypothetical example is described for illustrative purposes. The respondent was asked to point to where he or she lived and was asked to draw a circle on the ground to represent their household. Respondents were asked to stand within that circle and were orientated towards the Angwa river, a feature all could point to from any place within Masoka. Then for each year since their arrival in Masoka, respondents were asked to draw the fields they had opened or used. Respondents were asked to indicate the size (acres) and soil type(s) of these fields as well as the crops they had grown, the yields they had achieved and any problems they had encountered. When this exercise was carried out with VRs as respondents the VR was asked to stand in particular fields and to pretend that they were the field. They were then interviewed by me and other VRs as if they were the field. In some instances, a second VR was asked to pretend that he or she was the farmer so that the field interview went through the "farmer" to the "field". Questions related to weed populations, yields, fertility and general soil condition were asked.

To obtain a clearer picture of the politically sensitive issue of land allocation to new settlers or sons of local residents VRs were asked to adopt the roles of the various actors involved in land allocation and to present a short play of the proceedings. Once a play was completed the actors were switched around so that different perspectives and emphases could be observed. Plays were observed for a would be new settler and a long-term resident seeking land. The dialogue in these plays was translated for my benefit and discussed after each performance, which lasted only a few minutes.

Spidergrams were used to identify the attributes that VRs considered useful in determining a household's ability to continuously satisfy needs. The central node asked the question "What do you look for to tell you that a household is able to satisfy its needs?" Major factors, and sub-factors that could be used to measure these major factors were identified, added to the branched nodes and weighted in the usual way.

Well-being ranking (based on wealth ranking methods, Grandin, 1988) of all households in Masoka was used to identify classes of household based on their ability to satisfy needs. VRs were asked to define a household and to define classes of well-being in Masoka. The name of each household head was then written on a card and the cards shuffled together. The VRs, working as a group, selected each card and discussed the attributes of the household before placing it into one of the well-being classes. Decisions were reached by consensus. Thereafter, VRs ranked the cards in each well-being class according to the household's ability to satisfy needs. The name of each household was read out to the group of VRs. VRs discussed whether or not that household was better or less able to satisfy needs than each card that had already been discussed. The card under discussion would be moved through the stack, from bottom to top, until the household was no longer considered to be better able to satisfy household needs than the household represented by the next card on the stack. VRs worked in smaller groups to identify the number of children and adults in each household as well as the number of acres of river-land that each household possessed and whether or not the household was an employer or an employee of other households, had a family member in other forms of employment or received remittances.

Using an open-ended interview format, VRs were asked to recall the expenses they had incurred and the prices they had received in producing each crop (maize, cotton and sorghum) in the previous season (1990/91). VRs also developed labor requirement calendars (matrices) for each crop that indicated the number of labor days (per acre) required for each task, in each month of the growing season. Possibility diagrams were developed to indicate the possibility of one adult completing each activity on one acre in at least a given number of days. These data (expenses, prices and labor budgets) were used to develop cash and labor budgets for each crop.

Methodological validity and data accuracy

The issue of the validity of the measures made in this study as well as their accuracy and precision is of obvious importance and is perhaps the most difficult issue to logically and statistically resolve. As discussed previously there are two broad areas of concern. The first of these is the degree to which the methods employed bias the results obtained and the second is the accuracy and precision of the measures made.

All interactions with VRs and other community informants required some measure of translation; translation of the question from English to ChiSezuru (Shona) and then the translation of the responses from Shona to English. To avoid gathering biased information then we need to be confident that: a) the translation of English symbolism into Shona symbolism was accurate; b) how the respondent perceived the translated symbols was consistent with how the analyst perceived these symbols; c) the respondent was accurately portraying their knowledge of the phenomena under consideration; d) the translation of Shona symbolism into English symbolism was accurate; and e) how the analyst perceived these translated symbols was consistent with how the respondent perceived these symbols. This process alone, had enormous potential for introducing error. The approach to dealing with these problems in this study had been to use, as far as possible, graphic representations of questions, situations and responses. The assumption being made was that graphic representations provide a common set of symbols that minimize the translations required as well as forcing both analyst and respondent to simplify all communications. Wherever possible specific, real world symbols were used to illustrate important phenomena; an old maize cob might be used to represent maize in a spidergram, for example.

Content validity (Mitchell and Carson, 1989) was assumed to be minimized by the following circumstances. If there was a distortion in the translation process we might expect answers to either be inconsistent with expectations or for divergent answers to be expressed. All data were discussed almost as soon as they were generated. There was therefore, opportunity for immediate discussion if the data did not conform to expectations or appeared inconsistent. Consensus was sought on all data developed by the VRs and in most cases groups of VRs independently developed data representations and then had to defend their representations to the entire VR team. This worked much like the scientific peer review system. In most situations, the VRs themselves defined the specific information they presented. The analyst posed general questions or concepts but allowed VRs to define the specifics of each issue. In some instances, the use of different elicitation methods enabled us to identify whether or not there was divergence in the recorded information.

The second test of the validity of the methods used was the extent to which they generated results that were consistent with other measures of the same population. For most data collected in this study, the requirement that these alternative criteria be "unequivocally closer to the theoretical construct than the measure whose validity is being tested" (Mitchell and Carson, 1989) was impossible to satisfy. There just are no reliable data for most of the factors of interest in Masoka or in similar situations. The best that can be done is to use published results that are most likely to have populations, of the factors of interest, that are similar to those under scrutiny in Masoka.

The final test of the validity of the methods used was the degree to which they produce results that were either consistent with what might be predicted by theory or were correlated to measures from the same theoretical population. For example, the Department of Meteorological Services (DMS) literature on rainfall in Zimbabwe (DMS, 1975) provides a distribution of storm duration that we can use to test the information provided by VRs. We might also expect different correlations between yield and rainfall on different soil types - expectations that we can test.

The issue of data accuracy and precision was very difficult to completely resolve. To some extent the tests of validity discussed above will enable us to, at least qualitatively, establish the accuracy of the results we observed. If the methods are shown to be valid, then if the same populations are measured using different methods and each method yields the same result then we may feel confident in the accuracy of these results. In addition, if the sample statistics we observe are close to those published in the literature then we may feel confident in the accuracy and precision of these results. Problems obviously arise when different methods produce different results or the results we obtain are inconsistent with the literature or there are no comparable results. The approach adopted in these cases was firstly, to examine the validity of the measures using the three types of validity tests discussed by Mitchell and Carson (1989). We recognize criterion validity as being the strongest test and content validity as being the weakest. If the measure is shown to be valid and we find no reason to believe that the responses are systematically biased, then we will accept the information. Quite clearly, the degree of confidence we hold in particular information will be related to the strengths of the tests that information has withstood.

The theoretical model (logical hypothesis) which underpins our data collection is as follows: Masoka residents have a long history of depending on the biophysical environment to provide most of their food and other material needs. Household well-being has been, and is, dependent on their knowledge of the structure and patterns of their environment as well as their ability to manipulate their environment and the resources at their disposal to satisfy their needs. Two sets of predictions are deducible from this model. The first of these is that Masoka residents (as represented by the VRs) can accurately describe the structure and patterns of key environmental inputs to household needs satisfaction. The second of these is that VRs can correctly describe the results they are likely to achieve using commonly used combinations of controllable inputs with different resources and under commonly experienced environmental situations. The grounds for accepting or rejecting a prediction in this study are difficult, because in most cases, there are insufficient data or their form is such that statistical analyses are impractical. The decision to accept or reject a prediction will therefore, be based on careful evaluation of the validity of the measure and comparison of the measure to comparable results published in the literature. These decisions will be made as transparent as possible so readers are able to reach their own conclusions.

RESULTS

Key actors and household classes

In response to the question "Which individuals or groups have greatest influence on agriculture in Masoka?" both male and female VR groups identified the spirit medium, headman and ward councillor as key actors (Figures 4.1 and 4.2). These data also illustrate the power split between traditional leaders (Headman and Kraalheads) and the more recent elected leaders (ward councillor and Village development committee (VIDCO) chairmen). The importance of spirit mediums in community decision making within Zambezi Valley communities has been noted by Lan (1985) and by more recent anthropological research (Hasler, 1992; Derman, 1992). The split of power between traditional leadership and the post 1980 elected leadership appears common through much of Zimbabwe (Drinkwater, 1991). The male and female VRs differ most in their perceptions of the importance of VIDCO Chairmen, with the women perceiving them to be the third most important group whilst the men considered them least important.

Both male and female VRs used size as a primary factor for classifying households within the community (Figures 4.3 and 4.4). Male VRs extended their classification to include wealth as a second factor to differentiate household classes (Figure 4.3). Male VRs perceived most households to be in the large and wealthy category. Using the household size classification rules of Chapter 3 to allocate female VR classes to large medium or small, their analysis indicates that

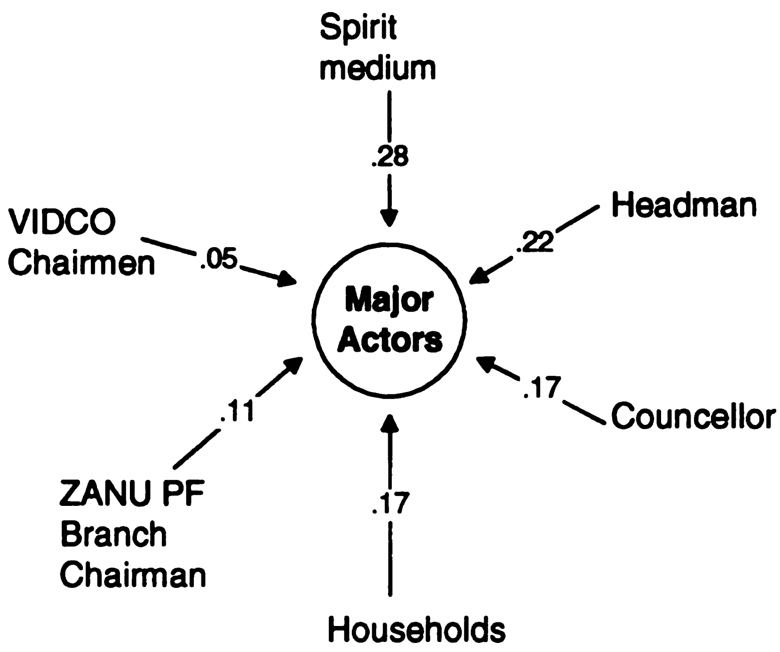

Figure 4.1. Major actors influencing agricultural production in Masoka and their relative importance weights. Female VR perspective.

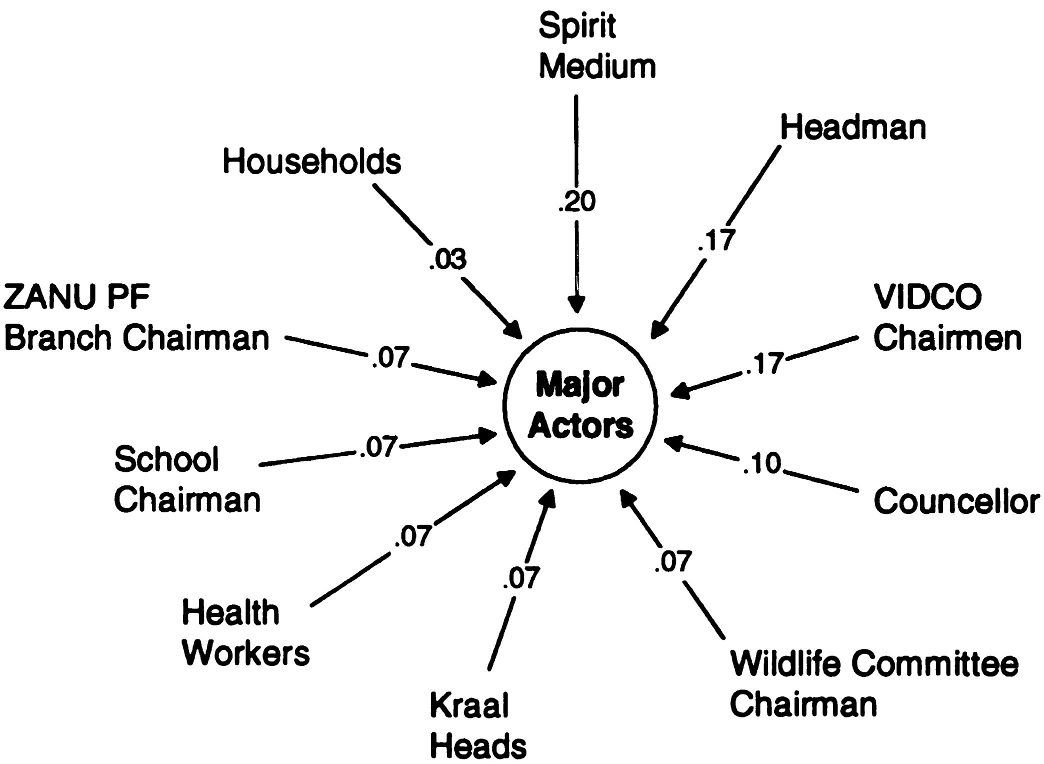

Figure 4.2. Major actors influencing agricultural production in Masoka and their relative importance weights. Male VR perspective.

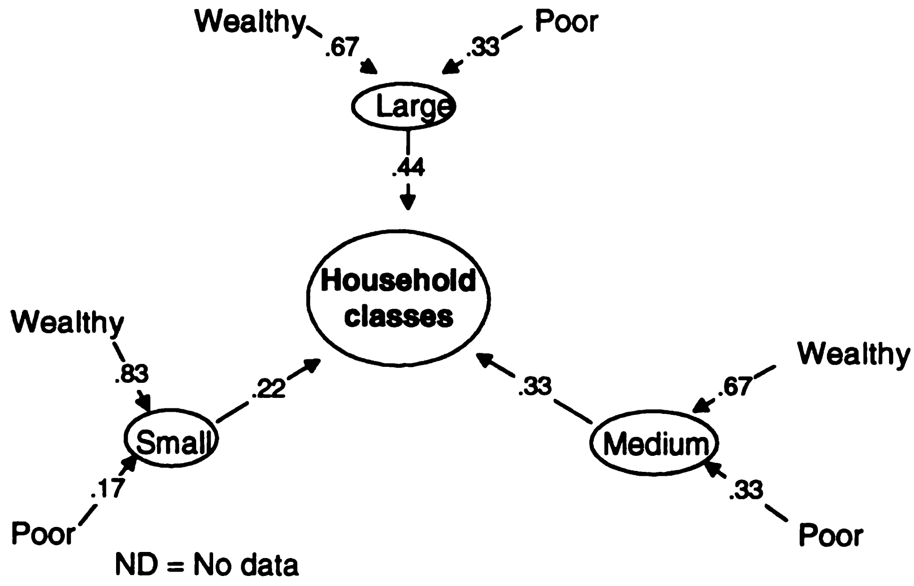

Figure 4.3. Household classification and the relative importance weights of each household class. Male VR perspective.

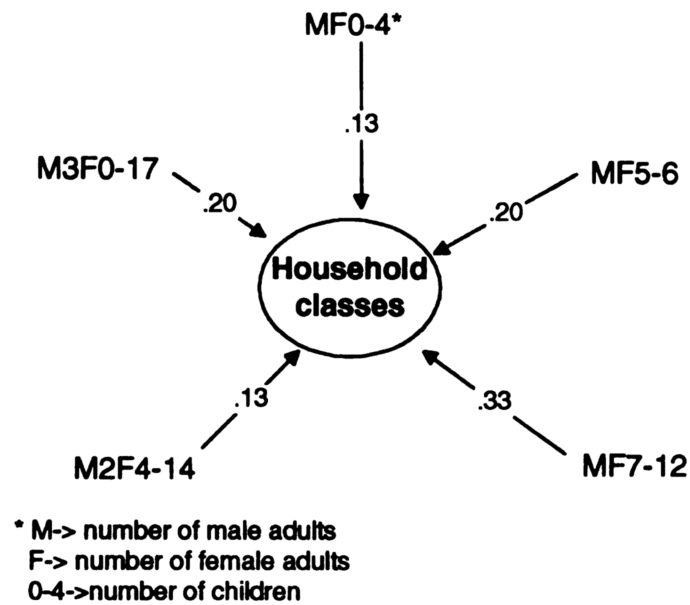

Figure 4.4. Household classification and the relative importance weights of each class. Female VR perspective.

medium sized households dominate (Figure 4.4). For all household size classes male VRs indicated wealthy households dominate. This latter result is in contradiction to the result presented by the community members present at the meeting when the VRs were elected. At this meeting households were classed as poor (RIW=.8) and not so poor (RIW=.2) indicating a predominance of poorer households. This contradiction suggests that the male VR spidergram did not adequately represent the question of interest - "What types of household occur in Masoka and which are the most common?" It appears that the male VRs were perhaps answering the question "What types of household occur in Masoka and which have the greatest influence?" The male VR spidergram does however, provide useful information.

Household needs

In answering the question "What do households need in order to live a satisfactory life in Masoka?" female and male VR groups developed the spidergrams shown in Figures 4.5 through 4.8. Both female and male VRs identified food and cash as most important household needs as has been reported elsewhere in Zimbabwe (Shumba, 1988). The female VRs also indicated the importance of trees and water, land and a clinic (Figure 4.5). From their perspective, major inputs to satisfying household food needs were maize, cash, chickens, pumpkins and finger millet. Major inputs to household cash needs satisfaction were maize, cotton, chickens and brewing beer.

In the male VR perspective, household needs and their RIW were indicated for each household class (Figures 4.6 to 4.8). For most household classes male VRs identified maize, chickens, sorghum, pumpkins and vegetables as major inputs to household food needs satisfaction. Male VRs also noted the greater relative importance of food to poor households compared to wealthy households. They perceived cotton and maize as major inputs to household cash needs satisfaction for wealthy households whilst cotton, craft and sales of fish or honey were identified as major inputs to household cash needs satisfaction for poorer households (Figures 4.6 to 4.8). These data indicate a decrease in the number of production activities with decreasing household size and to a lesser extent with wealth. Similarly, Jackson and Collier (1991) found an increase in the per capita incomes of households with increasing number of productive activities.

Also notable from Figures 4.6 to 4.8 is the shift from relying almost totally on crop production, for wealthy households, to increased reliance on indigenous resources by the poor households of each size class. This latter observation is in accord with the coping strategies of households in deficit conditions described by Zinyama *et al.*, (1987) in which households make increasing use of indigenous (wild) resources as food scarcity intensifies. These authors also suggest that it is the women who tend to guide the household through these difficult times. The sensitivity of women, as expressed by the female VRs, to household needs for indigenous resources (Figure 4.5) supports this proposition. Women are also more directly concerned with the daily collection of water and fuelwood and are

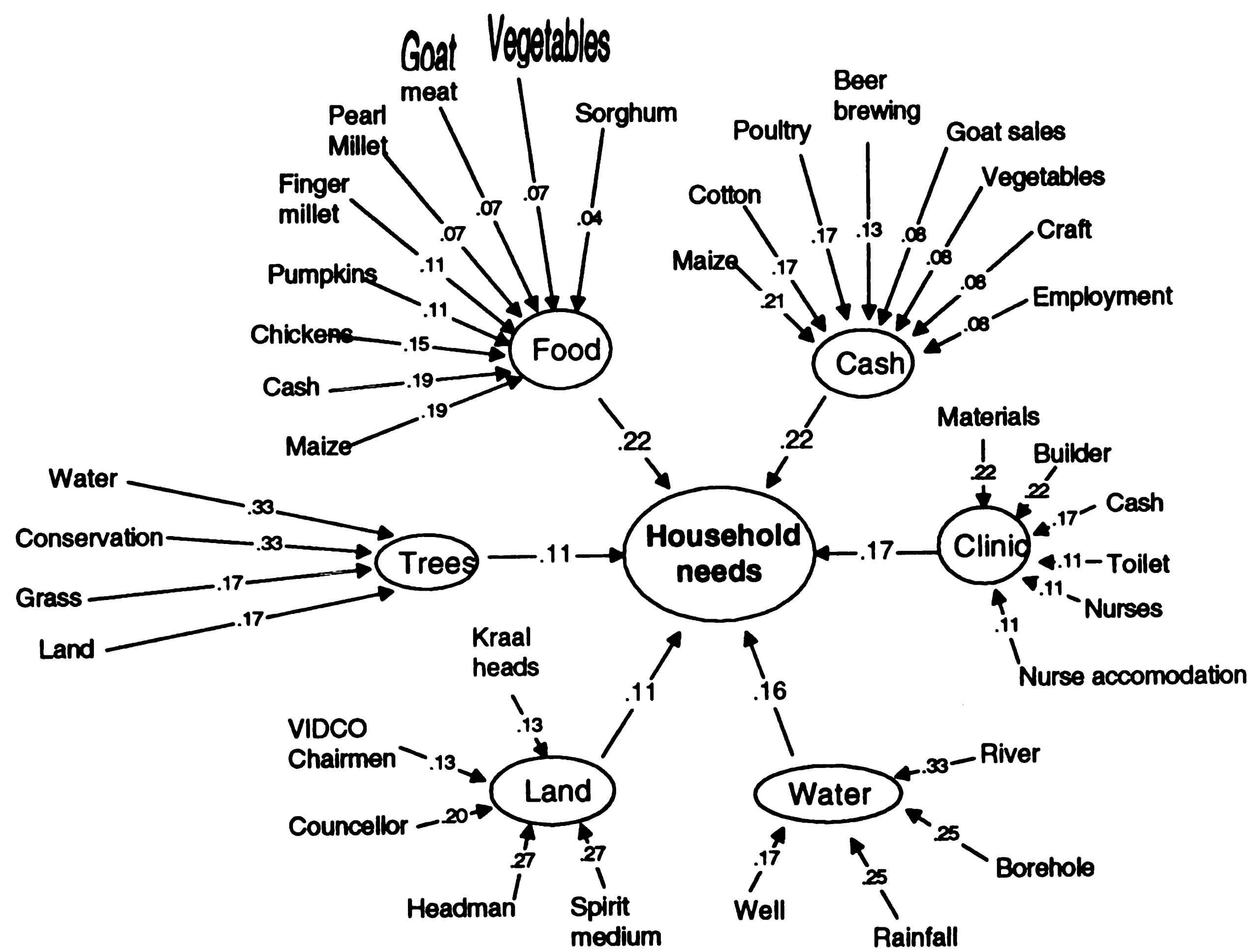

Figure 4.5. Household needs, with their relative importance weights (RIW), as well as the major inputs to those needs with their RIW. Female VR perspective.

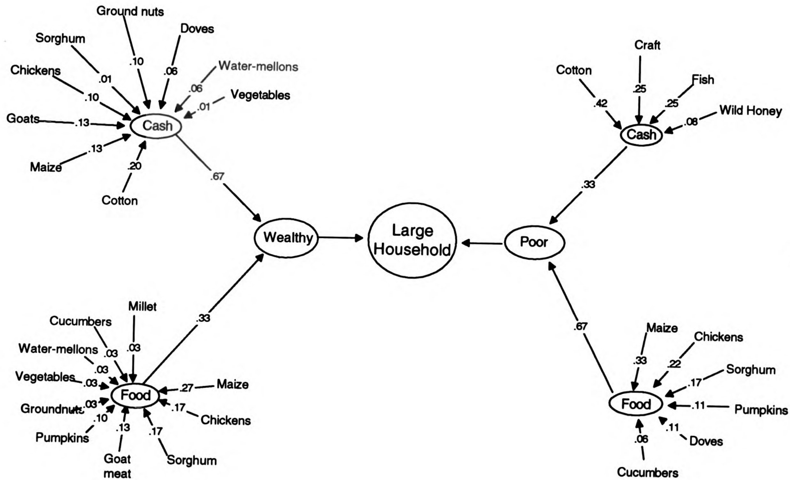

Figure 4.6. Household needs, with their relative importance weights (RIW), for a large household as well as the major inputs to those needs with their RIW. Male VR perspective.

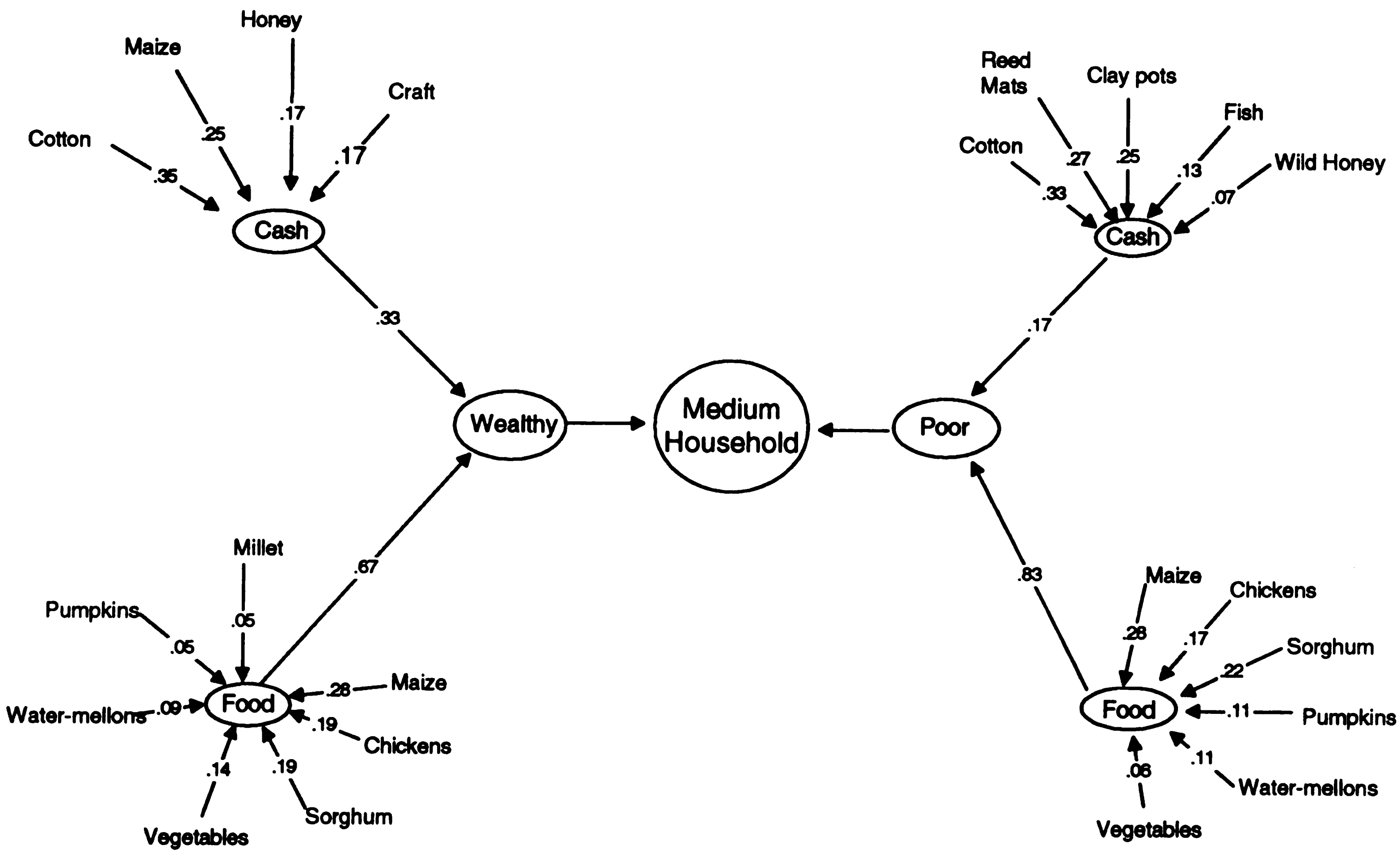

Figure 4.7. Household needs, with their relative importance weights (RIW), for a medium household as well as the major inputs to those needs with their RIW. Male VR perspective.

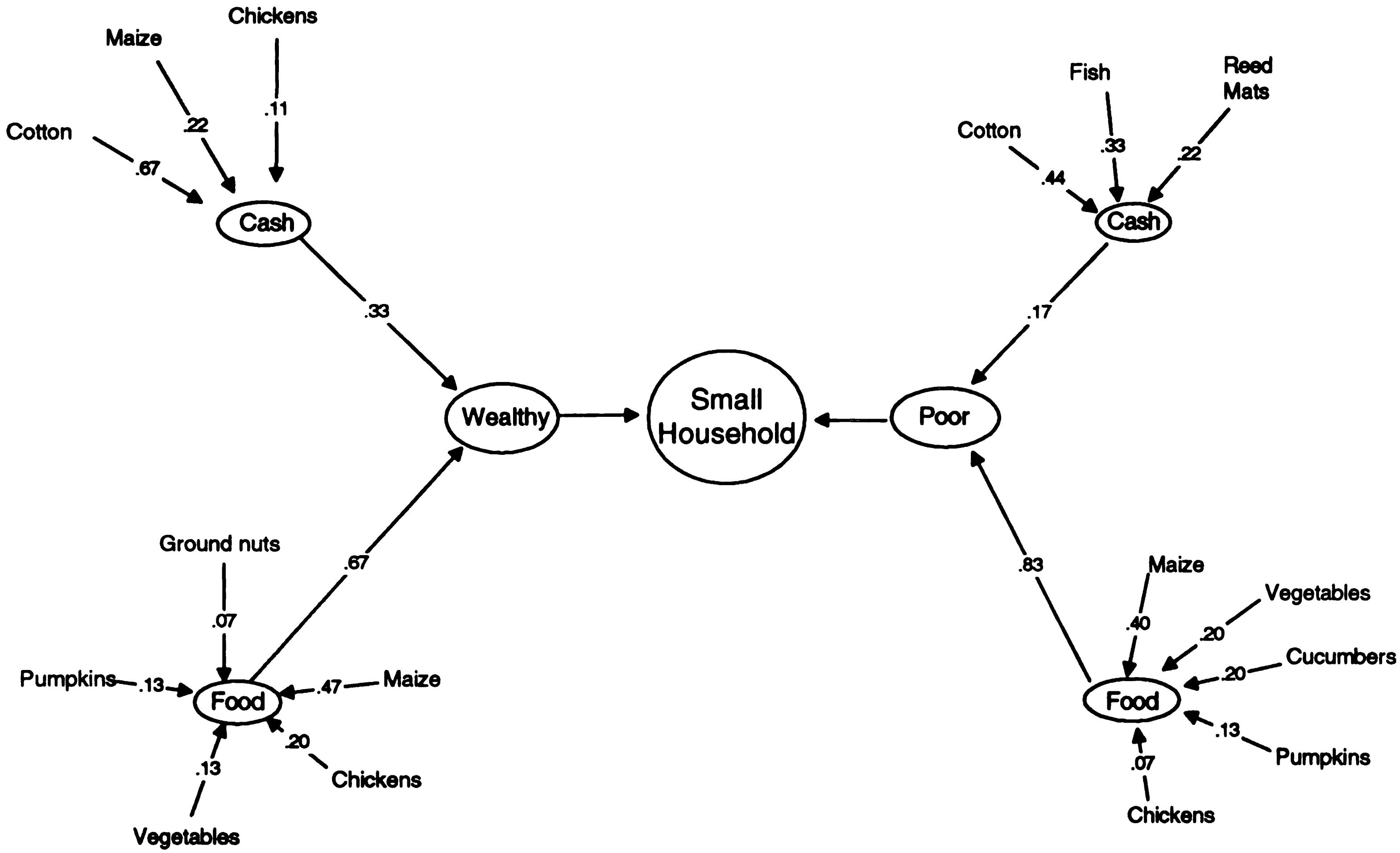

Figure 4.8. Household needs, with their relative importance weights (RIW), for small households as well as the major inputs to those needs with their RIW. Male VR perspective.

therefore, more likely to be aware of the importance of these resources than are men. The greater reliance of poorer households than wealthy households, on craft production for the generation of cash incomes (Figures 4.6 to 4.8) suggests that these households could be important initiators of informal sector production enterprises. Boserup's (1965) model of agricultural development implies these groups play an important role in rural development.

What is surprising from these analyses, is that only the female VRs indicated the importance of land to household needs satisfaction (Figure 4.5). This is particularly noteworthy in that women do not have the same rights to land as do men. Their rights of use are normally derived from their husbands or fathers, and sometimes even their children (Reynolds, 1991). Perhaps because of this relative landlessness, women have a greater sensitivity to land scarcity than do men.

System Identification

Spidergrams were developed to illustrate the inputs to, and losses from, each component of household needs. Only the spidergrams for maize, cotton and sorghum are developed and discussed in this chapter. The importance of these crops as inputs to both household food and cash needs (Figures 4.5 to 4.8 and Tables 4.16 to 4.18) suggests their selection is appropriate.

Maize production

In answering the question "What is needed to produce a good yield of maize?" both the male and female VRs identified rainfall, soil, crop variety and labor as key inputs (Figures 4.9 and 4.10). Female VRs noted the importance of land but male VRs did not. Major losses from the maize production sub-system were identified as being caused by wild animal damage (particularly from elephant, buffalo and wild pigs) by both male and female groups of VRs. Insect pests were not identified as major loss causing agents although the male VRs identified termites as causing loss.

Female VRs developed a more detailed breakdown of labor inputs to each task than did male VRs. Gender differentiation of tasks is evident as is the importance of the labor of children, findings that are in accord with those of Reynolds (1991) for the Tonga people of the Zambezi Valley. Female VRs also indicated a greater appreciation of natural resources than did male VRs through their inclusion of trees and grass as inputs to maize production; These inputs are important in restoring field fertility.

Male and female VR perceptions of the relative importance of different soil types for maize production differed considerably. The female VR group stressed the importance of katondo and bepe with shapi and jecha being similarly weighted. Very few households in Masoka have access to katondo soils. These soils are red soils with a high clay content. Discussion with the VRs indicated that they were identifying these soils with the red soils of the major maize growing

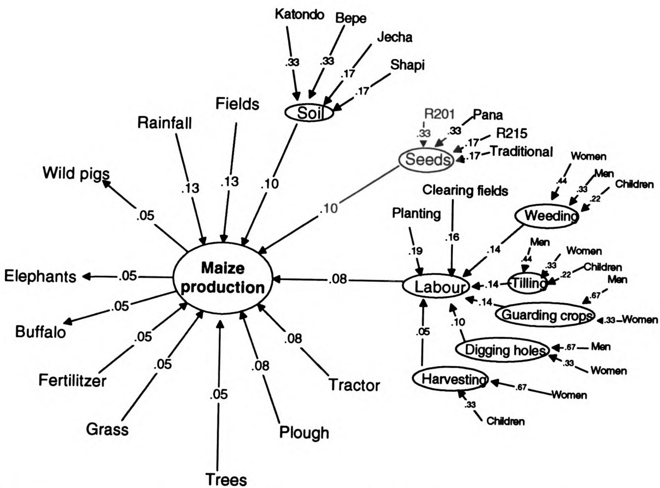

Figure 4.9. Female VR perspective of what is required for, and what detracts from, the achievement of good maize yields.

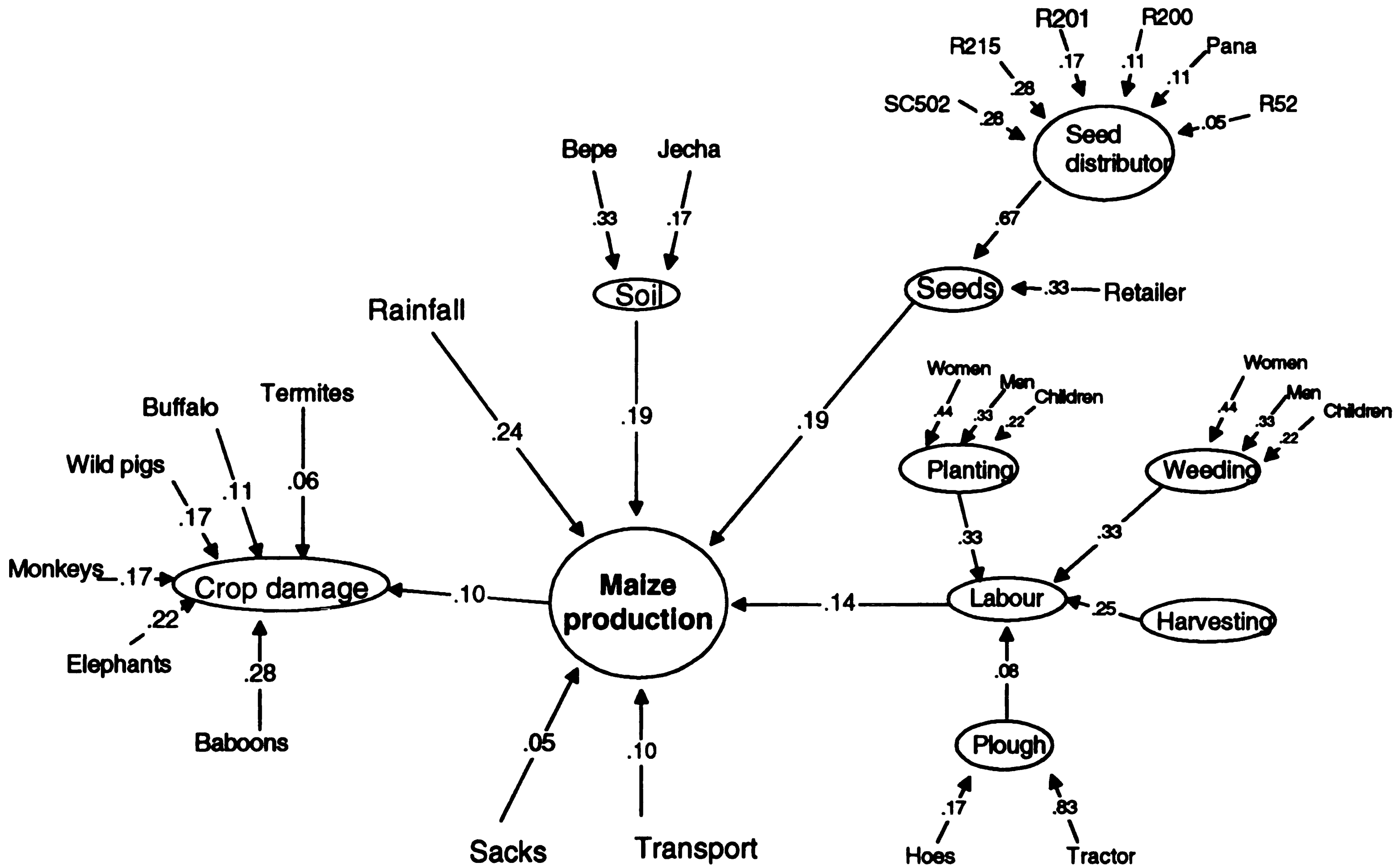

Figure 4.10. Male VR perspective on what is required for, and what detracts from, the achievement of good maize yields.

areas of Zimbabwe. Thus the women were being true to the question in identifying these soils as being best for achieving good maize yields. Of the soils that are generally available to households, both male and female VR groups agreed on the relative importance of bepe over jecha. There appears to have been some confusion as to the identification of shapi soils. Only one household in the community was observed to grow crops on shapi, suggesting that few households had any experience with this soil type. It is also important to recognize that at this early stage of the analysis the VR groups were not distinguishing between the riverine sandy soils (river jecha) and the alluvial terrace sandy soils (jecha). These distinctions only became apparent later in the analysis when dealing with the yield potential of different soils.

Female VRs identified maize variety R201 as being the best which agrees with the varietal recommendations made by Whingwiri and Harahwa (1985) for NR III and with those of Shumba (1984a). The selection by male VRs, of variety R215, a long season variety, in preference to R201 and R200, both short season varieties is more difficult to understand. Whingwiri and Harahwa (1985) suggest that R215 is a poor performer in a low yielding environment but can respond significantly to an improvement in the environment. The interaction of soil and variety was not investigated in this study but could be a fruitful subject for future research.

Cotton production

In contrast to the maize production sub-system, female and male VR group perceptions of the relative importance of inputs to cotton production were quite different. In answering the question "What is needed to achieve good cotton yields?", both groups indicated the importance of soil and chemicals (Figures 4.11 and 4.12). Female VRs considered rainfall and crop variety to be less important than labor, whereas male VRs perceived rainfall to be the most important input and both rainfall and crop variety were perceived as being more important than labor. The RIWs ascribed to women's labor by both male and female VRs (Figures 4.11 and 4.12) suggests why female VRs perceived labor to be of such great importance. Women are the dominant source of labor for all of the major activities except land clearing. Cotton production adds appreciably to the demands made on household labor and particularly that of women and children.

Male and female VRs differed also in what they perceived to be the major losses from the cotton production sub-system. Male VRs identified insect pests as being less important than monkeys and baboons whilst the female VRs identified red bollworm as the major loss and did not note losses due to wild animals.

Both male and female VR groups identified jecha as the most important soil type for cotton production but differed greatly on the relative importance of the other soil types.

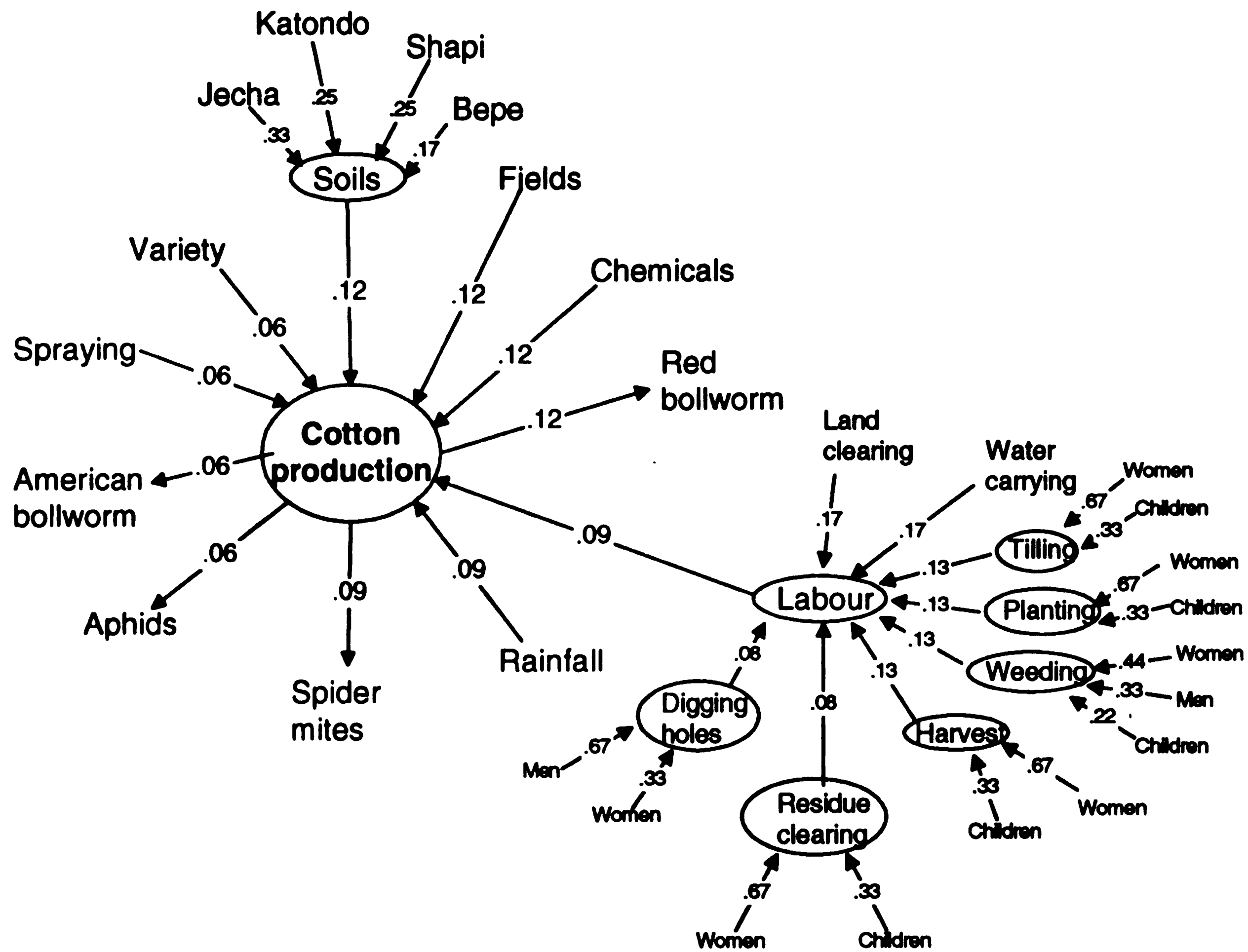

Figure 4.11. Female VR perspective on what is required for, and what detracts from, the achievement of good cotton yields.

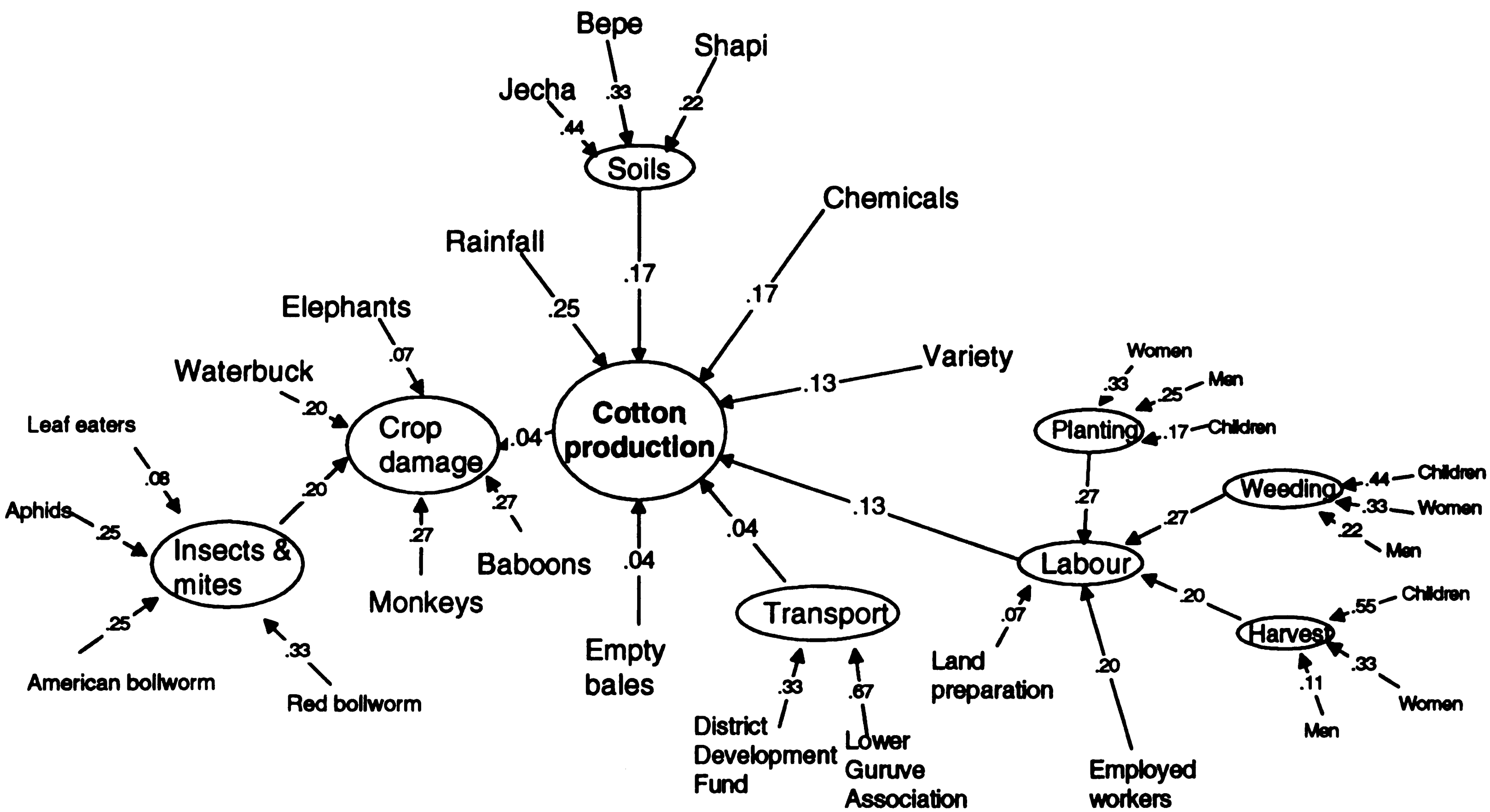

Figure 4.12. Male VR perspective on what is required for, and what detracts from, the achievement of good cotton yields.

Sorghum production

In answering the question "What is needed to achieve good sorghum yields?" both male and female VR groups identified rainfall, labor and seed variety as major inputs (Figures 4.13 and 4.14). The most notable differences in the female and male VR perceptions were the inclusion of land by the female VRs and the much higher importance of soil type in the male VR analysis than in the female VR analysis.

As with the maize and cotton production spidergrams, the female VRs developed more detailed labor components to their spidergrams than did the male VRs. The importance of male labor in so many of the activities of sorghum production (Figure 4.13), the identification of a male householder as the local expert on sorghum production, as well as the greater detail in the variety component of the male VR spidergram (Figure 4.14) suggested that sorghum is less of a women's crop than is generally believed.

The relative importance of local seed sources compared to commercially available hybrids and the relatively high weights given to bepe soils by both male and female VRs are consistent with Reynold's (1991) findings elsewhere in the Zambezi valley.

Summary of inputs to and losses from crop production sub-systems

For maize, cotton and sorghum rainfall, soil type, seed variety and labor were identified as the major determinants of good yields by both male and female

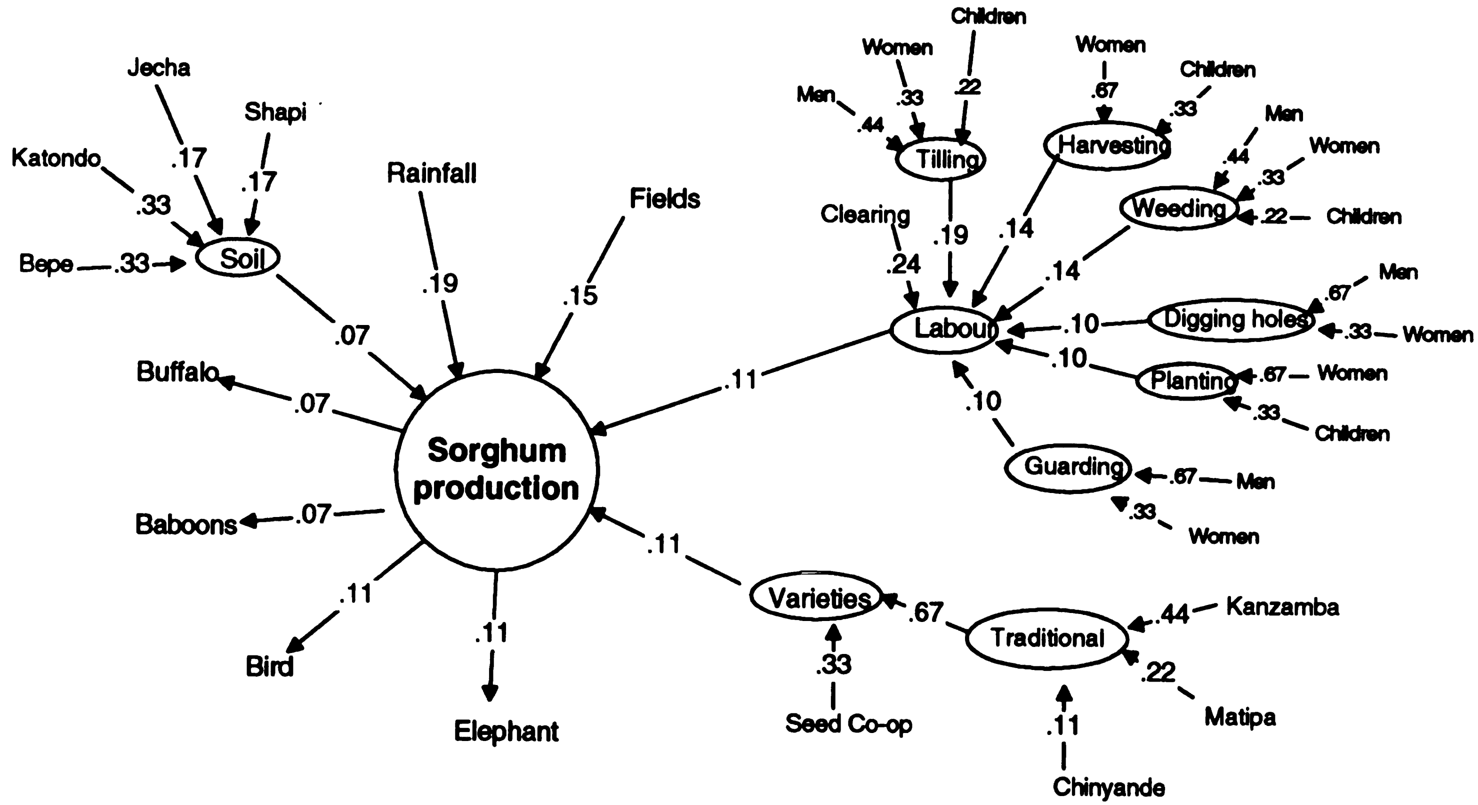

Figure 4.13. Female VR perspective on what is required for, and what detracts from, the achievement of good sorghum yields.

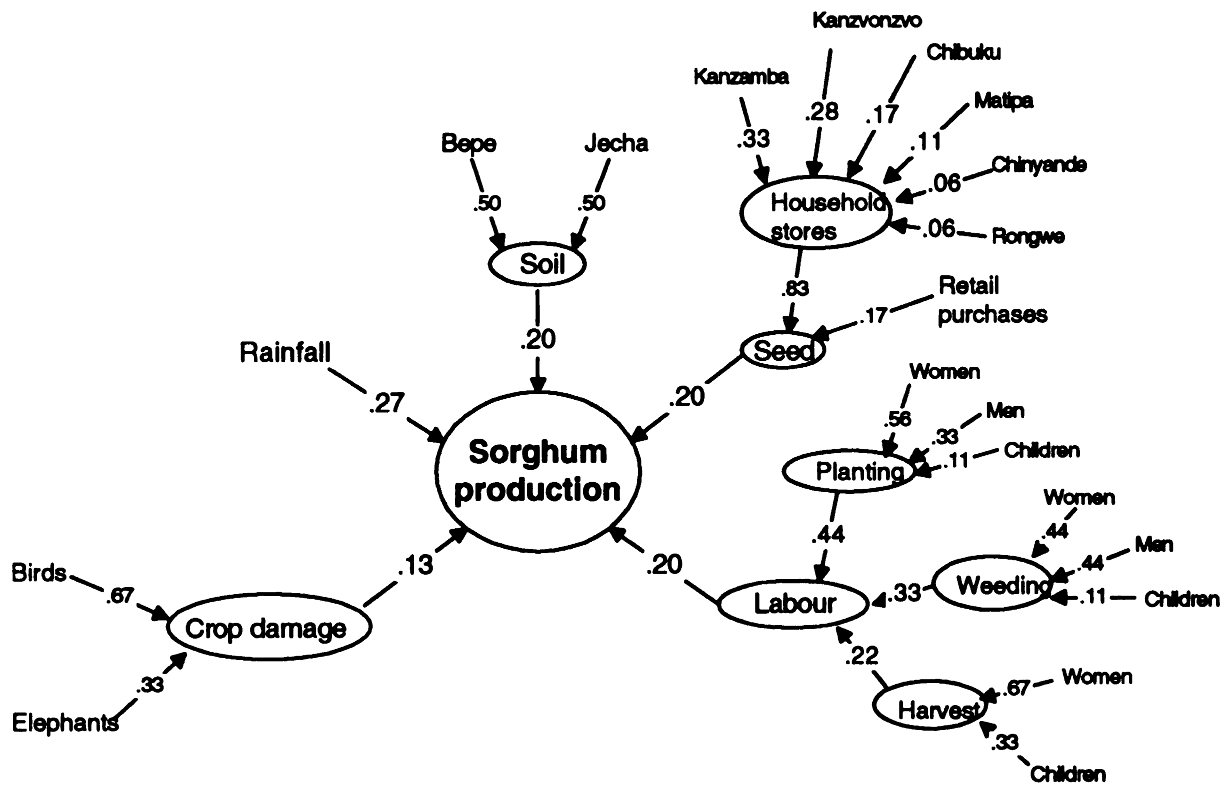

Figure 4.14. Male VR perspective on what is required for, and what detracts from, the achievement of good sorghum yields.

VR groups. Wild animals were held responsible for a large proportion of the perceived losses from maize, cotton and sorghum production whilst insect and mite pests were important loss causing agents only in cotton. Female VRs consistently expressed their perception of the importance of land and, in the case of maize, their perception of the importance of trees and grass for fertility restoration. Women appeared to be the dominant source of labor in cotton and perhaps in maize although the trend was not as clear as for cotton. Men seemed to have a greater role in sorghum production than is generally recognized. Children contributed importantly to the labor requirements of the household in most major crop production activities. Commercially available seed varieties (hybrids) are most important for maize and cotton but traditional (open pollinated) varieties are most important in sorghum production.

More detailed analyses of the rainfall, soil and labor inputs to crop production were conducted and the results are presented below. Despite the stated importance of crop variety in achievement of household needs satisfaction, this factor was not investigated further.

Rainfall analysis

The VRs identified four distinct rainfall types: The first, named Mhepo (called thunder in subsequent discussions), occurs throughout the season and is characterized by wind and thunder with only a light rainfall over short periods of time. The second rainfall type, Mhunurukwa (called heavy rain in subsequent discussions) is characterized by heavy rainfall with storms lasting longer than several hours. This rainfall type occurs mostly in January and February. The third rainfall type Mvuramabwe (called hail in subsequent discussions), is characterized by hail, occurs infrequently and usually lasts for less than 30 minutes. The fourth rainfall type, Pfunambuya (called light rain in subsequent discussions), is a light rain that continues for several hours and sometimes even a whole day.

The VR data indicated a high probability of the rainfall season beginning in the first two weeks of November and certainly beginning in the last two weeks of November (Table 4.1). The Department of Meteorological Services (DMS) indicated November 22nd as the mean date of the first rainy pentad for the eastern mid-Zambezi valley and the end of the rainy season occurring in the first two weeks of March (DMS, 1981). The VR data suggested the last certain rains occur in the first two weeks of March (Table 4.1) but recognized a high probability of light rain occurring through until the first two weeks in April. The DMS also indicated the mean number of raindays of 1mm or more as being between 50 and 60 days for that region of the Zambezi Valley (DMS, 1981). If we take the sum of events with possibility scores greater than zero as an upper bound on the number of rain events and those with a possibility score of 0.5 or greater as a lower bound (Table 4.1) then the VRs indicated a range of between 41 and 76 rain events a season. We should expect these figures to be slightly higher than the DMS values due to the possibility of multiple rain events in one rain-day. The DMS identified the major hail season as occurring in October, November and then declining sharply in

Table 4.1 Subjective probabilities indicating VR perceptions of the probability of the number of rainfall events, of each rainfall type, occurring in any two week period of the rainy season.

Rain type	Month	Oct	Nov		Dec		Jan		Feb		Mar		Apr
	Week	3/4	1/2	3/4	1/2	3/4	1/2	3/4	1/2	3/4	1/2	3/4	1/2
	# Events												
Hail	1	.2	.8	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0	0	0	0
	6	0	0	0	0	0	0	0	0	0	0	0	0
Heavy rain	1	0	.8	1	1	1	1	1	1	1	.5	0	0
	2	0	.2	1	1	1	1	1	1	.7	.2	0	0
	3	0	0	.5	.5	.5	.5	1	.6	.3	.1	0	0
	4	0	0	.3	.2	.2	.3	.4	.5	.1	0	0	0
	5	0	0	.1	0	0	0	.1	.2	0	0	0	0
	6	0	0	0	0	0	0	0	0	0	0	0	0
Thunder	1	0	0	0	0	1	1	.4	.4	.3	.2	0	0
	2	0	0	0	0	1	1	.2	.2	.1	.1	0	0
	3	0	0	0	0	.8	.5	0	.1	0	0	0	0
	4	0	0	0	0	.5	.3	0	0	0	0	0	0
	5	0	0	0	0	.2	.1	0	0	0	0	0	0
	6	0	0	0	0	0	0	0	0	0	0	0	0
Light rain	1	0	0	0	0	0	0	0	1	1	1	.5	.8
	2	0	0	0	0	0	0	0	1	1	.7	.3	.2
	3	0	0	0	0	0	0	0	.8	.9	.2	.2	0
	4	0	0	0	0	0	0	0	.4	.4	0	.1	0
	5	0	0	0	0	0	0	0	.1	.1	0	0	0
	6	0	0	0	0	0	0	0	0	0	0	0	0

December (DMS, 1981). These expectations were consistent with the VR perceptions of a low possibility of hail in late October and a high probability in early November (Table 4.1, Figure 4.15). The VRs did not recognize any possibility of hail occurring in December. VRs indicated a high probability of thunder activity in late December through to the beginning of March (Table 4.1, Figure 4.15) which

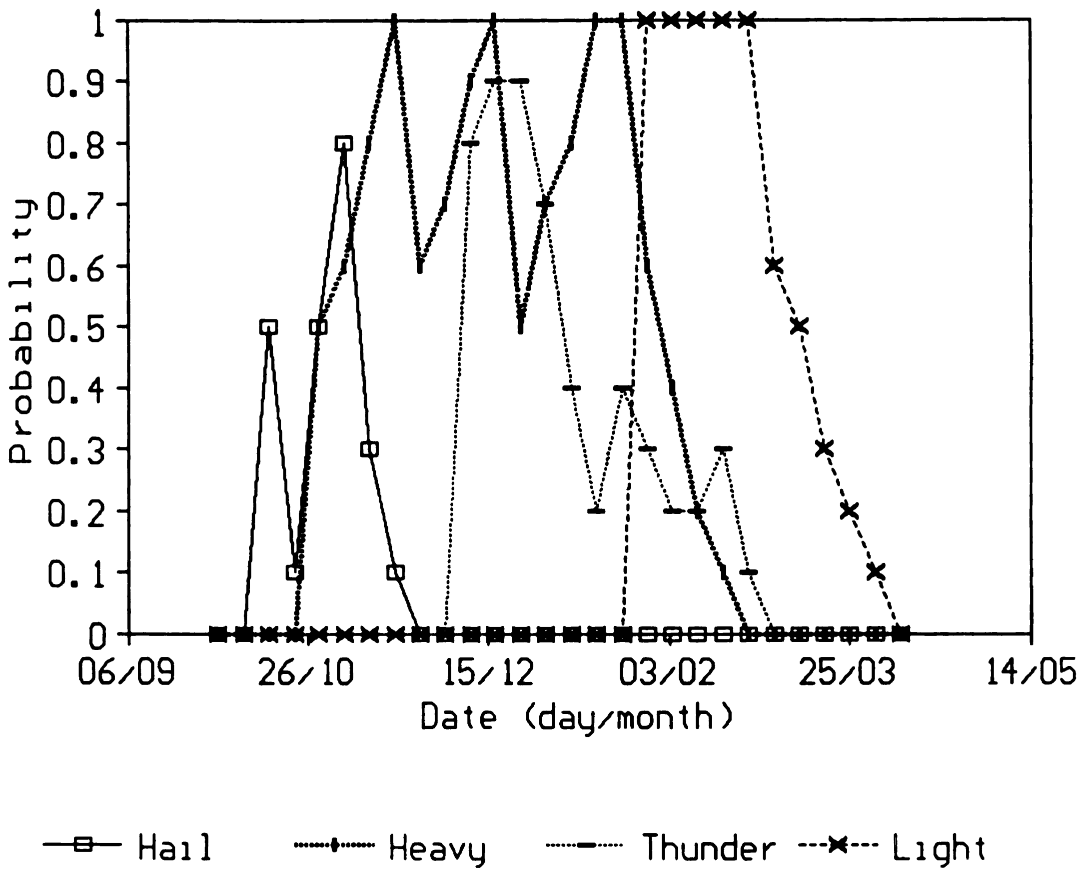

Figure 4.15. Probability of a rainfall event of each of four rainfall types occurring in each week of the rainy season.

is consistent with the DMS reports of high thunder activity in November through to the end of February and then dropping rapidly in March (DMS, 1981).

The DMS reported the frequencies of rainfall storms lasting for particular periods of time (DMS, 1975). These data may be used to compare the rainfall event duration probabilities developed by the VRs for each rainfall type (Figure 4.16). The DMS indicated a 45% probability of a storm lasting for one hour or less, 26% probability of a storm lasting for two hours, a 14% probability of lasting three hours, an 8% probability of lasting four hours, a 5% probability of lasting five hours and a 1% probability of lasting 6 hours. The VRs indicated a 30% probability of a heavy rainfall event lasting one hour or less, a 30% probability of it lasting two hours, a 10% probability of it lasting three hours a 20% probability of it lasting four hours, a 10% probability of it lasting five hours and no probability of it lasting as long as six hours (Figure 4.16). VRs indicated that light rain events would, in general last, longer than the heavy storms (Figure 4.16).

Masoka residents, VRs and a local expert, identified by the VRs, classified previous rainfall seasons as being either good, average or poor. The VRs, working as a group, and the local expert classified the previous ten seasons whilst in the questionnaire survey presented in Chapter 3 all respondents were asked to classify three seasons ending 1990/91. The results of these classifications, together with the rainfall measured at Angwa Bridge are shown in Table 4.2.

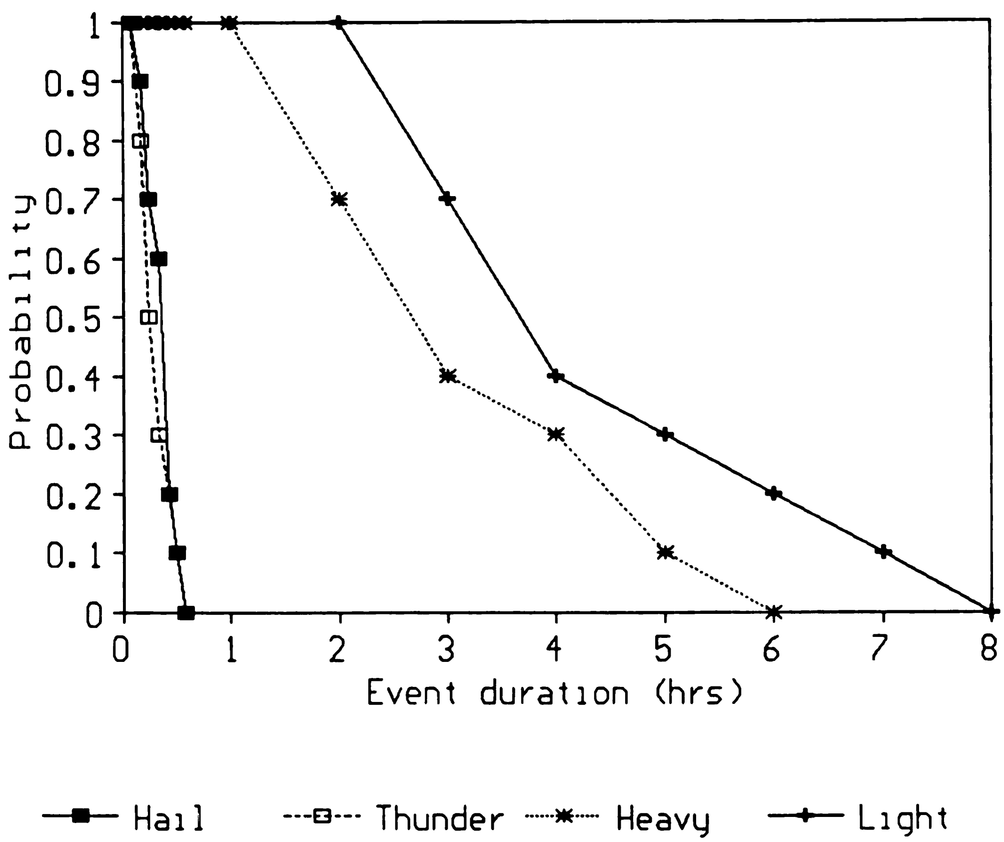

Figure 4.16. Probability of a rainfall event lasting at least a certain time for each of the four types of rainfall.

Table 4.2 Classification of ten rainfall seasons ending 1991/92 as good (G), average (A) or poor (P) by village representatives (VRs), a local informant and questionnaire survey (1988/89 to 1990/91 only).

Rainfall season	Measured rainfall (mm yr^{-1}) at Angwa Bridge	Source of season classifications[1]				
		VRs	Local expert	Questionnaire survey		
				% Respondents		
				G	A	P
1982/83	561	P	P			
1983/84	529	G	A			
1984/85	1303	G	P			
1985/86	1067	A	G			
1986/87	558	G	G			
1987/88	579	A	P			
1988/89	911	A	P	76	2	22
1989/90	803	P	nd	41	25	34
1990/91	478	P	nd	14	14	72
1991/92	431	P	nd			

1. Season classes: G = good, A = average and P = poor. nd = no data.

These data show an inconsistent pattern of agreement between rainfall amount at Angwa Bridge and the season classification. Some of this inconsistency is attributable to the spatial variability of rainfall in the Zambezi Valley area; quite possibly the rainfall at Masoka differed significantly from that at Angwa Bridge in any one season. We could expect some overlap in seasons classed as good with average or poor with average but we would not expect a consistent classification system to confuse good and poor. We note one such conflict (for the 1984/85 season) between the VR classification and that of the local expert (Table 4.2). The VR classification, based on a consensus of eight people, was consistent with the rainfall data. If we accept that the VR classification is correct then the proportions of good, average and poor seasons are .3, .3 and .4.

Consistency in results of the rainfall analysis that were obtained using different methods (Table 4.1 and Figure 4.15) gave us confidence that the results were not biased by the method of data collection. The good agreement between the published records of rainfall patterns and the observations of the VRs gave us further confidence in the validity of the methods used as well as in the accuracy and precision of the VR observations. The positively skewed distributions of rainfall event durations provided by the DMS (DMS, 1975) provide the theoretical expectation with which to compare VR data. As with previous tests the VR data were consistent with the theoretical distribution providing further support to the validity of the methods as well as the accuracy and reliability of the results. In each of these cases the results do not support the prediction that VRs are unable to provide accurate descriptions of the structure or patterns of key elements in their environment.

Labor requirements for each crop enterprise

Cotton has the highest labor demand per hectare (160 person days) of the three crops under consideration and sorghum the lowest with 84 person days (Tables 4.3 to 4.5). The most labor demanding activities were weeding, harvesting

Table 4.3 Labor requirements (days ha^{-1}), for each activity of maize production in each month of the growing season.

	Labor days ha^{-1} $month^{-1}$					
Activity	Nov	Dec	Jan	Feb	Mar	Total
Digging holes	10					10
Planting	5					5
Weeding	12	25	37	12		86
Harvesting					17	17
Collecting maize					7	7
TOTAL	27	25	37	12	24	125

and land preparation in all three crops with pest management (scouting and spraying) being demanding on cotton. Peak labor demands occurred in November, December and January which are similar to the results reported by Shumba (1985, 1988) for Mangwende CA. The Farm Management Research Section of the Economics and Markets Branch of the Ministry of Lands, Agriculture and Rural Resettlement provided labor input data input for maize, cotton and sorghum collected by questionnaire survey in several CAs of Zimbabwe (MLARR, 1989, 1990). Not all of the categories of activity in the MLARR report were comparable to those used by the VRs for Masoka but the general trends may be observed. The hourly labor requirements presented in the MLARR report have been divided by six to develop daily figures for comparison with the Masoka data. Reynolds (1991) reported working days of between four and six hours and Shumba (1986a) also uses a six hour working day in his analyses.

Table 4.4 Labor requirements (days ha^{-1}) for each activity of cotton production for each month of the growing season.

Activity	Dec	Jan	Feb	Mar	Apr	Total
	Labor days ha^{-1} month^{-1}					
Digging holes	12					12
Planting	5					5
Weeding	20	20	20	10		70
Scouting	2	5	5	2		14
Spraying chemicals	5	10	7	2		24
Picking					35	35
TOTAL	44	35	32	14	35	160

Table 4.5 Labor requirements (days ha^{-1}) for each activity of sorghum production, in each month of the growing season.

Activity	Oct	Nov	Dec	Jan	Feb	Mar	Total
	Labor days ha^{-1} month^{-1}						
Clearing	5						5
Digging holes		12					12
Planting		5					5
Weeding			20	17	10		47
Harvest						10	10
Carrying						5	5
TOTAL	5	17	20	17	10	15	84

For maize production the MLARR reported labor inputs as being between 63 and 127 labor days per hectare for their sample sites in Natural Regions III and IV. Due to the non-availability of animal draft power in Masoka and the limited ability of households to hire a tractor for ploughing operations we might expect

Masoka labor inputs to be higher than those in the areas reported by the MLARR. For the most part the VR data indicated a greater proportion of the labor allocated to weeding than is reported by the MLARR and less on harvesting than reported by the MLARR. Ascertaining from the MLARR report what activities are included in their harvesting category, which accounts for between 50 and 70% of the labor inputs reported for maize was not possible. Shumba (1986a) reported half the harvest labor, at approximately the same yield level as do the MLARR. These great differences suggest the MLARR harvest data included activities not used by the VR nor were in the data reported by Shumba.

The MLARR data on weeding labor ranged from 15 to 27 days per hectare in 1988/89. Possibility diagrams were developed by the VR depicting the probability of one adult completing a task in a given number of days. For weeding one hectare of maize the expected value (standard deviation in parentheses) for task completion was 16.3 (3.4) days which is close to the 17.5 days implied by Shumba (1986b). Shumba indicated that farmers weed their maize fields twice in a season. The VR data indicate six weeding rounds per season for maize which must be an ideal situation. If we assume two weeding rounds in Masoka then the total labor requirements for maize are 72 days ha^{-1}, much the same as Shumba's 73 days. Mangwende farmers used slightly more labor for planting (7.4 days ha^{-1}) as well as for harvesting (30 days ha^{-1}) (Shumba, 1986) than do farmers in Masoka. The lack of draft power in Masoka increased the labor demand by 15% for maize.

The MLARR data presented for cotton labor requirements ranged from 107 labor days for NR III to 172 labor days for NR IV (MLARR, 1989). Once again these overall totals were similar to those presented by the Masoka VRs (Table 4.4). The weeding labor figures for one of the MLARR sites (Nyjena, NR IV), 76 labor days, were similar to those expressed by the VR for Masoka (70 labor days, Table 4.4). The mean number of days for all sites was however, 36 days ha^{-1} which suggested about two weeding rounds a season. The harvest labor depicted by MLARR for cotton, 42 to 91 labor days, (MLARR, 1989) was higher than the 35 labor days expressed for Masoka by the VRs. The VRs did not develop a possibility scoring diagram for cotton picking but indicated that three picking rounds would be required; the first requiring about 14 labor days, the second 10 and the last 6. These data were consistent with the 35 days depicted in Table 4.4. It seems likely that VRs were representing an ideal situation in identifying four weeding rounds on cotton. As with maize it seemed likely that only two would be done. If this was the case then the weeding labor would be 40 days ha^{-1} and make the total labor requirement for cotton, 130 labor days ha^{-1}.

The MLARR labor input data for sorghum production indicate about 65 labor days were required per hectare (MLARR, 1989) which were lower than the 84 days indicated for Masoka by the VRs (Table 4.5). As with cotton and maize production we might expect Masoka labor requirements to be higher because of hand tillage requirements and the need to guard crops from wild animals. Guarding labor data were not included in the labor budgets and the labor required for digging holes was 12 labor days per hectare. With these days removed the Masoka labor data were much closer to those from the MLARR. As with cotton and maize however, the distribution of labor among tasks differed greatly: weeding labor in the MLARR sites (between 21 and 33 labor days ha^{-1}) was less than in Masoka and that for harvesting (29 labor days) much higher. As with the previous two crops we might assume that households weed their sorghum fields only twice (Chiduza *et al.*, 1992; Reynolds, 1991) which would make the Masoka data (37 labor days ha^{-1}) comparable to the MLARR data.

When the data from the labor matrices (Tables 4.3 to 4.5) were compared to those derived from possibility diagrams there was general agreement giving us confidence that the methods were not distorting the results. The results for maize presented by the VRs were very close to those described for Mangwende by Shumba (1986a) as well as being close to the more general patterns of labor input described by Reynolds (1991). The VRs appeared to be indicating optimal labor inputs in order to answer the question posed. We might expect therefore, the actual labor inputs to be more in line with those suggested by Shumba - particularly with regard to weeding. The MLARR data exhibit great variability in labor input data between sites and except for the harvest data, the Masoka labor input values were well within the ranges reported by the MLARR. Given the close agreement between VR harvest data for Masoka and that of Shumba (1986a) for Mangwende we may be reasonably confident that the labor input data reported by the VRs were valid and accurate. These results do not support the prediction that VRs were incapable of providing accurate descriptions of the structure or patterns of key elements in their environment.

Soils and soil fertility

VRs were asked to define and then map the soils of Masoka and then to select sites, representative of those soils, in which to dig soil pits and collect soil samples for soil analysis. A pedologist from the University of Zimbabwe, Dr. W. Verboem, was brought to Masoka to assist in mapping and classifying the local soils. He identified essentially the same soil classes as had the VRs.

VRs were asked to describe the indicators they used to determine how fertile or infertile a particular field was and how they would know when a fallowed field's fertility had been restored. Loss of fertility was indicated by yield decreases and the increasing cover of annual weed species commonly called *Warimani* and *Kambumbu*[10] (Table 4.6). They said this occurred after three to seven years on jecha soils and was consistent with the findings of Reynolds (1991). Fertility was indicated with the presence of tree and grass species, particularly *Acacia tortillus* (Table 4.6). They believed full fertility was restored on jecha soils after 15 years of being left fallow at which time *A. tortillus* reached a height of nine to 10 meters and a maximum biomass (Figure 4.17) although few farmers leave their fields fallow for that long. Grant (1981), in discussing the fertility of granitic sands in the CAs of Zimbabwe, suggested these soils could be cropped for three years and then left

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10 Botanical names for these plants were not available at the time of writing.

Table 4.6 **Relative importance weights (5 highest to 1 lowest) of tree and herb or grass species after a jecha field is left fallow.**

Local species name	Ind[1]	1	2	3	4	5	6	7	8+
		Years after cultivation ceases							
Trees									
Mzungu (*Acacia tortillus)*	F	1	2	3	4	5	5	5	5
Marowe	F		1	2	3	3	3	3	3
Mhangara (*Dalbergia melanoxylon)*				1	2	2	2	2	2
Mutohwe (*Azanza garckaena*)	F				1	2	2	2	2
Mupakasa (*Lonchocarpus capassa*)			1	2	2	2	2	2	2
Herbs and grasses									
Warimani	I	5	4	3	2	1			
Goso *(Trichodesma zeylancia)*		1	2	3	3	3	3	3	3
Mhunhuruwa		1	2	3	3	3	3	3	3
Tsikinya	F			1	2	3	3	3	3
Kambumbu	I	4	3	2	1				
Tsine *(Heteropogon contortus)*	F					1	2	3	3
Bande (*Urochloa trichopus*)	F					1	2	3	3

1. Ind = Fertility indicator. F = Indicator of fertile soil. I = Indicator of infertile soil.

fallow for 15 or more years until legumes of the genus *Croteliaria* indicated that the soil was again fertile. Attempts to establish normal fallowing practices in Masoka proved fruitless. No consistent pattern was discernable either from discussions with the VRs or from the people within the community that the VRs indicated were particularly knowledgeable about Masoka. Many farmers stated that they

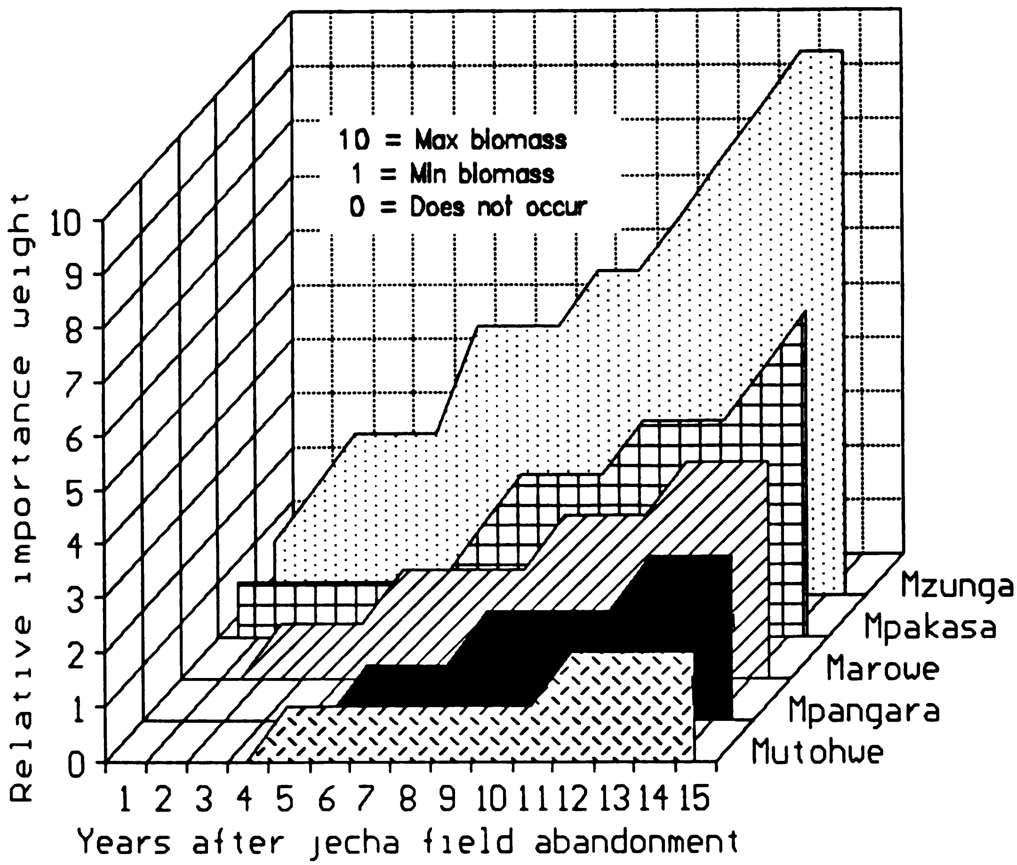

Figure 4.17. Increase in total tree biomass with time after field abandonment as a proportion of the maximum achievable in 15 years for major tree species growing on jecha.

would leave a field fallow after five years of continuous cultivation but when asked about the actual history of their fields few actually did what they said they should do. The period that fields were left fallow was equally difficult to discern clearly. One local expert, Mr. Dishon, who had been cropping in Masoka since 1964, indicated that he cropped his jecha fields for four consecutive years and expected slight yield reductions each year. In the fifth year he would plough the field with a tractor and the yields would increase to the same as those expected from a virgin field. Thereafter, they would steadily decline until the ninth year when he would leave the field fallow. He left the field fallow for five years and then restarted the cycle. Most Masoka residents that were questioned on this subject held approximately this view of the fallow cycle however, their actions were more diverse than this pattern indicates. This nebulous fallow practice was also reported by Reynolds (1991) for areas further west in the Zambezi Valley.

The VRs indicated that households seldom, if ever, left bepe or river jecha fields fallow. They knew of no one in the community who did so. Bepe soils were considered to be endlessly fertile and the periodic flooding of the Angwa river was considered to restore the fertility of the river jecha fields. None of the households in the community had had sufficient experience with cultivation of either katondo or shapi soils to know when fertility began to decline or how long to leave them fallow for fertility restoration.

The understanding of soil fertility by VRs was consistent with the trends reported in the literature but the practices of households differed considerably from what was considered good practice. Some farmers, for example, followed more or less regular fallowing cycles whilst in at least one case, a farmer had continuously cultivated the same fields with sorghum for at least 20 years and perhaps as much as 30 years. There was general agreement on the importance of trees, particularly *A. tortillus*, in restoring soil fertility and several tree and grass species were used as indicators of fertile soils. *A. albida* is considered a sacred tree in Masoka and residents may not cut one down. No attempts were observed or described by the VRs to enhance the nutrient restoration potential of these trees by silvicultural or management practices. The clear descriptive understanding VRs had of their soils, as well as the good relationship between the knowledge of VRs on soil fertility and that in the published literature, do not support the prediction that VRs were unable to provide accurate descriptions of the structure or patterns of key elements in their environment.

Crop yields

The yield estimates derived from asking household respondents to map household fields and asking them for their estimates of acreages and total yields generated the yields shown in Table 4.7. Analysis of variance indicated yields were different among seasons for maize ($p<.05$, $F=4.468$, $n=52$), for cotton ($p<.05$, $F=5.375$, $n=28$) and for the two classes of season (average and poor) for which there were sufficient sorghum yield data to make comparisons ($p<.01$, $F=8.439$, $n=26$). These data were similar to the average yields reported for the

Table 4.7 Mean (standard deviation in parentheses) yield estimates (kg ha^{-1}) for maize, cotton and sorghum, derived from household field maps and household respondent information.

Season	Maize	Cotton	Sorghum
	<------------	kg ha^{-1}	------------>
Good	1334 (786) n=2	766 (35) n=2	ND
Average	804 (515) n=14	915 (458) n=11	631 (445) n=8
Poor	511 (429) n=36	489 (209) n=15	235 (252) n=18
Weighted Mean[1]	846 (675) n=52	700 (337) n=28	---

1. Weighted mean. Season averages weighted by the probability of that season occurring. Good = .3, average = .3 and poor = .4. ND = No data.

Table 4.8 Maize, cotton and sorghum yields reported for the mid-Zambezi Valley.

	Brunt[1]			Harizi[2]			Hawkins[3]	Jassat[4]
	Avg.	Dry	East	Best	Avg.	1983/84		
Maize	700	200	300-1000	1800	720	180	846 (793)	1340
Cotton	700	nd	500-1800	1600	1200	950	981 (512)	1600
Sorghum	600	450	400	1600	900	450	540 (364)	910

1. Brunt *et al.* (1986). Average, drought year and eastern Zambezi valley yields. 1984/85 season. nd = No data.
2. Harizi (1985). Best, average and 1983/84 (drought) season yields for Muzarabani.
3. Hawkins Associates (1982). Mean (standard deviation in parentheses) yields for multiple sites in the eastern mid-Zambezi Valley area. 1981/82 season (low rainfall).
4. Jassat and Chakaodza (1986). Average yields, based on Agritex crop forecasts, for Rushinga District (NR IV and III), some of which lies in the eastern Zambezi Valley.

mid-Zambezi valley by Brunt *et al.* (1986) and to the maize yields reported by Hawkins Associates (1982) and Harizi (1985) as shown in Table 4.8. Cotton yields reported by Hawkins Associates (1982) and Harizi (1985) were higher than those presented in Table 4.7. Without good season yields for sorghum estimating the weighted mean and hence comparing these results to published yield figures was difficult. The values for an average season were however, reasonably close to the mean yields reported by Hawkins Associates (1982) and Brunt *et al.* (1986), but were much lower than those reported by Harizi (1985) as shown in Table 4.8. None of these authors reported yields on different soil types.

The data collected from field maps show reasonable agreement with published yields for this part of Zimbabwe and were within the range one could expect from national data sources. There may, however, be problems with the repeatability of these measurements; The mapping of household fields and requests of yields was repeated twice each for two VRs (one male, one female). This facilitated examining the repeatability of yield estimates derived in this manner. In both cases the responses differed quite markedly from one mapping exercise to another. Differences occurred in the statements of the acreages as well as in the total yields obtained. These anomalies, as well as the notable variation in yields reported for the Zambezi Valley (Table 4.8), prompted development of the possibility scoring method for estimating yields.

The expected yields of each soil type (Table 4.9) were weighted by that soil type expressed as a proportion of the total of cultivatable soils (bepe = .13, jecha

= .77 and river jecha = .1, when calculating cotton and maize values; bepe = .144 and jecha = .856 when calculating sorghum values). For jecha soils the average of virgin and five year cultivated jecha expected yields were used to derive the weighted means. These values are shown in the weighted mean column of Table 4.9. The weighted means across seasons were calculated by weighting the expected yields of each season by the proportion of those seasons calculated from Table 4.2 (good=.3, average=.3 and poor=.4).

The yields of all crops, on all soil types and for any season show considerable variability (Table 4.9) with co-efficients of variation between 10 and 133%. Variability among seasons appeared greater than that among soil types. VRs reported highest maize yields on river jecha soils in any season. The low per household proportion[11] of river jecha fields (p=.46 of households have river jecha and p = 0.1 of the lands are river jecha) reduced the impact of river jecha yields on household needs satisfaction. Maize yields on both bepe and river jecha were slightly higher in an average season than in a good season. This is consistent with what we expect because the high clay content of the bepe soils makes them waterlogged in wet years, thus reducing yields (Mittra and Stickler, 1961). On river jecha soils the flooding of the Angwa river in wet years reduces yields through waterlogging, lodging or being washed away. Poor season maize yields were higher than what we might expect on reading the literature; Yields on

[11] The proportion of river jecha fields was estimated using a digitized soil map. The procedure is described in Chapter 5.

Table 4.9 Expected values for maize, cotton and sorghum yields (kg ha^{-1}) on three soils and for good, average and poor rainfall seasons. Source, possibility diagrams.

Crop	Season class[1]	Bepe	Virgin jecha[2]	5yr cult jecha[3]	River jecha	Weighted mean[5] 1	Weighted mean[5] 2
	G	1800 (475)	2000 (530)	1100 (351)	3300 (427)	1750 (797)	1600 (621)
Maize	A	2000 (629)	1350 (571)	1000 (424)	3500 (330)	1500 (885)	1300 (614)
	P	700 (218)	550 (178)	250 (109)	1350 (209)	550 (362)	450 (236)
	Wtd. Mean[6]	1450 (745)	1200 (748)	750 (504)	2600 (1055)	1200 (883)	1050 (709)
	G	850 (385)	1200 (395)	650 (545)	1200 (395)	950 (526)	900 (531)
Cotton	A	1100 (484)	1050 (466)	700 (446)	1400 (370)	950 (506)	900 (494)
	P	250 (129)	250 (151)	150 (174)	400 (272)	250 (139)	200 (163)
	Wtd. Mean	650 (508)	750 (547)	450 (467)	950 (559)	650 (524)	650 (527)
	G	800 (149)	1100 (1127)	300 (181)	NA[4]	NA	700 (834)
Sorghum	A	1000 (285)	850 (259)	250 (323)	NA	NA	600 (422)
	P	50 (26)	150 (98)	50 (25)	NA	NA	100 (89)
	Wtd. Mean	550 (439)	650 (752)	200 (233)	NA	NA	450 (583)

1. Season class: G = good; A = Average; P = Poor.
2. Virgin jecha. Jecha soils that had not previously been cultivated.
3. 5yr cult jecha. Jecha soils that had been cultivated for five years continuously.
4. NA - not applicable. Sorghum was not grown on this soil type.
5. Weighted mean across soil types. The expected value for each soil type was weighted by that soil type expressed as a proportion of all cultivatable soil. For jecha the mean of virgin and 5 year cultivated expected values were used. 1 = All soil types including river jecha. 2 = All soil types excluding river jecha.
6. Weighted mean across seasons. The proportion of seasons in each class, G=.3, A=.3 and P=.4, were used to weight the expected values for each season.

bepe were comparable with national averages for the CAs, 695kg ha^{-1}, (Tattersfield, 1982)

and the yields on river jecha were well above the all-season averages reported for the Zambezi Valley (Table 4.8). In contrast, the poor season yields of cotton and sorghum were very low. These figures add support to the argument that sorghum is not as resistant to drought as is often believed (Shumba, 1990) and suggests why farmers continue to select maize as their major food crop (Johnson, 1992) even when they are considered to be outside the region of dryland farming, as Masoka is (Whitlow, 1980). The very noticeable drop in expected yields from an average to a poor season in each of these crops was remarkable. This implies a steeply sloping sigmoid curve rising rapidly between a poor season and an average season and then leveling out on (jecha soils) or declining slightly (on bepe and river jecha) in good seasons, trends that have been shown in the literature for jecha (Phia, 1992). There appeared to be little difference in expected yields among soil types for cotton and for sorghum.

Expected yields were lower on cropped jecha soils than on virgin jecha soils (Table 4.9) a trend that were consistent with the findings of Reynolds (1991). Cotton yields also appeared to be more variable on cultivated soils than on virgin.

The most striking feature of the data derived from VR probabilities were the great variability in yields, among soil types and among seasons (Table 4.9). This variability was reflected in the literature for the eastern mid-Zambezi Valley (Table 4.8). Mean maize yields derived from VR knowledge were similar to those reported in the literature (Table 4.8). If we take the cultivated jecha yields as a yardstick, (these soils being the most comparable to those of the eastern mid-Zambezi Valley as a whole) then the VR derived yields were entirely consistent with published yield records (Table 4.8). VR derived mean yields were also similar to the yields households achieved (Tables 3.2, 4.7). The average maize yields reported for Masoka appear to be slightly higher than the averages reported for the eastern mid-Zambezi Valley and were also slightly higher than the national average, 900kg ha^{-1}, for the period 1982 to 1989 (Ashworth, 1990).

Perhaps the most useful data with which to compare the yields derived from VR probability estimates was the frequency distribution of maize yields reported by the Farm Management Research Section of the Economics and Markets Branch, Ministry of Lands, Agriculture and Rural Resettlement (MLARR, 1989). This positively skewed distribution, with a mean (for NR III, IV and V sites) of 1100 and a standard deviation of 1060kg ha^{-1} was close to the VR estimated distribution, in terms of the mean and spread of the data. The MLARR data for the 1989/90 season showed a similar distribution.

The published data for average cotton yields were also highly variable with average yields between 500 and 1800kg ha^{-1} being reported (Table 4.8). The VR derived yield estimates were similar to what households achieved in good and average seasons (Table 4.7). The VR derived poor season cotton yields were much lower than what households achieved in the drought season of 1990/91 (Table 3.2) and less than the drought season yields reported by Harizi (Table 4.8).

In general, the average cotton yields predicted by the VRs were lower than the trends reported for the eastern mid-Zambezi valley (Table 4.8) but were close to the national average of 700kg ha^{-1}, for the period 1982 to 1989 (Ashworth, 1990). The MLARR (1989) data for cotton yield distributions are from a smaller sample size than the maize data (n=46 vs. n=255) so the distribution shape was not as clear. The mean of 630 and standard deviation of 509kg ha^{-1} were, however, very similar to the VR derived yields.

The published data for average sorghum yields also showed considerable variation (Table 4.8) with average yields ranging from 540 to 900kg ha^{-1}. The achieved, poor season yields (Tables 4.7 and 3.2) were higher than those predicted by the VRs (Table 4.9), but the great variability made detecting true trends difficult. The poor season yields achieved by Masoka households (Table 4.7) were closer to those predicted by the VRs (Table 4.9) than were the mean yields published in the literature (Table 4.8). The average season sorghum yields achieved by households and those predicted by VRs were very similar. In general, the sorghum yields households were likely to achieve in Masoka were lower than yields reported in the literature but were higher than the national average of 350kg ha^{-1} for the period 1982 to 1989 (Ashworth, 1990).

Deriving statistically satisfying tests of our hypotheses from these yield data was difficult. Inconsistencies in VR responses to field mapping yield estimates indicated that this method may bias the results. The consistency in yield estimates derived from two separate data collection exercises suggested that this method did not bias the results. Whilst collecting these yield data, I brought to the attention of the VRs the inconsistencies in yield estimates among methods. After much debate and reflection, the VRs re-examined each of their yield possibility diagrams and confirmed that these results represented their best estimates of yield relationships. These factors made us confident that the method was unbiased and provides reasonably accurate and precise information on yields under the specified conditions. Over the range of conditions investigated, these results are likely to be at least as accurate and precise as published data.

Performance measures

VRs were asked to develop a spidergram that would indicate what factors determine a household's ability to satisfy its needs (Figure 4.17). Knowledge was considered the most important factor (RIW=.42) followed by the availability of labor (RIW=.25) and access to good soils (RIW=.25). Wealth (RIW=.08) was considered least important. Each of these factors was then further defined in secondary, and in some cases tertiary, levels of indicators. Factors were included if households could be observed to posses or not posses that factor. Whilst developing Figure 4.17 VRs focused much of their discussion on the importance of, and their ability to observe or measure, a household's knowledge. The harvest component of knowledge involved establishing whether households had good harvests or not. Households consistently identified as the community's best farmers were identified as such due to their high total production. When, as a group exercise, the yields

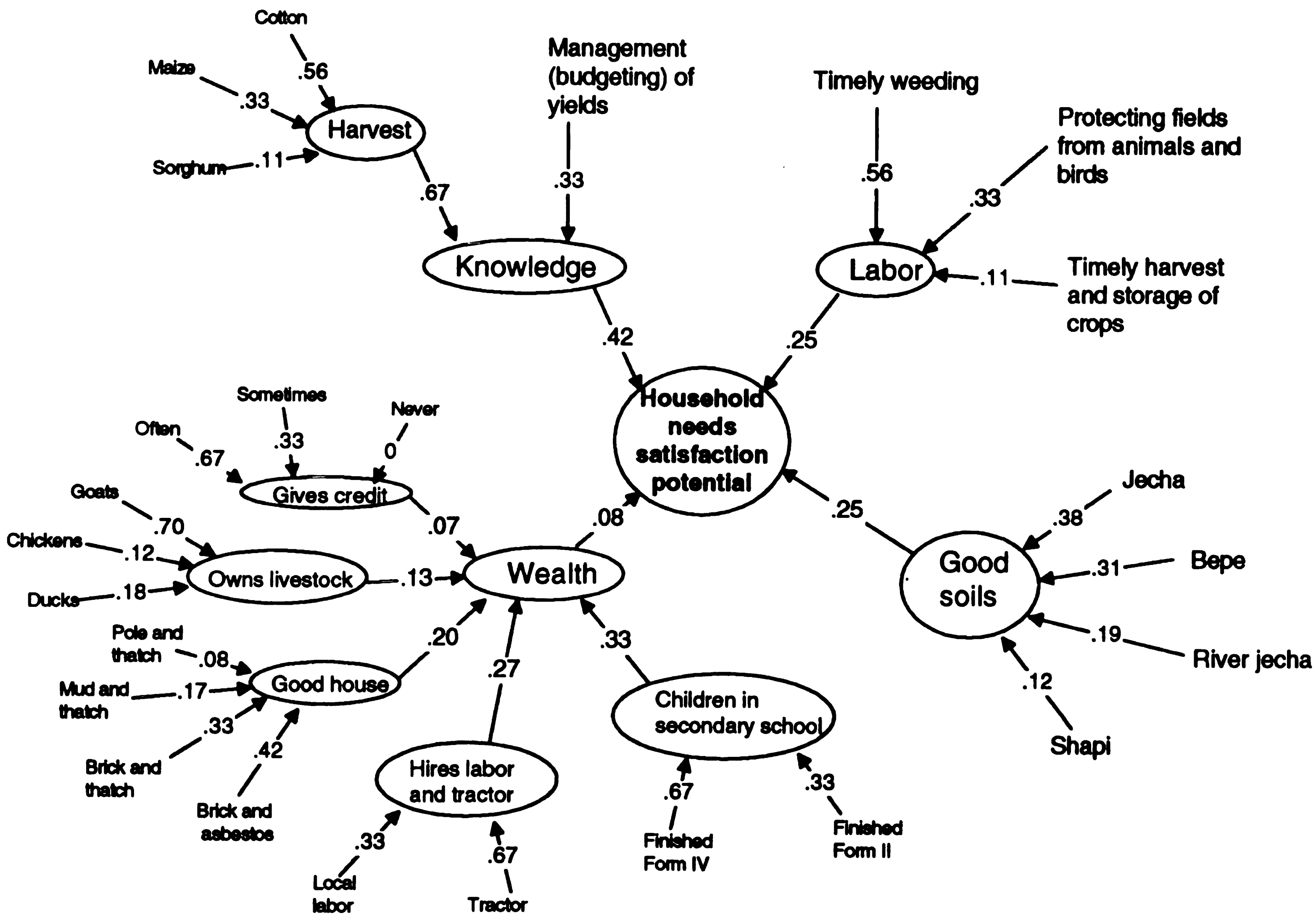

Figure 4.17. VR derived performance measures to assess the liklihood of a household satisfying its basic needs.

per hectare of some of these respected farmers were evaluated, their per hectare production was found to be much lower than many other producers. Most of the VRs however, retained their belief that these were still the best farmers in Masoka. Management of yields involved allocating points to a household for each month it had grain in its granary - up to a maximum of 15 points. If households had sufficient labor to weed their fields in good time, guard their fields from animals and birds as well as harvest and store crop yields, then these factors contributed importantly to that household's ability to satisfy its basic needs. The VRs considered a household having access to jecha soils as being more important than access to other soils types in determining the household's ability to satisfy its basic needs. Education, hiring of labor and hiring a tractor for ploughing as well as the qualities of the homestead building, were important indicators of household wealth.

VRs were asked to assign each household in the community to a class according to the household's ability to satisfy its basic needs. Three classes were defined: households that always satisfied their needs, those that sometimes satisfied their needs and those that rarely satisfied their needs. Of the households classified ($n=98$) 19% were classed as needs satisfiers, 45% were classed as households who sometimes satisfied needs and 36% were classed as households who seldom satisfied needs (Table 4.10). The numbers of adults differed among these three classes ($p<.01$, $n=98$, $F=6.349$) as did the number of children ($p<.01$, $n=98$, $F=5.68$) but the relationship with class was not clear. Households that sometimes satisfied needs generally had fewer adults and children than either of the other classes which had similar numbers of both adults and children. The number of years households had been resident in Masoka was not statistically different among household needs satisfaction classes. Households in the higher well-being classes were more likely to employ local labor than households in the lower well-being classes ($p<.001$, $n=98$, Spearman's rank correlation $r = -.271$). Households in the lower well-being classes were more likely to work for other households than households in the higher well-being classes ($p<.001$, $n=98$, Spearman's rank correlation $r = .35$).

The VRs developed a list of all households in the community and identified those who regularly employed members of other households as agricultural workers, as well as which households were regularly employed. Twenty one households (15%) were identified as regular employers of either school children or members of other households. This value is similar to the 13% of households employing labor in Mangwende CA, reported by Shumba (1985). Thirty two households (22%) were identified as being regularly employed by other households within the community. Thirty seven households (26%) were considered to be regular receivers of incomes from working for other households, from formal employment within or outside Masoka or from both of these sources. Only nine households (6%) were thought to receive remittances from relatives living outside of Kanyurira Ward. The proportion of households regularly employed by other households was almost double that reported by Jackson and Collier (1991) in their

Table 4.10 Mean (standard deviation in parentheses) number of adults, number of children and years residence in Masoka for classes of household well-being.

Household characteristic	Household well-being classes		
	Always satisfy needs (Class 1)	Sometimes satisfy needs (Class 2)	Seldom satisfy needs (Class 3)
Number of adults	2.4 (0.61) n=19	1.8 (0.48) n=44	2.2 (0.79) n=35
Number of children	5.4 (3.89) n=19	2.8 (1.82) n=44	4.0 (3.51) n=35
Family size (adults + children)	7.8 (4.22) n=19	4.6 (2.02) n=44	6.2 (3.69) n=35
Years resident in Masoka	15.9 (8.53) n=16	10.5 (10.91) n=41	9.6 (9.52) n=35
Dependency ratio (children / adults)	2.2 (1.3) n=19	1.5 (1.07) n=44	2.1 (2.19) n=35
Number employing local labor	10	6	5
Number employed as local labor	0	7	17[1]

1. The total number of employed reported here are less than 32 households described in the text as these tabled values do not include VaDoma households working for Masoka households but the totals reported in the text do.

national survey, whilst the proportion of households receiving remittances was very much less than the 37% of households reported by these authors. Stanning (1989) also reported much higher proportions of households receiving remittances in her study in Hurungwe District (88% of households, Table 5, p12) as well as 64% of households receiving local off-farm wages. Stanning, as well as Jackson and Collier, reported that local off-farm incomes contributed little to total household incomes. The 15% of regular employers reported by the VR was similar to the findings of Jackson and Collier (1991) that around 10% of communal area households dominated production and of Stanning (1989) who reported 30% of households in Hurungwe accounted for more than 75% of marketed maize production. Households whose members were employed as agricultural workers by other households were resident in Masoka for a shorter period of time than households that were not regularly employed and had a higher proportion of children to adults (dependency ratio) than households that were not regularly employed (Table 4.11). Employing households had a slightly larger number of

Table 4.11 Mean (standard deviation in parentheses) for characteristics of households in each of four employment classes.

Household characteristic	Household employment classes			
	Employing	Not-employing	Employed	Not-employed
Number of adults	2.5a (0.75) n=21	2.0a (0.58) n=77	2.0 (0.62) n=24	2.1 (0.68) n=74
Number of children	4.0 (4.14) n=21	3.6 (2.78) n=77	4.7 (3.53) n=24	3.4 (2.9) n=74
Family size (adults + children)	6.6 (4.37) n=21	5.6 (3.05) n=77	6.8 (3.8) n=24	5.5 (3.18) n=74
Years resident in Masoka	11.3 (7.20) n=19	11.0 (10.84) n=73	7.6b (8.0) n=24	12.3b (10.60) n=68
Dependency ratio (children / adults)	1.6 (1.5) n=21	1.9 (1.59) n=77	2.5c (2.16) n=24	1.7c (1.24) n=74

1. Values followed by the same letter were significantly different ($p<.05$):
a) $t=-3.766$, DF=96
b) $t=2.003$, DF=90
c) $t=-2.256$, DF=96

adults per household than non-employing households (Table 4.11). These results reconfirm the need to differentiate among households and incorporate household interactions in our predictive analysis.

The cash and labor budget data provided by the VRs were used to develop partial budgets for cotton, maize and sorghum (Tables 4.12 to 4.14). These tables give a clear indication that households faced complex decision making processes in selecting crop type, crop variety, soil and input mixes to satisfy their objectives. In each of these budgets, the B scenario approximates what the wealthier households might actually do. Scenario C showed the effect of changing producer prices on this scenario for maize and sorghum. Scenario D for maize and sorghum and C for cotton showed the effects of poor season yields. Scenario A was an all factors base case. Using the government stipulated producer price in the maize budget (Scenario C, Table 4.12) indicated quite clearly why no households sold maize to the Grain Marketing Board (GMB) in the past few seasons; The returns to household labor were well below the local daily wage rate (Z\$2.19 day^{-1}) and households stand to make substantial losses in poor seasons. With poor season yields and the Masoka maize price, household labor earned a little less than the local daily wage (Scenario D, Table 4.12).

The returns to labor and to land for cotton were substantially higher than those for maize. The returns to labor and land for cotton in a poor season were however, very much less than those for maize. What was interesting to notice was the relatively high return on investment for maize, in an average and poor season,

Table 4.12 Partial budgets for one hectare maize production enterprises with different input and pricing scenarios. 1991/92 season prices.

	Costs and returns ha^{-1}			
	Scenario A[1]	Scenario B	Scenario C	Scenario D
FIXED COSTS				
Transport to Guruve	22.00	22.00	22.00	22.00
Food	15.00	15.00	15.00	15.00
SUB-TOTAL	37.00	37.00	37.00	37.00
VARIABLE COSTS				
Seed (25kg ha^{-1})	46.56	46.56	46.56	46.56
Seed transport (Z$1.00 / bag)	2.47	2.47	2.47	2.47
Ploughing (Z$148.20 ha^{-1})	148.20	0.00	0.00	0.00
Fertilizer (Z$197.60 ha^{-1})	197.60	0.00	0.00	0.00
Weeding labor (Z$2.19 day^{-1})	51.45	51.45	51.45	51.45
SUB-TOTAL	446.28	100.48	100.48	100.48
HARVEST COSTS				
Bags (@Z$2.00 ea.)	23.07	23.07	23.07	10.03
Total Costs	506.35	160.55	160.55	147.51
Returns	818.75	818.75	262.42	355.90
NET MARGIN	312.40	658.20	101.87	208.39
RETURNS TO OWN LABOR	3.22	6.16	0.95	1.95
RETURNS PER HECTARE	312.40	658.20	101.87	208.39
RETURNS TO INVESTMENT[2]	0.62	4.10	0.63	1.41

1. Scenario A: Yield level 1050kg ha^{-1}, hired labor for two weeding rounds, tractor ploughed, 124 kg ha^{-1} each of Compound D and Ammonium Nitrate fertilizers, household uses own labor for all activities on 0.405ha. Local Masoka maize price used (Z$0.78 kg^{-1}).

Scenario B: As for Scenario A except hand cultivated instead of tractor cultivated, no fertilizer and hired labor used for two weeding rounds.

Scenario C: As for Scenario B except producer price of maize used (Z$0.25 kg^{-1}).

Scenario D: As for scenario B except poor season yield level used (450kg ha^{-1}).

2. Returns to investment = Gross returns / total costs.

Table 4.13 Partial budgets for one hectare cotton production enterprises with different input scenarios. 1991/92 season prices.

	Costs and returns ha^{-1}		
	Scenario A	Scenario B	Scenario C
FIXED COSTS			
Transport to Mahuwe	44.00	44.00	44.00
Food	30.00	30.00	30.00
Transport & cost of empty bales	15.00	15.00	15.00
Knapsack spray hire (for season)	15.00	15.00	15.00
SUB-TOTAL	104.00	104.00	104.00
VARIABLE COSTS			
Seed (25kg ha^{-1})	30.88	30.88	30.88
Seed transport (Z$1.00 / 10 kg bag)	2.47	2.47	2.47
Ploughing (Z$148.20 ha^{-1})	148.20	0.00	0.00
Fertilizer & chemicals (Agritex 1 acre packs @Z$140.00/pack)	345.80	345.80	345.80
Weeding labor (@Z$2.19 day^{-1})	102.90	51.45	51.45
SUB-TOTAL	630.25	430.60	430.60
HARVEST COSTS			
Harvest labor (@Z$18.00 $bale^{-1}$)	59.13	59.13	18.23
Transport (@Z$32.00 $bale^{-1}$)	105.12	105.12	32.41
SUB-TOTAL	164.26	164.26	50.64
Total costs	847.05	698.85	585.23
Returns	1918.50	1918.50	591.42
NET MARGIN	1071.45	1219.65	6.19
RETURNS TO OWN LABOR	10.51	10.67	0.05
RETURNS PER HECTARE	1071.45	1219.65	6.19
RETURNS TO INVESTMENT	1.26	1.74	0.01

1. Scenario A: Yield level 650kg ha^{-1}. Hired labor used for weeding two rounds, tractor ploughed, cotton producer price Z$2.92 kg^{-1}. Household labor used exclusively for all activities on 0.405ha.

Scenario B: As for Scenario A except hand cultivated rather than tractor ploughed.

Scenario C: As for Scenario B except poor season yield used (200kg ha^{-1}).

compared to cotton. This suggested, that for poor households that are short of money to invest in crop inputs, cotton was not as attractive an investment as maize. Sorghum however, showed substantially higher returns to investment in an

Table 4.14 Partial budgets for one hectare sorghum production enterprises with different input and price scenarios. 1991/92 season price data.

	Costs and returns ha^{-1}			
	Scenario A[1]	Scenario B	Scenario C	Scenario D
VARIABLE COSTS				
Seed (7.41 kg ha^{-1})	3.71	3.71	3.71	3.71
Harvest labor (@Z$2.19 day^{-1})	27.05	27.05	27.05	27.05
Weeding labor (@Z$2.19 day^{-1})	51.45	0.00	0.00	0.00
Total costs	82.80	30.75	30.75	30.75
Returns	247.50	247.50	100.38	55.63
NET MARGIN	168.75	220.20	69.63	24.88
RETURNS TO OWN LABOR	3.66	4.77	1.51	0.54
RETURNS PER HECTARE	168.75	220.20	69.63	24.88
RETURNS TO INVESTMENT	2.05	7.16	2.26	0.81

1. Scenario A: Yield level 450kg ha^{-1}. Hired labor used for harvest and two weeding rounds, Masoka price (Z$0.55 kg^{-1}) used. Household labor used exclusively for all activities, except harvest, on 0.405ha.

Scenario B: As for Scenario A except hired labor only used for harvesting.

Scenario C: As for scenario B except producer price (Z$0.22 kg^{-1}) used.

Scenario D: As for Scenario B except poor season yield (120kg ha^{-1}) used.

average season than either maize or cotton and greater returns than cotton in a poor season. We can clearly see from scenario C of sorghum why few households sell grain sorghum to commercial buyers - their returns to labor, land and their initial investment would be just a fraction of what they earn by trading within

Masoka. Returns to labor for sorghum were double the local daily wage in an average season but only one quarter the local wage in a poor season.

If we take the expected yield for each season on a each soil type, multiply it by the probability of a season type and then sum these for each season we obtain the expected returns households face for each crop on each soil (Table 4.15). Looking at the returns to land and labor, cotton was clearly a more attractive

Table 4.15 Expected returns (Z$ ha^{-1}) to land, to labor and to initial investment for maize, cotton and sorghum on each soil type.

Crop	Soil	Returns to land (Z$ ha^{-1})	Returns to labor (Z$ ha^{-1})	Returns to investment (Z$ Z$$^{-1}$)
	Bepe	951.25	8.90	5.45
Maize	Virgin jecha	802.34	7.51	4.67
	Cultivated jecha	422.56	3.96	2.64
	River jecha	1840.30	17.22	9.09
	Bepe	1314.35	11.50	1.70
Cotton	Virgin jecha	1559.68	13.64	1.93
	Cultivated jecha	719.49	6.30	1.00
	River jecha	2006.66	17.55	2.41
	Bepe	280.78	6.08	9.14
Sorghum	Virgin jecha	195.43	7.11	10.67
	Cultivated jecha	72.16	1.57	2.35

crop on any soil type than either maize or sorghum and sorghum was by far the poorest performer. The returns to labor for maize and sorghum were close for comparable soils except maize out-performs sorghum on cultivated jecha. When we look at the returns to initial investment however, a remarkably different picture emerges: Overall, cotton was easily the worst performer and the least attractive option. Returns to dollars invested in sorghum were far higher than maize except on cultivated jecha where maize returns to investment were a little higher. These findings had obvious importance for developing predictions as to what we might expect different classes of household to grow and on what soils. We might expect the poorest households to focus on sorghum production because they may still achieve a respectable return on their investment. We also might expect strongly risk averse households to focus on maize, because even in poor seasons on the poorest soil, maize yields positive returns to land, labor and to initial investment. Both cotton and sorghum however, might yield negative returns in poor seasons on cultivated jecha soils - the soil type that comprised most of the average household's land holdings. Households that try to maximize their incomes and are not labor constrained might focus on cotton as the returns to land and labor for this crop are far higher than for either maize or sorghum.

To summarize, the performance criteria developed by the VR and extended in the partial budget analysis, the VRs identified household knowledge, the availability of labor to a household, a household's access to good soils and the wealth of a household as being key determinants of a household's ability to satisfy its basic needs. Of these factors, knowledge was considered almost twice as important as any of the other factors. Households in the community were classed into one of three well-being classes; those who always satisfied their needs, those who sometimes satisfied their needs and those who seldom satisfied their needs. Households in the first of these classes were more likely to be employers of local labor whilst households in the last of these classes were more likely to be local farm wage employees. Employed households had generally lived in Masoka for fewer years and had a greater number of dependents than employing households.

The data presented in Table 4.15 provide support to the VR assessment of the importance of soils and labor; households that only had access to cultivated jecha fields were less likely to be able to satisfy their needs than those who had access to all soil types, particularly river jecha and bepe. Households that were labor constrained might not be able to either clear new fields so that exhausted jecha soils could be rested or they may not be able to meet the higher labor demands of cotton or maize. Both factors would reduce their ability to satisfy needs.

Problem formulation

In this section, the needs that VRs indicated households attempted to satisfy were quantitatively presented. These data were important in that they were used to set the household objectives to be incorporated in latter simulation analyses.

The detailed needs for an average woman, an average man and an average child are presented in Tables 4.14, 4.15 and 4.16. The importance weights placed on these needs indicated which needs a person cannot live without (weight = 5), to which needs are essentially luxury (weight = 1). The weights assigned to each month reflected the periods of greatest scarcity (weight = 1) to least scarcity (weight = 5). For both groups maize was the principle food with chickens and pumpkins also being important. There were some notable inconsistencies when comparing these data and the RIW associated with needs identified in Figures 4.5 to 4.8. In their needs calendar, female VRs identified both fresh vegetables and sorghum as being more important than pumpkins (Table 4.14) but in their needs spidergram, female VRs identified vegetables and sorghum as being less important than pumpkins (Figure 4.6). The spidergrams were developed in mid-March, a period towards the end of the growing season but where pumpkins and pumpkin leaves[12] were readily available and fresh vegetables are becoming available. The needs calendars were developed in late June when all forms of fresh food were becoming scarce. The shifts in perceived relative importance of these items is therefore, not surprising. This suggests that the importance weights that VRs associated with needs may be seasonally biased, particularly in regard to seasonally available inputs to needs satisfaction.

Female VRs suggested that women needed (used) a greater diversity of food types and needed more of each food item. Males required about one third more cash each year than women (Table 4.16). Children had approximately the same food needs as men but required only about half quantity adult males

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12 Pumpkin leaves are an important vegetable relish; a side dish used to garnish the staple food of maize meal porridge.

Table 4.16 Monthly needs, their importance weightings and monthly needs scarcity weights for an average woman.

		Month												
		J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
Scarcity Wt[1] ->		5	5	5	5	5	5	4	4	3	3	2	3	
Needs	Wt[2]													
Maize (kg)	5	20	20	20	20	20	20	20	20	20	20	20	20	240
Cash (Z$)	5	20	20	20	20	20	20	20	20	20	20	20	26	252
Fresh veg (bndls)	5			10	10	10	15							45
Salt (kg)	5	2			2			2			2			6
Dried vegetables (kg)	4	5	5	5	2	2	2	2	2	3	3	3	3	57
Chickens (whole)	4				1			1		1		1	2	6
Meat (kg)	4												15	15
Sugar (kg)	4	4	4	4	4	4	4	4	4	4	4	4	4	48
Green maize	4		120	120	60									300
Sorghum (kg)	4	20	20	20	20	20	20	20	20	20	20	20	20	240
Clothes (Z$)	4						300						60	360
Bread (loaves)	3	3			2	1			2			2	4	14
Pumpkins	3			15	15	15								45
Sweet potatoes (kg)	3				30	30	30	30	30	15	15	10		190
Eggs	2	4	3	2		2	3	1	5	7	10	4	20	61
Doves	2	2			2				2				4	10
Onions (kg)	1	5	5	5	5	5	5	5	5	5	5	5	10	65
Watermelons	1		15	30	30	30								105
Cucumbers	1	30	15	10										55
Tomatoes (kg)	1			10	10	10	10	10	10	10	10	10	20	110
Millet (kg)	1	20	20									20	20	80

1. Scarcity weight. 5 = enough, 1 = extremely short
2. Importance weight. 5 = absolutely must have, 1 = luxury and can do without.

Table 4.17 Monthly needs, their importance weightings and monthly needs scarcity weights for an average man.

		Month												
		J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
Scarcity Wt[1] ->		3	5	5	4	4	4	3	5	3	3	2	3	
Needs	Wt[2]													
Maize (kg)	5	15	15	15	15	15	15	15	15	15	15	15	15	180
Cash (Z$)	5	20	20	20	20	20	20	20	20	20	20	20	51	275
Fresh veg (bndls)	4				9	9	9	4						31
Dried vegetables (kg)	3	5							5	5	5	5	5	30
Chickens (whole)	2				1					1			1	3
Meat (kg)	2												20	20
Green maize	2		300	60										360
Sorghum (kg)	3	20	20	20	20	20	20	20	20	20	20	20	20	240
Clothes (Z$)	4						500						150	650
Sweet potatoes (kg)	2						24	24	24					72
Eggs	1						4	4	4					12
Millet (kg)	1	7	7								7	7	7	35
Fish (kg)	3	2	2	3	3	2			2	2			3	19

1. Scarcity weight. 5 = enough, 1 = extremely short
2. Importance weight. 5 = absolutely must have, 1 = luxury and can do without.

Table 4.18 Monthly needs, importance weightings and monthly needs scarcity weights for an average child (<=9 years old).

		Month												
		J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
Scarcity Wt[1]->		4	5	5	4	3	3	3	3	3	2	2	3	
Needs	Wt[2]													
Maize (kg)	5	10	10	10	10	10	10	10	10	10	10	10	10	120
Cash (Z$)	5	6	6	6	6	6	6	6	6	6	6	6	6	72
Fresh veg (bndls)	4			7	6	6	5	5	4					35
Chickens (whole)	3												.12	.12
Meat (kg)	2												3	3
Clothes (Z$)	3	45						100					150	295
Sweet potatoes (kg)	2						12	12	6					30
Eggs	2										5			5
Millet (kg)	2	1										1		2
Groundnuts (kg)	2				1	1								2
Cucumbers	1		50	40	20									110
Watermellons	2		6	6	6	6								24
Sugar cane (stick)	1			6	6									12

1. Scarcity weight. 5 = enough, 1 = extremely short
2. Importance weight. 5 = absolutely must have, 1 = luxury and can do without.

required (Table 4.18).

The RIW given to needs in the male VR spidergrams (Figures 4.7 to 4.9) appeared more consistent with the weights given to needs identified in Table 4.17 than those of the women. Maize, chickens, vegetables and sorghum were consistently rated as important needs.

For the most part, the data presented in Tables 4.16 to 4.18 cannot be validated by comparative reports as, with the exception of Stanning's work (1987a) there are no published accounts of Zimbabwean communal area household needs or objectives. The maize needs identified in Tables 4.16 to 4.18 were similar to the data published elsewhere. Jayne and Chisvo (1991) reported per capita grain requirements of 219kg while Akwabi-Ameyaw (1990) reported mean per capita maize retentions in Mufurudzi resettlement scheme for 1984/85 season of 232kg. Stanning (1987a) reported per capita maize grain retentions, in Hurungwe, of about 190kg for the 1983/84 and 1984/85 seasons but only 130kg per capita in the 1985/86 season (Stanning, 1987b). The sorghum retentions reported by Stanning (1987a) however, were very much lower than those reported by Masoka VRs.

Periods of greatest food scarcity were the months of September through January - the period immediately prior to the growing season through to the time of the first harvests. The male VR needs matrix showed November to be the month of greatest scarcity. Children have a greater proportion of months with high scarcity weights than either adult males of females (Tables 4.18, 4.16, 4.17).

SUMMARY AND CONCLUSIONS

An account of the methods of identifying key actors and groups, of establishing the needs of client groups, of identifying the components of the system that households use to satisfy needs as well as the criteria they use for evaluating needs satisfaction is presented. The results of applying these methods to an analysis of the Masoka agroecosystem are described and discussed. This study differs from reports in the literature by using local farmers to state their objectives, identify their production system and the controls they use to achieve their objectives.

Households attempt to satisfy cash and food needs from a broad range of agriculturally based, as well as some non-agricultural production activities. The relative importance of each of these needs, as well as the inputs to satisfy these needs, were identified. Major inputs to achieving good yields of maize, cotton and sorghum were identified as rainfall, soil, crop variety and labor. Each of these factors, except crop variety, were analyzed in greater detail. Household differentiation, as well the interactions among households, were shown to be important factors to include in our predictive analysis.

VRs used possibility diagrams to indicate the probability of households achieving specific yield levels of each of three crops, on particular soil types in any season class. Expected yield values were derived from these possibility diagrams and these yields compared favorably to published yield levels under similar conditions. Despite the great variability in the yields reported by the VRs, as well as those reported in the literature, the yield functions developed from VR information are considered to be reasonably accurate representations of the yields households achieve.

These yields were combined with labor input and price data to develop partial budgets for maize, cotton and sorghum. These budgets indicated the far greater profitability of cotton when considered from the perspective of returns to land and labor but when evaluated from the perspective of returns to initial investment cotton was a poor performer. From this latter perspective, sorghum was easily the best performer, except on cultivated jecha. Soil type had a notable effect on the returns to crops; maize generated the best returns on river jecha, followed by bepe; cotton generated best returns on river jecha and then virgin jecha; and sorghum returns were best on virgin jecha. Declines in soil fertility on jecha soils generally more than halved the returns from a particular crop.

VRs indicated that farmer knowledge, access to labor, access to good soils and wealth were key determinants of a household's ability to satisfy needs.

The measures used to record the VR responses to examination of their knowledge were shown to be unbiased for all cases except in collecting yield information. These biases were due to the field mapping method of eliciting yield information. The possibility scoring method provided yield distributions that were repeatable as well as being similar to published yield distributions. The pattern of yields by season, on different soil types, were also found to conform to theoretical expectations which increased our confidence in the methods and in the results.

Despite the difficulty of quantitatively testing the predictions posed earlier in this chapter, the results of these analyses provide little justification for us to accept the alternatives to the predictions:

1) That households are able to accurately describe the patterns or their environment.
2) That households can correctly describe the results they are likely to achieve using commonly used combinations of controllable inputs with different resources and under commonly experienced environmental situations.

We may therefore, conclude that our model of accurate and reliable local knowledge being essential for survival in Masoka can, for the moment at least, be accepted. We may then feel confident in using this information to develop a simulation model with which to investigate various household, community and policy level questions on the ability of households to satisfy their basic needs in the future.

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Chapter 5.

Simulation model: development, structure and testing

INTRODUCTION

"All models are wrong, but some are useful." (Box, 1979).

To make meaningful evaluations of the performance of an agroecosystem using performance criteria such as stability, sustainability, resilience, efficiency or productivity, we need a thorough understanding of the structure and functioning of the agroecosystem and the ability to predict agroecosystem behavior. In the case of Masoka, and perhaps most communal area farming systems in Zimbabwe, neither this level of understanding nor these predictive capabilities are, as yet, well developed.

The development and implementation of models can be a useful method of enhancing our understanding of the structure and functioning of complex systems (Shannon, 1975; Dent and Anderson, 1971; Wright, 1971). They may also provide hypotheses with which to test our understanding, both of the structure and of the functioning of the agroecosystem. At this early stage of our investigations, our objective is as full an understanding as is possible. We expect therefore, a model of the Masoka agroecosystem to mirror the complexity of the real world system (Wright, 1971).

The simulation of entire farming systems or agroecosystems is a complex and difficult task. Difficulties arise from a) the lack of suitable biological data; b) uncertainty in the input data and in the state of the system at any time; c) the problem of obtaining the correct balance of detail in the various components of the model; d) the propensity of farming systems to change; and e) uncertainty in the influence of the controls farmers may use to achieve their objectives (Halfon, 1979; Dent and Anderson, 1971; Wright, 1971). The difficulty of the task is reflected in the literature where no published accounts could be found of farming systems simulation models, that simultaneously simulate multiple households producing multiple crops.

Whilst there are several examples of conceptual models of agroecosystems in Zimbabwe (Swift *et al.*, 1989; FSRU, 1985), as elsewhere (Fresco, 1986), none of these models have been implemented as simulation or analytical models. Where peasant farming systems have been simulated the models are of only a single household or farm unit and most often use some form of mathematical programming (Berdegue *et al.*, 1989; Maino *et al.*, 1993; Ngambeki *et al.*, 1992) or a mixture of dynamic models and mathematical programming models (Crawford, 1982). Dynamic models of single farms or farm enterprises have been used in commercial agricultural analysis (Deybe and Flichman, 1991; Ungar, 1990) but here again mathematical programming models dominate (Kingwell *et al.*, 1992; Kingwell and Pannell, 1987). When dealing with regional studies that require information on micro-scale impacts Klein *et al.* (1989) used individual farm dynamic simulation models to generate activities that were then fed into a regional input-output model. Deybe and Flichman (1991) used a dynamic model (EPIC) to generate activities that were subsequently incorporated into a linear programming model for the region. Owsinski (1982) used a suite of linear programming models for agricultural development planning in Poland. Despite their widespread use, mathematical programming models are far from ideal for modeling agroecosystems because they have only limited capabilities for simulating temporal change in state variables and of incorporating the effects of feedback and feed-forward processes on production (Dent and Anderson, 1971).

Missing from previous modeling studies of peasant farming systems is the ability to examine the effects of household interactions on household needs satisfaction and on the biophysical resources of the agroecosystem. In virtually all of these studies, the independence of households is implicitly assumed. In Zimbabwean communal area farming systems however, inter-household sharing of equipment and labor is important (Steinfeld, 1988; FSRU, 1985). Equally important is the inter-household provision of support in drought years (Zinyama *et al.*, 1988).

Commonly, analysts simplify the task of modeling farming systems by assuming households to be homogenous. They are then justified in using aggregated data (means) to predict household performance. The heterogeneity of Zimbabwean communal area households has however, been well documented (Steinfeld, 1988; Shumba, 1988; FSRU, 1985). Debrah and Hall (1989) clearly show the dangers of using aggregated data for the development of farm plans; aggregated data grossly underestimated the income variability faced by farmers when selecting a farm plan. Individual farm yields were between two and a half and eight times more variable than aggregated yields. Thus, whilst aggregated analyses will be useful for some purposes they are unlikely to be as productive, in terms of increasing our understanding of the Masoka agroecosystem, as analyses that allow us to examine the behavior of individual households interacting with other households.

Models may take many forms. There is a considerable body of literature concerned with their classification (Naylor *et al.*, 1966; Shannon, 1975; Steiner, 1989; Vemuri, 1978). When dealing with complex and large scale systems simulation models are frequently identified as the most suitable approach to analyzing the system of interest (Anderson, 1974; Manetsch *et al.*, 1971; Naylor *et al.*, 1966; Vemuri, 1978).

There is no generally accepted definition of simulation (Pritsker, 1979). For the purposes of this study simulation is defined as "the process of designing a model of a real system and conducting experiments with this model for the purpose of either understanding the behavior of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system" (Shannon, 1975).

Models represent a synthesis of our understanding of the system of interest. The ultimate test of this understanding is our ability to accurately predict the behavior of the system, given any set of initial conditions and system inputs. This is typically called model validation. The terms verification and validation are however, often used synonymously. In this analysis, verification is used to mean the process of determining that the simulation model is working as intended whilst validation is the process of determining whether the model is an adequate representation of the real world system of interest (Sargent, 1982).

The problem of model validation is complex and has not been resolved (Balci and Sargent, 1984; Naylor *et al.*, 1966). Much of the difficulty stems from the philosophical problems of proving that a hypothesis is true (Giere, 1991; Naylor *et al.*, 1966; Popper, 1968) but also from the objectives for which the model is designed. Officer and Dillon (1968) argue that results based on classical significance tests have no relevance to real world managerial decision making because they are "absolutely devoid of any economic appraisal of real-world consequences of alternative decisions". Mankin *et al.* (1975) suggest that, by definition, all models are invalid (model behavior does not correspond to real system behavior under all conditions of interest) and we should focus on questions of usefulness, especially when the models are designed to further understanding. These authors define a useful model as one that accurately represents some of the system behavior under consideration and claim it is useless if it does not. In the business literature, the issue of validity is extended to include credibility, or the extent to which a simulation model and its results are accepted by the user and are used to assist in making decisions (Law and Kelton, 1991). Law and Kelton (1991) describe a comprehensive approach to validation based on the three stage approach of Naylor and Finger (1967).

In this Chapter I describe a dynamic stochastic simulation model of the Masoka agroecosystem. The model was developed to improve our understanding of the structure and behavior of the agroecosystem and also as part of a developing methodology for the analysis of complex agroecosytems. More specifically, the model was designed to enable me to examine the interactions among agroecosystem components and in so doing identify those which significantly contributed to a household being able to satisfy needs. It was hoped that, once fully validated, the model might assist in evaluating policy and household decision options from both a household and a community perspective.

MODEL DESCRIPTION

Overall approach

There are an infinite number of possible models of the Masoka agroecosystem. The model that was developed was the result of attempting to satisfy a changing set of modeling objectives within the constraints imposed by the abilities and world view of the modeler as well as by the available technology. In this section, those aspects of the modeler's world view that were important influences on development of the model are briefly discussed. The model was designed to be used in Zimbabwe and therefore, was designed for use on a personal computer.

The temporal and spatial scale at which the system was modeled was expected to have a significant impact on the results that were produced and the interpretations that could be made (Firbank, 1993; Meentemeyer and Box, 1987; Wiegart, 1988; Wiens 1989; Wiens *et al.*, 1986). The primary scale of interest was the scale at which Masoka residents manage their resources. Essentially, this was the scale of the field, usually between a half acre and one acre. Our hope was to model the Masoka agroecosystem at three scales. Whilst the current model went some way towards meeting this objective, the limited resolution within the household, as well as within seasons, is less than what was originally desired.

Complexity and uncertainty were considered important properties of the Masoka agroecosystem. A useful and valid representation of the Masoka agroecosystem was expected to incorporate these characteristics. Complexity was defined as the property of having interacting components with non-trivial detail at several scales. Uncertainty was defined as the inability to know or predict the outcome of some event or action, with accuracy, before the event had occurred (Anderson, 1991).

Spatial heterogeneity and spatial interactions among agroecosystem components were believed likely to be important determinants of agroecosystem behavior (Baudry, 1993; Sauget and Balent, 1993). The model was therefore, designed so that these agroecosystem attributes could be included where appropriate. Spatial interactions were not however, included in this version of the model.

As discussed in Chapter 4, knowledge of the goals, objectives and experiences of Masoka residents were essential building blocks for our understanding of the agroecosystem. The model was, therefore, developed to incorporate both local farmer knowledge as well as formal scientific knowledge.

The models presented in this chapter were the result of numerous false starts, the exploration of several paths of investigation and multiple iterations of model development. These were essential precursors to the models presented in this chapter. Not all of the capabilities that were originally planned were incorporated into the model but where these were considered important, the model was designed so that these aspects could be added in the future.

Model overview

The Zambezi Valley Agroecosystem Model, (ZVAM) comprised three main sub-models (Figure 5.1): An initializing model (INITIAL), a rainfall generating model (RAINGEN) and an agroecosystem simulation model (MASOKA1). Both INITIAL and MASOKA1 used ASCII data layers (maps) developed using a geographical information system (GIS). GIS data layers were in raster format with cells (pixels) of 64m. INITIAL was used to generate a number of households, each with a

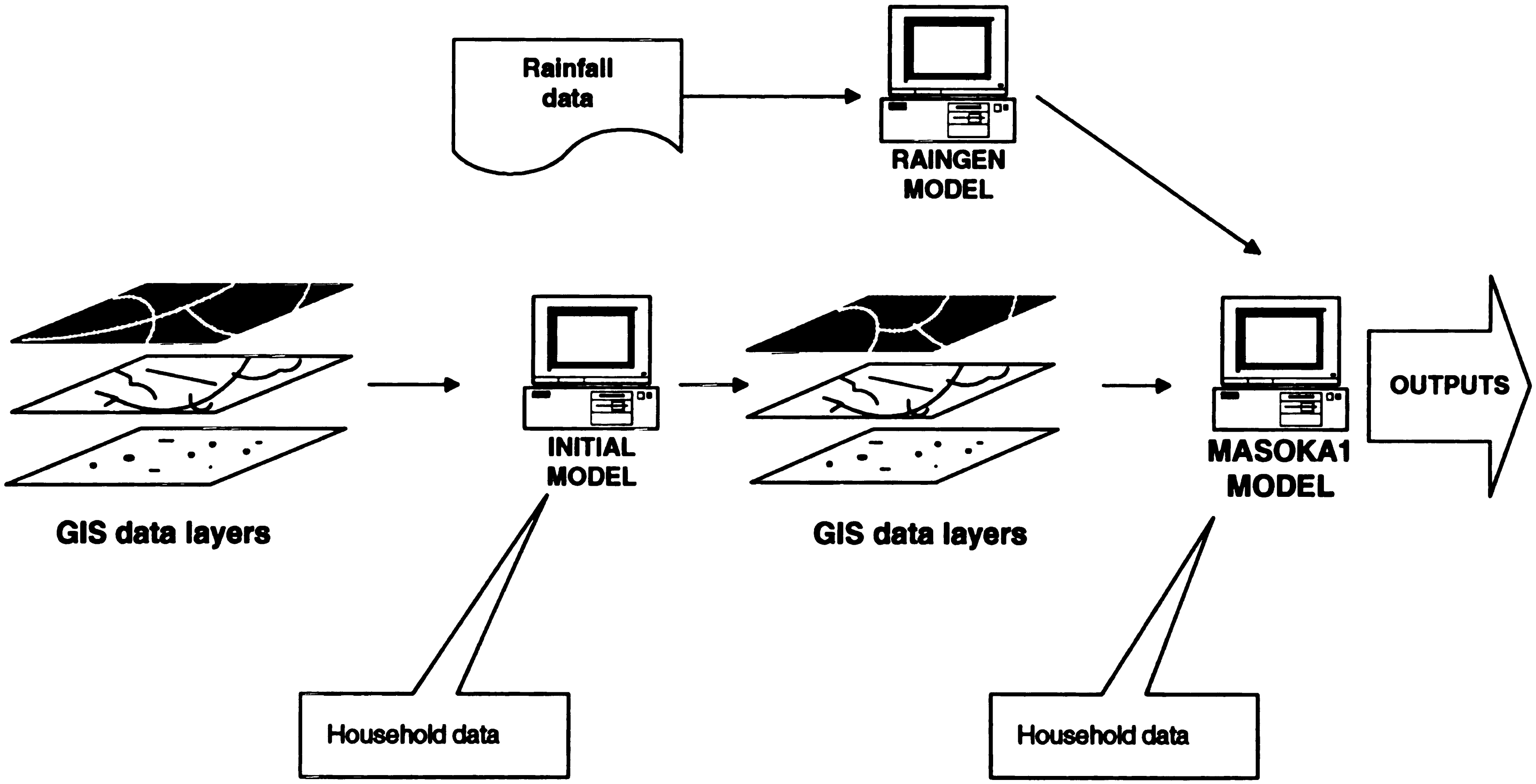

Figure 5.1. Major components of the Zambezi Valley Agroecosystem Model (ZVAM).

randomly generated number of adults, children, upland[13] cells and riverland cells.

INITIAL also randomly placed households on the Masoka landscape and located household fields around the household site (non-riverland cells) and along the river. Output files from INITIAL were used as input files to MASOKA1 (Figure 5.1).

RAINGEN was used to generate an annual rainfall amount based on a gamma distribution. The rainfall was written to an ASCII file for use by MASOKA1.

MASOKA1 read in household and biophysical data from the files created by RAINGEN and INITIAL as well as the slope file created in the GIS. Up to 300 households could be simulated at a time over an area of about 1500 ha and with an annual time step. The population of households and the number of adults and children in a household were kept constant within any simulation. The number of fields households owned also remained constant in any simulation. Households could vary the number of their fields they planted in any season and the crops they planted. Values in each cell (n=3695) of the landscape (soil erodibility, crop yield, yield potential, crop cover) were updated once each growing season (October to April). MASOKA1 used an erosion model developed by Elwell (1980) and estimated erosion for each cell.

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[13] Upland cells were those jecha cells inside the fenced area and on the older alluvial terraces. Riverland cells were those lands outside the fence on the most recent alluvium.

Rainfall generating model (RAINGEN)

Fifteen years of rainfall data from Angwa Bridge were used to generate the two parameters (alpha and k) required to describe annual rainfall with a gamma distribution. The algorithm of Naylor *et al.*, (1966) was used to generate a gamma random variable with mean = 725mm and k = 10.9.

Naylor *et al.* (1966) suggested estimating alpha by setting alpha equal to the mean annual rainfall divided by the variance in the mean. For the Angwa Bridge data this yielded an alpha value of 0.011866. These authors also suggested setting k equal to the square of the mean annual rainfall divided by the variance, yielding 8.6 for the Angwa Bridge data. Hutchinson and Unganai (1992) provide a regression equation (r^2 = 0.832) to estimate the k parameter of the gamma distribution for annual rainfall in Zimbabwe:

$$k = 0.7004 + 0.0141 * MAR$$

Where	k	=	the shape parameter for the gamma distribution and
	MAR	=	the mean annual rainfall in millimeters.

This equation yields a k value of 10.9 for Angwa Bridge. Given the paucity of rainfall data for Angwa Bridge this general function was considered preferable to using the methods of Naylor *et al.*, (1966) to derive the k parameter. The alpha value used in RAINGEN was set equal to k / mean (i.e. 0.015). In generating the gamma variate the subroutine was coded to generate an integer number of exponentially distributed variates. The integer was set equal to the rounded value of k (i.e. 11).

Initializing model (INITIAL)

The purpose of INITIAL was to generate households with size and land holding characteristics from known distributions and then to randomly place these households on a GIS data layer of Masoka that could be read into MASOKA1 as an input file. INITIAL also generated random cropping histories (the number of years cultivated) and vegetation cover (%) for each cell in the landscape. Randomly generated households patterns were used to facilitate more general analyses. As simulation results had implications, both good and bad, for individual households it was considered inappropriate to use real household data in simulation experiments.

Household size generation and household field allocation

Prior to running INITIAL a household site suitability data layer and a field suitability data layer were created. The suitability index of a site for household residence was based on distance from the Angwa river (the primary source of water for most households), the soil type and the slope. A data layer of distances from the Angwa river was created with 250 meter distance classes scored from one to 10 with increasing distance from the river. Slope was re-classed into 10 slope classes with class one representing areas with slopes between 0 and 1.999%, class two representing areas with slopes between 2 and 2.999% and so on. The tenth class included all areas with slopes greater than, or equal to, 9%. Riverland, riverine, bepe and sodic soils were re-classed as zero values. The remaining soils (jecha, elevated and mopane soils) were re-classed as follows: Jecha soil was classed as one, elevated soil as five and mopane soil as eight. These values reflected the analyst's judgement as to the relative desirability of these soils for household sites with the lowest values being best. These three data layers were then overlaid by multiplying the individual cell values for each of these factors. The lowest, non-zero, scores in the resulting data layer reflected the best household sites.

A data layer of a field suitability was generated based on soil type and slope. Areas with slopes less than 6% were scored with a one and all other areas with a zero. Bepe, jecha and elevated area soils were scored with a one, riverland jecha scored with a two and all other soils scored with a zero. The field suitability index data layer was created by multiplying these two data layers (slope and soil) together (i.e. they were overlaid by multiplying the values). Sites were therefore classed as being zero, one or two. Non-zero classes were suitable for cultivation. By giving riverland and non-riverland cells different identifiers they could be differentially allocated to households.

Once executed, INITIAL searched for the lowest scores of the household site suitability scores and placed households on those cells. Then, in a clockwise direction INITIAL would search for cells immediately adjacent to the household site that had a cultivation suitability score of one (i.e. were non-riverland) and were not already owned. These were allocated to the household being initialized by giving the cell the household number in the HSESITE.IMG file. If the household's cell quota (the number of hectares of non-riverland that a household was allocated represented as a number of cells) was not fulfilled then the search was expanded to the next ring of cells around the house site and once again INITIAL searched clockwise for suitable cells. This procedure was repeated until a household's quota of cells were allocated or the number of search layers exceeded 20 (i.e. equivalent to 1.28km in all directions from the household site). For households that had riverland fields, INITIAL searched row by row across the data layer until available riverland cells (cultivation suitability score of two) were found to allocate to that household. The data layer or map of fields for every household was saved (HSESITE.IMG) for use as an input file to MASOKA1.

The number of cells of land to be cultivated and the number of riverland cells to be cultivated by each household were randomly generated from the distributions observed in Masoka. The distributions of areas cultivated by number of adults were taken from the questionnaire survey data described in Chapter 3. The number of fields (hectares) of riverland cultivated per household were derived from data provided by the VRs. These data were a list of all households that owned or used riverland fields, the number of adults and children in the household and the size of the riverland fields. The number of adults and children in each household were randomly generated from distributions derived from the questionnaire survey data described in Chapter 3. The number of non-riverland cells that a household cultivated as well as the number of riverland cells that a household had under its control could be increased or decreased using a separate multiplier for each land type.

Cropping history

INITIAL allocated a randomly generated number of years of previous cropping to each cell. These random variates were normally distributed and generated using the function:

$$CULT = INT\ (1 + (UL - LL) * RND)$$

Where CULT = The number of years that cell had been previously cultivated;

INT = A function returning a rounded integer;

UL = The maximum number of years cultivation was likely to occur on that soil type;

LL = The minimum number of years cultivation was likely to occur on that soil type;

RND = A pseudo random number from a standardized normal distribution (zero mean and variance = 1).

The lower and upper limits were derived from the VR data.

Vegetation cover

Two measures were aggregated to develop a random vegetation cover generator for each cell of the Masoka landscape. The first was an estimate of tree cover and the second was an estimate of grass and herb cover. The following procedure was used to estimate tree and shrub cover: A transparent, 2.5mm grid was placed on 1:9750 air photographs of Masoka. Five samples each were taken for jecha, bepe, elevated ground, mopane and hilly soil types. Four samples were taken for riverine and two for sodic soils. Each sample comprised a block of 25*25, 2.5mm squares that were randomly selected so as to cover an area of the soil type of interest. Within these squares the number of grid lines that intersected over a tree or bush were counted to yield a percentage tree cover for the sample. Mean and standard deviation tree cover values were calculated for each soil type from these samples.

Estimates of grass and herb cover were based on field measurements made in Masoka in October, 1992. Three transects were marked across a cultivated, alluvial terrace and four across an uncultivated, alluvial terrace (both with bepe and jecha soils). Transects on each alluvial terrace were between 300 and 350 meters long, parallel, and 100 meters apart. Point samples of the cover class were made every five meters along each of these transects. Cover classes were bare ground, litter, grass, tree or burnt ash. The means and standard deviations of these measurements were used to develop the natural vegetation grass and herb cover values.

Final cover values were generated by creating a function for each soil type of the form:

$$C = GM + GS * RND + TM + TS * RND$$

Where	C	=	Total vegetation cover (%)
	RND	=	A pseudo random number from a standardized normal distribution (zero mean and variance = 1)
	GM	=	The mean cover of grass and herbs (%)
	GS	=	The standard deviation of cover for grass and herbs (%)
	TM	=	The mean cover of trees and shrubs (%)
	TS	=	The standard deviation of cover for trees and shrubs (%).

Outputs from INITIAL

INITIAL generated six output files (Figure 5.2). Three of these were GIS data layers with values for cell of the landscape. The first of these data layer files (HSEITE.IMG) was a data layer of all household fields. The second of these images (COVER.IMG) was the vegetation cover data layer and the third (FERTIL.IMG) was a data layer of the number of years each cell had been cultivated. Of the remaining three files the first was an ASCII file (HOUSEHLD.DAT) with the household number,

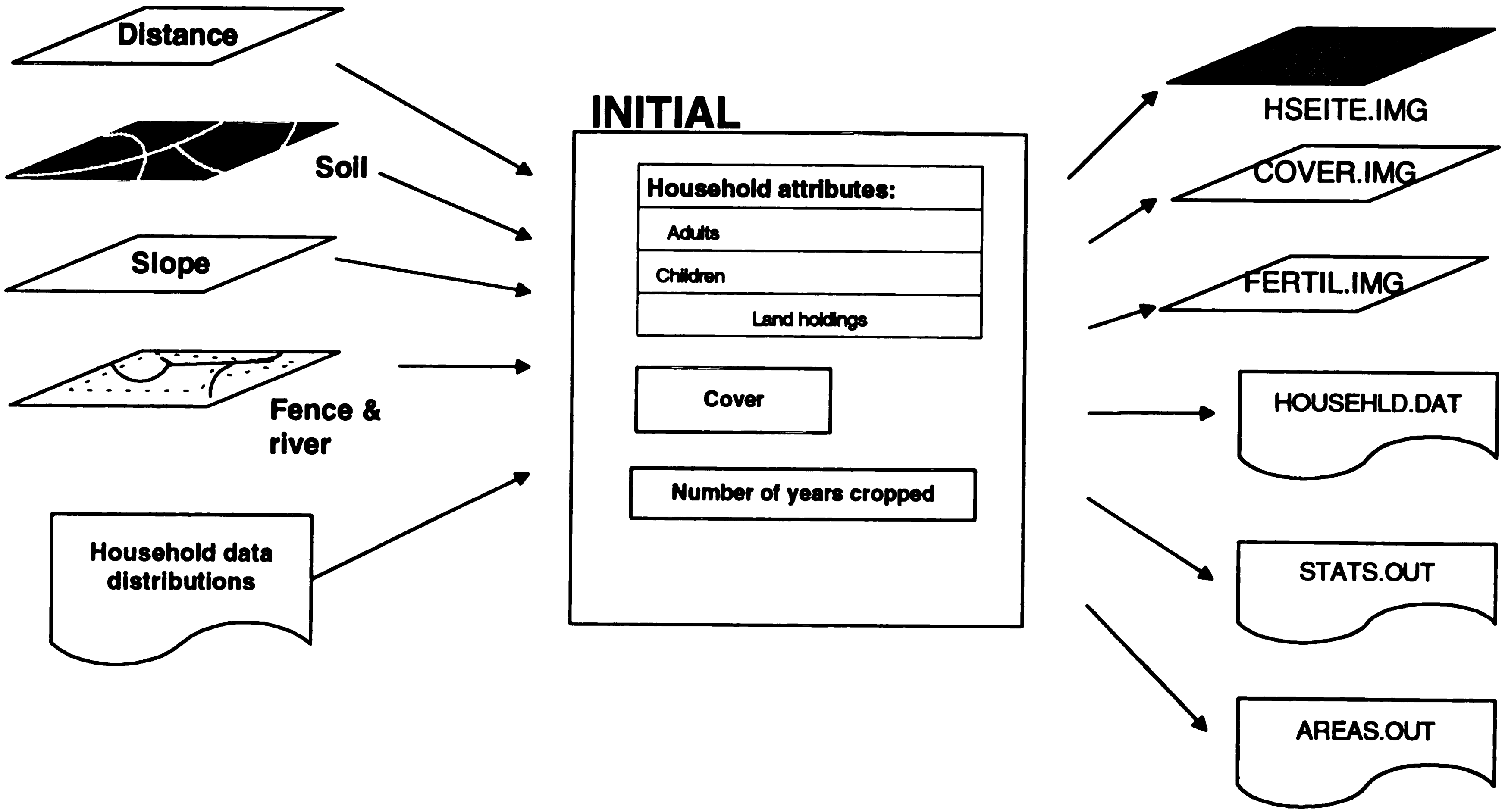

Figure 5.2. Input and output files for the initializing model (INITIAL).

the number of adults and children in the household as well as the number of non-riverland cells and riverland cells the household owned. The second output file (STATS.OUT) was used to write goodness of fit test statistics for the number of adults and children per household. The third output file (AREAS.OUT) was used to record the total areas of cultivation, areas of riverland cultivation, the number of cells cultivated, the number of riverland cells cultivated and the total number of adults and children in the landscape.

Agroecosystem model (MASOKA1)

MASOKA1 read in five GIS data layer files (slope, soil type, field and household sites, vegetation cover and the number of years of cultivation) and two ASCII data files (household data and rainfall, Figure 5.3). Conceptually, the model has seven major sub-systems or components (Figure 5.3): a STORAGE sub-system, an ALLOCATIVE or decision making sub-system, a LABOR sub-system, a CROP sub-system, an EROSION sub-system, an ECONOMIC sub-system and an OUTPUT sub-system. The sequence of activities in MASOKA1 are outlined in Figure 5.4.

The STORAGE sub-system

In the STORAGE sub-system household needs were established and household production (maize, cotton and sorghum) was compared with these needs. Production could be converted from one form to another based on the

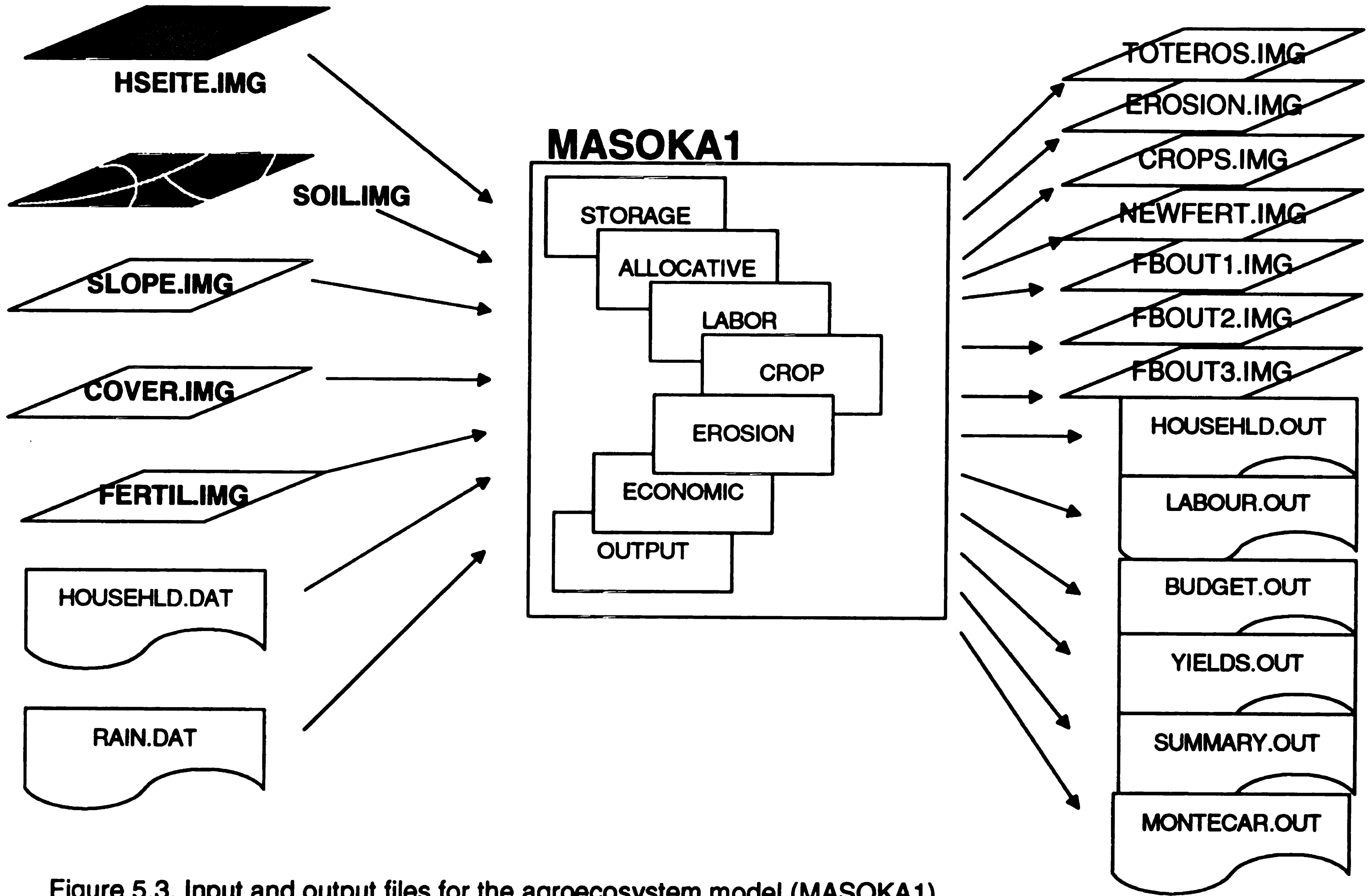

Figure 5.3. Input and output files for the agroecosystem model (MASOKA1).

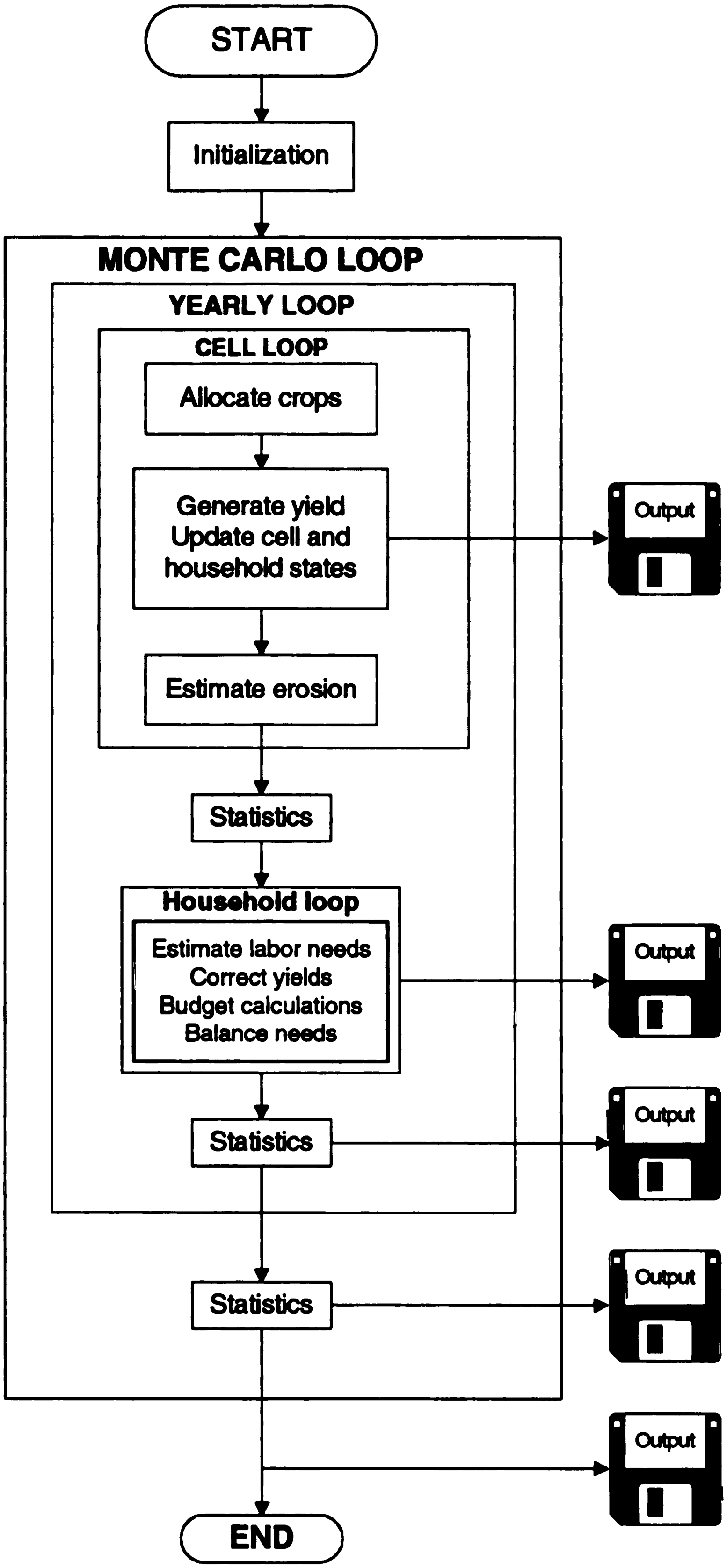

Figure 5.4. Sequence of major components of MASOKA1.

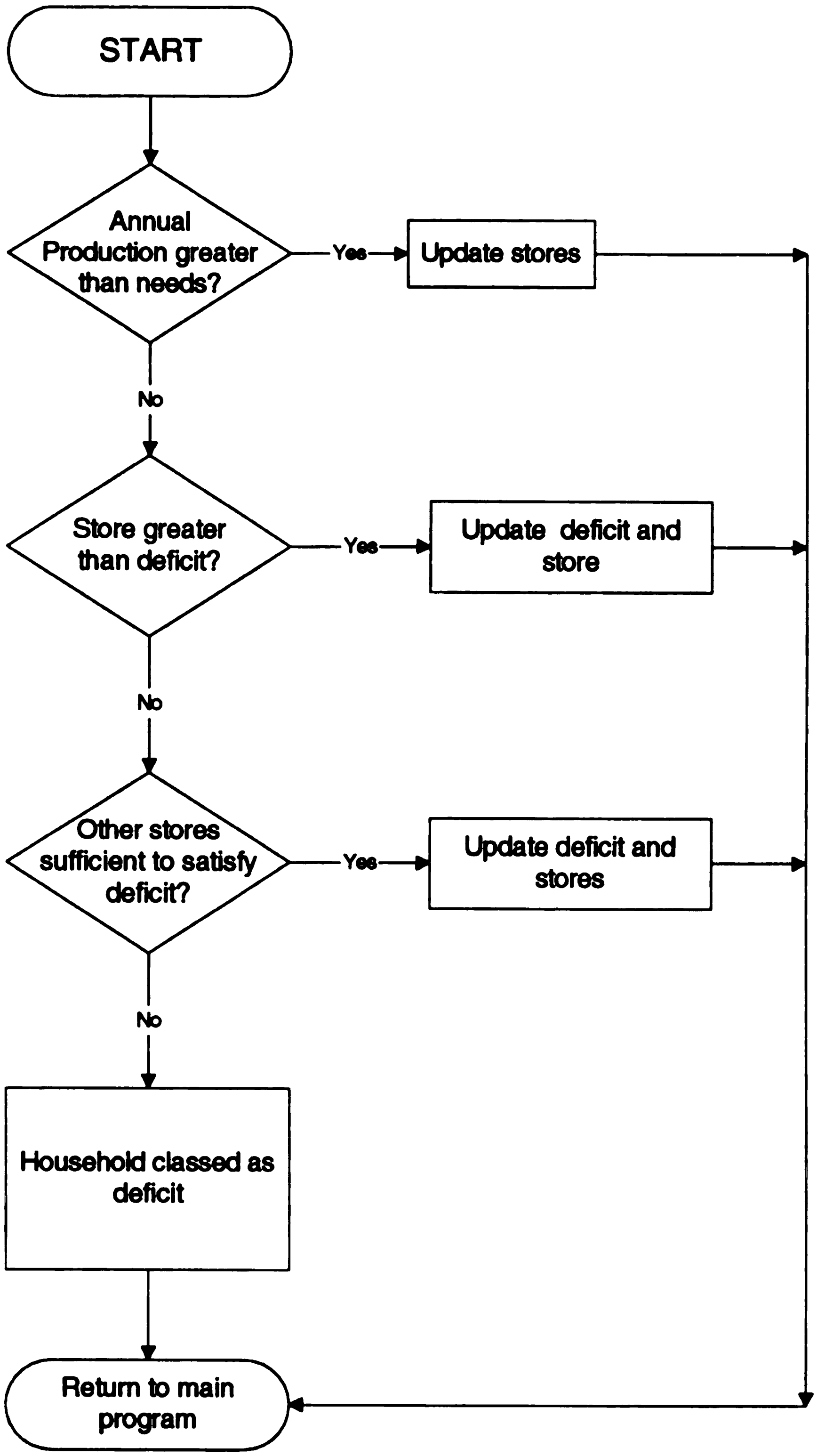

Figure 5.5. Flow chart illustrating sequence of events in STORAGE sub-system.

prices used in the model (Figure 5.5). For most simulations these were the local, Masoka cash prices. Production in excess of needs was placed in storage, from which there was no loss. If household needs could not be met from production an attempt was made to meet them from storage (including using cash stores to purchase needs). If this was not possible the household was considered deficit for that particular need.

The ALLOCATIVE sub-system

The ALLOCATIVE sub-system allocated each household to a production and to a tillage strategy. Fixed proportions of households were allocated to each strategy at the beginning of each simulation. Households maintained the same strategy for the duration of the simulation. The production strategy governed what crops a household grew, the proportion of cells that the household planted to each crop and household fallowing practices. Tillage strategies governed whether a household used hand or tractor cultivation (tractor cultivation was only used on cotton and had no impact on yields and whether a household planted with, or at an angle to, the contour. These factors were important only in their effect on erosion.

Four production strategies could be used in any simulation. These strategies differed in the parameters that defined: a) the proportion of fields households planted to each crop; b) the number of years a household cultivated a field before leaving it fallow; and c) the proportion of fallowable fields households

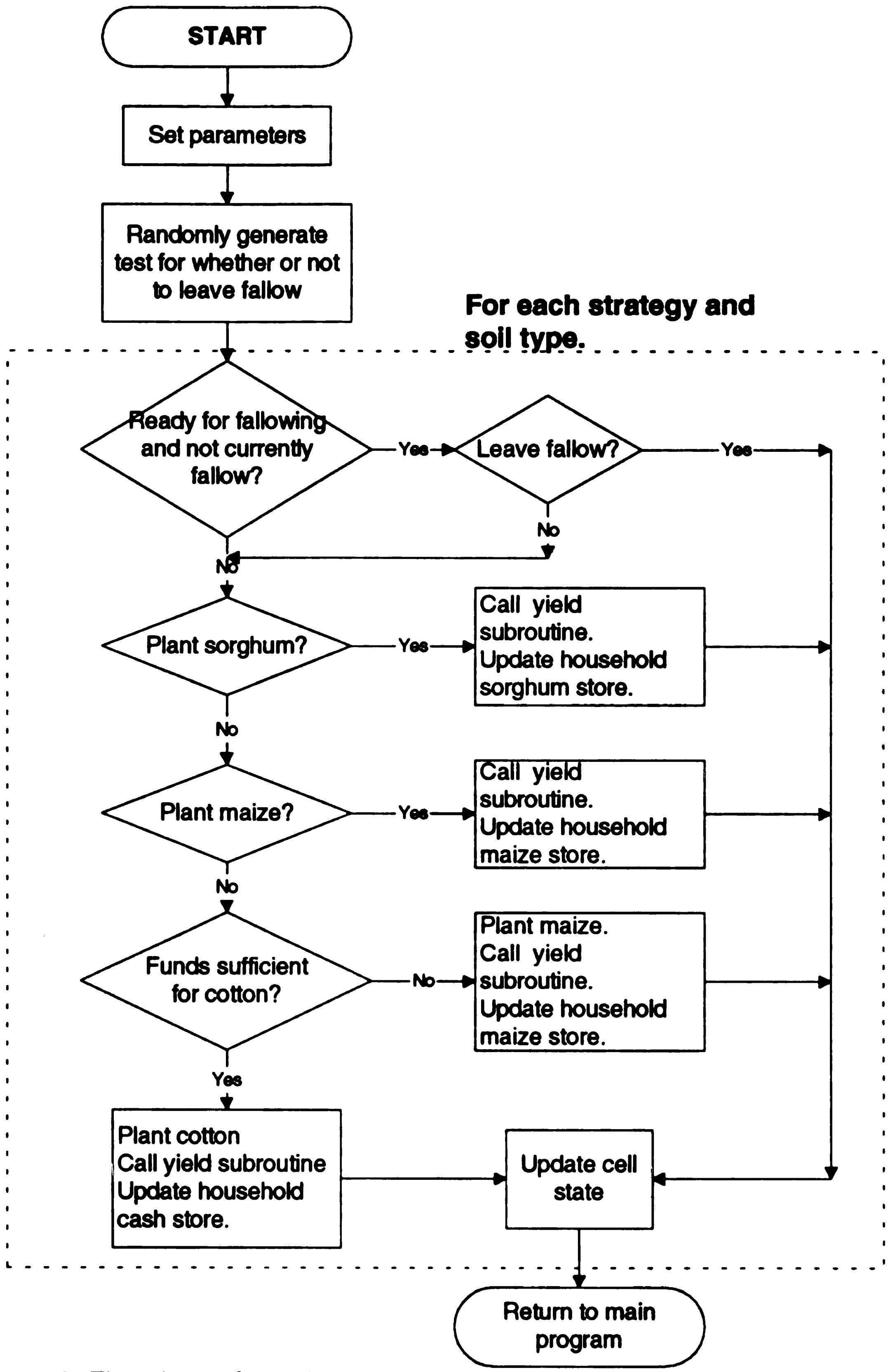

Figure 5.6. Flowchart of activities in the ALLOCATIVE sub-system.

actually left fallow each year (Figure 5.6). These parameters were important control variables that could be set for any simulation experiment.

Households planted a fixed proportion of their fields to each crop in each year. These proportions were fixed for each production strategy. Whilst not a realistic representation of household decision making the use of fixed proportions simplified model development. The model was designed so that more complex cropping decision patterns could be incorporated at a later date. For sensitivity analyses only two strategies were used, income maximizers (INCMAX) and needs satisfaction variance minimizers (MINVAR). INCMAX households produced a higher proportion of cotton (50% of cells on all soil types), planted little sorghum (15% of jecha cells) and used shorter fallow periods (minimum cropping period four years, maximum of 10 years) than other households. MINVAR households planted mostly maize (50% of bepe and river jecha and 35% of jecha cells) with a little cotton (50% of bepe and river jecha cells) and sorghum (35% of jecha cells) and used longer fallow periods (minimum cropping period of four years and a maximum of seven years).

The decision whether or not to leave a particular field fallow was only pertinent on jecha soils; neither bepe nor riverland soils were left fallow. The decision to leave a field fallow was a probability based on the household production strategy and the number of years the field (cell) had been cultivated. In Figure 5.7 the cumulative probability curves of a household leaving a jecha field fallow are shown for each production strategy. An income maximizing (MAXINC) household, for example, would not leave a field fallow before the field had been cultivated for at least four years. Thereafter, the probability of leaving a field fallow increased with increasing cultivation until, after ten years of cultivation the probability of leaving the field fallow was one. Other production strategies used different cumulative probability curves reflecting what I believed were reasoned approximations of some likely approaches to fallowing (Figure 5.7).

The LABOR sub-system

In the LABOR sub-system available household labor for each month of the growing season was estimated by multiplying the number of adults by 25 working days in the month. Based on Reynold's data (Reynolds, 1991) 44% of children were considered to be in the age group that contributes to the labor force (10 to 20 years of age). Children were considered to provide labor equivalent to 42% of an adult. This value was a mean of the proportions given by Reynolds (1991) for clearing, planting, re-planting and weeding.

Once a household's fields had been planted to a crop the LABOR sub-system identified the labor requirements (person days) in each month of thegrowing season (October to March) based on the VR labor budgets presented in Chapter 4. These requirements were compared to household labor availability. If households were labor deficit and they had cash or grain balances they could search for available labor from other households (Figure 5.8). Households that had labor greater than their needs and were deficit in cash or maize could supply labor

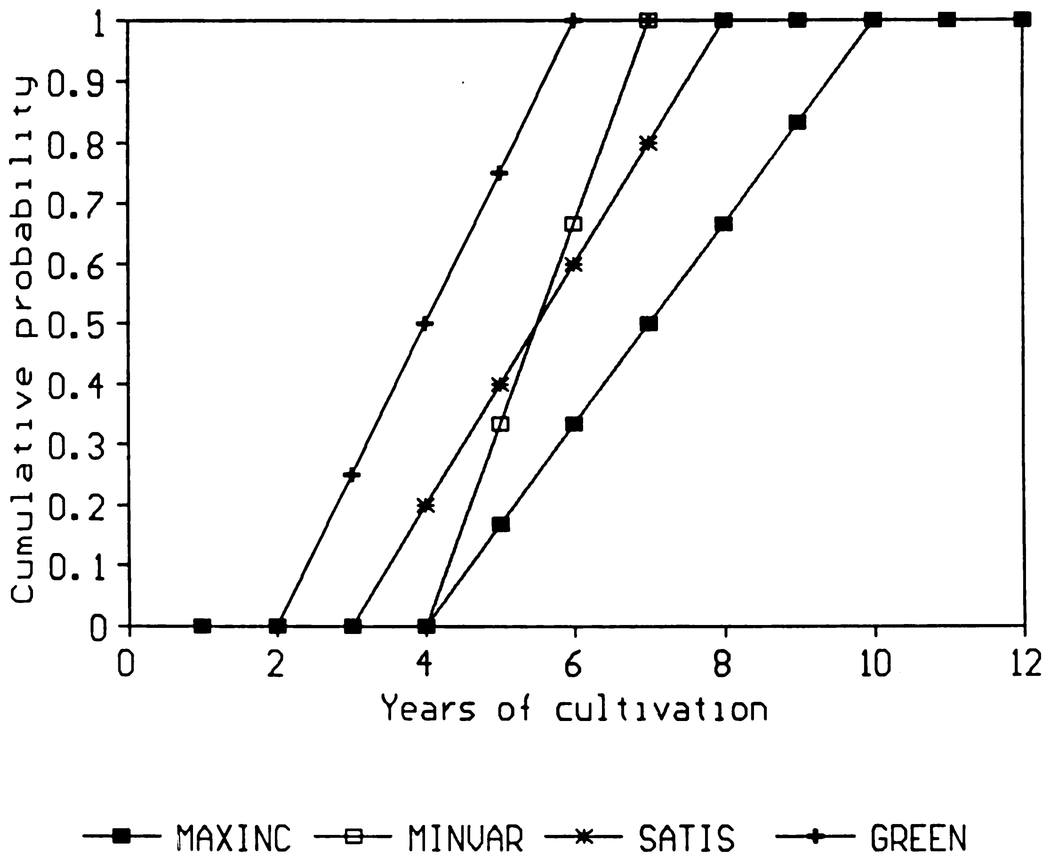

Figure 5.7. The cumulative probability of leaving a jecha field fallow for households using income maximizing (MAXINC), variance minimizing (MINVAR), needs satisfying (SATIS) and environmentally protective (GREEN) production strategies.

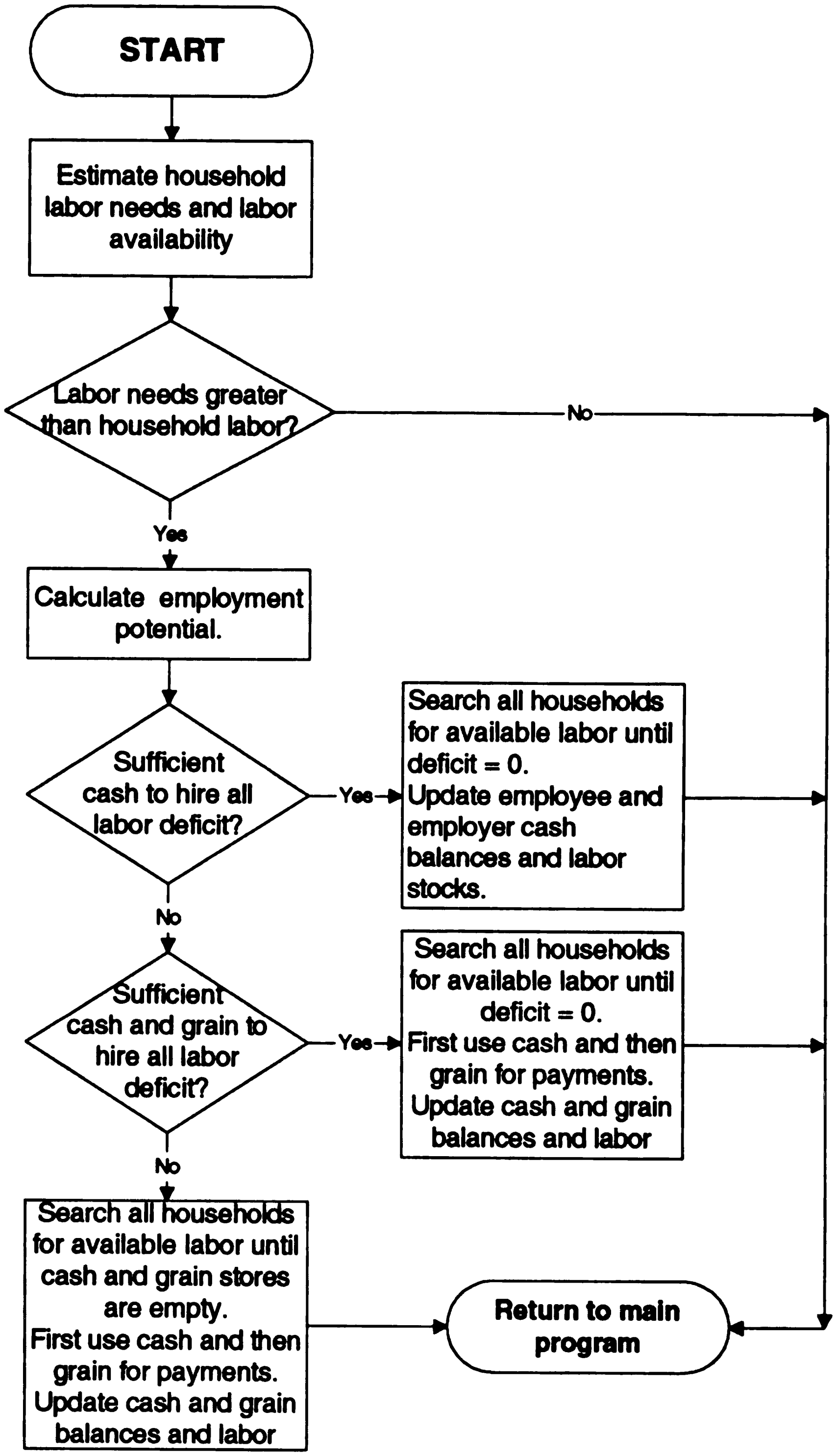

Figure 5.8. Flowchart of major activities in the EMPLOY component of the LABOR sub-system.

to households that were labor deficit. Labor was hired from other households at the local wage rate (Z$2.54 day^{-1}) in cash or grain equivalent calculated using the Masoka prices for maize. Sorghum was not used to pay for hiring labor. When labor was employed the labor balances of both the employing and the employed households were updated.

If households were still labor deficit, either through there being no available labor or through not having the resources to hire labor then the yields of each crop were adjusted. Where labor deficits occurred the resulting yield reductions were first allocated to sorghum, then to cotton and finally to maize (Figure 5.9). Thus, if the total labor deficit was less than the total labor required for sorghum then only the sorghum yields were corrected. If the total labor deficit was greater than the labor required for sorghum then as much of the deficit as possible was used on sorghum before yield reductions were made on cotton. The reduction in yield due to labor deficits was calculated as the product of the proportion of labor needs that were deficit times the yield reduction for that time period expressed as a proportion.

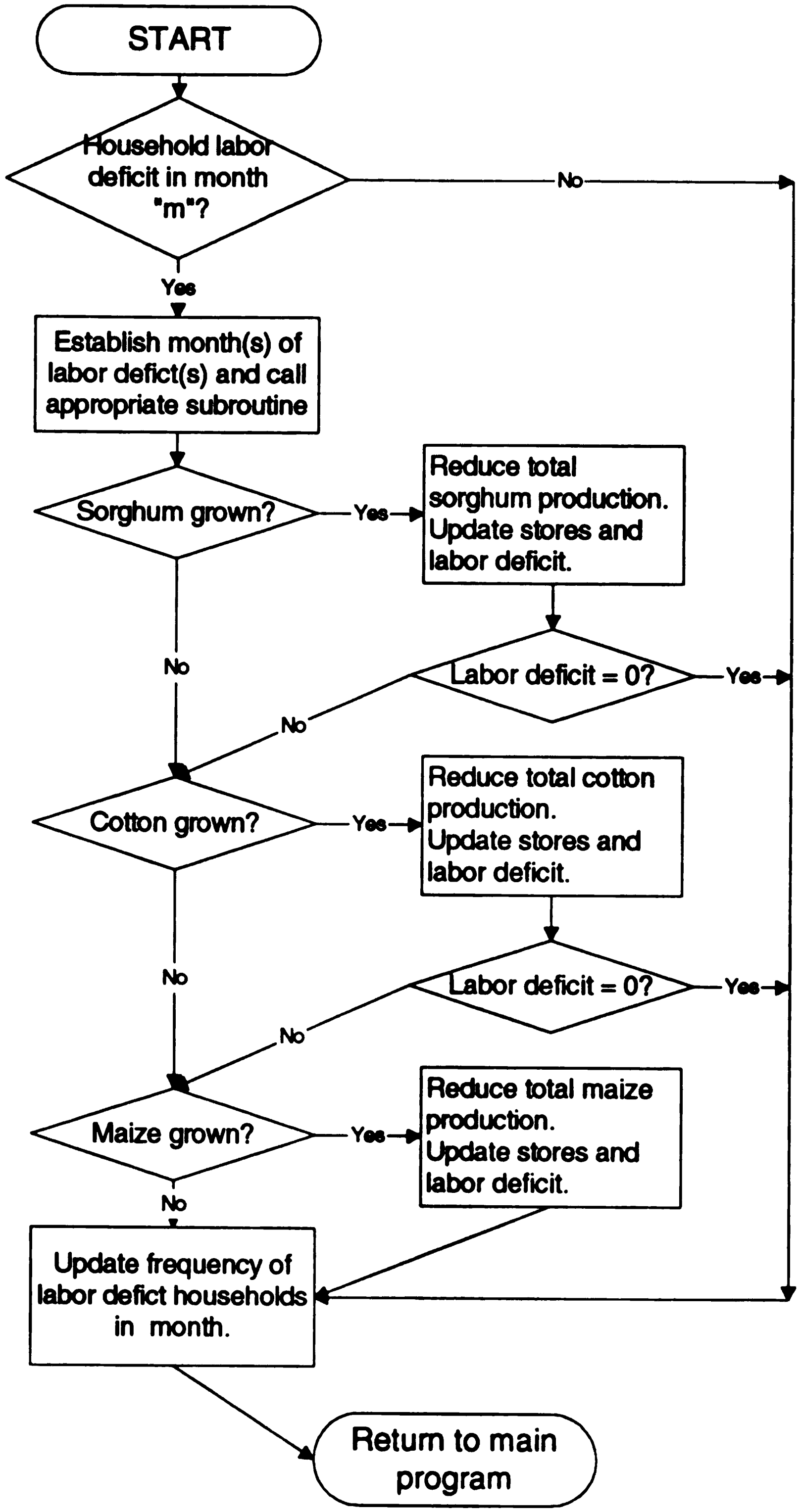

Figure 5.9. Flowchart of major activities in yield correction component of the LABOR sub-system.

Final yield (Y_f) was expressed as:

$$Y_f \quad = \quad Y_i - (Y_i * LD * YR)$$

Where Y_i = the initial, uncorrected yield. LD = the labor deficit expressed as a proportion of the required labor.

YR = the yield reduction factor expressed as a proportion of the uncorrected yields.

For sorghum the yield reduction factors were based on the results of Burnside and Wicks (1967). Sorghum was assumed to be planted in mid-November. A labor deficit in December led to a 12% yield reduction. A deficit in December and also in January resulted in a 36% yield reduction. A labor deficit in January (but not in December) led to a 3% yield reduction.

Yield reduction factors for cotton were derived from Buchanan and Burns (1970) and Schwerzel and Thomas (1971). Cotton was assumed to be planted at the beginning of December. A labor deficit in December reduced yields by 13%. A labor deficit in December and in January resulted in a 54% yield reduction. Labor deficits in December, January and February reduced yields by 100% as did labor deficits in December, January, February and March. A labor deficit in January (but not in December) reduced yields by 56%.

Yield reduction factors for maize were derived from Hall *et al.* (1992). Maize was assumed to be planted in November after the first rains. A labor deficit in November had no effect on yields. A labor deficit in December reduced yields by 10%. A labor deficit in December and January reduced yields by 35%. If there was also a deficit in February then yields were reduced 45%. A deficit in January (but not in December) reduced yields by 25% whilst a deficit in February (but not in December or January) reduced yields by 10%.

The CROP sub-system

Yields for three crops, (maize, cotton and sorghum) were generated in MASOKA1. Households planted their fields (cells) to one of these crops (or left the cell fallow) each year (Figure 5.10). Yields, for each of these three crops, were a function of soil type, time since fallow (on jecha soils only) and rainfall season. Yield functions were derived from the yield possibility diagrams developed, by the VRs, for each crop, soil and season combination.

To derive a rainfall season from the annual rainfall amount generated by RAINGEN membership functions for good, average and poor seasons were derived, using fuzzy set membership functions. Good, average and poor seasons were considered to be fuzzy sets. The membership functions described the relationship between annual rainfall amount and the degree of membership in each of these sets. Annual rainfall amounts had graded membership, from zero (not a member) to one (full member) in one or more of these sets. The data on Masoka

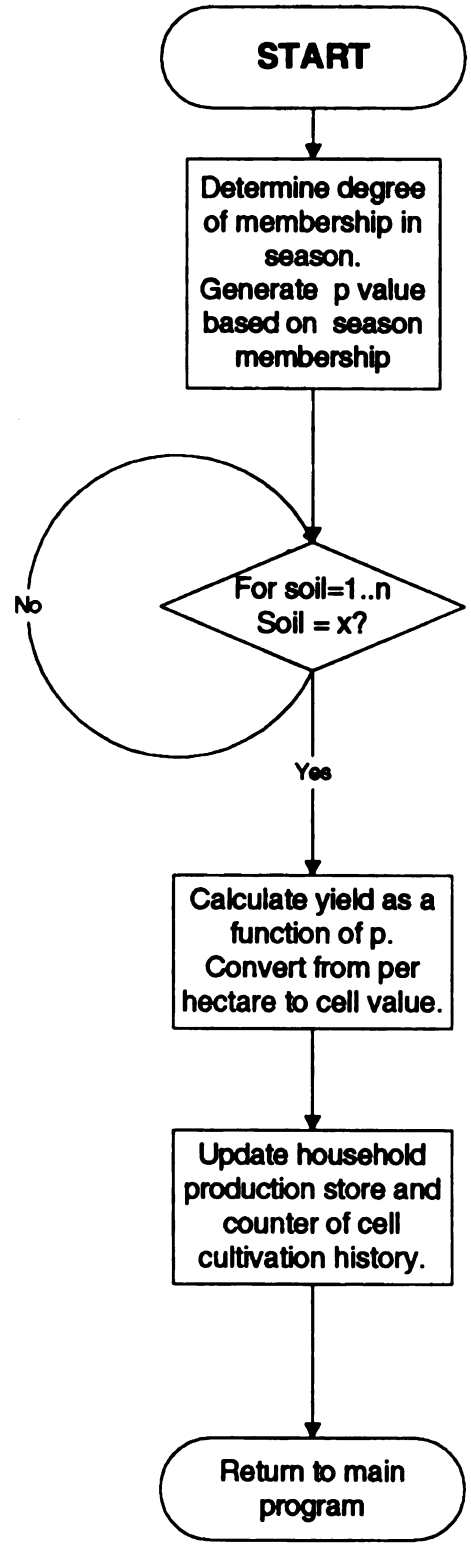

Figure 5.10. Flowchart of major activities in CROP sub-system.

resident classification of each season (Chapter 4, Table 4.2) were used to derive the membership functions for good and poor season. The proportion of respondents allocating each rainfall year to a particular season class (good, average or poor, Table 4.2) were plotted against Angwa Bridge rainfall (Figure 5.11). Clear peaks were discernable for a good season (1000mm) and a poor season (500mm) but the trends for an average season were not at all clear. These peaks were used to define the boundary of rainfall amounts that were definitely members of the set of either good or poor seasons. Thus, for any rainfall amountless than or equal to 500mm the membership of that rainfall amount in the set of poor seasons was set equal to one ($ux_{poor} = 1$). For any rainfall amount greater than or equal to 1000mm the membership of that amount in the set of good seasons equalled one ($ux_{good} = 1$). For any rainfall amount greater than 500mm but less than 600mm the degree of membership of that rainfall amount in the set of poor seasons declined according to the membership function fitted to the curve shown in Figure 5.12. Initial tests of model yield predictions found good season yields to be consistently more than predicted yields when comparing the simulated means with those derived from the VR distributions. To reduce this deviation from the expected means the value at which $ux_{good} = 1$ was increased to 1124mm. With this correction simulated mean and median yields were closer to the expected values. For any rainfall amount less than 1124mm but greater than 767mm the degree of membership in the set of good seasons declined according to the function fitted to the good season curve shown in Figure 5.12. These curves

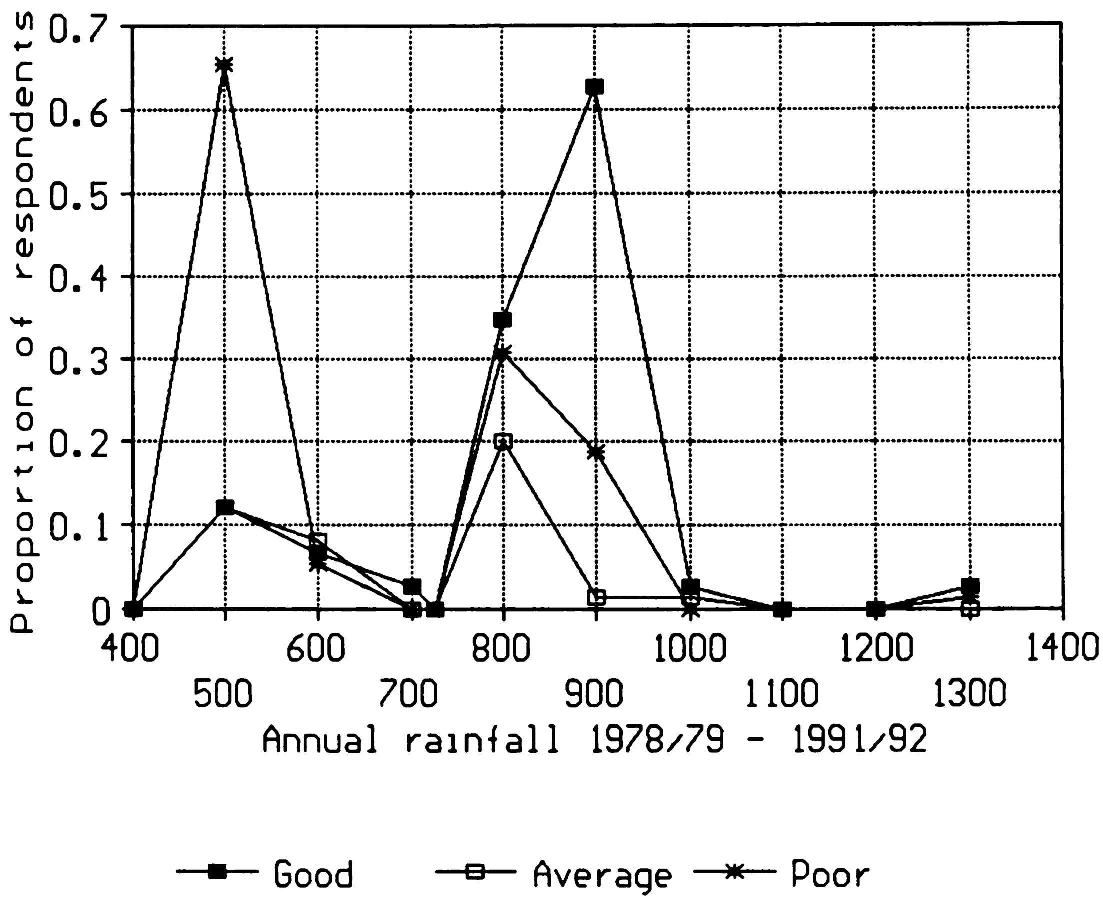

Figure 5.11. The proportion of respondents allocating each growing season from 1978/79 to 19911/92 to good, average or poor seasons plotted against the rainfall for that season measured at Angwa Bridge. Rainfall data from the Department of Meteorological Services, Harare.

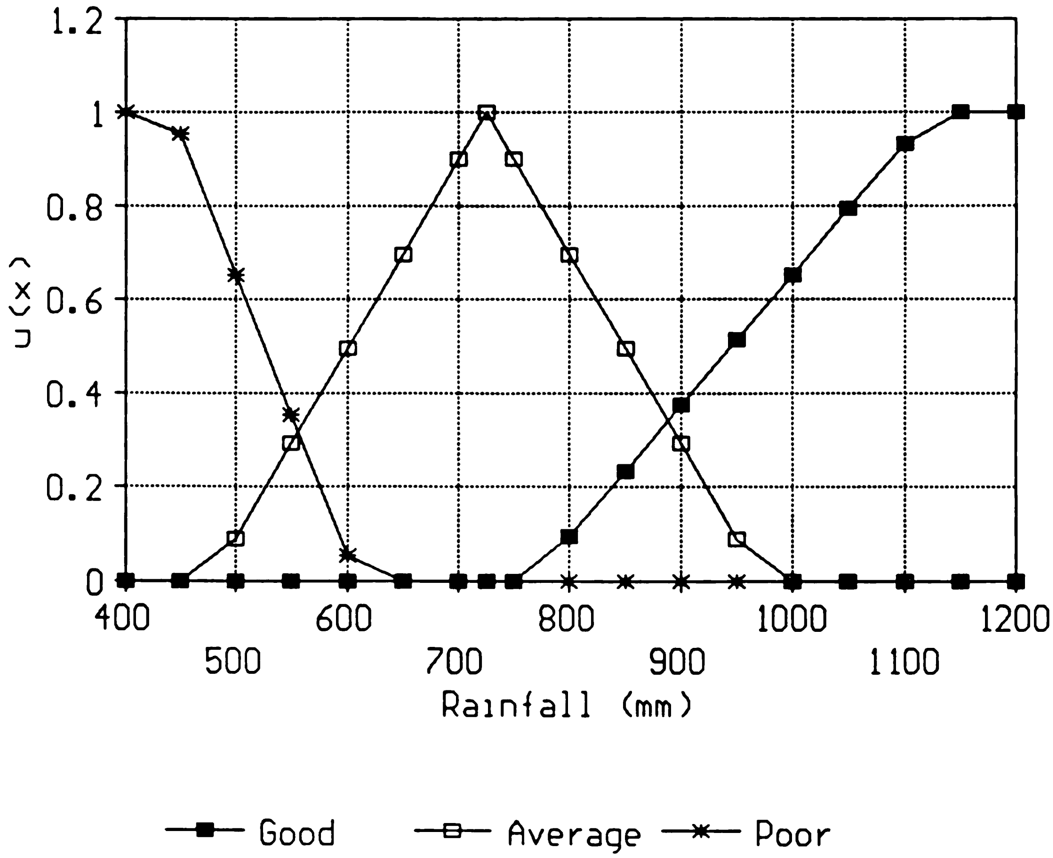

Figure 5.12. Membership functions for good, average and poor seasons used in MASOKA1.

describe the membership functions for good and poor seasons and were defined as follows:

u_{poor}	=	**5.592 - rain / 108.89**	500 <= rain < 600
	=	**1**	rain < 500
	=	**0**	otherwise
u_{good}	=	**1**	**rain >= 1124**
	=	**rain / 357.14 - 2.15**	767 <= rain < 1124
	=	**0**	otherwise

Where rain = The annual rainfall in millimeters.

Because there was no clear trend with which to describe the average season membership function the mean annual rainfall (725mm) was identified as having a membership of one in the set of average seasons. The membership function was then described so the lower and upper boundaries of annual rainfall events, that were members of set of average seasons, occurred plus or minus one standard deviation (247mm) from the mean (i.e. 478 and 972mm). The membership function for the set of average seasons was therefore:

$u_{average}$	=	**rain / 247 - 1.935**	478 < rain <= 725
	=	**3.935 - rain / 247**	725 < rain <= 972
	=	**0**	otherwise

The maximum membership value was used to class seasons when a rainfall amount had membership values greater than one in more than one season.

Functions were fitted to each yield cumulative probability distribution generated by the VRs (Chapter 4). The general form of these functions were as follows:

$$YIELD_{ijk}=ae^{-b*p}+ce^{-d*p^2} \tag{5}$$

Where	YIELD	=	The yield in kg ha^{-1}
	i,j,k	=	The ith crop grown on the jth soil in the kth was season
	a,b,c,d	=	parameters fitted to the function
	e	=	the base of natural logarithms
	p	=	a pseudo random number between zero and one.

To derive the specific yield for a cell the following procedure was used. The maximum seasonal membership value was identified and used to class the season as good, average or poor. A random number (r) in the range (0,1) was generated and compared to the membership value of that season. For a poor season the probability (p) value used in the yield function equalled the minimum of the random variable and the degree of membership of a poor season (MIN(r,u_{poor})). For a good season, p = MAX(1-u_{good},1-r). These derivations may be more clearly explained with reference to Figures 5.12 and 5.13. As the p value increases the generated yield decreases (Figure 5.13). In a poor season, as rainfall increased the membership of that season decreased (Figure 5.12) and, logically, we expected higher yields. Thus, by using the minimum of the membership value and r we generated yields whose lower bound was the yield achievable for that membership value and whose upper bound was the maximum yield achievable for that season. In Figure 5.13, for example, if the membership of the poor season was 0.4 we expected yields of between 2000 and 2900 kg ha^{-1}. In a good season the reverse was true. As rainfall increased, u_{good} increased and yields were expected to increase to the maximum possible for that season. In this case, however, p needed to be smaller as u_{good} got bigger. I, therefore, took the maximum of one minus the membership value or one minus r. In this case, and looking at Figure 5.13, if u_{good} = 0.4 then expected yields would fall in the range 1100 to 1700 kg ha^{-1}.

The logic behind the average season yield derivation is a little more complex. With rainfall less than 725mm, $u_{average}$ increased with increasing rainfall but then decreased again as rainfall increased beyond 725mm. Yields were, however, expected to increase with increasing rainfall. This problem was dealt with in the following way. Average season membership values were greater than the poor and good season membership values between annual rainfall amounts of 568 and 873mm. A linear regression model (r^2 = 0.9985, 12 DF) was developed to describe the relationship between rainfall and k, where k was the membership value of a dummy average season. Membership of this season was governed by

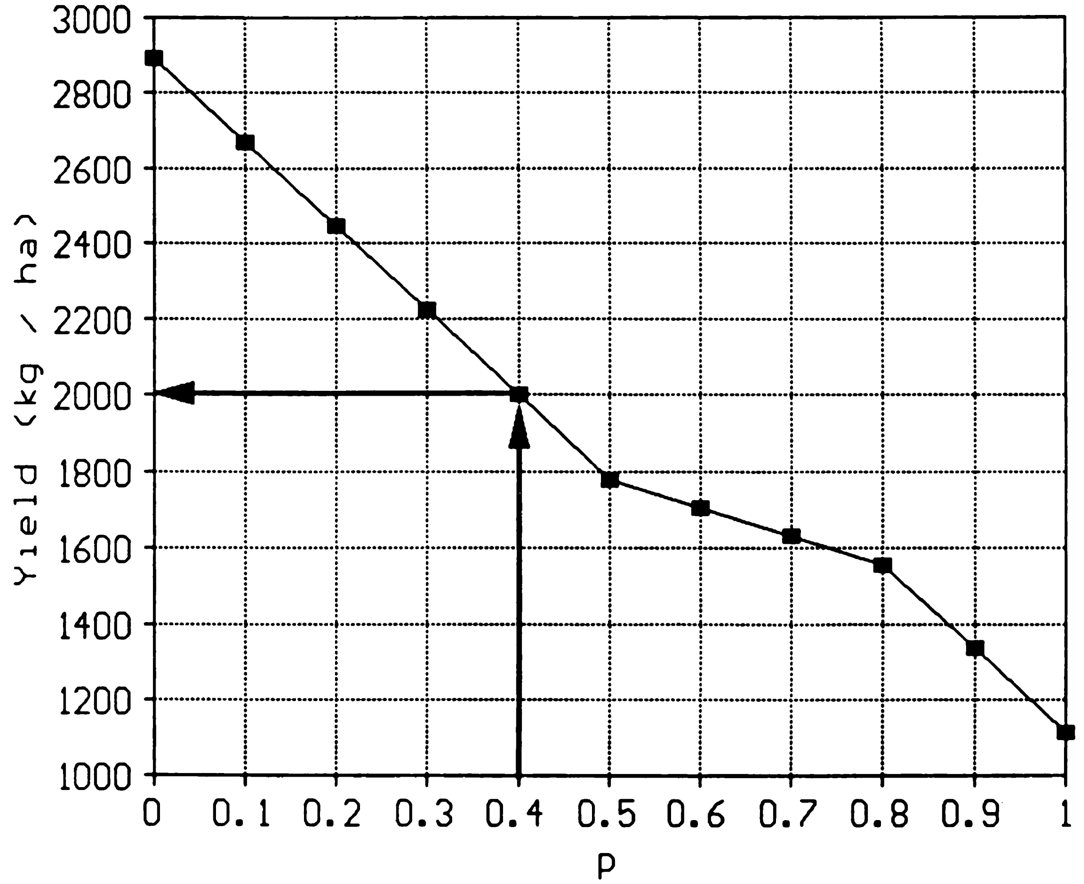

Figure 5.13. Example yield generation function from MASOKA1. Dependent variable is yield (kg ha^{-1}) and independent variable is the random variate p.

the equation (k = -1.70476 + 0.03069 * rainfall) between rainfall amounts of 550 and 875mm and was zero otherwise. After determining the k value for the average season, the procedure for deriving a p value was much like that of deriving the p value for a good season but with p = MAX(1-k,1-r).

For crops grown on jecha soils, soil fertility had an important effect on yields. If a soil had been previously cultivated, yields were derived using the following form:

$$YIELD = 5YR\_YLD + (VIRG\_YLD - 5YR\_YLD) / YRSCLT$$

Where	5YR_YLD	=	The yield from a soil continuously cultivated for five years derived from equation 1, above;
	VIRG_YLD	=	The yield from a virgin soil derived from equation 1, above;
	YRSCLT	=	The number of years the soil had been previously cultivated.

The EROSION sub-system

The Soil Loss Estimation Model for Southern Africa (SLEMSA) developed by Elwell (1980) was used in ZVAM. SLEMSA calculates erosion (Z), in t ha^{-1} as a function of three sub-models yielding K, C and X:

$$Z = K * C * X$$

Where Z = Predicted mean annual soil loss, t ha^{-1} yr^{-1} from the land under evaluation;

K = Mean annual soil loss (t ha^{-1} yr^{-1}) from a standard tilled field plot 30m * 10m at 4.5% slope, for a soil of known erodibility (F) under a weed free, bare fallow;

C = The ratio of soil loss from a cropped plot to that from a bare fallow;

X = the ratio of soil loss from a plot of length L meters and slope percent (S), to that lost from the standard plot.

Elwell (1980) identified five control variables which were used in SLEMSA: rainfall energy (E), soil erodibility (F), percent energy intercepted by the crop (i), slope percent (S) and slope length (L).

Rainfall energy (E) was calculated for non-guti[14] areas using:

$$E = 18.846 * \text{rainfall}$$

Where Rainfall = the annual rainfall in millimeters.

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[14] Guti is a light rainfall that occurs in parts of Zimbabwe but not in the study area.

The erodibility of soils in the study area was determined by using a rainfall simulation method described in Elwell (1986). The erodibility factor is an estimate of the soil loss from a bare soil at 4.5% slope. Soil samples of approximately 300kg were collected from virgin and from cultivated sites representative of each soil type in Masoka. Each soil sample was collected from the top 10 to 15 cm of soil in a contiguous area or plot. Based on these simulations Elwell (personal communication) estimated the Fb values used in the model (Table 5.1).

Table 5.1 Erodibility values for cultivated and uncultivated jecha and bepe soils in Masoka. Source Elwell, personal communication.

Soil	Fb	
	Cultivated	Uncultivated
Jecha	2	4
Bepe	1	7

Crop cover curves were based on measured data provided by Elwell (personal communication) for maize, cotton and sorghum. For maize the minimum cover values were doubled to reflect the under sowing with cucubits that was common practice in Masoka. The following cover equations were used:

$$MC = 48.02 + 0.00608 * maize\_yield$$

$$CC = 46.97 + 0.0043 * cotton\_yield$$

$$SC = 69.1 + 0.005366 * sorghum\_yield$$

Where MC, CC and SC are maize, cotton and sorghum cover values (%) and the yield values are expressed in kg ha^{-1}.

From these crop cover curves the soil loss ratio (C) was estimated using the following equations (Elwell, 1980):

$$C = e^{-0.06*i} \qquad i < 50\%$$

$$= (2.3 - 0.01*i) / 30 \qquad 50\% <= i$$

Where i = the crop cover value (MC, CC or SC) indicating the percentage energy intercepted.

Slope values were determined for each cell using the IDRISI GIS system. Ten meter contours, over the entire study area, were digitized into IDRISI. This vector file was converted into a raster file (with pixels 64 * 64 meters) and the IDRISI Intercon routine used to create a digital elevation model (DEM). A mean (low pass) filter was used to smooth the image. The SURFACE routine in IDRISI was then used to calculate the slope of each 64 meter cell. Slope length was considered to be the length of one side of a cell (64m).

The tillage practices of concern in Masoka were hand cultivation and tractor ploughing. Elwell (1980) provided data used to update the Fb values based on tillage type and planting and ploughing directions. For the EROSION sub-system the soil loss from the previous year factor, the planting and ploughing direction factors, the land rough-ploughed only factor and an estimate of hand cultivation factor were used. According to Elwell (personal communication) hand cultivation (planting of seeds into holes made with a hand hoe) would increase the soil erodibility compared to a soil with a fine powdery tilth. The hand cultivation factor was therefore set to -0.75.

From these values the F factor is estimated as:

F = Fb + tf + ppf + prvf

Where tf = the tillage factor set = 1 if tractor ploughed and to -0.75 if hand cultivated;

ppf = the ploughing and planting factor, set to 0 if planting and ploughing carried out on or level to the contour, set to -0.25 if these operations at an acute angle to the contour and set to -0.5 if these operations at right angles to the contour;

prvf = the previous years erosion factor, set to 0 if the previous years erosion was < 10 t ha^{-1}, set to -0.5 if the previous years erosion was between 10 and 20 t ha^{-1} and set to -1.0 if the previous years erosion was greater than 20 t ha^{-1}.

The K value in the EROSION sub-system was thereafter estimated using (Elwell, 1980):

$$K = e^{((0.4681 + 0.7663*F) * \ln(E) + 2.884 - 8.1209 * F)}$$

Where F = The soil erodibility factor defined above.

E = The rainfall energy defined above.

The final factor, X, was estimated using the following equation (Elwell, 1980):

$$X = L^{0.5} * (0.76 + 0.53S + 0.076S^2) / 25.65 \qquad S > 4\%$$

$$= S*L^{0.5} / (10.742S + 8.038) \qquad 1\% <= S$$

Where L = The slope length in meters;

S = The slope angle expressed as a percent.

Erosion was estimated for each cell in the Masoka landscape and then summed to give a total landscape erosion (t ha^{-1}), a mean and standard deviation (t ha^{-1}) as well as the mean, and standard deviation, per hectare of cultivated land for each household. The sequence of activities in the EROSION model are shown in Figure 5.14. Estimated soil loss did not affect soil properties or yields.

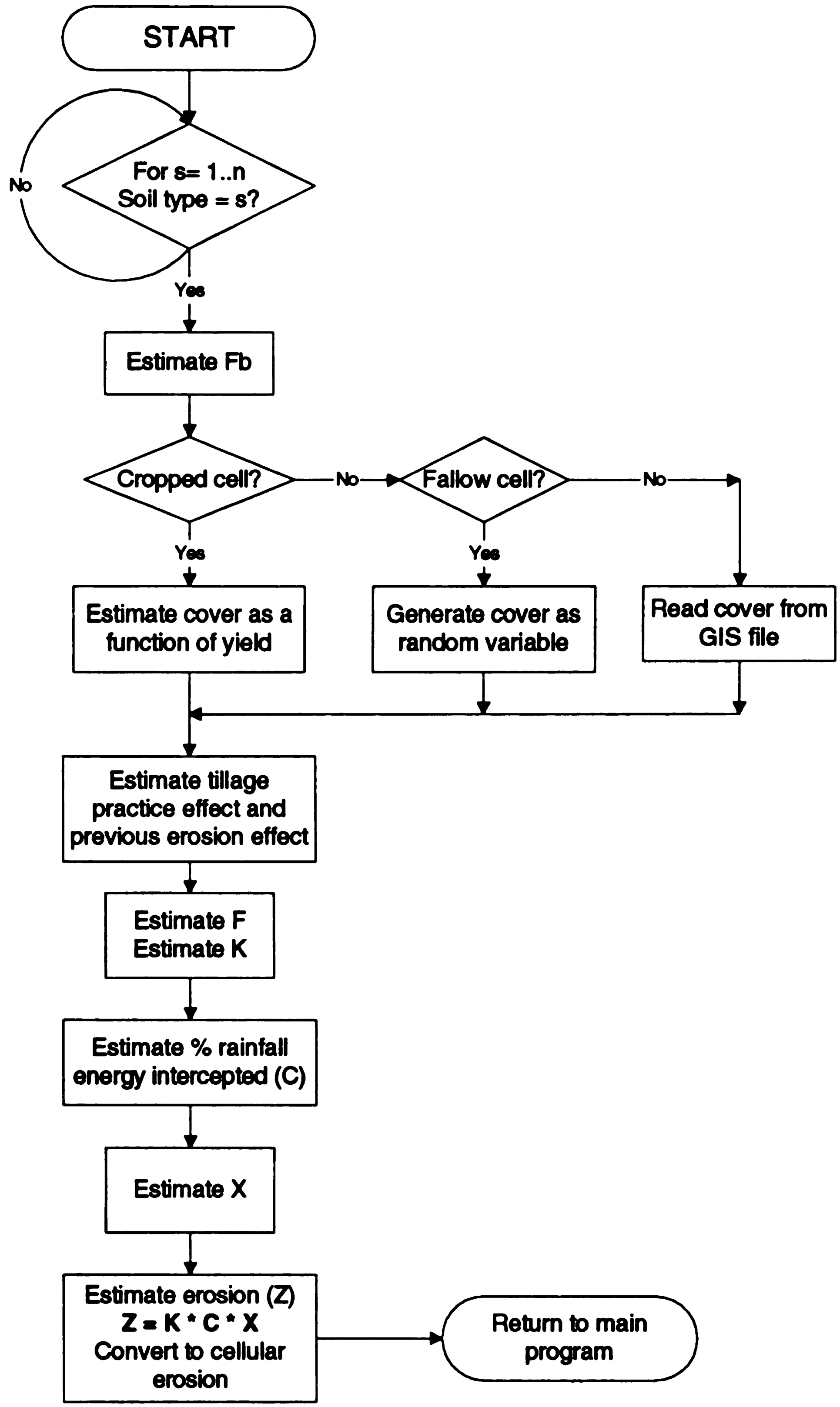

Figure 5.14. Flowchart of major activities in EROSION sub-system.

The ECONOMIC sub-system

I assumed that households were able to sell all of the cotton they produced, to the Cotton Marketing Board (CMB), as well as all of the maize and sorghum they wished to sell. Maize and sorghum were only sold within Masoka and were traded at the 1990/91 season prices used in Masoka: Z$0.78 kg^{-1} for maize and Z$0.55 kg^{-1} for sorghum. Labor was valued at the local (Masoka) daily wage which varied between Z$2.00 and Z$3.44 per day. The average value (Z$2.54 day^{-1}) was used as a constant in the model. Hired labor could be paid in cash or the grain equivalent of the daily wage. All households were assumed to face the same costs except INCMAX households that hired a tractor for ploughing had to pay the going rate of Z$148.00 ha^{-1} for ploughing. Households growing cotton were assumed to use the cotton packs supplied by Agritex which included all fertilizer and chemicals for 0.4096 ha (one acre). In allocating crops to a cell (ALLOCATE sub-system) a test was made to determine if the household had sufficient cash or maize reserves to pay for the basic costs of producing one cell (0.4096ha) of cotton. This value was set at Z$155.00[15]. Only the variable costs were used in calculating this amount and it excluded weeding and ploughing costs. A zero / one switch could be set in the model that would disallow / allow households to obtain loans for this amount and up to a maximum number of cells. The number of cells for which loans were obtained were recorded and later used to update the returns

15 This value was derived from the cotton partial budget presented in Chapter 4 (Table 4.13) and consists of seed (Z$30.88) + seed transport (Z$2.47) + fertilizer and chemical costs (Z$345.80) multiplied by the hectare to cell conversion factor of 0.4096.

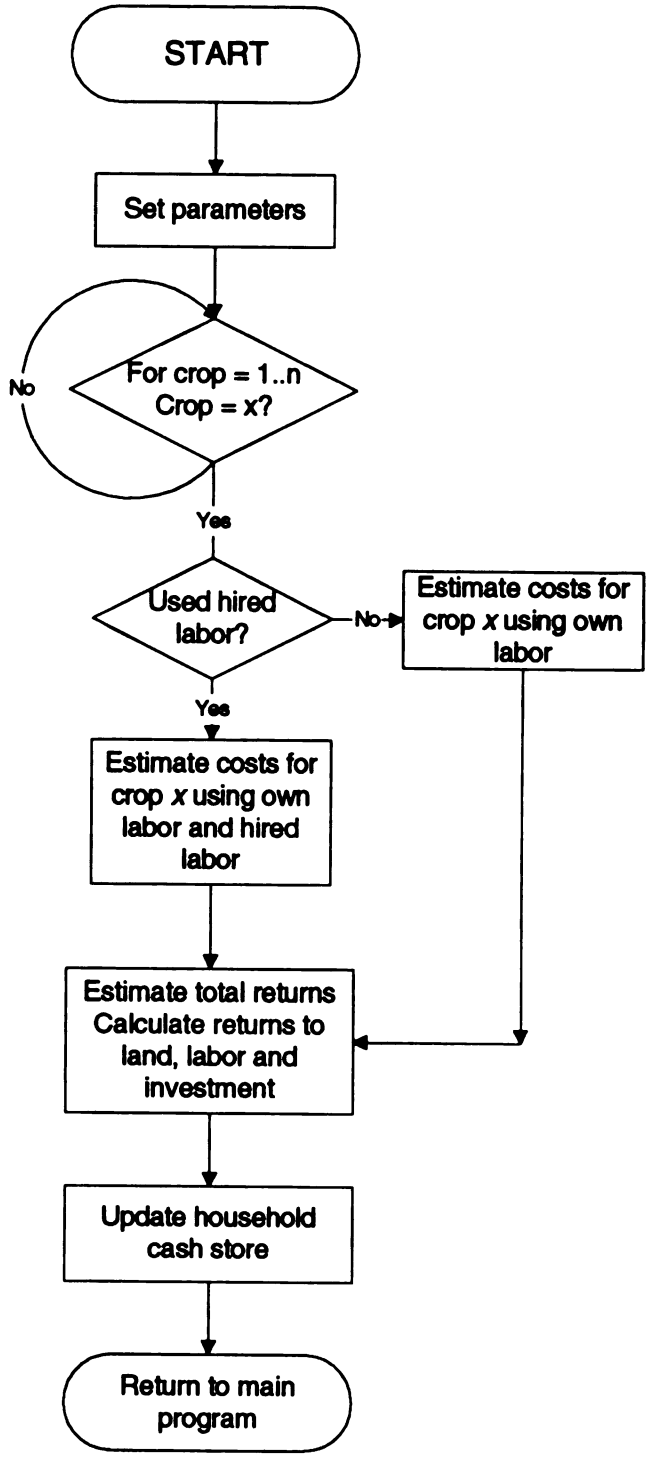

Figure 5.11. Flowchart of major activities in ECONOMIC sub-system.

to cotton. No interest was charged on these loans. The general sequence of activities in the ECONOMIC sub-system are shown in Figure 5.15.

A partial budget format similar to that of Chapter 4 was used to calculate the returns to land, to labor and to initial investment for each crop. Returns to labor were calculated as the returns to household labor and management.

The OUTPUT sub-system

The OUTPUT sub-system facilitated sub-sampling of individual households, yields, Fb values or erosion periodically during any simulation experiment. Thirteen output files were produced as required (Figure 5.3).

Data for each household in each season were written to the HOUSEHLD.OUT file (Table 5.2). These data describe general household characteristics, household needs and household production. Data for all households or for a random selection of households could be written to this file. If the model was being run in monte carlo mode then the same set of randomly sampled households could be used in each monte carlo run.

Mean erosion over the simulation period, for each cell in the landscape, was written to a GIS image file (TOTEROS.IMG). The model could also write the mean erosion of any season to a GIS image file (EROSION.IMG).

Yields, uncorrected for labor deficits, were written to file (YIELDS.OUT) for each cell in each season. Data written to this file included the year identifier, the season classifier, the soil type of the cell and the number of years the cell had been cultivated.

A GIS data layer file (CROPS.IMG) was generated for each season to show what crops had been grown in each cell in that season. Each cell in the landscape was assigned a crop identifier to indicate what crop had been grown in that season.

If required, a GIS data layer (NEWFERT.IMG) of the cropping history of the landscape (how many years each cell had been cultivated) could be written at the end of a simulation experiment.

The labor requirements, labor available and labor surpluses or deficits for each month of the growing season could be written to a file (LABOUR.OUT) for each household in each season or for randomly sampled households in randomly sampled seasons. Also written to this file were each household's production strategy class and the number of cells of each crop planted by the household.

Returns to land, labor and to initial investment as well as information on the number of cells of each crop the household planted, the number of labor days hired out and hired in and the number of cells for which cotton loans were received were written to the file BUDGET.OUT for each household in each season. If required the data from a random sample of households could be written to the file.

Two summary data files were generated (Table 5.3). In the first, SUMMARY.OUT, data averaged over all households were produced each season. These included season attributes as well as production, erosion and economic

Table 5.2 Summary of output variables written to household output file (HOUSEHLD.OUT).

VARIABLE	DESCRIPTION
ADLTS	Number of adults (i.e. 16yrs old or greater) in the household.
CHLD	Number of children (i.e. 16yrs old or greater) in the household.
CELLS	Number of non-riverland cells household owns.
RIV	Number of riverland cells household owns.
PROD	Household production strategy (MAXINC, MINVAR, SATIS, GREEN).
TILL	Household tillage strategy.
CASHND	Household annual cash needs (Z$).
MZND	Household annual maize needs (kg).
SORND	Household annual sorghum needs (kg).
CASHBAL	Household cash balance (Z$).
MAIZEBAL	Household maize store balance (kg).
SORBAL	Household sorghum store balance (kg).
CASH	Total household cash generated for the year (Z$).
MAIZE	Total household maize production for the year (kg).
SORGHUM	Total household sorghum production for the year (kg).
CASHDEF	Surplus (deficit) of household cash production minus cash needs (Z$).
MAIZEDEF	Surplus (deficit) of household maize production minus maize needs (kg).
SORDEF	Surplus (deficit) of household sorghum production minus sorghum needs (kg).
DAYEMPL	Labor days hired in that season.
DAYWORK	Labor days hired out that season.
LOANCEL	Number of cells for which cotton loans received.
TEROS	Total erosion over household fields (t ha^{-1}).
CEROS	Mean erosion (t ha^{-1}) over household fields.

Table 5.3 Summary of output variables written to SUMMARY.OUT and to MONTECAR.OUT.

VARIABLE	DESCRIPTION	S	M
YEAR	Annual or seasonal identifier	X	
MONTE	Monte-carlo run identifier		X
SEAS	Season class (good, average, poor)	X	
TOTEROS	Average erosion over the landscape (t ha^{-1})	X	X
ANCASHDEF	Households that were cash deficit (%)	X	X
ANMAIZEDEF	Households that were maize deficit (%)	X	X
ANSORDEF	Households that were sorghum deficit (%)	X	X
MZEHA, MZESD, COTHA, COTSD, SORHA, SORSD	Average and standard deviation of uncorrected yields for maize, cotton and sorghum (kg ha^{-1})	X	X
MZCELLS, COTCELLS, SORCELLS	Total number of cells planted to maize, to cotton and to sorghum	X	
OCTDEF, NOVDEF, DECDEF, JANDEF, FEBDEF, MARDEF, APRDEF	Percentages of households with labour deficits in each month (October through April) (%)	X	
MNMZRET, SDMZRET, MNCTRET, SDCTRET, MNSORET, SDSORET	Mean and standard deviation of total returns to maize, cotton and sorghum (Z$ $household^{-1}$)	X	
MNMZACR, SDMZACR, MNCTACR, SDCTACR, MNSORACR, SDSORACR	Mean and standard deviation of per hectare returns to maize, cotton and sorghum (Z$ ha^{-1})	X	
MNMZLAB, SDMZLAB, MNCTLAB, SDCTLAB, MNSORLAB, SDSORLAB	Mean and standard deviation of returns to labor for maize, cotton and sorghum (Z$ ha^{-1})	X	
MNMZINV, SDMZINV, MNCTINV, SDCTINV, MNSORINV, SDSORINV	Mean and standard deviation of returns to initial investment for maize, cotton and sorghum (Z$ ha^{-1})	X	
MNEMPLDYS, MNWRKDYS	Mean number of labor days hired in and hired out per household	X	
MNCRCTMZ, SDCRCTMZ, MNCRCTCT, SDCRCTCT, MNCRCTSR, SDCRCTSR	Mean and standard deviation of corrected maize, cotton and sorghum yields (kg ha^{-1})	X	
GOOD, AVERAGE, POOR	Frequencies of good, average and poor rainfall seasons		X
INITFRT, ENDFRT, CHGFRT	Initial, final and change in years cropped summed over all cells	X	X
TOTFB	Total Fb value summed over all cells	X	X

attributes.

In the second summary file, MONTECAR.OUT, essentially the same data were presented except they were the averages over each year in a monte carlo run. Data that were in the SUMMARY.OUT file but not in the MONTECAR.OUT file were labor deficit data and household returns data. Data included in MONTECAR.OUT but not in SUMMARY.OUT were the frequencies of good, average and poor rainfall seasons.

METHODS

Verification, validation, usefulness

All model sub-systems and code segments were checked several times for correct representation, logic, the accuracy of outputs, data correctness and the correct sequencing of events. Wherever possible, analytical checks were made of calculations made by the model. The maximum and minimum as well as mean and standard deviation of output data for each module were used to identify incorrectly functioning model components. For example, the ranges of possible yields derived from VR cumulative probability distributions were be used to check that simulated yields were within the correct range.

Given the objective of an enhanced understanding of the Masoka agroecosystem, evaluation of model performance was more concerned with model usefulness than with the accuracy of predictions. The model was considered to be useful if it did any of the following:

a) Demonstrated the utility (or lack thereof) of the approach to analyzing complex agroecosystems. Did the model provide insights that wwould not have been likely or possible with any other analytical approach;

b) Helped identify gaps in our understanding of the Masoka agroecosystem;

c) Enabled us to improve the management of the Masoka agroecosystem; or

d) Enabled us to make comparisons of different system configurations in a design situation.

I assumed, *a priori*, that the model was an inaccurate representation of the real world system. As far as was possible major components of the model were tested to establish the degree to which they accurately represented the real world processes of interest. This was difficult however, as there are no measured data on production, erosion or on household needs satisfaction. A major part of model validation that was not completed was the iterative evaluation of model results with Masoka VRs and leaders as well as with development professionals actively involved in the design, analysis and management of Zambezi Valley agroecosystems.

The model presented here was not expected to withstand rigorous deductive testing. Rather, it was developed as a working hypothesis with which to focus discussion and further research. Given the complexity of the Masoka agroecosystem the model was neither complete nor sufficiently accurate to facilitate making reliable predictions of Masoka's future. The model was expected to provide useful information on the direction and perhaps relative magnitudes of changes in the agroecosystem. The model was also expected to be able to identify what known populations could be supported with the levels of technology and needs used in the model.

Evaluation of the Masoka agroecosystem model broadly followed the procedures described by Law and Kelton (1991): Input data were checked for correctness and representativeness. The distributions of output variables generated by the model were tested for goodness of fit to the original distributions using Chi square, log-likelihood and Kolmogorov-Smirnov tests. Model outputs were compared to observed system data where these existed or to theoretical distributions where appropriate.

The total area cultivated each year in a simulations was found to fluctuate notably in the first few years of a simulation. For all simulations with MASOKA1 the data from an initial warm up period of 20 years were discarded. The length of this period was calculated following Welch (1983). This procedure requires estimating and plotting moving averages, with different window sizes of the variable of interest. The window size would be steadily increased until a relatively stable plot of the variable of interest against time was achieved. For these calculations the total number of cells cultivated in any year were used.

To verify that the crop yield component of MASOKA1 generated yields that did not differ from expected yields (Table 4.9) the model was run for 50 years with 100 households on a landscape generated with INITIAL. In generating the initial conditions the land allocation multipliers were set to one. Yield data, uncorrected for labor shortages, were collected for each cell over the 30 year period starting from year 21. Mean rainfall over the 70 year period was 721mm with a standard deviation of 243mm.

Sensitivity analysis

Sensitivity analyses were carried out to identify the sensitivity of model response variables to changes in model parameters and inputs (factors). There were more than 100 factors and decision variables that could have affected model responses. Examining the effects of all of these was not possible. A 2^5 fractional factorial design[16] was used with 13 factors (Table 5.4). Where appropriate I

selected model parameter values so that the +1 level was the normal (standard model) mean plus one standard deviation and the -1 level was the mean minus one standard deviation. To facilitate the examination of a larger number of factors, some factors were selected to represent a group of factors. The assumption being made was that the interaction effects among these grouped factors would not cancel each other. Where grouped factors were found to significantly influence model response variables the effects of factors within the group could be evaluated at a later date.

With INITIAL, two sets of initial conditions were generated. In the first

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[16] I am grateful to Professor D. Gilliland, of the Department of Statistics and Probability, Michigan State University, for his able assistance in generating, and analyzing the results of, this design.

Table 5.4 Factors and factor levels used in sensitivity analysis of MASOKA1.

Factor	+1	-1
Mean annual rainfall (mm)	972	478
Good season classification membership function	u_{good} = 1 rainfall >= 1124	u_{good} = 1 rainfall >= 1000
Average season classification membership function	Mean $\pm$ 1*SD	Mean $\pm$ 0.5*SD
Poor season classification membership function	u_{poor} = 1 rainfall <= 500	u_{poor} = 1 rainfall <= 442
Percentage of children that work	59	29
Loan or dividend	Loan = Z$155 Dividend = Z$0	Loan = Z$0 Dividend = Z$155
Households could employ labor	Yes	No
Maize price	.80 Z$ kg^{-1}	.26 Z$ kg^{-1}
Household cash needs	base+.41*base	base-.41*base
Proportion of households in production strategies	80% MINVAR 20% INCMAX	20% MINVAR 80% INCMAX
Wage rate	Z$3.07 day^{-1}	Z$2.01 day^{-1}
Land multiplier for riverland and non-riverland cells	1.7	.63
Minimum and maximum years jecha fields cropped before leaving fallow	Min 0 Max 10	Min 5[1] Max 7

1. The model included an error for these analyses. For the income maximizing strategists the minimum number of years cultivated before a field was left fallow was six and not five.

(INIT63) the land multiplier was set to 0.63 for both riverland and non-riverland cells and the number of households was set to 100. The vegetation cover and cropping history maps produced in this run were used for all subsequent sensitivity simulation experiments. In the second run (INIT17) the land multiplier was set to 1.7 for both riverland and non-riverland cells. The household data and field map files were saved for use in subsequent sensitivity simulation experiments.

Two rainfall files were generated. For the first, the rainfall mean was set to 972mm. Using the equation of Hutchinson and Unganai (1992) this mean yielded a k value of 14.41. For the second rainfall file the mean was set to 478 with a k value of 7.44. Two membership functions were used for classifying good season rainfall. In the first, the membership function described earlier in this chapter was used. In the second, the membership function was derived so that u_{good} = 1 when rainfall = 1000mm. Two membership functions were also used for each average and poor season classification. For average seasons the first function was that described earlier in this chapter. The second was fitted so that $u_{average}$ = 0 when rainfall was less than 600mm (725 - 0.5*247) and when rainfall was greater than 850mm (725 + 0.5*247). The poor season membership function described earlier in this chapter was used for the +1 level of this factor and for the -1 level the function was fitted so that u_{poor} = 1 when rainfall = 600mm.

Reynolds (1991, Table 1.1) provides data on the number of children in each of six classes (broken down by age and gender) from which the mean and standard deviation of the percentage of children that worked were estimated. Children in the 10 to 20 year-old class were considered likely to work.

The mean dividend received by households over the four year period 1989 to 1992 was Z$150 (Chapter 2). I decided to examine the relative effects of these dividends compared to a loan of the same amount, but which was provided in the form of inputs to cotton production. The +1 level of this factor was a loan of Z$155 (sufficient for one cell) with no dividend and the -1 level was a dividend of Z$155 and no loan.

The two levels of employment used were simply an on / off switch. At the +1 level households were able to employ labor and at the -1 level they could not.

The maize price factor levels were set at the mean (Z$0.53 kg^{-1}) plus one standard deviation (Z$0.27 kg^{-1}) and the mean minus one standard deviation of the government producer price (Z$0.25 kg^{-1}), the consumer price of maize meal (Z$0.55 kg^{-1}) and the Masoka maize price (Z$0.78 kg^{-1}) were used to calculate a mean and standard deviation maize price. The +1 level maize price was this mean plus one standard deviation (Z$0.80 kg^{-1}) and the -1 level was the mean minus one standard deviation (Z$0.26 kg^{-1}).

To derive a standard deviation for household cash needs the data from the questionnaire survey described in Chapter 2 were used to develop a regression model of cotton needs (dependent variable) on family size (independent variable). The standard error of the coefficient on family size (0.413) was used to derive the range in household cash needs. The factor levels were set at the VR derived value plus or minus 41%.

The VRs provided data on the number of households in each well-being class (Chapter 4). The proportion of households in the class of households who always satisfied needs (19%) were assumed to be income maximizers. The remaining households were considered to be risk averse or variance minimizers. These values were rounded to 20 and 80% and were used as the +1 factor level for the proportion of households in each production strategy. For the -1 level these proportions were reversed.

The levels of wage used in the sensitivity analysis were derived from the VR data on the prices that were paid for weeding and the mean times to completing a weeding task. Daily wage rates ranged from Z$1.77 to Z$3.04 day^{-1}. The mean (Z$2.54) and standard deviation (Z$0.53) of these were calculated. Factor levels were set at the mean plus and the mean minus one standard deviation.

The values used for the minimum and maximum number of years before a field was left fallow were derived from my discussions with Vrs and other community members. The ranges used in the sensitivity analysis were selected to reflect a mean of 5.5 years with a large variance (+1 level) and a mean of 6.5 years with low variance (-1 level).

Ten monte-carlo runs, each of 50 years with a 20 year warm-up period, were run for each combination of experimental factors. Data were collected from all monte-carlo runs. A random sample of 20% of the 100 households were saved for subsequent analyses.

Mean effects due to each factor were computed using Yates algorithm (Yates, 1937, described in Box *et al.*, 1978). Tests of significance for each response variable were made by comparing the following ratio to the t-distribution with three degrees of freedom:

$$\frac{A}{\sqrt{(\frac{s^2}{8})}}, \frac{B}{\sqrt{(\frac{s^2}{8})}},\ldots$$

where;

$$s^2 = \frac{(ABC)^2 + (CDE)^2 + (BCD)^2}{3}$$

A, B... were the mean effects of factor A, B,...N on the response variable of interest, (N=13);

ABE, CDE, BCD were the effects of runs 30,31 and 32 combined as error terms.

The results of sensitivity analyses were presented as the mean effect of each factor changing from the low (-1) to the high (+1) level. The sign on these means indicated the direction of the effect. Also shown in the results tables were the mean effects expressed as percentages of the overall mean for the response variable of interest. To calculate the value of the response variable at the low level one need only subtract half of the mean effect for the factor of interest from the overall mean effect for the variable of interest. The value of the response variable at the upper limit would be calculated by adding half of the mean effect to the overall mean effect.

VERIFICATION AND VALIDATION

Rainfall and seasons

RAINGEN was used to generate 10,000 annual rainfall values. The mean (725mm) and standard deviation (222mm) of these values were no different to those observed for Angwa Bridge ($t=-.004$, $DF = 9998$, $p>.99$).

The season classifier in MASOKA1 was used to classify each season for which there was data from Angwa Bridge (1977/78 to 19991/92). The difficulties of comparing these classes to those derived from local knowledge have been discussed in Chapter 4. Where we have the broadest data for classification (1988/89 to 1990/91) from the questionnaire survey, the model and data classifications were the same. In the period 1980/81 to 1987/88 the model and VR classifications agree completely in five out of the eight seasons, differ by one season class in one season and differ by two season classes in two seasons. Given the good agreement between the survey and model classifications, and the reasonably good agreement between VR and model classifications, the model season classification system was accepted as being useful and sufficiently accurate for the purposes of this study.

Initial conditions

Soil characteristics were assumed to be homogenous for specific types of soils. The accuracy of the soil, the slope and the vegetation cover data layers were not determined. The spatial patterns of household placement on the Masoka landscape were similar to patterns observed on air photographs of the Masoka agroecosystem.

To verify that INITIAL was working correctly it was used to generate 100 households in 10 separate and independent runs. The household data files produced were saved and the distributions of adults, children and land analyzed. The distributions of number of adults per household, produced by INITIAL, did not differ from observed distributions (Mann-Whitney U = 36195.5, p>.937). The distributions of numbers of children for each number of adults, generated by INITIAL, did not differ from observed distributions (Table 5.5).

Table 5.5 Goodness of fit test statistics for the distribution of numbers of children per number of adults.

Number of Adults	Chi Square[1,2]
1	2.16
2	3.44
3	4.84
4	8.94
5	10.40
6	5.77
7	6.97
8	4.89
9	20.21

1. Critical value of the Chi square distribution for $v=14$, $a=.05$ is 23.685. The hypothesis that the generated data were from the specified distribution was rejected if the Chi square values in the table were greater than this critical value.
2. Cells with fewer than five values were grouped.

The distributions of land for each household class (i.e. based on the number of adults) were derived from only 70 data points. In many cases the data in the tails were smoothed to give a continuous distribution of land area rather than the discontinuous distributions described by the data. To compare the non-riverland areas generated by INITIAL with those of the survey data, the 70 data points were compared to the 1000 points generated by INITIAL. Quantile plots were produced of the generated data and of the survey data (Figures 5.16a,b). These plots show the proportion of the data that were in each quantile. The similarity in these plots suggests that the land generation routines in INITIAL produced land holdings from the same distribution as occurs in Masoka.

The proportion of households with riverlands (60%) was not very different from the observed proportion (54%). The mean areas of riverland per household generated by INITIAL were not different from those provided by the Vrs (Mann-Whitney U = 33825.5, p>.33). The distributions of these two data sets were however, somewhat different. The survey data were from a more positively skewed distribution (G1[17] = 4.578) than the generated data (G1 = 1.353) and exhibited a very much more platykurtic distribution (G2 = 27.712) than the generated distribution (G2 = 0.956). With the exclusion of the one outlier in the survey data these distributions (Figures 5.17a,b) were however, sufficiently similar to warrant

17 The G1 and G2 statistics refer to the third and fourth moments about the mean - the skewness and kurtosis of the distribution (Zar, 1984).

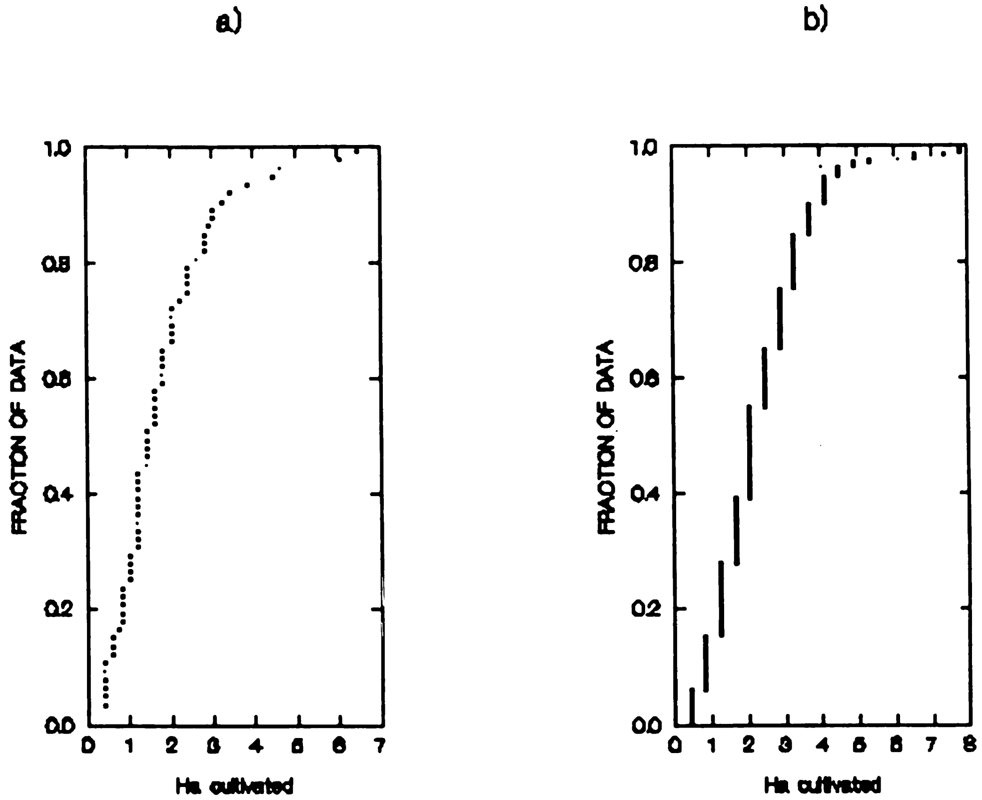

Figure 5.16. The cumulative proportion of a) actual (n=70) and b) simulated (n=1000) Masoka households cultivating a given area of non-riverland.

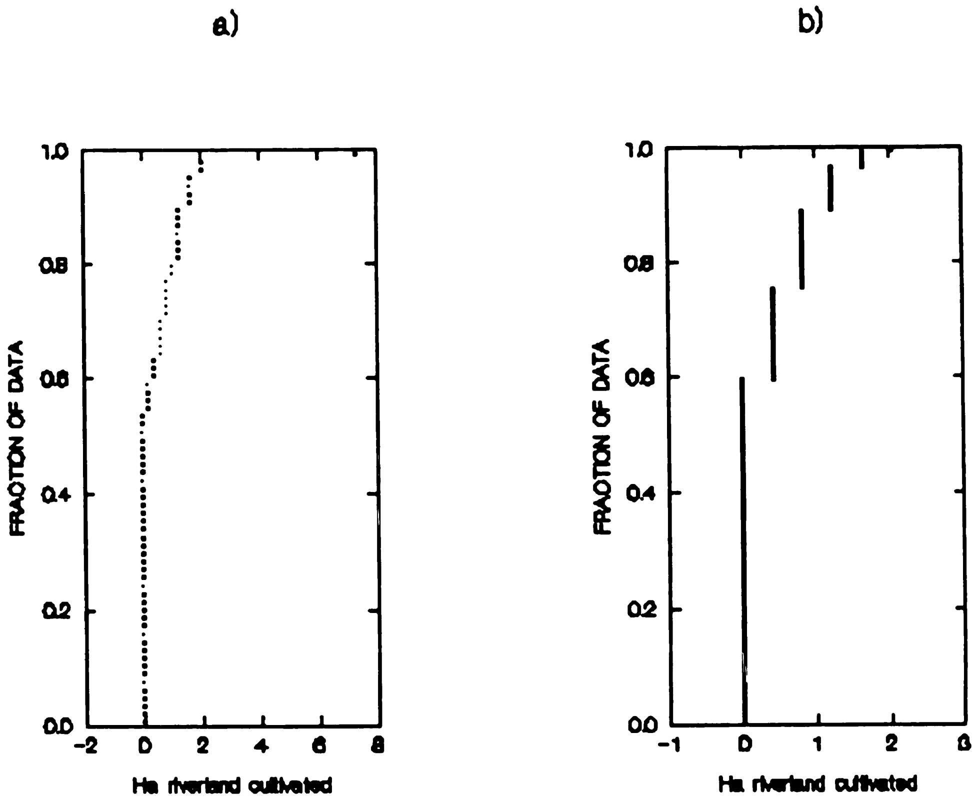

Figure 5.17. The cumulative proportion of a) actual (n=70) and b) simulated (n=1000) Masoka households cultivating a given area of riverland.

our acceptance of the INITIAL riverland generating routine.

In summary, the data generation functions built into the INITIAL model produce distributions of adults, children and land that are similar to those observed in Masoka.

Maize yields

The simulated yield statistics of maize grown on each soil for good and average seasons (Table 5.6) were the same as the expected means derived from VR probability distributions (Table 4.9). Poor season, simulated yields were between 11 and 25% higher than expected means (Table 5.6). These differences were expected. When, in the model, the season was classed as poor with membership one, any yield value within the set of poor season yields was possible. As the membership of a poor season declined (and rainfall increased) the lower yields from the set of possible yields were excluded. This would result in an increasing mean yield with increasing rainfall. The simulated yields for poor seasons were, therefore, expected to have higher means than those of Table 4.9.

Statistics of yields for each season and for each soil type were confounded by the proportions of seasons and each soil type used in the model compared to those used in deriving statistics for Table 4.9. The proportion of good, average and poor seasons in the verification rainfall data were .16, .56 and .27 compared to the .3, .3 and .4 values used in Table 4.9. These probabilities of each season type were used to calculate yield statistics for each soil type, based on the data of

Table 5.6 Simulated maize yields (kg ha^{-1}) for each soil and in each season. Data are means with standard deviations in parentheses, medians and the sample size.

Season	Soil type	Bepe (kg ha^{-1})	Jecha (kg ha^{-1}	River jecha (kg ha^{-1})	Mean (kg ha^{-1})
		1800	1600	3350	2150
Good		(384)	(486)	(401)	(918)
		1700	1500	3350	1900
		n=131	n=433	n=248	n=812
		1800	1050	3450	1950
Average		(428)	(423)	(268)	(1139)
		1750	950	3400	1550
		n=473	n=1499	n=936	n=2908
		850	500	1500	850
Poor		(218)	(191)	(218)	(494)
		850	500	1500	700
		n=212	n=674	n=421	n=1307
		1550	1000	2900	1700
Mean		(566)	(522)	(892)	(1092)
		1550	850	3300	
		n=816	n=2606	n=1605	n=5027

Table 4.9. The means derived for bepe, jecha and river jecha soils (1600, 1000 and 2900 kg ha^{-1}) were no different to the simulated means (Table 5.6). These results suggest that the approach to season classification and yield calculation used for maize was appropriate and produced acceptable maize yield values.

Seasonal mean yields were expected to be more variable than soil means owing to the dependence of jecha yields on cropping history. The mean yield of virgin jecha and of jecha cultivated continuously for five years from Table 4.9 and the probabilities of each soil type derived from the verifying simulations (bepe=.16, jecha=.52 and river jecha=.32) were used to calculate seasonal mean yields. The good and average season yields (2150 and 2050 kg ha^{-1}) were essentially the same as simulated yields whilst the poor season mean yield (750 kg ha^{-1}), as expected, was lower than the simulated value.

Cotton yields

The simulated yield statistics for cotton (Table 5.7) were similar to those derived from VR yield probability distributions. Mean yields for bepe, jecha and river jecha (850, 700 and 1100 kg ha^{-1}) calculated using the VR derived means (Table 4.9) and the season probabilities used in the verifying simulations, were

Table 5.7 Simulated cotton yields (kg ha^{-1}) for each soil and in each season. Data are means with standard deviations in parentheses, medians and the sample size.

Season \ Soil	Bepe (kg ha^{-1})	Jecha (kg ha^{-1})	River jecha (kg ha^{-1})	Mean (kg ha^{-1})
Good	1000 (379) 900 n=44	1000 (476) 1100 n=290	1350 (421) 1300 n=167	1150 (471) 1200 n=501
Average	1050 (370) 950 n=157	800 (430) 750 n=1015	1400 (295) 1300 n=558	1050 (469) 1100 n=1730
Poor	350 (159) 300 n=68	300 (180) 300 n=421	700 (342) 650 n=243	450 (308) 350 n=732
Mean	850 (452) 800 n=269	750 (473) 650 n=1726	1200 (448) 1200 n=968	900 (513) 850 n=2963

close to the simulated mean yields for each soil type (Table 5.7). As with maize yields the simulated, poor season means were higher than VR derived means for each soil type. The simulated yields on each soil type in a good season suggest a bias toward yields higher than might be expected from the VR derived yield probability distributions (Table 5.7).

The mean yields for each season were compared to those derived from the VR yield probability distributions using the proportions of each soil type used in the model simulations. Mean cotton yields for a good, an average and a poor season were 1000, 1050 and 300 kg ha^{-1}. Apart from the poor season mean which we expect to be a little higher than the VR derived mean, these values are satisfactorily close to the means derived from VR yield probability distributions.

Sorghum yields

The simulated yield statistics for sorghum, grown on jecha soils (Table 5.8) were slightly higher than VR derived values in a good season (Table 4.9). Average and poor season yields were the same as means derived from VR probability distributions. The overall simulated mean for sorghum (500 kg ha^{-1}) was not different than the mean yield derived from the VR yield probability distributions (450 kg ha^{-1}).

In general, the simulated yields compared favorably with expectations. These results increased our confidence in the season classification system and in our ability to generate yield patterns that conform to the VR probability distributions.

Table 5.8 Simulated sorghum yields (kg ha^{-1}) on jecha in each season. Data are means, with standard deviations in parentheses, medians and the sample size.

Soil Season	Jecha (kg ha^{-1})
Good	800 (337) n=275
Average	550 (268) 500 n=1015
Poor	100 (122) 50 n=438
Mean	500 (351) 400 n=1728

As discussed in Chapter 4 there were no published measurements of actual yields that could be used as empirical comparisons of these simulated yield statistics. The yield values of Table 4.7 were all within the range of values that the

MASOKA1 model generated. The mean, poor season maize yields on jecha that households claimed to have harvested (500 kg ha^{-1}, Table 3.2) was the same as that predicted by the model. Both the poor season cotton and sorghum yields reported in Table 3.2 appear lower than those derived from the model but were still within the range of yields predicted by the model. The yields of Table 4.7 were difficult to compare with the model derived values because these statistics were from situations where the proportions of soil types were unknown. Despite these unknowns the model generated yield statistics for poor season maize and cotton and average season cotton and sorghum that were reasonably close to the observed yields presented in Table 4.7. The average season means derived from the model, whilst appearing far higher than the average season data of Table 4.7, were variable and we expected mean yields as low as 800 kg ha^{-1} with a high probability. There were too few samples of good season yields presented in Table 4.7 to enable meaningful comparisons with the model.

Erosion

SLEMSA was validated in the high rainfall areas of Zimbabwe (Elwell, 1978) but not in the low rainfall areas, such as the Zambezi Valley. The model was, however, in general use throughout the SADC region.

Erosion results were perceived as an index of erosion risk rather than actual erosion amounts that might be experienced under the conditions described in any model simulation. Simulated erosion for cultivated areas of Masoka were between

1.4 and 9.3 t ha^{-1} $year^{-1}$ on cropped lands. These values were reasonably close to the erosion values estimated for each soil type by Elwell (1978), using a rainfall simulator (0.8 and 9.3 t ha^{-1} for bepe with 3.8 and 5.7 t ha^{-1} on virgin and cultivated jecha). The EROSION sub-system was the least closely examined of the sub-systems in MASOKA1. In the original model design I planned to use a spatially dependent erosion model. That aspect of MASOKA1 was not yet developed and an unaltered SLEMSA was used as an interim measure.

RESULTS

Sensitivity analysis

Model response variables were grouped as needs, yield, economic and resource responses. Needs responses included the mean proportion of households who failed to satisfy their cash (ACDF), maize (AMDF) or sorghum (ASDF) needs each year (Table 5.9).

Yield responses were the mean yields (kg ha^{-1}) of maize, cotton and sorghum, from all fields, corrected for labour deficits, achieved over the 30 year simulation. These means were then averaged over the 10 monte carlo simulations. Economic response variables included, for maize, cotton and sorghum, mean total returns to a household (MZRET, CTRET, SRRET); mean returns per hectare (MZHA, CTHA, SRHA); mean returns to own labour and management (MZKAB, CTLAB, SRHA); and mean returns to initial investment (MZINV, CTINV, SRINV). As with the yield data these were the means of all households averaged over the 10 monte carlo runs.

The resource response variables were the changes in the total number of years that each jecha cell had been cultivated summed over the whole landscape (CHGFRT), the mean erosion (t ha^{-1}) over the landscape (MNERS), and the change in the total Fb value of the landscape, or the Fb value of each cell summed across the entire landscape at the beginning of the simulation minus the sum of all cell Fb values at the end of the simulation. Lower Fb values indicated a higher erodibility.

Household needs satisfaction

For the most part, the responses of ACDF, AMDF and ASDF were in the direction and of magnitudes that were expected. The effects of rainfall and the price of maize are obvious and require no explanation. The effects of factors such as the land multiplier, the proportion of households in each production strategy or the effects of the membership functions used were easily explained or the effects were too small to warrant discussion. Increasing household cash needs had a large impact on the proportion of households that satisfied cash and food needs. The effect was contrary to what was expected and required a more elaborate explanation.

At the +1 level of land availability, households attempted to cultivate, on average, 70% more land than the real world households in Masoka cultivated. Given that in the model households cultivated fixed proportions of the land available to them, irrespective of their labor resources, it was not surprising that more land would increase the levels of deficits as households would have had greater labor shortages and consequently achieved lower yields. Cotton's greater sensitivity to weed cover was reflected in the greater response of ACDF to increases in land availability (Table 5.9).

The mean percentage of households that were deficit for each need each year decreased when the poor season classification changed from the low to the high level (Table 5.9). This was expected because at the +1 level the season was classified as poor ($u_{poor} > u_{average}$) at higher rainfall levels than at the -1 level. The yield functions for all three crops showed higher yields as u_{poor} approached zero than when $u_{average}$ was small. Thus, at the +1 level of poor season classification I expected higher mean yields and, therefore, a lower percentage of households that were cash, maize or sorghum deficit. The classification of good seasons had a similar trend for households that were cash deficit but the opposite trend for the proportion of households that were maize deficit (Table 5.9). For the negative response of the percentage of households that were cash deficit the explanation was much the same as that for the poor season classification; the yields at the high end of an average season were higher than those at the low end of a good season. At the +1 factor level for good season classification, u_{good} is dominated by $u_{average}$ over a wider range of rainfall amounts than was the case at the -1 factor level. I expected, therefore, the mean yields to be higher at the +1 factor level and for there to be fewer cash deficit households. The explanation for

Table 5.9 Sensitivity of the mean of the % of households that were cash (ACDF), maize (AMDF) and sorghum (ASDF) deficit, each year, to changes in factor levels[3].

Factor	ACDF (% households)			AMDF (% households)			ASDF (% households)		
	Mean effect	%[1]	Sig[2]	Mean effect	%	Sig	Mean effect	%	Sig
Land multiplier	14.2	16	***			NS	6.6	9	**
Rainfall	-13.5	-15	***	-24.0	-54	***	-20.2	-27	***
Cash needs	-13.5	-15	***	-37.4	-84	***	-24.3	-33	***
Maize price	-5.0	-6	**			NS	-11.8	-16	**
Poor season classification	-4.9	-6	**	-1.1	-3	*	-3.0	-4	*
Proportion of MINVAR strategists	3.4	4	*	-2.7	-6	***			NS
Good season classification	-3.1	-3	*	1.0	2	*			NS
Loan or dividend			NS	8.8	20	***	29.0	39	***
Fallow practices			NS	-3.6	-8	***			NS
Average season classification			NS			NS	3.1	4	*
Overall mean	89.8			44.7			74.6		

1. % of overall mean effect for that factor.
2. Significance determined using Student's t test. Effects were different from zero at $p<=0.001$ (***), $p<=0.01$ (**), $p<=.05$ (*) and not different from zero at $p>.05$ (NS). See text for details of tests.
3. Data show the change in mean response to changing the factor of interest from the -1 to the +1 level.

the reverse of this expectation for maize deficit households was not clear. Firstly, the difference was slight (1%) and despite the significance (P<.05) could be due to random error. Secondly, the difference in yields between a high $u_{average}$ membership compared to a low u_{good} membership was not as great for maize as it was for cotton.

As expected, when the proportion of households that were classed as variance minimizers was low (level -1) the percentage of households with a cash deficit was higher and the percentage of households that were maize deficit was lower (Table 5.9). Income maximizers planted a greater proportion of their lands to cotton and less to maize than did variance minimizers. At the low factor level (80% income maximizers), therefore, I expected fewer households to have a cash deficit but more to have a maize deficit.

The percentage of households that had a maize deficit and the percentage that were sorghum deficit were sensitive to whether the Z$155 subsidy was paid as a dividend or as a loan (Table 5.9). In both cases (AMDF and ASDF), the provision of a loan resulted in a greater percentage of households with a deficit than did the payment of a dividend, and for sorghum the provision of a loan resulted in an almost 30% increase in deficit households. Loans were provided to only those households that grew cotton and were provided only as inputs to cotton. Dividends, on the other hand, were paid to all households and were not tied to any productive activity and could therefore, be used to satisfy household needs. With lower total inputs of cash to the community (not all households receiving loans) and loans being tied to cotton production, we expected a lower proportion of maize and sorghum deficit households with dividend payments than with tied loans.

Household fallowing practices had a significant impact on the percentage of households that had a maize deficit each year (Table 5.9). At the -1 factor level the minimum number of years that a field would be cultivated before being left fallow was five. All yields of maize grown on jecha at this factor level were based on the five-year cultivated jecha function which had a much lower mean yield than the uncultivated jecha function (Table 4.9). I expected, therefore, that at the +1 factor level, where yields could be based on the virgin and the cultivated functions, the mean maize yields would be higher and fewer households have a maize deficit. This expectation is consistent with the data of Table 5.9.

The effect of increasing household cash needs was to reduce the percentage of needs deficit households (Table 5.9). Similarly, several other model response variables responded to increasing household cash needs in ways that were contrary to expectations. A tentative explanation is presented (Figure 5.18). The argument had two components. The first was as follows: When household cash needs were increased more cash was required to satisfy basic household cash needs and less was available to meet the relatively high initial costs of

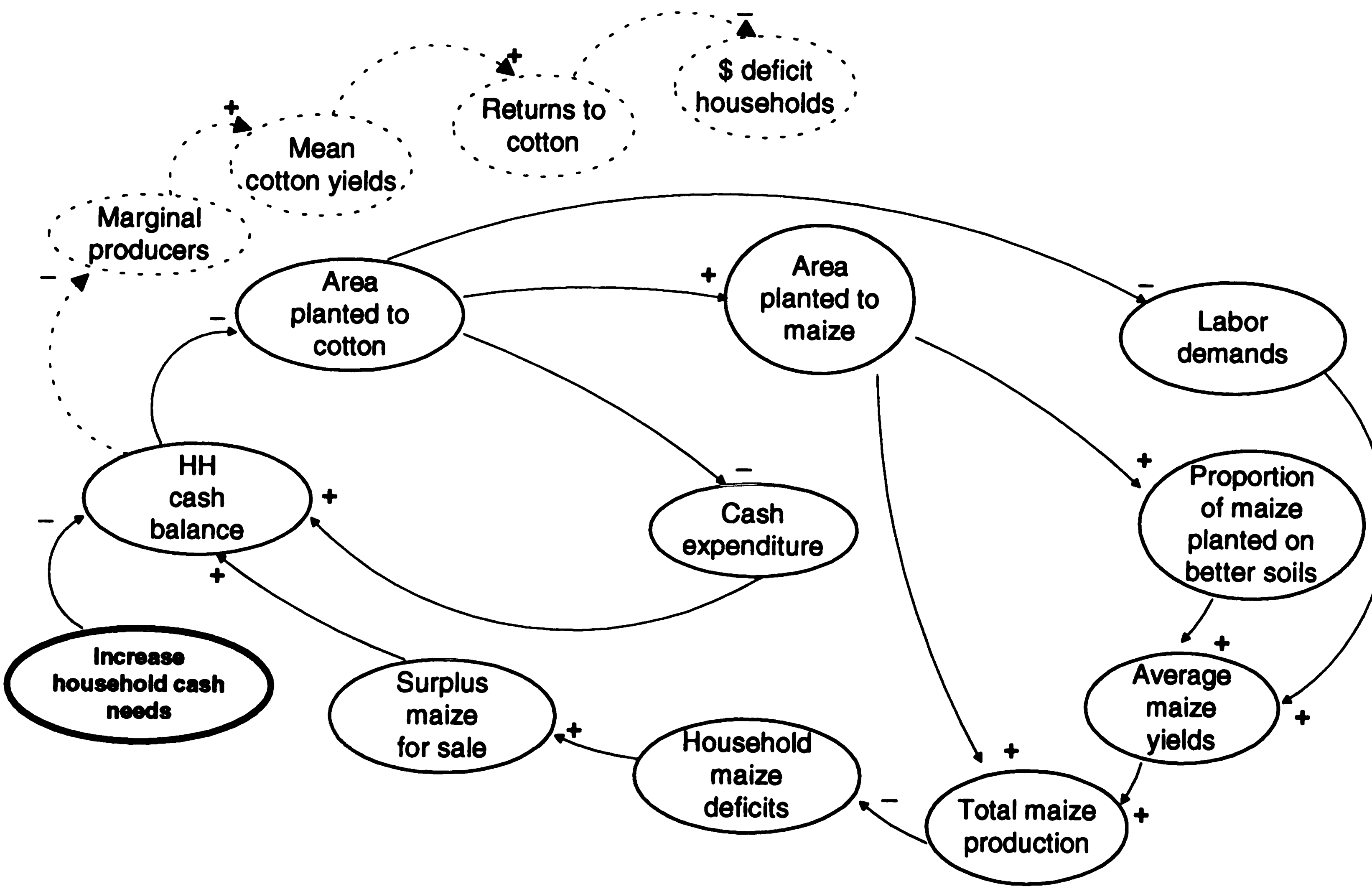

Figure 5.18. Causal loop diagram of the effects of increasing household cash needs on household maize and cash balances.

producing cotton. The per household area planted to cotton was therefore, expected to decrease. This decrease would have three important consequences. Firstly, household expenditure on agriculture would have decreased, leading to higher household cash balances which could be used to satisfy cash needs. Secondly, smaller areas of cotton would have resulted in lower labor demands, a lower likelihood of labor deficits and lower labor deficit induced yield reductions. The third, and probably most important consequence of reduced cotton planting would have been the increased areas planted to maize, including areas of the better soils. The greater area planted to maize, coupled with the higher average maize yields would lead to higher total maize production and hence to lower household maize deficits. Households with maize surpluses could sell their surpluses to offset their cash deficits. To reduce the same cash deficit households required between three and 10 times as much maize as they would cotton. Thus, once household maize and cash deficits were satisfied there was not likely to be a cash balance sufficient to support cotton production.

From this hypothesis a number of predictions were deduced. Based on this hypothesis we would have predicted that average maize yields would be higher when household cash needs were at the higher level. We would also predict that there would be a lower percentage of maize deficit households when household cash needs were at the higher level. Maize yields were higher when household cash needs were at the higher level (Table 5.10). From Table 5.9 we had already seen that higher household cash needs resulted in a lower percentage of households that were maize deficit each year. Acceptance of this hypothesis was contingent on acceptance of a few key assumptions, the most important of which was that whilst households unable to produce cotton would increase the probability of their satisfying household cash needs, they would not be earning sufficient cash to enter into cotton production. These assumptions required further analysis for me to have felt entirely comfortable with the hypothesis.

A second, and perhaps more plausible hypothesis (but not exclusive of the first) was as follows (depicted by the dotted lines in Figure 5.18): With increased household cash needs, many of the more marginal cotton producers (those with poor soils or who had a labour deficit) would be excluded from cotton production due to their not having the capital to invest in inputs as described in the previous hypothesis. These households would have to switch to maize production. The remaining cotton producers would be those households that were more likely to achieve high yields as they would not be labor constrained. They would also be more likely to satisfy household cash needs. The marginal cotton producers (i.e. those who were likely to be labor deficit) who had switched to maize were likely to have been those households that were not satisfying household cash needs, in part because of the high costs of cotton production. These households, relieved of the burden of cotton production might have been more likely to satisfy household needs through maize production owing to the lower costs of production. I assume here, that these households were generally smaller (hence the labor constraints) and therefore quite likely to satisfy household cash needs from maize and sorghum production. As with the first hypothesis this one required further investigation to be acceptable.

Although they may both be plausible, these hypotheses are related to explaining the behavior of the model and did not necessarily provide acceptable explanations of real world processes. It was clear that some aspects of the model specification were contributing to behavior that we would not have expected in the real world. In particular, households in the model planted a set proportion of their fields to specific crops, irrespective of the labor they had available. This could lead to households' reducing their chances of satisfying needs by planting areas that were larger than they could cope with. This was an unrealistic expectation which was to be corrected in future versions of the model.

By proposing these hypotheses, I did not discount the possibility that the model contained an error that resulted in the observed effects of increasing household cash needs.

Crop yields

As expected, mean yields of maize, cotton and sorghum were all markedly sensitive to changes in the mean annual rainfall (Table 5.10). The yields of maize and cotton more than doubled with the change from a low mean annual rainfall to a higher mean whilst the yields of sorghum more than tripled. The +1 level of fallowing practices led to a reduction in maize yields but increased cotton and sorghum yields. The effects on cotton and sorghum were what was expected; at

Table 5.10 Sensitivity of mean annual yields of maize (MZYLD), cotton (CTYLD) and sorghum (SRYLD) to changes in factor levels[3].

Factor	MZYLD (kg ha^{-1})			CTYLD (kg ha^{-1})			SRYLD (kg ha^{-1})		
	Mean effect	%[1]	Sig[2]	Mean effect	%	Sig	Mean effect	%	Sig
Rainfall	1000	68	***	621	79	***	576	116	***
Fallowing practices	-79	-5	***			NS	65	13	***
Average season classification	11.4	1	*			NS	1.7	<1	**
Cash needs	52	4	***			NS	6	1	***
Poor season classification	25	2	**	66	8	**	15	3	**
Overall mean	1463			784			488		

1. % of the overall mean for that effect.
2. Significance determined using Student's t test. Effects were different from zero at $p<=0.001$ (***), $p<=0.01$ (**), $p<=.05$ (*) and not different from zero at $p>.05$ (NS). See text for details of tests.
3. Data show the change in mean response to changing the factor of interest from the -1 to the +1 level.

c

b

a

se

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the +1 level we would expect a larger number of fields cultivated for fewer years resulting in higher yields. The reduction in maize yields at the +1 factor level was difficult to explain. Despite the significance of the result, the response (70 kg ha^{-1}) was within the range of error I expected from model yield functions.

Mean yields for all three crops were sensitive to the average season and the poor season membership functions used. The direction of the effects were all the same with an increase in yields at the +1 factor level for both seasons. With the poor season membership function at the +1 level we would expect higher yields as at all but the lowest u_{poor} levels the +1 level u_{poor} dominated -1 level u_{poor} (area c of Figure 5.19). For the average season membership function the explanation for higher yields at the +1 factor level was a little more difficult to visualize but was nonetheless straightforward; when moving from the +1 level to the -1 level the effect was to have a wider range of annual rainfall amounts dominated by low membership values of the set of poor season yields and a wider range of annual rainfall amounts dominated by low membership values of the set of good season yields (areas a and b in Figure 5.19). At the +1 level areas a and b of Figure 5.19 would have been dominated by low membership values of the average season (the A+1 curve). Yields at low membership values of an average season, on each soil type, were higher than yields at low membership values of either poor or good seasons. Thus, when areas a and b of Figure 5.19

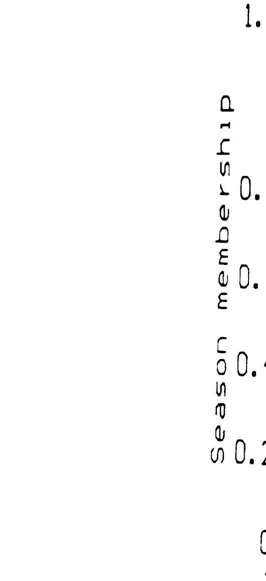

Figure 5.19

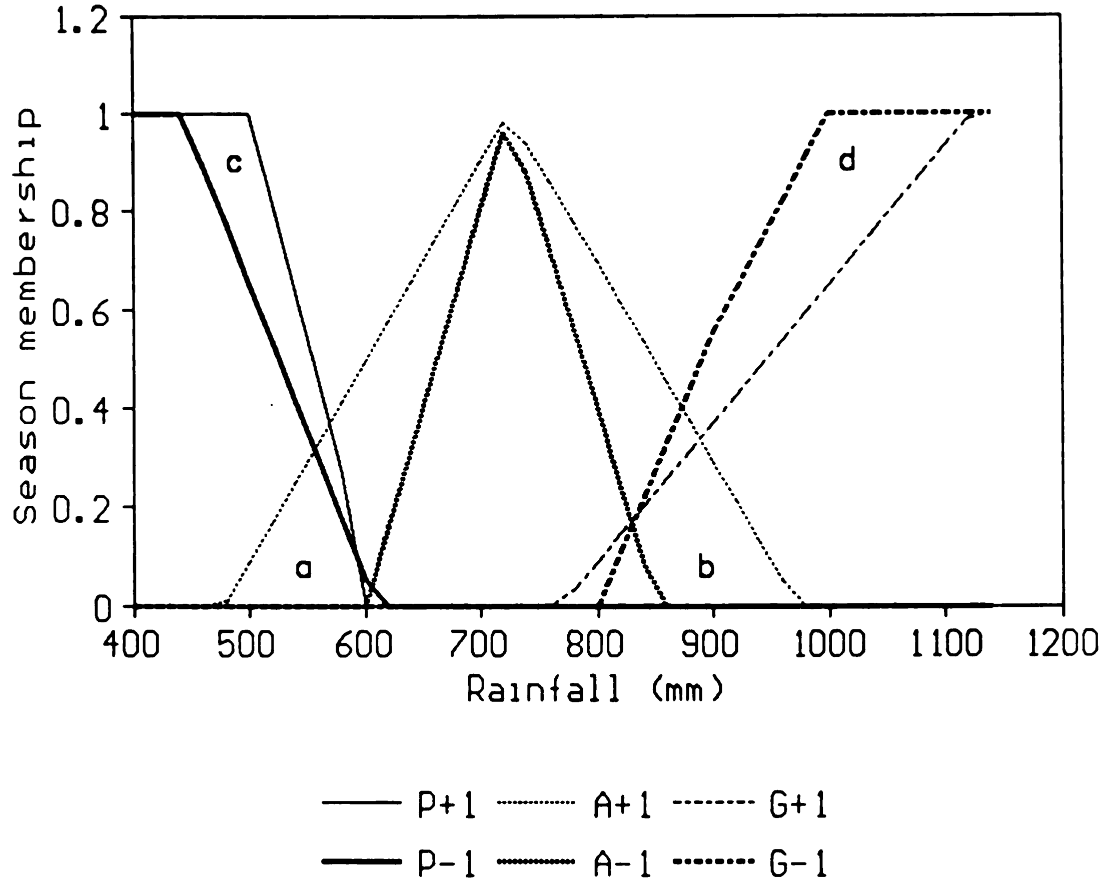

Figure 5.19. Good (G), average (A) and poor (P) season membership functions used for +1 and -1 levels in sensitivity analysis.

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were dominated by the average season membership function (at the +1 level) higher yields were achieved.

The responses of maize and sorghum yields to increases in household cash needs have been described in the previous section and with reference to Figure 5.18.

Economic response variables

Apart from the consistent sensitivity to rainfall and household cash needs there were no patterns of sensitivity to factor levels across all economic response variables.

Not unexpectedly the returns to maize were sensitive to the change in maize price (Table 5.11). Increasing the maize price from Z$0.26 kg^{-1} to Z$0.80 kg^{-1} (i.e. 208%) resulted in increases of 22% in returns to land, labor and initial investment as well as an increase of 17% in total returns to households from maize.

Increasing household cash needs by 41% increased returns to all inputs for maize. Given the explanatory model presented in Figure 5.18 these increases were expected. The model of Figure 5.18 indicates higher maize yields with increased household cash needs and therefore, higher returns to land, to labor, to initial investment and total returns to households.

Table 5.11 *The effects of factor level changes on the means of total returns (MZRET), returns to land (MZHA), labor (MZLAB) and to initial investment (MZINV) for maize[3].*

Factor	MZRET (Z$ household^{-1})	MZHA (Z$ ha^{-1})	MZLAB (Z$ day^{-1})	MZINV (Z$ Z$$^{-1}$)

Table 5.11 The effects of factor level changes on the means of total returns (MZRET), returns to land (MZHA), labor (MZLAB) and to initial investment (MZINV) for maize[3].

Factor	MZRET (Z$ household^{-1})			MZHA (Z$ ha^{-1})			MZLAB (Z$ day^{-1})			MZINV (Z$ Z$$^{-1}$)		
	Mean effect	%[1]	Sig[2]	Mean effect	%	Sig	Mean effect	%	Sig	Mean effect	%	Sig
Maize price	1059	117	***	788	121	***	9.52	121	***	6.11	122	***
Cash needs	782	86	***	52	8	***	0.6	8	***	1.33	26	***
Rainfall	649	72	***	505	78	***	6.1	77	***	3.18	63	***
Proportion of MINVAR strategists	211	23	***	13	2	*			NS	0.27	5	**
Average season classification	35	4	**			NS			NS			NS
Land multiplier	65	7	**	9	2	*			NS	0.15	3	**
Poor season classification	44	5	**	15	2	*	0.18	2	*	0.17	3	**
Loan / dividend	35	4	**	-10	-2	*			NS			NS
Fallow practices	-18	2	*	-41	-6	***	-0.5	6	**	-0.17	-3	**
Overall mean	908			650			7.84			5.02		

1. % of overall mean effect for that factor.
2. Significance determined using Student's t test. Effects were different from zero at $p<=0.001$ (***), $p<=0.01$ (**), $p<=.05$ (*) and not different from zero at $p>.05$ (NS). See text for details of tests.
3. Data show the change in mean response to changing the factor of interest from the -1 to the +1 level.

Table 5.12 The effects of factor level changes on the means of total returns (CTRET), returns to land (CTHA), labor (CTLAB) and to initial investment (CTINV) for cotton[3].

Factor	CTRET ($Z\$$ household^{-1})			CTHA ($Z\$$ ha^{-1})			CTLAB ($Z\$$ day^{-1})			CTINV ($Z\$$ $Z\$^{-1}$)		
	Mean effect	%[1]	Sig[2]	Mean effect	%	Sig	Mean effect	%	Sig	Mean effect	%	Sig
Rainfall	970	108	***	1274	99	***	9.95	99	***	0.86	91	***
Loan or dividend	-445	-50	***	35	3	*			NS	-0.11	-12	**
Cash needs	423	47	***			NS	0.31	3	*	-.03	-3	*
Proportion of MINVAR strategists	-190	-21	**			NS	0.34	3	*	-0.07	-7	*
Poor season classification	173	19	**	107	8	**	0.87	9	**	0.14	14	***
Land multiplier	-139	-16	**			NS			NS	-0.05	-5	*
Fallow practices	76	8	*			NS			NS	0.05	5	*
Good season classification	103	11	*			NS			NS			NS
Wage	64	7	*			NS			NS			NS
Maize price			NS	48	4	*			NS	0.06	6	*
Employment			NS			NS	0.75	7	**			NS
Overall mean	896			1282			10.0			0.95		

1. % of overall mean for that factor.
2. Significance determined using Student's t test. Effects were different from zero at $p<=0.001$ (***), $p<=0.01$ (**), $p<=.05$ (*) and no different from zero at $p>.05$ (NS). See text for details of tests.
3. Data show the change in mean response to changing the factor of interest from the -1 to the +1 level.

Table 5.13 *The effects of factor level*

Table 5.13 The effects of factor level changes on the means of total returns (SRRET), returns to land (SRHA), labor (SRLAB) and to initial investment (SRINV) to sorghum[3].

Factor	SRRET ($Z\$$ household^{-1})			SRHA ($Z\$$ ha^{-1})			SRLAB ($Z\$$ day^{-1})			SRINV ($Z\$$ $Z\$^{-1}$)		
	Mean effect	%[1]	Sig[2]	Mean effect	%	Sig	Mean effect	%	Sig	Mean effect		Sig
Rainfall	157	116	***	316	117	***	4.3	117	***	85.3	117	***
Cash needs	28	20	***	3	1	***	0.03	1	***	0.86	1	***
Fallow practices	15	11	***	35	13	***	0.39	11	***	9.52	13	***
Poor season classification	4	3	***	9	3	***	0.12	3	***	2.34	3	***
Overall mean	135			270			3.68			72		

1. % of overall mean for that factor.
2. Significance determined using Student's t test. Effects were different from zero at p<=0.001 (***), p<=0.01 (**), p<=.05 (*) and not different from zero at p>.05 (NS). See text for details of tests.
3. Data show the change in mean response to changing the factor of interest from the -1 to the +1 level.

At the +1 factor level total returns (per household) more than doubled, providing supporting evidence for the hypothesis of Figure 5.18 in which I suggested that the areas under maize production would increase when household cash needs increased. From greater areas I expected greater total returns. The unexpected higher total returns to cotton with increased household cash needs did not fit neatly into the explanatory model of Figure 5.18. One explanation was that, with the reduced areas planted to cotton and the consequent reductions in labor demands (and deficits) the yields of cotton (as well as those of sorghum and maize) would have increased. Whether those increases would have been sufficient to increase total returns by almost 50% required further investigation.

Rainfall had the expected effect of increasing total returns for maize, for cotton and for sorghum, as well as to all inputs for each of these crops.

The effect of increasing the proportion of variance minimizers from 20% (factor level -1) to 80% produced the results I had expected; variance minimizers planted a greater proportion of their land to maize so I expected higher total returns and slightly higher returns to land, labor and initial investment for maize. Only the returns to labor were not significantly improved at the higher level of variance minimizers (Table 5.11). With respect to cotton, the effect of changing the proportion of variance minimizers was not as clear. Variance minimizers planted less of their area to cotton so I expected, at the -1 factor level, the higher total returns to cotton as were found (Table 5.12). With larger areas however, I expected greater labor deficits and hence, lower yields per hectare with lower returns per hectare, per labor day and per Z$ invested. The data of Table 5.12 confirmed this expectation for returns to land and to labor but not for returns to initial investment. The effect for the latter, was however, very low (1% of the overall mean) and could be due to error.

Economic response variables for all three crops were sensitive to the poor season membership functions used, although, except for the effect of the poor season membership function on cotton returns, these effects were small compared to the factors discussed previously. Only total returns to maize were sensitive to the average season membership function used and the effect was small (Table 5.11). For the most part the effects of changes in the seasonal membership functions were due to changes in yields as discussed above. The increased yields due to the +1 level of the poor season membership function probably accounted for higher total returns and returns to land, labor and initial investment for cotton (Table 5.12).

Maize and cotton returns were notably sensitive to the land multiplier used (Tables 5.11, 5.12). Maize returns (except returns to labor) increased with increasing land availability whilst those for cotton decreased. These trends were not unexpected. With larger land areas households would have been less likely to have had sufficient capital to plant all of their normal quota of cotton fields than with smaller land areas. This would have been due to households having to plant a proportion of their fields to cotton. More maize and less cotton would, therefore, have been planted, thereby increasing the total returns to maize and reducing those to cotton.

Fallow practices had notable effects on sorghum returns and lesser effects on maize and cotton returns (Tables 5.11, 5.12, 5.13). For maize the returns to land, to labor and to initial investment decreased when fallow practices changed from the -1 to the +1 level by between 3% (MZINV) and 6% (MZHA, MZLAB) of the overall mean. Given the reduction in maize yields with the +1 level of fallow practices (Table 5.10) these changes in maize returns were expected. Cotton returns increased when fallow practices changed from the -1 to the +1 level. Total returns increased by 8 % and returns to initial investment increased by 5 % (Table 5.12). Yields at the +1 level of fallowing practice were expected to be higher than those at the -1 level; at the -1 level the cultivated jecha yield function would always be used (with lower yields) whilst at the +1 level the uncultivated jecha yields function would be used at least some of the time, leading to higher average yields.

Sorghum returns increased by about 12% when the fallow practice factor changed from the -1 to the +1 level. This was equivalent to the increase in mean sorghum yield (13%) due to the fallowing practice factor.

Total cotton returns increased by 7% as the wage rate increased from Z$2.01 to Z$3.07 (i.e. by 53%). I suspected that as the wage rate increased more of the marginal cotton producing households (i.e. those likely to experience labor shortages) would have gone out of cotton production. Expecting the mean total returns to cotton production to increase would have been plausible. Mean total returns r

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returns represented the total returns to cotton averaged among cotton producing households.

Total cotton returns, as well as returns to land and initial investment, were sensitive to the form that subsidies took with the mean of total cotton returns decreasing 50% when subsidies were paid in the form of dividends (Table 5.12). Loans increased the area planted to cotton but also facilitated more labor constrained households, that would otherwise not have been able to produce cotton, to plant cotton. Labor constrained households or those without access to bepe or riverlands faced relatively high risks of low or even negative returns to cotton. The effect of increasing the number of these households that were able to produce cotton would be to reduce the mean of the total returns to cotton. Although the effect was small, the higher returns to land from cotton were however, inconsistent with this model.

Erosion, erodibility and "fertility"

A number of the responses of the resource performance measures (MNER, CHGFRT and CHGFB) were completely contradictory to my expectations. In examining the model I realized that many of these responses were an artifact of how the changes had been calculated as well as the large temporal variability in the total number of years the landscape had been cultivated (and hence Fb). These problems made interpretation of the results of factor level changes on resource responses difficult.

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The change in the total number of years of cultivation summed over the landscape (CHGFRT) was calculated as:

$$CHGFRT = ENDFRT_{50} - STRTFRT_{21}$$

Where $CHGFRT$ = The change in the total number of years of cultivation in each cell summed across the 30 year simulation;

$ENDFRT_{50}$ = The total number of years of cultivation in each cell summed over the landscape at t=50;

$STRTFRT_{21}$ = The total number of years of cultivation in each cell summed over the landscape at t=21.

A simple simulation model that used the fallow functions of MASOKA1 was developed and initialized, with the same functions used in INITIAL, for cultivation history. The model was used, with only 100 cells, to examine the changes in the total number of years of cultivation of each cell summed across the landscape (TOTFRT) and over the same 30-year simulation period. Several independent simulations were carried out and produced the same results. TOTFRT as well as the number of cells left fallow each year were plotted in Figure 5.20. What became clear were the very large fluctuations in TOTFRT when the -1 level of fallow practices was used (5 year minimum and 7 year maximum). Despite the obviously lower mean TOTFRT at the +1 factor level, by using the above equation to calculate CHGFRT the +1 level of fallowing practices appeared to increase CHGFRT compared to the -1 level (Figure 5.20). These appearances were deceptive; the mean of several runs with the fallow test model showed that with 0-10 fallow practice mean TOTFRT over 30 years was 50% less than with the 5-7 fallow regime and 60% less with the 6-7 fallow regime that was used in error. Unfortunately, the sensitivity analyses were conducted using the CHGFRT and CHGFB values as calculated above (CHGFB was calculated in a similar manner) and the results were therefore, of little use. In future versions of the model it was planned to use more suitable analytical methods for these data, autoregressive moving averages or spectral analyses were tools that were thought likely to prove insightful.

Although mean erosion was calculated over the entire landscape and then averaged for each year, its dependence on Fb suggests that interpretations of the sensitivity of erosion (as well as Fb) to factor level changes should be made with far more attention paid to the time series than to the average values.

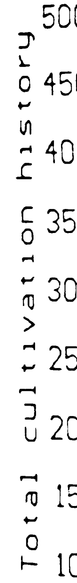

Figure 5.2

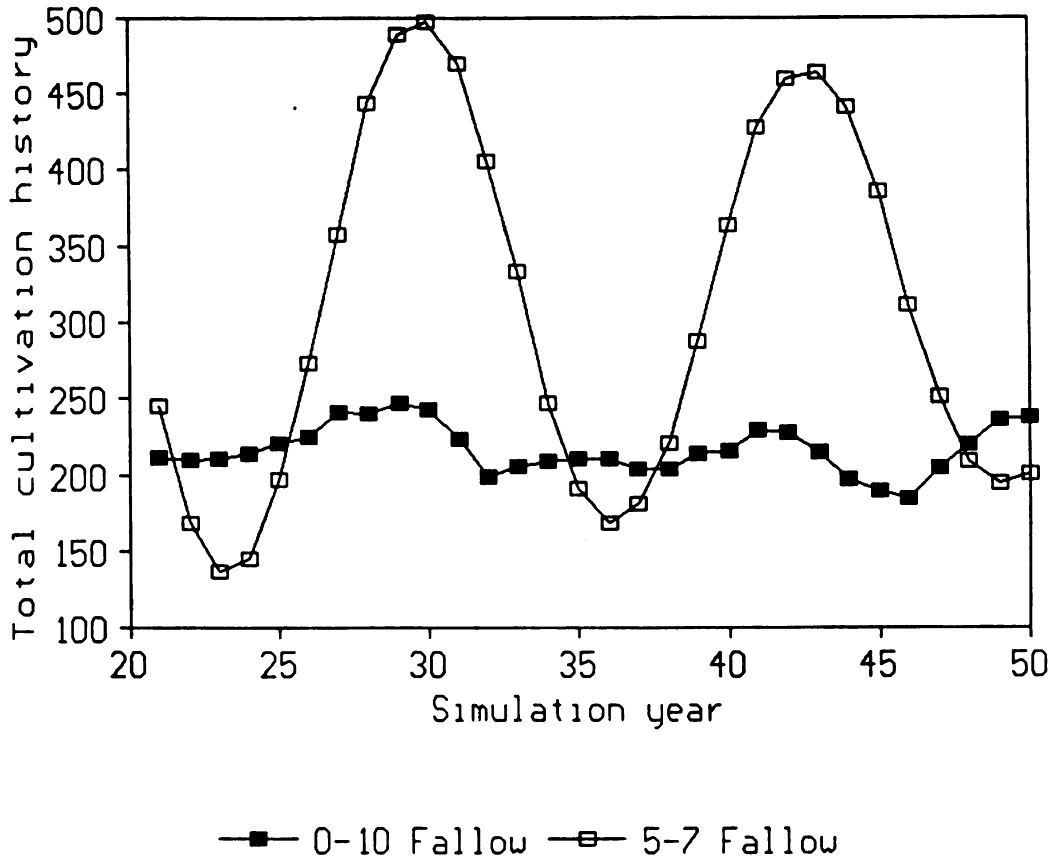

Figure 5.20. Total number of years each cell had been cultivated, summed over the landscape for +1 fallow practice factor level (min = 0, max = 10 years) and -1 factor level (min = 5, max = 7 years). Result of single simulation.

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SUMMARY AND CONCLUSIONS

The development and structure of simulation models of the Masoka agroecosystem were described and tests of model validity and sensitivity were presented. The model was developed to enhance our understanding of the structure and functioning of the Masoka agroecosystem and as part of a developing methodology for the analysis of complex agroecosystems.

Three models were described: The agroecosystem model (MASOKA1) simulated household decisions regarding which of three crops (maize, cotton and sorghum) to plant on each field in each year, compared household cash and food needs to production, compared labor needs to available household labor and sought to employ labor to make up deficits. The model also calculated household returns to land, labor and initial investment for each of the three crops and summary statistics for all performance measures on an annual time step. Inputs to the agroecosystem model were generated by the initializing model (INITIAL) and the rainfall generator (RAINGEN). Yields were generated, within MASOKA1, using yield probability distribution functions fitted to yield probabilities provided by village representatives for each of three soils and three classes of season (good, average and poor). Elements of fuzzy set theory were used to develop continuous yield functions. The degree of membership in each season of each annual rainfall amount was used to determine the yields achieved by each household on each cell in that season.

Household production was corrected if households experienced labor deficits in key months of the growing season for each crop. Households that were labor deficit could employ labor from households that had labor surpluses but were food or cash deficit if the employing household had the cash or food to pay for the hired labor. Once household production was corrected for labor deficits the model used household yields, land areas planted and labor hired to calculate the total returns to the household for each crop as well as the returns to land, to labor and to initial investment. The model also estimated the erosion on each cell of the landscape, using the SLEMSA model of Elwell (1980).

Outputs from the model were written to data files each year. Outputs of individual household performance could be written to files or random samples of household data could be written to data files. Household data were aggregated each year and written to separate output files. These data in turn were aggregated when the model was run in monte carlo mode and the output written to a monte carlo output file. GIS data layers of soil, slope, household field holdings, cultivation history and vegetation cover were key input files to the model. The model produced an updated cultivation history GIS data layer at the end of the simulation as well as data layers of erosion and the change in soil erodibility over the landscape. The latter data layers could be produced at up to three times during the course of a simulation.

Outputs from the rainfall generator and initializing model were tested against the original data distributions taken from Masoka and were found to generate f

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rainfall and initial conditions that were acceptably close to the original distributions. The yields generated by the agroecosystem model were compared to the yield distributions developed by the VRs and were found to work adequately. Interactive validation of model results with Masoka residents and VRs as well as Zimbabwean development professionals was still required at the time of writing.

Preliminary sensitivity analyses of the model examined the effects of 13 factors on response variables. Crop yields were particularly sensitive to rainfall. The percentage of households that were cash, maize and sorghum deficit each year were sensitive to rainfall, the land area available to households, the cash needs of households, the membership functions used for each season, whether subsidies were provided as loans or dividends and fallowing practices. For the most part the relationships between factor levels and response variables conformed to expectations. The decrease in households experiencing needs deficits with increased household cash needs was surprising. A tentative model, not yet tested, was described to explain the effect.

The effects of factor levels on economic response variables were largely attributable to the effects of rainfall on yields, and in the case of maize, to changes in the maize price. Maize returns were particularly sensitive to the maize price, rainfall, household cash needs and the proportions of households that were in each of the two household production strategies used for these simulations. Cotton returns were particularly sensitive to rainfall, the membership functions used for each season, the proportion of households in each production strategy and fallow

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fallowing practices. Sorghum returns were particularly sensitive to rainfall, household cash needs, fallowing practices and to the membership functions used for each season.

The model estimates of changes in cultivation intensity and soil erodibility did not take the cyclic nature of these changes into consideration. Interpretation of the results of sensitivity analyses on the responses of these variables to changes in the 13 factors were therefore, ambiguous and required further investigation.

In conclusion, I proposed that the models developed for analyzing the Masoka agroecosystem, although incompletely evaluated, were useful:

1) The models enabled me to examine the responses of a very complex system to changes both in exogenous inputs typical of policy decisions as well as to endogenous changes typical of household production decisions.
2) The models enabled me to examine the feasibility of integrating indigenous knowledge as well as formal scientific knowledge to provide a predictive simulation model.
3) The models enabled me to examine, simultaneously, the effects of various management or policy options on household and community performance measures.
4) The models enabled us to use biophysical, social and economic performance criteria, in our evaluations of policy or management options. This capability would enable us to observe the relative trade-offs between

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these criteria and could lead to more informed decision making.

As an aid to understanding the structure and behavior, the models proved informative and represent a largely untapped source of insight and hypotheses. The modeling methodology shows promise as an aid to decision making in data scarce environments. We would do well however, to remember that "..in running the models we investigate the consequences of the guesses and assumptions incorporated in them - model output may tell us nothing new about empirical reality." (Landsberg, 1987).

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Chapter 6.

Overview and key issues for further research

INTRODUCTION

In this chapter the results of Chapters 3 through 5 are integrated and discussed with respect to the research objectives defined in Chapter 1. In the last section of the chapter, key issues requiring further research are identified.

OVERVIEW

In Chapter 1 it was suggested that two problems needed to be overcome in conducting agroecosystems analyses. The first of these was the problem of applying performance criteria such as sustainabilty, stability, resilience, productivity and equitability. The second was the lack of a sound philosophical and methodological basis for conducting the analysis. The checklist of Grimm *et al.*, (1992) was suggested as being a minimum set of definitions required when using these performance criteria; these factors were a) the level of description; b) the variable of interest; c) the referential behavior of the variable of interest; d) the nature of the disturbance; e) the spatial scale; and f) the temporal scale.

The field data collection and modeling methodologies presented in the preceding chapters not only required that I make explicit the primary level of analysis but facilitated use of several levels of analysis simultaneously. With these capabilities the modeling methodology in particular, could be used where emergent properties and multi-objective evaluations were likely to be problems. By using several levels of analysis, the household compared to the community for example, the policy maker could examine the impacts of policies from the household perspective. Given that several scales of analysis were possible in any simulation experiment, the impacts of household practices or policies on emergent properties could be examined.

The large number of performance measures in model output provided an integrated assortment of social, economic and bio-physical variables that were available to evaluate agroecosystem performance. This cross section of variables facilitated evaluation of the trade-offs that might have to be made in the analysis of real world agroecosystems.

The simulation models developed in this study were capable of generating expected or referential behavior based on a wide variety of assumptions regarding initial conditions, inputs and model parameter values. These referential behaviors could be used in evaluating the behavior of the agroecosystem.

The large number of factors that were changed in the sensitivity analysis were indicative of changes that could be made to examine the effects of particular disturbances on agroecosystem behavior. The approach thus enabled the me to

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specify the nature, direction and magnitude of a disturbance and to observe the impacts of these changes on the behavior of the agroecosystem using any of the large number performance measures estimated by the model. Both spatial and temporal scales were fixed parameters in the model with respect to some variables but not to others. The simulation time step and cell size were fixed parameters. The number of households was, however, a variable factor whose value might affect the values of performance criteria. Household numbers were explicitly set in each simulation.

Viewed as a whole, the field and modeling methodologies provide a useful set of tools with which to address questions about agroecosystem behavior when either static or dynamic performance criteria were to be used in evaluating agroecosystem behavior. Some aspects the model expanded the criteria suggested by Grimm *et al.*, (1992); the model provided information to examine the effects of changes in endogenous or exogenous control variables on agroecosystem performance criteria at several levels simultaneously; the model provided information that could be used to examine the effects of changes in endogenous or exogenous control variables on several response variables and several dynamic performance criteria. This capability would enable decision makers to evaluate the relative trade-offs that would be made under different policy or experimental conditions.

The development of a simulation model as part of the methodology would enable me to conduct controlled simulation experiments which could be used to

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explore the consequences of policy or household level changes in control variables.

The unavailability of data was a major constraint in planning the analysis described in previous chapters. Methodologies were developed and used that enabled me to develop useful insights in to the structure and behavior of the agroecosystem using the best available data. Much of this data was in the form of the knowledge of agroecosystem residents. The methodology presented was sufficiently flexible to incorporate data from local knowledge sources as well as more formally measured data. These data varied greatly in quantity and quality but were integrated into a simulation model. Very little data was available on the Masoka agroecosystem before the analysis was conducted. The methods developed in this study enabled meaningful examinations of the agroecosystem to be conducted in spite of the limited availability of quantitative data. In particular the use of spidergrams facilitated quantitative analyses of the components and relative importance of inputs to and outputs from these components for an entire production system. The resulting graph of the production system could prove useful for focusing further investigations. The spidergrams also helped select those components of the production system that were likely to be most important and needed to be included in the simulation model.

Although an approach to analyzing the behavior of the Masoka agroecosystem was presented the analysis was far from complete. Few statements could therefore, be made regarding the actual performance of the agroecosystem wit

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with regard to sustainability, stability, resilience and productivity. What became clear as the analysis proceeded was the dependence of these performance criteria on those factors listed in the checklist of Grimm *et al.* (1992). The widespread use of these performance criteria belies the difficulty of actually applying them in the real world. Although tentative, the analysis presented in Chapter 5 indicated that the ability of households to satisfy cash and food needs were critically dependent on rainfall, the land available to them both through physical availability as well as through the labor available to manage a given area and also on the level of cash needs that households expected to satisfy. The land available to each household and the quality of life expected by households were key community and household decisions. The analytical approach adopted, with the emphasis on community participation, could assist the community and households to make these decisions with at least some information on the trade-offs that needed to be made.

There was no doubt that aspects of the agroecosystem model lacked realism; The fixed proportion of a household's lands that were allocated to each crop in each season was certainly not a reflection of reality. A more flexible household decision making algorithm, in which household plantings were made as a function of both cash and labor resources available was planned for future versions of the model. The use of a constant number of households with unchanging land holdings and number of adults and children were also not realistic but considerably simplified the model. The use of constant prices and wage rates was obviously an over simplification of what is likely to be a complex p

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and changing set of values. Within season rainfall distributions are likely to have significant impacts on yields and erosion, yet the poor within season resolution of the model made analysis of these effects impossible. Despite these many shortcomings however, the model provided a useful first attempt at simulating a very complex production system at several scales; the complex interactions that were apparent in the results of the sensitivity analyses justified using the multi-scaled systems approach; despite the scarcity of measured data I was able to develop a meaningful model of the agroecosystem. I was also able to use the model to examine the effects of changes in the policy environment (crop price changes for example) as well as the household decision making environment (switches in fallowing practices for example) on several performance measures. The model could therefore, have utility both as a tool for planning extension packages as well as for examining the effects of various agricultural policies.

In conclusion, whilst the analysis and evaluation of the methodology were not complete, the methodology developed for analyzing the Masoka agroecosystem was useful and enabled the development of a fuller understanding of agroecosystem behavior. Some of the methods developed could prove useful in analyses of similar problems in similar classes of agroecosystem.

KEY ISSUES FOR FUTURE RESEARCH

The approach to agroecosystem analysis described in this dissertation is clearly far from adequate. Several issues emerged from the analysis and subsequent writing.

1. A methodological approach to validating expert knowledge has not been reported in the literature. Validation of indigenous knowledge (Chapter 4) was difficult and the methods of doing so were not well developed. If, as is likely, indigenous knowledge is to be an important source of information then the issue of validating this knowledge needed to be addressed.
2. Methods of analyzing the results of data collected from VRs were not readily apparent and require further investigation. In this regard Bayesian probability theory appeared to be a suitable starting point.
3. The simulation models developed for analyzing the Masoka agroecosystem were quantitatively based. Although some use was made of fuzzy set theory, greater use of these concepts could have resolved some of the problems associated with using indigenous technical knowledge, such as the conversion of total production to production per hectare.
4. Some analyses were not completed due to time constraints. Important among those was the expansion of model sensitivity analyses to finer scales of resolution. Were different classes of household, for example, differentially sensitive to changes in factor levels? How sensitive were the same performance criteria to simulation experiments conducted over longer

periods of simulated time?

5. A key issue that was not dealt with in the prototype agroecosystem model was the effect of spatial dependence on erosion simulation. The erosion modeling component of the version of MASOKA1 presented in these chapters was far from adequate and perhaps the weakest aspect of that model.

6. As was discussed earlier, the model and model results should be validated against VR opinion. The opinions of WWF MAPS Project staff would also be needed to establish the usefulness of the model and the approach.

7. It was likely that the spidergrams that were developed during the field data collection were biased by conditions that were dominant at the time (the drought for example). Investigations were needed that would indicate the relative changes in the components and weights of components of spidergrams if these analyses were conducted at different times and places.

8. The model as well as the overall approach to analyzing agroecosystems have potential utility both for evaluating government policy (extension packages or resettlement in the Zambezi valley for example), community level policies of land allocation and expansion as well as for identifying optimal household production practices. To utilize that potential the approach and results needed to be communicated to audiences that differed greatly in their technical understanding of the approach as well as in their objectives and values. One of the major challenges for the future

would be to present the findings of the study to these different groups and then to integrate their responses into future analyses.

9. Despite its complexity the model was a greatly simplified version of the Masoka production system; only three of the 13 production activities listed by female VRs were simulated in the model. It was quite possible that a greater diversity of production activities could significantly affect the results of analyses of the agroecosystem. Methods of evaluating the sensitivity of model response variables to the way the model was specified needed to be devised and tested. A potential solution to this problem might have been to examine the effects of allocating income to specific households at specific times in a simulation to represent income generated by these other activities. The income so generated could be either in the form of food (to represent vegetables or poultry for example) or as cash generated by craft or beer brewing. An advantage of the modeling approach used was the ability to examine effects such as these on different classes of household.

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