MODELLING LAND/RESOURCE-USE OPTIONS OPEN TO SMALLHOLDER FARMERS IN THE NORTHERN REGION OF ZAMBIA: A MULTIPLE OBJECTIVE PROGRAMMING APPROACH.

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For Kufekisa,

who by now appreciates

"how much better is it to get wisdom than gold! and to get understanding rather to be chosen than silver"!

(Proverbs Chapt. 16 Vs. 16).

I hereby declare that this thesis has been composed by myself, and is the product of my own work.

Signed: Date: 28.08.96.

ABSTRACT.

The farming systems of the Northern Region of Zambia were analysed along with other options in the context of farm family resource structures by use of a Single and Multiple Objective Mathematical Programming Models. Paucity of specific data relating to the area made estimation of good technical coefficients difficult. Production activities were therefore described using data from a variety of sources, thereby allowing exploration beyond historically observed activities.

The Multilevel Systems Approach used in this research where individual farm-level decision models are aggregated into a regional resource planning model is presented and the resulting model structure is described. The models are used to investigate land/resource use options open to smallholder farmers in the Northern Region of Zambia. In addition, the models attempt to explore an approach which takes preferences from the farm-level through to regional-level planning and decision-making.

The overall implication of the findings of the study seem to suggest that land-use options with lower and more realistic quantities of resource material would surfice under current smallholder behavioural patterns. This is consistent with regional expectations where poverty significantly constrains behaviour and survival seems to be the overriding objective. Opportunities exist for raising living standards in the rural areas if the liquidity position of the smallholder farmer at the beginning of the growing season can be improved. In an average rainfall year, an increase in cash availability would enable the farmer to purchase fertiliser, hire labour and buy other inputs - all of which would serve to increase food security and rural welfare in the long run.

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Chapter 1.

1.0 **Introduction.**

1.1 **Study proposal.**

The ideal of sustainable agriculture is not being realised in the Northern Region of Zambia. Several factors combine to cause significant constraints to agriculture development in particular and management of the natural resource systems in general leading to declining agriculture production and environmental degradation and the subsequent weakening of the economic development potential (Nkowani *et al.*, 1995b). These constraints have coincided with the flagging national economy reliant on the dwindling income from copper, with increasing dependence on donor aid support, and lack of positive, cohesive national directive in agriculture and natural resource development.

Competition for scarce resources at both farm and regional-level is also a source of concern. Main concerns of farmers include that of achieving stability or increase in food production, cash income, fuelwood, construction poles, having extra time for leisure, involvement in community, fulfilling cultural obligations, decreasing cost of production, limiting the amount of debt to be serviced and uncertainty (Dent & McGregor, 1993). At regional-level, the government on the other hand, sees food as a source of foreign exchange and government revenues, and as a strategic commodity which can be used as a means of control, a political weapon, and an instrument of social welfare (Chuzu, 1993; Tabucanon, 1993). The government's other concerns include the provision of services and infrastructure, regional expenditure, employment and reduction of environmental degradation by reason of increased indiscriminate cutting of trees in the name of shifting cultivation, collection of fuelwood and construction poles leading to problems related to soil deterioration and a reduction in biological activity. Objectives of farm families in the context of rural development, no doubt are in conflict with the wider aims of regional policy makers.

There is an obvious need to select and promote farm production systems that generate a level of productivity that satisfies the material (productivity) and social (identity) needs of the farm household and that of the society at large with certain margins of security and without long-term resource depletion. As the objectives of security, continuity and identity usually compete with immediate productivity, a 'satisficing' instead of maximum level of productivity has to be sought in order to ensure sustainability of various productive systems at both farm and regional-level. Goal Programming method has been proposed as a viable way to highlight the potential use of explorative land/resource-use studies to make consequences of and trade-offs between different aims and perceptions explicit at both levels of modelling.

1.2 **Objectives**

The farming systems of the Northern Region of Zambia are analysed along with other options in the context of farm family resource structures by use of a Single and Multiple Objective Mathematical Programming Models. Paucity of specific data relating to the area made estimation of good technical coefficients difficult. Production activities were therefore described using data from a variety of source, thereby allowing exploration beyond historically observed activities.

The Multilevel Systems Approach used in this study where individual Farm-Level Decision Models are aggregated into a Regional Resource Planning Model are presented and the resulting model structures prescribed.

The general objectives of the study are:

(1) To identify and understand the technical, social and economic factors, and their relative importance and their complex interactions, that dictate smallholders' decisions in the uptake of any specific land-use option.

(2) To identify major features or characteristics for each farming system.

(3) Attempt to mimic smallholder farmer (land user) production behaviour by using Linear Programming (LP) and Pre-emptive Goal Programming (PGP) models. The comparison of both techniques is not emphaised in this study.

(4) Provide a tool which could be used by decision makers in choosing appropriate policy objectives to induce change at farm-level, in order to realise wider aims at aggregate level (regional-level).

(5) Consider policy implications of the findings in designing technologies for sustainable development.

The specific objective of this study is:

To investigate land/resource-use options open to smallholder farmers in the Northern Region of Zambia. In addition, the study attempts to explore an approach which takes preferences from the farm-level through to regional-level planning and decision-making.

1.3 **Hypotheses.**

The following hypotheses will be addressed:

(1) Planning for sustainable agriculture is not being realised in the Northern Province of Zambia. The existing decision-making methodologies are inadequate for technical, social, economic and environmental planning in land-use systems at both farm and regional-level, in particular:

- At both farm and regional-level, competition for scarce resources is a major consideration and often the cause of conflict. Micro, and regional-levels should be integrated in a multisystems concept to understand and model decisions and linkages at and between all levels.

(2) Current agricultural development policies and practices are not sufficient to address the perceived needs of smallholder farmers, but for any alternative technology to be acceptable, it must be at least be as productive as existing technologies in relation to the resource constraints and preferences of smallholder farmers in the area.

- Smallholder farmers' main concern is to strive to find an ideal compromise over a set of farming objectives based on individual and/or community value systems rather than pursuing maximisation of profit. In a multiple objective framework, they are also more likely to adopt technologies that are designed to guarantee satisfaction of the higher priority goals such as production and consumption.

The hypotheses of this study are presented to permit insights into certain aspects of household behaviour and their production systems, and relate these to regional planning decision-making, and the consequences this behaviour may have for the use of land and associated resources in a sustainable development perspective.

1.4 Outline of the thesis

The thesis consists of four parts:

Part one presents the background to the study. In chapter 1 the definition of the problem is presented. This is followed by the description of the study objectives, hypotheses, and the overall outline of the thesis. Chapter 2 presents an overview of Zambia as a nation in relation to it's location, area and climate. This is followed by the presentation of Zambia's' economic performance and agriculture development in particular. Chapter 3 focuses on the Northern Region of Zambia - the study area. In this Section, the areas' location, extent and climate, biological resources, geology and soils, and economy are presented. Land tenure and current main farm types are described The potential long term implications of these land-use systems on the resource base are discussed. Chapter 4 describes the rationale behind the use of goal programming in particular and multiple objective decision making approaches in investigating land/resource-use systems at both farm and regional-levels. Characteristics of the problem in the study area are highlighted and the arguments behind the application of pre-emptive goal programming technique in decision-making processes associated with resource allocation at both farm and also in the wider area of land-use at the regional-level is discussed.

Part two presents the study survey methodology and results. Chapter 5 describes the study research methodology, sample selection method and examines data representativeness. The limitation to data obtained during the survey is discussed, followed by an outline of the analytical approach chosen. Chapter 6 presents the statistical results of the survey. The data analysis about the household economy and farming systems enabled the researcher to identify farmers priorities, production capabilities and potential. These findings together with secondary research data, scientific information and other sources of information form the major source of data input for the development of a logical mathematical framework for representative linear programming and multiple objective models in the next chapter.

Part three presents the development of a multilevel mathematical modelling framework. In Chapter 7 the four farm system types (distinct from farm household types) described and analysed in Chapter 6 are explored along with other options in the context of farm family resource structures. In this chapter, the multilevel methodology where individual farm-level models are aggregated into the regional model is developed and the resulting model structure presented. The steps taken in specifying activities and constraints for the Linear and (PGP) models are outlined. The single and multiple objectives at both farm and regional-level are considered. While priorities, target levels and the goals and objective functions of the PGP are ascribed too. The models are used to investigate land/resource-use options open to smallholder farmers in the Region. In addition, the models attempt to explore an approach which takes preferences from the farm-level through to regional-level planning and decision-making.

Part four presents the discussion and applicability of the study findings. In chapter 8 the analysis and results of the single and multiple objective modelling frameworks are presented. The assumptions of the planning framework along with the validation of LP and PGP model outputs at both farm and regional-level are discussed. The implications of both levels of modelling are also discussed and the strengths and weaknesses of the model results are underlined. In Chapter 9, conclusions are drawn and implications of the study findings are presented. Limitations of the present study are described and suggestions for further research work are provided.

Chapter 2.

2.0 Zambia.

2.1 Location, area and climate.

2.2 Economy.

2.3 National Development Plans.

2.4 Economic Policies for Agriculture.

2.5 Summary.

2.0 **Zambia.**

2.1 **Location, area and climate.**

Zambia is a land-locked country with an area of 752,614 Km^2 in the centre of Southern Africa between Latitude 8^0 and 18^0 South and Longitude 22^0 and 34^0 East (see Figure 2.1). It is divided into nine provinces, with a current population estimated at 10.04 million, compared with 6.24 million in mid-1983 (EIU, 1996). It is a high plateau country with an elevation of between 900 and 1,500 m above sea level occasionally broken by isolated hills of low ranges (Davies, 1971; Lawton, 1978). This topography influences its rainfall and distribution of soils and vegetation which are crucial factors to the farming community.

Monomodal rainfall seasons vary from 5 months in the South and progressively increases to 7 months in the North. This pattern of rainfall also has a profound effect on both the distribution of the country's soils and its vegetation. In the higher rainfall zone where the wetter miombo[1] is found the soils are leached and strongly weathered. These soils are the sandveld (ferralitic) soils which in the low rainfall zone are moderately leached.

Although there are marked differences in ecology and agriculture potential in Zambia, depending on climate and soils, there are limited areas of good soils (Lungu & Chinene, 1993). However, the reliable 4-5 months of rains over most of the country provides potential for it to be sufficient in food production.

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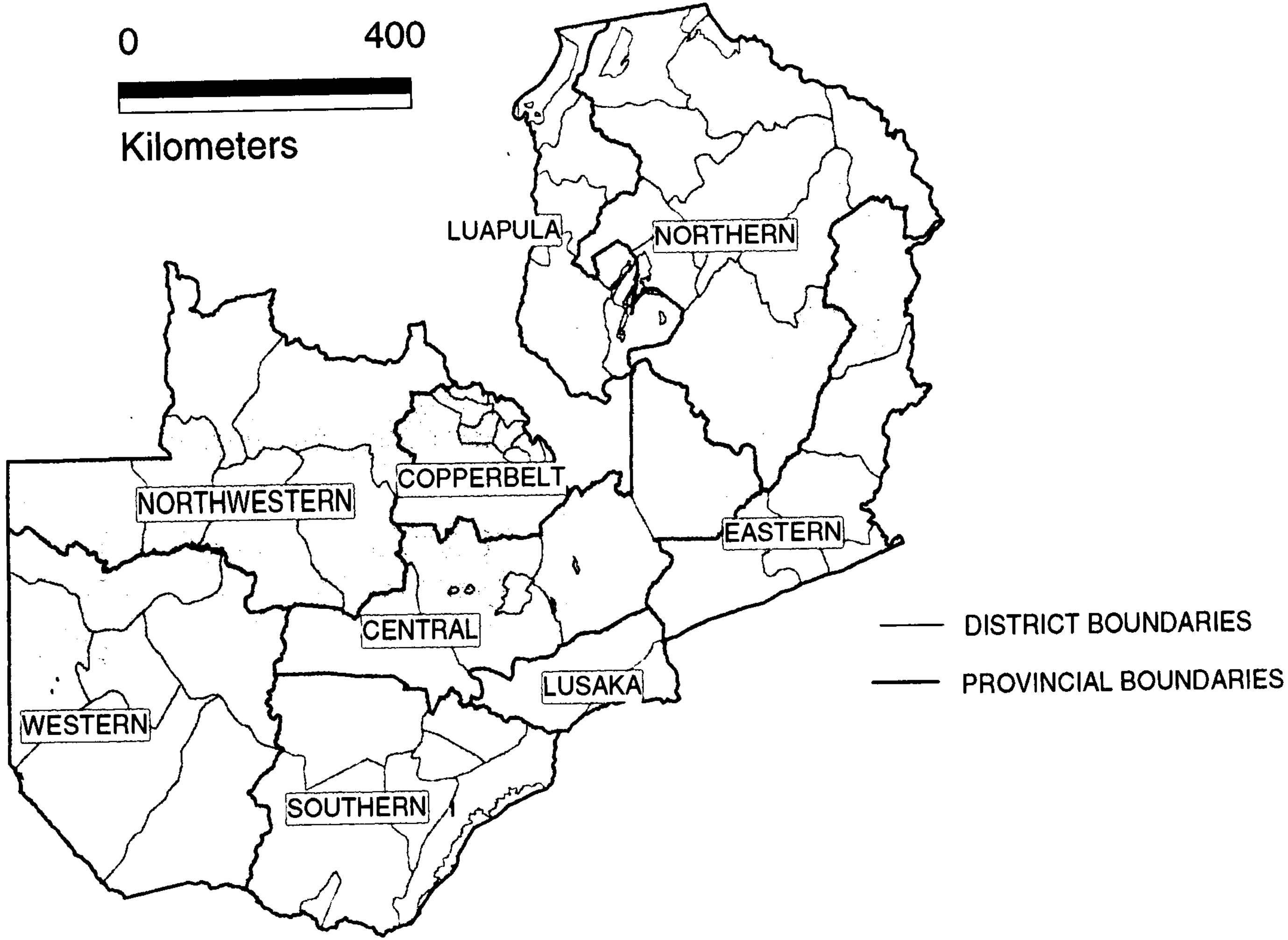
[1] Semi-decidous miombo woodland is a two storied woodland with an open or slightly closed canopy commonly dominated by wood species of the *Caesalpinioidae* sub-family including *Brachystegia*, *Isoberlia*, *Jubernadia* and associated genera (Fashawe, 1969).


0
400
Kilometers
LUAPULA
NORTHERN
NORTHWESTERN
COPPERBELT
EASTERN
CENTRAL
LUSAKA
WESTERN
SOUTHERN
DISTRICT BOUNDARIES
PROVINCIAL BOUNDARIES

2.2 **Economy.**

Until 1975, the Zambian economy was one of the most prosperous countries in Sub-Sahara Africa (EIU, 1996). The wealth, and the development of the infrastructure and the public services which went with it was however, founded on one export - copper accounting for 90 per cent of foreign exchange income (The Observer, 1993). When the world copper price slumped in 1975, so did the rest of the economy. Zambia was left with a legacy of debt, foreign exchange shortages and a falling copper output (see Table 2.1 for figures for a period between 1987-95).

Copper is the mainstay of the Zambian economy and it is estimated to have accounted for more than 78.4 per cent of export earnings in 1995 (Bank of Zambia, 1995). A decision on the privatisation of the state-owned copper mining giant, Zambia Consolidated Copper Mines (ZCCM), is still to be made, although commitment to this course of action was restated in the 1996 budget. Industry dominated by mining contributed for 45 per cent of the Gross Domestic Product (GDP) in 1995, while the service sector accounted for 43 per cent of GDP. More than half the population lives in urban areas and, partly as a result of this, the agriculture sector provided less than 12 per cent of GDP in 1995, despite the availability of ample arable land.

The economic policy will continue to be driven by the need to optimise relations with the IMF and therefore the rest of the donor and creditor community (EIU, 1996). High among the priorities of Zambian government outlined with IMF and others as part of the Enhanced Structural Adjustment Facility[2] (ESAF) are a reduction in the rate of consumer price inflation, a narrowing of the current-account deficit and the simulation of the economic activity, especially in the private sector (NCDP, 1993).

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[2] Ritva (1990) views Structural Adjustment as: "...involving a comprehensive set of economic measures designed to achieve macro-economic goals, such as an improvement in the balance of payments, a more efficient use of the productive potential, an increase in the long-term rate of economic growth, and low inflation. The concept is derived from two economic notions: First, structural means changing the structure of the economy, for instance by permanent changes in price incentives in order to achieve a more efficient allocation of resources. Adjustment refers to attainment of an equilibrium in the external and internal balance. In other words, an economy must be adjusted to internal and external shocks. The underlying view is that only efficiency in resource allocation and economic equilibrium can bring about long-term growth.

Table 2.1: **Economic Structure**

Macro-economic indicators	1987	1988	1989	1990	1991	1992	1993	1994[a]	1995[a]
GDP at market prices Zk m	19779	30021	55181	113340	219353	469564	1640748	2335168	n/a
Real GDP growth %	2.7	6.3	-1.0	-0.5	-0.4	-0.6	5.1	-5.4	-3.7
Consumer price inflation %	45.6	54.9	128.7	111.9	92.6	197.4	189	55	30
Population m	7.28	7.56	7.79	7.97	8.39	8.64	9.09	9.73	10.08
Export fob $ m	906	1191	1429	1350	1172	1177	1013	1075	1150
Import cif $ m	752	828	993	1298	752	829	803	845	900
Current account	-248	-295	-183	-105	307	-288	-258	-200	-90
Reserves excl. gold $ m	108.8	134	116.2	193.1	184.6	150	192.3	297	n/a
Total external debts $ billion	6.60	6.80	6.74	7.22	7.60	6.94	6.79	6.89	7.0
External debt service ratio %	17	13.1	12.4	12.8	51.1	29.5	32.8	31.0	25.0
Copper output '000 tons	473	416	448	442	387	432	392	350	330
Exchange rate (av.) Zk/$	8.89	8.22	12.99	28.99	64.64	172.21	452.76	669	910

[a] Provisional; m = million.

Source: Central Statistical Office; UN, Monthly Statistical Bulletin.

In addition to the three main microeconomic target areas, a series of structural reforms are being monitored: the ability of the Bank of Zambia (BoZ, the central bank) to exercise monetary control; civil service numbers to be reduced by 20 per cent, and the privatisation programme to be pursued, in particular as it concerns the sale of the state-owned copper mining company, ZCCM (EIU, 1996).

2.3 **National development plans.**

Each of Zambia's national development plans covering the years 1966-70, 1972-77, 1980-84 (originally scheduled for 1977-81), 1985-89 and 1990-95 was less ambitious than the last in terms of targets growth rates, and each was blown off course by a lower than expected copper prices and transport difficulties (see Table 2.2) (EIU, 1996). The general thrust of planning was towards the diversification of the economy, the encouragement of agriculture and industry, the improvement of social services and transport, and raising of rural incomes. In practice, however, government policy until the start of the International Monetary Fund (IMF) reform programme in 1983 tended to maintain the strong urban, import dependent bias that characterised the immediate post - independence period, with agriculture being neglected in particular (Killick, 1992a). In addition, failure to cut back on recurrent public spending during the period undermined efforts to shift the economy away from consumption towards investment expenditure.

The structural adjustment programmes too remain deeply flawed (The Economist, 1996). The IMF appears to be overly obsessed with *price stability*. Standard bank programmes call on weak, debt-ridden governments to introduce value added taxes, new customs administration, civil-service reforms, privatisation of infrastructure, decentralised public administration often within months (Sachs & Warner, 1996). Zambia's long-term growth predicament was mainly as a result of much higher trade barriers; excessive tax rates; lower saving rates; and adverse structural conditions, including international transport plus a high reliance on natural-resource exports. The nation needs development plans which emphasise on simple, low taxes, with modest targets as a share of GDP. All this is possible if the government itself holds it's own spending to the necessary minimum. According to Sachs and Warner (1996) aid works only when it is limited in time (and thus is not a narcotic), and is part of an overall market-driven growth strategy. International Monetary Fund programmes have rarely constituted a growth strategy.

Table 2.2: **Trends of GDP at factor cost**

Total Zk million	1986	1987	1988	1989	1990	1991	1992	1993	1994
At current prices	12963	19779	30021	55181	113340	219353	469564	1640748	2335168
At constant prices	2059	2114	2247	2224	2213	2209	2094	2297	2181
Real growth rate %	0.7	2.7	6.3	-1.0	-0.5	-0.4	-0.6	5.1	-5.4
Per head Zk									
At current prices	1852	2713	4008	7074	13993	26113	65467	183441	256612
At constant (1977) prices	294	290	300	285.1	273.2	263	240.7	258.1	239.7
Real growth %	-3.3	-1.4	3.4	-4.5	-4.2	-3.7	-8.5	-7.2	-7.1

Source: Central Statistical Office.

2.4 **Economic Policies for Agriculture**

The underdevelopment of the Zambian agricultural sector predates independence. During the period of Central African Federation (CAF) agricultural production was discouraged in Zambia (then Northern Rhodesia) so that it could concentrate on mineral production and consume the agricultural surplus from Zimbabwe (Southern Rhodesia) (Muuka, 1992).

Since independence, government development programmes have constantly stressed agricultural growth as a priority (Colcough, 1988). Until 1980 the results were extremely disappointing. Agriculture's contribution to GDP remained at 14-15 per cent, while the share of smallholder and subsistence farmers in agricultural output declined from over 80 per cent in 1964 to under 60 per cent in 1980 (The Observer, 7 March 1993). The main contributory factors were, un attractive pricing policies, inefficient marketing and input distribution by the parastatals notably the National Agricultural and Marketing Board (NAMBOARD), chronic under-financing of both capital and recurrent spending with the majority of budgetary allocations to agriculture spent on subsidising parastatal losses and urban food industry, inadequate training and lack of skilled staff and appropriate extension programmes, inadequate agricultural credit facilities, and shortages of production inputs.

Between 1980 and 1986, the government tried to achieve food self sufficiency and to boost agricultural exports as part of the process of restructuring the economy away from copper dependence (Financial Times, 1992). Incentives introduced included a two year tax write off and exemption from customs duty on agricultural equipment, foreign exchange bonuses for farmers whose output of maize, wheat, soya beans or virginia tobacco exceeds certain ceilings, and a reduction in farm income tax to 15 per cent. Agriculture also became the main beneficialy of a 50 per cent foreign exchange retention incentive for non-traditional exporters introduced in 1983. A 100 per cent foreign exchange retention is now allowed for local and foreign investors since the 1991 Investment Act (GRZ, 1992).

However in 1987, the government began to backtrack on this highly successful policy (EIU, 1992). In 1987/88 producer prices were increased by less than the inflation rate, and that of maize by only 2.6 per cent, although in 1988/89 prices were increased substantially for most crops. As part of government moves to reduce central control of the economy and encourage production, in June 1989 prices of all crops, except maize, were deregulated in parallel with the deregulation of all prices on all other products.

Government prices became a guaranteed minima, with farmers free to negotiate higher prices where possible (The Guardian, 1992). Farmers generally welcomed the move, although it also meant substantially higher input prices. Continued control of price of the staple food crops reduced returns to unattractive levels for many producers, resulting in substantial cutbacks in the area planted to maize in both 1989/90 and 1990/91 seasons.

Since 1991 the government has been determined to stick to it's debt-service obligations with the IMF and other creditors. State intervention has been drastically reduced (EIU, 1996). Subsidies on food and other goods have been eliminated and producer prices have risen. Marketing of fertiliser has also been decontrolled, as has the state monopoly of fertiliser imports. All financing of maize purchases, collection and distribution have been privatised. Fiscal expenditure has been tightened. Interest rates and exchange rates have been liberalised, promising increased competitiveness for Zambian products in coming years. Finally, agricultural sector reforms should result in higher output, as long as access to credit facilities for farmers is improved and rainfall levels remain close to their normal annual levels.

However, these policies have magnified the problems of unemployment and poverty in Zambia, where 80 per cent of the economy was previously controlled by government (Nkowani *et al.*, 1995b). The government has been caught between the Structural Adjustment Programme (SAP) drawn to enable it to pay off huge foreign debt on one hand and the need to cushion the vulnerable section of the society (mostly smallholder farmers) from the worst aspect of the monetary squeeze on the other. Current evidence points to a dangerous imbalance, with the poor being hit hardest.

2.5 **Summary**

In this chapter, attempts have been made briefly to describe the location, area and climate of Zambia. Economic performance and it's severe short falls in terms of targeted growth rates have been analysed. It is concluded that the aims of SAP rightly focuses on markets but the set priorities in reform still remain questionable.

Chapter 3.

3.0 **The study area: Northern Region of Zambia.**

3.1 **Location, area and climate.**

The Northern Region is located on the African high plateau elevating most of Zambia. The altitude is of 1000 to 1250 m interrupted by downwarps of river basins, swamps or lakes like lake Tanganyika, lake Mweru Wantipa and lake Bangueulu (Veldcamp, 1987a). It covers an area of 148,000 Km^2 bordering to the North and North-East the Republic of Zaire, Tanzania and Malawi, to the East the Eastern region, to the South and South-West the Central Region and to the West Luapula Region (Figure 3.1).

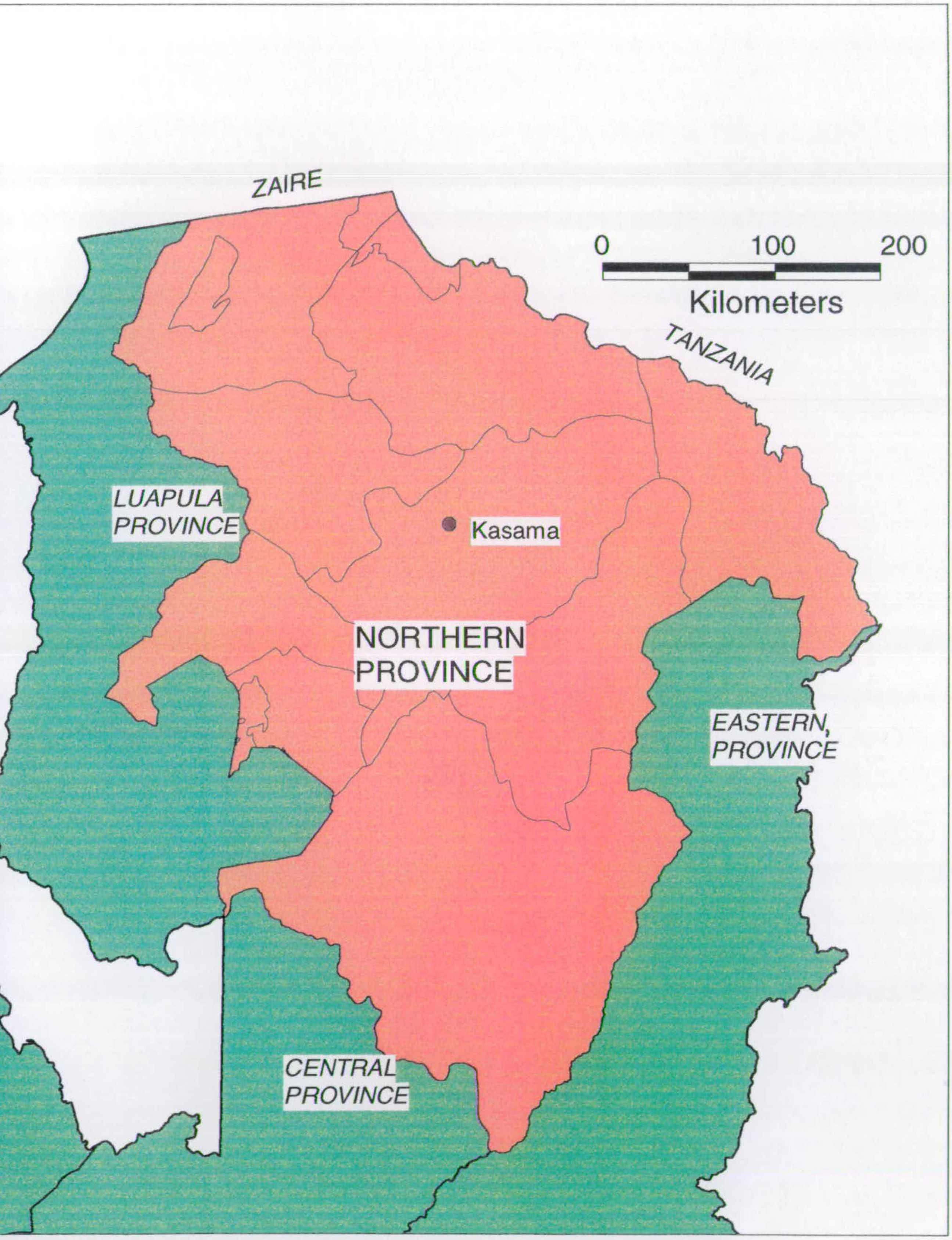
Under the Koppen system (1923) the Northern Province climate is classified as humid mesothermal. In the warmest month (October) the mean temperature exceeds 16^0 c and a mean of 8^0 c is found in the coldest month (Reid *et al.,* 1986). The winter is dry with the rainy season from November to April with an average annual precipitation of 1200 mm (Sano, 1989). Most of the areas experience less than one drought per growing season and there is no risk of frost with mean daily temperatures of 10^0C and mean daily maximum of (30^0 c). The length of the growing season (based on soil moisture availability ranges from 140 to170 days, with less than 700 sunshine hours in the high rainfall belt (covering western Mbala and north-western Luwingu districts) increasing to 850 in the other areas of the province (Veldcamp *et al.,* 1984).

3.2 **Biological resources.**

3.2.1 **Vegetation.**

The vegetation in the Northern region consists of four types (Museshe, Chipya, Mateshi and Riparian), three woodland types (Miombo, Mopane and Munga), grassland and a variety of vegetation types associated with terminaria (Fashawe, 1969). Grasslands are mainly edaphic and are found in depressions (dambo) on the plateau, on the flood plains and in swamps where soils are seasonally or permanently waterlogged. Terminaria vegetation is also associated with these edaphic grasslands. The contact zone between edaphic grasslands and the plateau carries a chipya forest which is characterised by isolated tall trees, e.g. over a sparse woody understorey undergrown by tall grass. In the Mweru-Wa-Ntipa area the Chipya forest is replaced by a thicket vegetation called Mateshi (the itigi of Fashawe, 1969) in which species of *Baphia, Bosca,* and *Busea* are dominant.

ure 3.1: Administrative Map of Northern Province Showing International, vincial and District Boundaries



Mopane and Munga woodlands are largely confined to the Luangwa valley. Mopane is dominated by *Colophospermum mopane*, and is often associated with sodium-rich clay soils of arid areas.

The Miombo woodland is the most extensive vegetation type in the northern region and covers most of the plateau area. The woodland is dominated by species of the genera *Brachystegia, Julbernadia* and *Isoberlinia* forming a 15-20 m high, single storey, light but closed canopy over a forest floor consisting mainly of *Hyparrhenia* and *Digitaria grass species* (Matthews *et al.,* 1992a). The extent of these vegetation types is given in Table 3.1

Table 3.1: **Extent of vegetation types in the Northern Region.**

Vegetation type:	Extent (Km^2)	Relative area in (%).
Museshe forest.	430	0.30
Chipya forest.	7,300	5.04
Mateshi forest.	1,430	0.99
Riparian forest	30	0.02
Miombo woodland	95,240	65.80
Mopane woodland.	10,080	6.94
Munga woodland.	810	0.56
Terminaria	6590	4.55
Grassland	22,830	15.77
Land area	144,740	99.99

Source: NORAGRIC & IUCN (1989).

Valuable timber species in the vegetation of northern region include *Pterocarpus angolensis* (mukwa), *Afzelia quenzensis* (mupapa), and *Faurea saligna* (saninga). The Chipya forest contains a larger stock of timber (2.0 t ha^{-1}) than Miombo woodland (0.6 t ha^{-1}), according to the Forestry Department Management Book for the northern region. The natural forest also contains many useful plants. Storrs (1988) lists 41 species of edible fruit and seed, eight of which contribute to relish and side dishes, as well as 43 fodder species. Although the complete list of medicinal plants is not known, Storrs (1988) gives 29 species with reputed medicinal properties.

3.3 **Geology and soils.**

Soils are a product of parent material, relief, time, vegetation, climate and human influence (Mansfield *et al.,* 1975). In the study area the parent material is mainly composed of acidic rocks of Cambrian origin. Excluding the Luangwa valley, approximately 96 percent of the soils are underlain by rocks with less than 10 per cent basicity, i.e. more than 90 per cent of the minerals are acidic. The high degree of leaching and weathering in the high rainfall areas of this region may have confused the clear distinction between soils derived from acidic sedimentary rocks and those from acidic igneous rocks, thus giving plateau soils that are rather uniform in texture and chemical properties (Veldcamp, 1987a). However, the small areas of moderately leached soils in the region are derived from basic, rather resistant, igneous rocks.

The major soils of the region (Oxisols and Utisols) are characterised by low pH, low in Cation Exchange Capacity (CEC), high Al and Mn, low nutrient retention, low organic matter content, and medium to high P fixation (Singh *et al.,* 1987; Singh, 1989). The main constraints to crop production in acid soils are toxicities of Al and sometimes Mn and deficiencies of Ca and Mg (Mansfield *et al.,* 1975; Kamprath, 1980; Singh, 1989). The fairly low pH levels in the soils allows them to become easily acidic during cultivation mainly due to leaching, crop removal and the acidifying effects of nitrogenous fertilisers (Goma & Singh, 1993). To maintain fertility and allow permanent cultivation of these soils, an application of lime has been recommended (Uprichard, 1991). However, this presents practical problems, because lime is both expensive and difficult to transfer from main centres to outlying areas in quantities required (Nkowani *et al.,* 1995b). It is also frequently not available. Even if it was available in quantities required, it would not provide a panacea because raising the pH has been reported by Matthews *et al.* (1992a) to induce deficiencies of Zn, Mn and Iron, which are often already very scarce. Smallholder farmers have therefore evolved forms of shifting cultivation characterised by short cropping rotations, but because the soils are not given time to generate their fertility, there is a general decline in yield. It is now generally accepted that provided chemical constraints can be removed, these soils have good agricultural potential, because of ample and regular rainfall.

The productivity of land is also linked to the physical properties of the soils (SPRP, 1987). The major soils in the region have low water retention capacity and some (Utisols) are prone to soil erosion (Singh *et al.,* 1987). Levain (1983) showed that the soils in the study area have high soil erodibility factor which combined with the rainfall erosivity index, resulted in the soil loss of 330 t ha $^{-1}$ year $^{-1}$ on a slope of 5^0 over a length of 100 m. However, there are only a few areas in the region which have such high slope. Sheet erosion on the top soil on research plots on fairly flat land (slope less than 2^0) have been recorded on numerous occasions (SPSP, 1989; 90; 91; 92; 93).

3.4 **Economy**.

3.4.1 **Infrastructure.**

The region is divided into 10 districts and 300 wards (the smallest administrative units). Mwali *et al.* (1989) recorded 1,000 km of tarred roads, 2000 km of all weather gravel roads, and 5000 km (dirt) feeder roads within the province. Some of the dirt roads may be difficult to pass during the wet season (Sano, 1989). The distance by road from Kasama, the regional capital to the nation's capital, Lusaka is 880 km, and to the coast from Kasama to Dar-es-Salaam (in Tanzania) is approximately 1100 km.

The Tanzania Zambia railway (TAZARA) running North-South through the region links Kapiri-Mposhi to the coast at Dar-es-Salaaam. Other important infrastructural features are regular air connections from Kasama/Kasaba Bay to Lusaka and the Copperbelt. There also at least one airstrip in each district in the region.

3.4.2 **Population and society**.

The region is inhabited by the Bemba people, the Bisa, the Lungu, the Iwa, the Inamwanga and the Mambwe (Sano, 1989). The Bemba language is the dominant venarcular and Bemba is understood by people from Zaire to lake Malawi and from Kabwe to lake Tanganyika.

The diet basically consists of nshima (a thick porridge) and relish (sauce), with beer and munkoyo brewed from millet and munkoyo roots respectively as the predominant beverage. Nshima is a staple element of the diet, made from either millet or maize meal by subsistence households until reserves are exhausted, when cassava is included to tide over until harvest. Relish can be made out of vegetables (e.g. beans, spinach, cabbage, cassava and pumpkin leaves) fish, meat or chicken and provides a tasty nutrient source.

The population distribution in the region has a decisive influence on options given to people for sustainable use of local natural resources (ARPT, 1988a). The size, pattern and density of human settlements influence the rate and extent of natural resource use. The present population distribution of the rural population in the area reflects reliance on public services and the growing importance of roads, railways and service centres for choice of residence (NORAGRIC & IUCN, 1989). Access to co-operative depots, urban markets, health clinics, primary schools and hammer mills are becoming more important for people's settlement decisions.

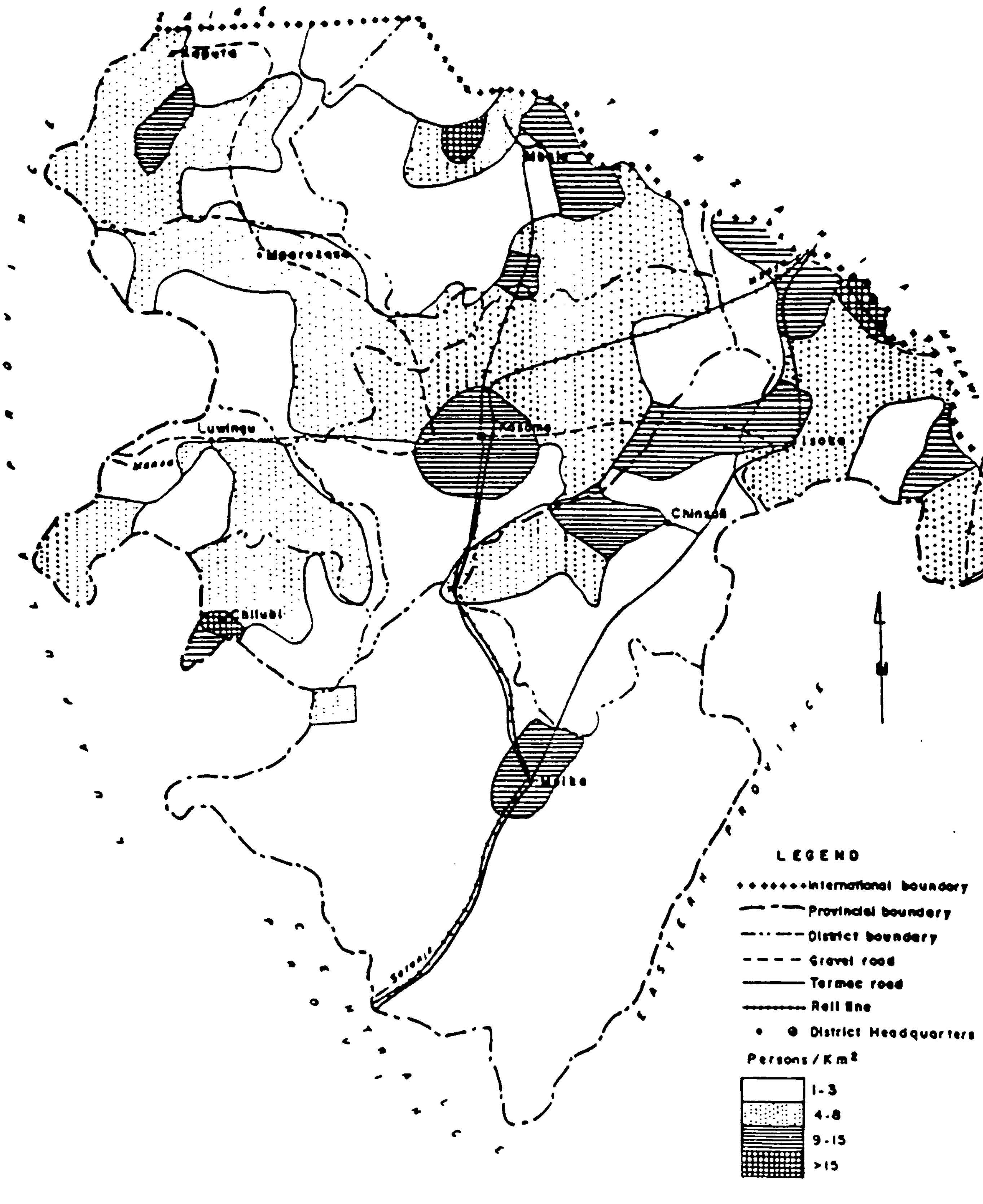
Negative population growth (-0.6% per annum) was experienced between 1963 and 1969, mainly due to high male labour migration to Lusaka and the Copperbelt in search of better paying jobs (Pottier, 1986). In the seventies and eighties (1970-80 and 1980-1989) natural population growth exceeded net migration causing a halt to a declining population trend in the region. In 1989, the provincial population numbered 924,750 of which 85 per cent lived in rural areas (Sano, 1989). The population density in some areas of the region has been recorded at 15 persons km^{-2} (Reid *et al.,* 1986; Pottier, 1988), while Economic Report (1993) reports 1990 population density in some areas of over 15 persons km^{-2} well above the capacity of slash and burn type of farming practices (see Figure 3.2). The positive population growth (of 2% per annum) have contributed possibly to two main factors: (a) decreasing out-migration and perhaps (b) increasing in-migration of former labour migrants.

The decrease out-migration from the region has apparently coincided with a change in migration within region (Pottier, 1988, 1993). District towns have become increasingly important as new centres for rural migration putting more pressure on land, water and forest resources in peri-urban areas.

3.4.3 **Occupation pattern.**

More than 85 per cent of the workers in the rural areas are cultivators, followed by nearly 15 per cent as agriculture labourers. In sharp contrast to this, more than 85 per cent of the workers in urban areas are in the category of the "other workers" and only 15 per cent are cultivators or agricultural labourers (Economic Report, 1993).

Figure 3.2: Map showing the estimated Rural Population Density in 1990 in Northern Province.



APPROX. SCALE 1: 330,0000

Labour

Household labour is central to the production of traditional food crops, with chitemene (May-June) and fundikila (February) placing peak demands. In the traditional sector, adults contribute 50-60 per cent of family labour and children 20-25 per cent (Bolt & Kerven, 1988). With increased commercialisation the contribution made by children is reduced. In addition to their domestic responsibilities wives and female heads of households spend more time on agricultural activities than their male equivalents (Bolt & Kerven, 1988).

Labour is mainly paid in cash (58 %), although this can be of limited value in the rural communities with poor retail facilities. Labour is also paid in food (27 %) and household commodities such as soap, salt, clothing etc. (15 %) (Kerven & Sikana, 1987). Most of the hired labour is employed in the production of maize (54 %) and millet for land preparation and harvest (Bolt & Silavwe, 1988). Shortages of funds limit follow-up practices such as weeding. Traditionally, households do at times provide labour on a reciprocal basis during peak labour requirement, with beer and munkoyo beverage provided as a token of appreciation.

The inability to recruit labour for food farming during peak times such as land preparation, weeding, and harvesting is becoming more wide spread and difficult to overcome (Kerven & Sikana, 1987; Pottier, 1993). One major cause is that men mostly control the labour of their wives and tend to deploy that labour power away from food into cash farming (Nkowani *et al.*, 1995b). Other contributing causes have been the introduction of modern high yielding varieties, which impose rigorous timing constraints and labour peaks, and the inrceasing pursuit of off-farm activities have become more attractive than raising expensive crops (Bolt & Sikana, 1988; Pottier, 1993). This change in circumstances, imposed from outside, lowers the priority status of food for the home. An additional cause of reduced access to labour has been identified by Pottier (1986), and points to the decline in community-based or other mutual support mechanisms, a decline often related to broad organisational changes such as the transition from large community groupings to nuclear households.

Income

Farm income is highly seasonal, with payment for maize being effected between October to December and sales of beans occurring between June and July. Other sources of funds emanate from sales of chicken, beer, groundnuts, millet, cassava etc. On average, off-farm income has been recorded by Bolt and Silavwe (1988) to account for 40 per cent of the total household income being of greater importance to the traditional sector, 44 per cent than small commercial sector, 26 per cent. Off-farm work provides a relatively steady flow of income and is the primary means of funding daily household needs throughout the year. Sources of off-farm income include; fishing, hunting small game, gathering, charcoal making, fuelwood collection, domesticated animal sales, beer and munkoyo sales, crafts remittances, gifts and informal and formal loans.

Credit facilities from the government and banking institutions are directed towards cash crop production of the more commercialised farmers and is not used by/available to, the traditional sector (Killick, 1992a; Matthews *et al.,* 1992b). However, repayment of the loan is required after harvest and the potential of harvest failure creates a considerable element of risk and uncertainty, exacerbated by poor yields due to untimely and inadequate deliveries of hybrid seed and fertiliser (ARPT, 1988a). Poor access to credit inhibits small farmers (who are the majority) from purchasing seed and fertiliser or, more importantly, from hiring labour (Eklund, 1990). There appears to be an urgent need to look at the criteria used for assessing credit applications (Nkowani *et al.*, 1995b). Given the success of group responsibility approach to credit repayment, serious consideration should be given to application among resource-poor farmers (ARPT, 1988a). An approach of this kind may appear to present risk to credit agencies, but with careful planning and administration, this could be minimised, with great potential financial and social benefits to the community. Literature elsewhere, (for instance: Pottier, 1993) has a different view, who argues that credit schemes of this nature create risks that pin the smallholder farmer down in what is basically a *'no-win'* situation.

Expenditure

Agricultural expenditure mainly occurs at the beginning of the growing season (October-January). Between 40 to 60 per cent of the previous seasons' farm income is ploughed back into crop inputs (ARPT, 1988a). Fertiliser and hybrid seed for crops such as maize, beans and groundnuts are available from the provincial co-operative union depots. However, there is a general reluctance to apply fertiliser to traditional crops although it may be obtained in relatively small quantities on the open market. There is also no significant use of hybrid seed, purchased herbicides and pesticides.

Non-agricultural expenditure is dependent on the availability of cash, particularly in the traditional sector (ARPT, 1988a). Items may include, payments for staple foods, loan repayments and remittances, education fees, family budget, milling groceries, clothes, consumer durables, travel and relish and relish ingredients.

3.5 **Land area and tenure.**

3.5.1 **Land area.**

Land *per se* is not a limiting factor in the region (Chidumayo, 1987). However, the shortage of cleared land reflects the scarcity of labour, and cash for land preparation and other inputs (Bolt & Silavwe, 1988). The average holding in the region during the early part of the century was 1 ha, and few were as large as 2 ha, but farm size has increased as a result of the introduction of more intensive farming systems. This is supported by a recent study carried out by Reid (1994) which reported that the number of plots worked for each farmer in the North-Eastern parts of the region ranged from one to fifteen, with most farmers having eight. Slightly less than half of the households fell within the range of four to ten plots each. The largest was a 6 ha ibala field and the smallest a chitemene of 2 ha.

3.5.2 **Land tenure.**

The system of customary and statutory law pertaining to land tenure is of particular importance when considering resource development. In Zambia, there are three categories of land: State, Reserves and Trust Land. In most parts of the country and more specifically in the study area, the distribution of land is still the responsibility of the chiefs, as is the holding of courts for certain civil disputes within the area governed by chiefs, known as chiefdoms. Chiefdoms vary in size and population, however the region has some of the largest chiefdoms in Zambia approximating 4,500 km^2 (Waern, 1984).

State land is mainly devoted to urban and industrial use and large scale commercial farming. Trust land and Reserves are areas where subsistence and emergent farming systems prevail. Statutory land rights (i.e. leaseholds) under the Land Tenure Act of 1970 apply to State land only, while customary tenure rules still predominate in traditional farming areas.

In this region by far the largest portion of land is held under customary law by jurisdiction of the chiefs (NORAGRIC & IUCN, 1989). The chiefs are represented on District Councils. The chiefdoms are traditionally divided into village headman areas. Hence the Bemba people have no permanent system of land tenure; the chief holds the land in trust and an individual maintains rights to a field as long as he or she has it under cultivation, before fertility declines and they move on (Holden & Joseph, 1991; Chinene & Lungu, 1992).

It is important to note that rights over land under customary law have mainly been restricted to arable land (Chinene & Lungu, 1992). Chiefs have powers to set aside certain land for common use such as grazing, burial grounds and other cultural uses (Waern, 1984). Rent of an annual fee of Zk 6.80 per hectare under state law is collected from commercial farmers and more recently from the semi-commercial farmers by the Forestry Department. The lease contract period for land rental may be up to a maximum of 99 years.

Land, therefore, may be looked at as a constraint in the sense that it is held in trust by the chief whose decisions over land may not reflect the needs and priorities of individual farmers (Nkowani *et al.,* 1995b). In addition, the chiefs have no means or skills to enforce restrictions on land-use. Land degradation problems have, therefore, continued to persist (Chinene & lungu, 1992). Communal grazing on the other hand has resulted in poor management of the grazing lands because none of the farmers will take any responsibility. The stocking rates are never monitored or controlled and in some areas are overgrazed, leading to the inevitable consequences of excessive erosion and general degradation of land (Lungu & Chinene, 1993). As a result it has proven difficult to control destructive farming practices since there is no incentive for maintaining fertility over prolonged periods, and indeed, any attempt to do so (such as planting trees) is often regarded with deep suspicion because it establishes the basis in customary law for a claim to land (Holden & Joseph, 1991). Security of tenure and rights regarding land, water, livestock and trees are, thus, preconditions for a farmer to take the long view and invest in good husbandry (Nkowani *et al.*, 1995b; Chinene & Lungu, 1992).

3.6 **Land-use systems.**

A striking feature of the Northern Region is the diversity in agro-ecological and social-economic conditions, leading to complexity in land-use patterns (Bolt & Holdworth, 1987; Bolt & Silavwe, 1988; Stromgaard, 1984, 89; Matthews *et al.*, 1992a). Traditionally, cultivation in the province has been based on the shifting system[3] of "slash and burn" (chitemene) but more "semi-permanent" (fundikila) and "permanent systems" (Ibala) are being adopted. Not only can differences in land-use systems be detected between households in the same village, but also among villages of the same region, and among regions.

3.6.1 **Chitemene System (Slash and Burn System).**

Chitemene has been well described by several authors (for instance; Niang, 1990; Chidumayo, 1987; Bolt & Silavwe, 1988; Stromgaard, 1989; Matthews *et al.,* 1992a). It is a form of "slash and burn" cultivation, but unique in that the lopped area is much larger than the cropped area. There is some evidence that the system is indigenous to the Zaire-Zambezi watershed, and that it was brought from that area during migrations in the 17th century (Stromgaard, 1989). Although there are variations described by (Stromgaard, 1989), the main feature of the chitemene is the enrichment of the area selected for cropping by adding to it leaves and branches lopped from trees in the surrounding area. From an energy efficiency view-point, the chitemene is seen as an extremely, unproductive system as it capitalises large quantities of biomass and, therefore, is a high input system (McGrath, 1987). On the other hand, it may be considered as a low external input system with high efficiency from a peasant economy perspective (Boserup, 1965; Richards, 1984). The basic (or 'Large Circle') form of chitemene is as follows:

Branches are lopped from trees within the selected area between (May-June) laid out to dry, and before the beginning of the rains in November, are gathered into heaps in the centre of the cut area. The major site selection criteria include the quantity and quality of the trees in terms of supply of material to be burnt (SPRP, 1986). The size of the cut area depends on the quality of woody biomass in the area, labour to cut, transport, and heap it (Stromgaard, 1991). Usually men do the cutting and women the

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[3] According to Chidumayo (1987), shifting cultivation is characterised by: (a) short cropping periods alternating with long fallow periods, (b) during the fallow, natural vegetation reoccupies the land, (c) the fallow period is not managed, (d) soil fertility is restored during the fallow by the combined activity of plants and other organisms, (e) besides sunlight, human labour is the major source of energy.

carrying and heaping. Estimated ratios of cropping area to area supplying plant material range from 1:5-1:20 with a mean of about 1:10 (Trapnell, 1953; Haug, 1981; Stromgaard, 1989, 91; Chidumayo, 1987).

The area is left to dry and then burnt before the beginning of the rainy season. Finger millet (*Eleusine coracana (*L.*) Gaertn.*) usually is the first crop sown in the ash plot. The subsequent cropping sequence varies, but typically is groundnut (*Arachis hypogea* (L.*)*), millet, and beans (*Phaseolus vulgaris (*L.*)).* Often cassava (*Manihot esculenta Crantz*) is planted as an inter-crop with the millet in the first year and harvested gradually from the third year onwards. When the field is exhausted after 4-5 years, it is abandoned and traditionally left to fallow (Stromgaard, 1985), and another field is opened.

The period required for soil fertility restoration by natural regeneration in chitemene depends on; (a) composition of vegetation, (b) soil, (c) climate and (d) the frequency of bush fires. Most estimates (for instance; Trapnell, 1953; Allan, 1967; Mansfield *et al.,* 1975; Stromgaard, 1985, 89) give regeneration periods of 20-35 years. However, Haug (1981) found areas where 5-10 years were adequate.

The system is only sustainable under low population density conditions as its carrying capacity has been estimated to run from 2-4 persons per km^2 depending on the proportion of land suitable for cropping (Manfield *et al.,* 1975). Svads (1983) put the population densities of the Northern Province at 1-4 persons per km^2 but pointed out that there were areas with densities of 4-10 persons per km^2. Reid *et al.* (1986) and Pottier (1988) put the figure at 15 persons per km^2, while Higgins *et al.* (1982) estimated that 50-100 persons per km^2 could be supported in northern Zambia. Chitemene in its present form still persists in areas with high population densities because it is less labour demanding than more intensive systems of cultivation (Ruthenberg, 1980; Holden, 1993).

3.6.2 **The Fundikila or Grass Mound System (Semi-permanent System).**

In the North-Eastern part of the region, where the population is higher and there are fewer trees, the Mambwe people have developed the fundikila or "grass-mound" system of cultivation. This is a semi-permanent bush/fallow system[4]. The origins of this system are not clear. Speculations are it evolved either from chitemene following

[4] The major features according to Stromgaard (1988) are: (a) rotation of a sequence of crops and the fallow of grass and, (b) composting of the grass from the fallow in mounds.

destruction of the woodland, or from the natural grassland of Tanzania. Both suggestions are plausible in that the stock carrying capacity is much higher than that of chitemene, and the Mambwes who practice the system are also cattle keepers who could have come from a grassland area (SPRP, 1986; Stromgaard, 1989).

Detailed description of the fundikila process are given in Stromgaard (1988). The process begins late in the rainy season (March) with the burying of grass (predominantly *Hyparrhenia filipendula* and *Pennisetum purpareum*) in the mounds formed with hoes. Mounds are about 0.6 m high with diameters of 1.8-2.4 m. During the dry season the grass in the mounds decomposes, forming a kind of compost. At the beginning of the next rains, (2nd year), new weeds are worked into the soil and the mounds levelled. During the levelling the compost is spread evenly to give a fairly uniformly fertile soil. Finger millet is then planted. This may be followed in the second season by a variety of crops including maize (*Zea mays* (L.)), sorghum (*Sorghum bicolor* (L.) *Moench*), and groundnuts. Millet is usually planted again in the third year, followed by a legume. In some cases, the field may be mounded every third year, and the crop planted on the mounds.

After the fourth year or fifth year the land is fallowed for 4-10 years. There is some confusion on the required length of the fallow. Mansfield *et al.* (1973) suggest 15-20 years while Schultz (1976) and Haug (1981) found 5 years adequate. Trapnell's (1953) postulation that land may be regarded as ready when pump grass *Hyparrhenia filipendula* becomes dominant, supports those who contend that weeds, rather than soil exhaustion, is the cause for cessation of cultivation. Increasingly, maize production and the use of inorganic fertiliser may have influenced the cropping sequence and the length of fallow periods, but these assumptions have not been substantiated by research data.

Because cattle are an integral component of the Mambwe agriculture, oxen ploughing is often used in the grass mound system. The land preparation sequences used with ploughing is similar to that of hoeing.

This combination of green manuring and alternating cereal crops with legumes helps to slow exhaustion of soil fertility. There is some evidence that the system is sustainable (Stromgaard, 1990). The carrying capacity of the fundikila system is estimated at 20-40 persons per sq. km considerably more than the chitemene system (SPRP, 1986).

3.6.3 **Ibala System (Permanent Cultivation System).**

The Ibala system[5], has evolved in chitemene areas from the small permanent gardens which were traditionally maintained around homesteads for the cultivation of subsidiary crops (SPRP, 1986). These have been substantially extended to encompass the commercial production of maize, prompted by the government policy of self sufficiency during the late 1970s and 1980s (ARPT, 1988a). Although fertilised maize is the main crop grown on ibala fields, finger millet also has come to be grown on these fields, some times with the use of low levels of fertilisers (Reid & Silavwe, 1986). No clear pattern seems to have emerged with the crop sequences employed on ibala fields; maize production, as the main reason for their adoption, is clearly a dominant feature. To date, such information as exists on the productivity of permanent field systems point to the inevitability of added fertiliser certainly of nitrogen and phosphates (Njos, 1983), and probably including lime (SPRP, 1987). In peri-urban areas of the province, permanent field systems support much greater population densities than the other two farming systems, albeit often with substantial fertiliser input.

The improvement of chitemene and fundikila systems were neglected due to encouragement on the hybrid-maize/fertiliser based agricultural policy but since the soils are not given time to regenerate their fertility in the ibala system, there is a general decline in crop yields (Matthews *et al.,* 1992a). Further more, with the recent removal of subsidies on seed, fertiliser, transportation and marketing, farmers have no alternative but to return to these traditional systems (The Observer, 1993; Nkowani *et al.*, 1995b; Matthews *et al.,* 1992b).

3.6.4 **Agroforestry Systems.**

Recent developments in farming systems research in the region, have emphasised problems of soil acidity, poor water retention, and soil loss and the need for the development of more sustainable agricultural production systems that address the needs and problems of smallholder farmers (Holden & Joseph, 1991; Eklund, 1990; Gatter & Sikana, 1989; Young, 1991; Matthews *et al.*, 1992b).

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[5] Ibala system as documented by SPRP (1986) is associated with: (a) use of inorganic fertilisers, and plant protection chemicals, (b) human labour supplemented with animal and or fossil fuel energy, (c) if there is a fallow, the fallow is usually shorter than the cropping period, (d) when fallowing is practised the fallow is managed and more efficient soil fertility restoring plants are planted on the land during the fallow.

Biological methods of maintaining soil fertility, and agroforestry technologies in particular, were suggested as possible means to sustain soil fertility (Huxley *et al.*, 1986; Wilson *et al.*, 1986; Kwesiga & Kamau, 1989; Mattson, 1989; SPRP, 1987) Among the agroforestry technologies reviewed by the International Council for Research in Agroforestry (ICRAF) and the International Institute for Tropical Agriculture (IITA), alley cropping (hedgerow intercropping or avenue cropping) was proposed as a potential viable alternative to chitemene, fundikila and ibala farming systems (SPRP, 1987). Other tentative strategies on the research agenda included boundary and woodlot planting.

The key concepts of agroforestry are now well established (see for instance: Lundgren, 1987; Young, 1989a; Nair, 1991; Corlett *et al.*, 1992b;). It is generally accepted that agroforestry:

(i) is a collective name for land-use systems involving trees combined with crops and/or animals on the same unit of land in some form of spatial arrangement (intercropping) or temporal sequence (crop rotation);

(ii) combines production of multiple outputs with protection of the resource base;

(iii) places emphasis on the use of indigenous, multipurpose trees and shrubs;

(iv) is particularly suitable for low-input conditions and fragile environments;

(v) is structurally and functionally more complex than monoculture.

The aim and rationale of most agroforestry systems are to optimise the positive interactions in order to obtain a higher total, a more diversified and/or a more suitable production from the available resources than is possible with other forms of land use under prevailing ecological, technological and socio-economic conditions (Lundgren, 1982; Nair & Fernandes, 1985; Macdicken & Vegara, 1990; Nair, 1990; Kang *et al.*, 1990).

Alley cropping (Hedgerow intercropping or Avenue cropping).

Alley cropping describes a land management practice in which agricultural crops are grown in the interspaces between rows of deliberately planted woody shrub or tree species (usually legumes) (Wilson & Kang, 1980; IITA, 1983; Kang *et al.*, 1981;

Huxley, 1986). The main tree species being researched upon in the Northern Region of Zambia have evolved around: *Leucaena leucocephala*, *Gliricidia sepium*, *Flemingia congesta*, *Cassia siamea*, *Cassia spectasbilis*, *Cassia calothyrosus*, *Albizia factaria*, *Sesbania sesban*, and *Tephrosia vogelii*. The woody plants are periodically pruned during the cropping season to provide plant nutrients in the form of green manure and/or mulch, to prevent shading and sometimes to provide stakes or fuelwood (Kang *et al.*, 1981, 1990; Ssekabembe, 1985; Zimmermann, 1986). The bigger branches remaining after pruning are particularly suitable for poles or fuelwood after the leaves decompose. Whether more prunings, stakes and fuelwood are obtained depends, to a large extent, on how the alleys are managed.

Depending on the growth habit of the woody species used in the alleys, the interaction between the trees and the annual crops in the alleys can be restricted to the border of the two species (the tree/crop interface) or may extend further into the alleys when the roots of the trees extend far into the crop. When the alleys are pruned the interaction between the trees and the annual crops is spread throughout the alleys, when the prunings are applied uniformly as mulch or incorporated every where in the alleys. Incorporation of the prunings into the soil provides a sure way of transferring the nitrogen fixed by the alleys to the associated food crops because direct transfer of biologically fixed nitrogen to the associated annual crops may be minimal or even non existant. Besides addition of humus, which improves soil physical conditions and provision of mineral nutrients for crop uptake, favourable conditions for both macro and micro-organisms are created (IITA, 1987; Budelman, 1988b, 1989a; Lal, 1989a, c).

When intercropping with pruned alleys is followed by a period in which the trees on the alley are allowed to grow into full-grown trees that cover all the alleys for sometime, and constitutes a fallow period, the practice is referred to as rotational alley cropping (Amare-Getahun, 1980). This is advisable when production of fuelwood, stakes or poles is desired, and the fallow period should be at least one year (IITA, 1987).

Todate, most of the research on alley cropping in northern region of Zambia has been devoted to identifying suitable species (Bolt & Holdsworth, 1987; Holden & Joseph, 1991; SPRP, 1987,88,89,90; Mathews *et al.*, 1992a, 1992b, 1992c; Stromgaard, 1984) and to measuring biomass production and refining management of the alleys in order to ensure compatibility with agricultural crops (SPRP, 1992). Aspects of soil fertility or nutrient contribution of alley tree species and their effect on crop yields has also been fairly well investigated with some annual crops (Reid, 1993; Mathews *et al.*, 1992b; Singh, 1989; Goma & Singh, 1993; Tveitnes, 1986; SPRP, 1991, 1992). The importance of soil physical properties in relation to soil moisture, temperature and crop yields is still being investigated (Tveines, 1983; SPRP, 1993) and so are changes in soil chemical properties, and the extent of weed suppression through mulch application (Dalland & Vaje, 1991).

3.7 **Some observations about current land-use systems.**

3.7.1 **Chitemene system.**

Soil fertility.

Studies conducted in northern region of Zambia (Steinshamn, 1984; SPRP, 1986; Singh, 1987, 89) and elsewhere (Zinke *et al.*, 1978; Kang & Lal, 1981) have shown that slash and burn resulted in an increase in soil pH, phosphorus and available bases leading to an increase in crop yield. However, the increase is short lived (Singh, 1989; Cooper *et al.*, 1986). After two to three years after burning, this increase has been observed to decrease due to loss of nutrients through leaching and presumably uptake by crops. Weeds too build up in these areas. The most common practice among farmers is to leave the cultivated areas to fallow. Farmers also respond to declining soil fertility by choosing a cropping sequence in which a high nutrient demanding crop, e.g. millet, is grown first and less demanding crop, e.g. cassava, is grown last. Cassava is furthermore acid tolerant (Svads, 1986).

Physical properties of the soil.

Reducing forest biomass by tree clearing in the chitemene system affects soil temperature (SPRP, 1989). In some cases soil surface temperatures can reach levels sufficient to sterilise the soil to the depth of several centimetres (Tveitness, 1986). Infact, according to Lungu & Chinene (1993) clearing and cultivation may result in a gradual deterioration of soil tilth and soil structure, probably due to rapid decline in the organic matter content of the soil and drastic reduction in the microbial activities.

Soil erosion.

Despite alteration in soil-water balance, the surface run-off and erosion losses are generally low in the chitemene system of cultivation in the region (SPRP, 1988; Grunder, 1992). Work carried out by Lal (1981) in Nigeria also found that water run-off and erosion were negligible in plots cleared by traditional farming methods.

3.7.2. **Fundikila or Grass Mound System (Semi-permanent System).**

Soil fertility.

In following vegetation succession with continuous cropping on the same land in fundikila, legumes often disappear, leaving a vegetation dominated by *Hyparrhenia* grass spp. which has a very low manuring value for food crops leading to a substantial decrease in crop yields (Trapnell, 1953). This has been attributed to depletion of plant nutrients and build up of weeds (Stromgaard, 1989). The grass mound system dominated by *Hyparrhenia* grass spp. may also immoblise the nutrients added through fertilisers, thereby reducing the utilisation efficiency of the nutrients added (SPRP, 1987). Trapnell (1953) postulates that often weeds, rather than soil exhaustion, is the cause for cessation of cultivation in the grass mound system.

Soil erosion.

Due to shorter fallow period in densely populated areas, soils remain with a sparse canopy cover over a long period of time and may be subjected to more run-off and soil erosion. This has been experienced in some of the areas of Mbala and Isoka districts (SPRP, 1989).

3.7.3 **Ibala System (Permanent System).**

Soil fertility.

Banda and Singh (1989) observed that after continuous cultivation of mono-crops for many years, deficiency of micro nutrients (such as; Zn, B and Cu) is likely to arise and seriously affect yields. Mono-cropping of maize, especially, has been shown to decrease biomass carbon and the population of micro-organisms in the soil (*Matthews et al.,* 1992b). In addition, due to low buffering capacity of the soils, acidity problems intensify with the use of fertilisers (Goma & Singh, 1993), and severe yield decline has been reported (Matthews *et al.,* 1992c). For sustainable production, soil acidity needs to be ameriolated. Moderate rates of lime (600-1200 kg/ha) in these soils have been found to amneriorate soil acidity up to 4-5 years after application (LIMA, 1991).

Physical properties of the soil.

Loss of organic matter in soils under mono-crops result in structural breakdown and consequent compaction leading to soil structure deterioration (NORAGRIC & IUCN, 1989). Such changes are, however, more apparent with mechanised cultivation than with manual hoe cultivation. Alteration in soil surface structure has been reported by

(SPRP, 1991) to affect soil moisture retention. The exposed canopy of monocrops, particularly maize is known to reduce the soil moisture retention capacity.

Soil erosion.

Row cultivation of maize has been known to cause soil compaction giving rise to soil erosion under mechanised or partially mechanised cultivation practices (SPRP, 1987).

3.7.4 **Alley Cropping (Hedgerow or Avenue Cropping).**

Soil fertility.

Research todate has shown that the only beneficial effect on crop yields obtained by alley cropping has been the combination between tree species of *Leucaena leucocephala* and maize, and to some extent *Flemingia congesta*, both where the soil has been heavily limed (Matthews *et al.,* 1992b). In all on-station and on-farm trials, bean yields were either not affected or were depressed by addition of prunings, supporting the growing amount of evidence that alley cropping does not benefit leguminous crop plants (e.g. Ngambeki, 1985; Lal, 1989a).

The annual biomass production of tree species in the region has been observed to be considerably lower than in other studies where alley cropping has been beneficial to crop yields (SPRP, 1992). The mean annual biomass production for *Leucaena leucocephala* of 2.2 t DM ha $^{-1}$ y $^{-1}$ was twice that of the next best performer, *Cassia spectabilis*, 1.1 t DM ha $^{-1}$ y $^{-1}$. Yield varied between 0.6-0.8 t DM ha $^{-1}$ y $^{-1}$ for all the other species. In comparison, in the moist subhumid region in Nigeria, Kang *et al.*, (1985), measured *Leucaena leucocephala* production of 6-8 t DM ha $^{-1}$ y $^{-1}$, Yamao *et al.*, (1986b) recorded biomass of 10.8, 16.9 and 14.8 t DM ha $^{-1}$ y $^{-1}$ for *Glicidia sepium, Flemingia congesta* and *Cassia spectabilis* respectively over the first three years of growth, and Duguma *et al.*, (1988) measured up to 16 t DM ha $^{-1}$ y $^{-1}$ for *Leucaena leucocephala.* Similarly, in the Ivory Coast, Budelman (1988b) reported values of 15.4, 12.4 and 10.5 t DM ha $^{-1}$ y $^{-1}$ for *Leucaena leucocephala, Flemingia congesta,* and *Glicidia sepium* respectively. Only on the acid soils of Yaramaguas, Peru, similar in many respects to the soils of northern region of Zambia (see Sanchez, 1987), was *Leucaena leucocephala* production lower than what has been shown; Szott (1987) reports values of 0.5-0.8 t DM ha $^{-1}$ y $^{-1}$.

There is no clear effect of alley cropping on soil chemical characteristics in the region yet (Matthwes *et al.*, 1992c). Elsewhere, long term alley cropping trials in Nigeria, Kang & Wilson (1987) showed a significant improvement in both chemical and physical soil properties. Yamao *et al.*, (1986c) reported increases in organic matter content, nitrogen, and phosphorus, and an improvement in soil physical properties, under alley cropping with *Cassia siamea.* However, other studies have reported declines in soil fertility. Szott (1987) observed that there was less P, K, and Ca+Mg in the surface soil of alley cropping treatments than in the control treatments in trials in Peru, and concluded that one of the reasons for lower yields in the alley crops was due to root competition for nutrients. Lal (1989) in alley cropping trials in Nigeria found that soil organic matter, total N, pH, and exchangeable bases declined and total acidity and Al^{2+} increased significantly in all treatments, although these trends were least marked in *Leucaena leucocephala* and *Glicidia sepium* alley crop. It appears that soil improvement may occur when the soil fertility is already relatively high, but where it is low, then even further depletion may occur (Matthews *et al.*, 1992b).

The use of *Leucaena* as an alley cropping tree species in other parts of the world is well documented, although the effects on crop yields have not been consistent (SPRP, 1993). Kang *et al.* (1985), for example, found that continuous alley cropping with *Leucaena* on an Entisol (pH 6) for six years could maintain maize yields at around 2 t ha^{-1} with no additional fertiliser. Plots receiving prunings also had a higher nutrient content than those without. In the Philippines, *Leucaena leucocephala* with no additional fertiliser increased maize yield by 0.7 t ha^{-1} compared to only 0.3 t ha^{-1} with fertiliser (O'Sullivan, 1985), and by 1.4 t ha^{-1} with or without fertiliser (Watson & Langnihon, 1985). However, attempts to extrapolate this system to a highly weathered Utisol in Peru were not successful (Szott, 1987), the main reasons being the susceptibility of *Leucaena* to Al toxicity, and the low nutrient base content of subsoil which reduced the cycling pool. Similarly, Lal (1989a) found that maize and cowpea yields in a *Leucaena* alley crop declined over a six year period, and were lower than in the sole[6] treatments.

The use of *Flemingia congesta* in alley cropping is less well documented. In Nigeria, Yamao *et al.*, (1986b) reported significant increases in alley cropped yield with *Flemingia congesta* compared to the 'no-trees' control, although surprisingly there was no difference in alley crop yields whether *Flemingia* prunings were added or not. Buldeman (1989a) considers the species to be more suitable for mulching and weed control than *Leucaena* or *Glicidia* because of the slow decomposition rate of its leaves.

[6] According to Lal (1989a), sole treatments refer to units of land (plots) designated for only a single crop.

Glicidia sepium has shown to have no effect on crop yields over six years of alley cropping, even though it has been observed to contribute more nitrogen than *Flemingia congesta.* This species has been shown to be beneficial in other alley cropping systems (Yamao *et al.*, 1986b), although problems with mortality necessitated replanting (Lal, 1989a), a requirement also noticed in the northern region of Zambia. The complete loss of leaves by *Glicidia* over the dry season in the region could have attributed to its lack of effect on crop yields (Matthews *et al*, 1992b).

Both *Sesbania sesban* and *Tephrosia vogelii* have been found to perform very poorly due to their inability to survive the dry season following pruning (SPRP, 1993). Yamao & Burleigh (1990) concluded that *Sesbania* was not suitable for alley cropping in Rwanda for the same reason, and suggested that this was due to *Sesbania* not having a solid wood stem so that it was not able to store carbohydrates to facilitate regeneration after pruning. *Albizia falcataria* also proved to be unsuitable for alley cropping. Its growth habit resulted in excessive shading of the crop, and a high proportion (75 %) of its prunings were woody with slow decomposition rates. *Cassia spectabilis* was found to respond well to pruning, and to also have a high N content in its prunings, but its relatively low biomass production (1.1 t ha $^{-1}$ y $^{-1}$) and lack of nitrogen fixing ability (Young, 1989a) limited its usefulness as an alley cropping species.

The success of *Leucaena* has only been achieved through the use of lime; in complimentary on-farm trials in which liming had not been carried out, *Leucaena* was found to perform very poorly on the acid soils of the region (Matthews *et al.*, 1992c). The discussion in this section supports the recommendation of Sachez and Benites (1987) that on acid soils it is necessary to use lime to aid in the establishment of tree species particularly *Leucaena.*

3.8 **Summary.**

The location of the study area, extent and climate have been described along with its physical and human resources. The main land-use systems including the agroforestry component being researched on in the region has also been presented. Finally, some observations are made about the current land-use practices, and are examined in terms of soil fertility depletion, productivity and sustainability and soil erosion. In the next chapter, a Multiple Criteria Decision-Making (MCDM) Technique - Goal Programming is proposed as viable way to examine the decision-making behavioural pattern between smallholders (land-users) and regional policy-makers (planners) in the allocation of land and associated resources in a sustainable development perspective. The application of GP is wide spread and has been found to correspond well with the usual conceptions of the resource manager's decision-making process: those of goal setting and goal ranking.

Chapter 4.

4.0 **Goal Programming and Multiple Objective Decision-Making in Agriculture and Natural Resource Systems.**

4.1 **Rationale behind the use multiple objective decision-making approach**

4.1.1 **Criticism of the traditional paradigm in decision-making**

The traditional framework (or paradigm) used for the analysis of decision making[7] at firm-level presupposes the existence of three elements: a decision maker (an individual or a group recognised as a single entity); an array of feasible choices and constraints to unlimited action; and a well defined criterion such as utility or profit (Romero & Rehman 1989). The given criterion can then be used to associate a number with each alternative so that the feasible set of options can be ranked or ordered to find the optimum value.

The use of goal and multiple objective programming models for dealing with decision making problems is based on similar theoretical structure (Cohon, 1978; Romero, 1991; Romero & Rehman, 1987, 89; Hazel & Norton, 1986). But in this case, the decision maker has strong motivation to seek satisfaction of several objectives or goals rather than pursue the maximisation of a single one. Hence, the feasible solutions from this structure are ordered according to a given criterion referred to as the objective function, representing the preferences of the decision maker.

Notwithstanding the fact that this paradigm has been widely supported, it does not faithfully reflect real life decision situations (Romero, 1991; Romero & Rehman, 1993; Tabucanon, 1993; Berbel, 1993; Ignizio, 1994). A wide variety of real world problems involve multiple, conflicting objectives and both hard and soft constraints - problems that could not be effectively addressed by conventional means without the imposition of numerous simplifying (and questionable) assumptions. The decision-maker is usually not interested in ordering the feasible set according to just a single criterion but seems to be striving to find an ideal compromise amongst several objectives[8], or seeks to achieve 'satisficing' levels of his goals (Romero, 1991;

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[7] Starr and Zeleny (1977) defines decision-making as: "a dynamic process: complex, redundant with feedback and sideways, full of search, detours, information gathering and information ignoring, fuelled by fluctuating uncertainty, fuzziness and conflict; it is organic unity of both pre-decision and post-decision stages of the overlapping regions of partial decisions."

[8] Objectives represent directions of improvement for one or more of the attributes (Romero and Rehman (1993).

Romero & Rehman, 93). Hence, characterisation of decision problems as monocriterion is likely to be unsatisfactory, since they do not reflect the heterogeneity and conflicting nature of many interplaying factors (Mendoza *et al.,* 1986; Tabucanon, 1993).

The situation in agricultural decision making and management of natural resource systems is not different and the existence of multiple objectives is a general rather than a unique occurrence (Zeleny, 1982; Romero & Rehman, 1993; Olocilja & Ritchie, 1991).

Another drawback of the traditional paradigm lies in assuming that the constraints that define the feasible set are rigid and cannot be violated under any circumstances (Cohon, 1978; Mendoza & Sprouse, 1989; Romero & Rehman, 1989; Romero, 1991). In real life, this is not always the case and often it is possible to accept a certain amount of violation of at least some of the constraints. This is especially true where the technical knowledge is not precise enough to impose rigid constraints (Romero & Rehman, 1989).

In general, the occurrence of externalities, risks, uncertainties, irreconcilable interests, and soft information make the application of many traditional decision techniques questionable (RAC, 1992; Tabacanon, 1993).

4.1.2 **The heterogeneity and conflicting nature of decision-making at farm and regional-level**

Decisions that are taken to run and manage agricultural and natural resource systems at farm and regional-level are complex. The essential aspect of this complexity is the multidimensional nature (e.g. spatial and temporal) of the decisions taken. Another fundamental source of complexity stems from the fact that any 'good', or 'service' being produced may have multiple uses (e.g., basic food, cash income, soil conservation and soil fertility improvement) and multiple products (production of various crops, forage, and livestock). Furthermore, quite often the managerial control involves both public and private interests. Any attempt, then, to devise a framework for planning[9] at farm and regional-level should consider these features and be capable

[9] Begetoft and Pruzan (1991) defines planning as: "a process by which analysts perceive a problem, define it, collect data about it, formulate it, and generate and evaluate alternatives for solving it, leading to the end of the process when decision makers choose an alternative for implementation."

of resolving the conflicts inherent therein (Mendoza *et al.,* 1986; Romero & Rehman, 1984, 1993; Dent & McGregor, 1993; Dent & Jones, 1993).

The consideration of many objectives in the planning process accomplishes three major improvements in solving complex problems (Mendoza *et al.,* 1986; 1987). First, it promotes more appropriate roles for the participants in the planning and decision-making processes. Second, a wider range of alternatives is usually identified than when a single objective methodology is employed. Third, models (if they are used) or the analyst's perception of a problem will be more realistic if many objectives are considered.

4.1.3 **Decision-making under uncertainty or a fuzzy environment**

Decision-makers at farm and regional-level often have to deal with insufficient or imperfect information due to the inherent complexity of the systems in which they operate (Dent & McGregor, 1993; Mendoza *et al.,* 1993; Berbel, 1993; Allen & Gould, 1986; Millan & Berbel, 1994; Ignizio, 1994). In such situations, the use of models that mimic decision-making processes of complex planning environments (such as: farm-level decision-making unit) can help in comparing possible policy scenarios in terms of their economic and social benefits and costs.

The term 'uncertainty' has been widely used to denote several phenomena (Mendoza *et al.,* 1993). It has been used to represent risks, imprecision, randomness, inaccuracy, ambiguity or inexactness. Likewise, the concept of fuzziness has no semantically unique definition that is universally accepted among researchers and practitioners (Mendoza & Sprouse, 1989). Nonetheless, the concept has generally been associated with complexity, vagueness, ambiguity, and imprecision. Fuzziness has also been interpreted either in the context of imprecise numbers (i.e., coefficients or parameters), or in the functional relationships, such as in the objective function or constraints (Millan & Berbel, 1994).

There are several reasons for incorporating uncertainty in models of agricultural and natural resource systems (Mendoza *et al.,* 1993; Berbel, 1993; Millan & Berbel, 1994). First, management of the systems involves short-term and long-term planning horizons. Short term projections may be easier to make. Future outcomes for the long-term are at best only educated guesses. Prices and market conditions for agricultural and natural resource products, for instance are highly dependent on several unpredictable variables (such as weather which may influence crop yields). Moreover, most land-use systems produce multiple goods and services which are valued differently by users. Some of these uses can be adequately measured while others are inherently difficult to quantify. Finally, managing agricultural and natural resource systems often requires the incorporation of human subjectivity which is both difficult to elicit and express in quantitative terms. Therefore, the use of models that mimic decision-making processes of complex planning environments (such as farm-level decision-making unit) would permit, for example, a comparison of a possible policy scenario with another in terms of its economic and social benefits and costs.

4.2 **Characteristics of the problem in the study area**

The major issue in agricultural and natural resource management in the study area has been declining agriculture production and environmental degradation leading to the subsequent weakening of economic development potential. Several factors combine to cause significant constraints to agriculture development in particular and management of the natural resource systems in general (Nkowani *et al.,* 1995b).

Competition for scarce resources at both farm and regional-level is also a source of concern. The main concerns of farmers include that of achieving stability or increase in food production, cash income, fuelwood, construction poles, having extra time for leisure, decreasing costs of production, limiting the amount of debt to be serviced and uncertainty (Dent & McGregor, 1993). At regional-level, the government on the other hand, sees food as a source of foreign exchange and government revenues, and as a strategic commodity which can be used as a means of control, a political weapon, and an instrument of social welfare (Chuzu, 1992; Tabucanon, 1993). The government's other concerns include the provision of services and infrastructure, regional expenditure, employment and reduction of environmental degradation by reason of increased indiscriminate cutting of trees in the name of Chitemene farming system, collection of fuelwood and construction poles leading to problems related to soil deterioration and a reduction in biological activity. Objectives of farm families in the context of rural development, to some extent, are in conflict with the wider aims of regional policy makers.

There is an obvious need to promote farm production systems that generate a level of productivity that satisfies the material (productivity) and social (identity) needs of farm households and that of the society at large with certain margins of security and without long-term resource depletion. As the objectives of security, continuity and identity usually compete with immediate productivity, a 'satisficing' instead of maximum level of productivity has to be sought in order to ensure sustainability of various productive systems at farm and regional-level. Goal Programming has been proposed as a viable way of resolving such conflicts at individual farm-level (see for instance; Barnett *et al.,* 1982; Flinn *et al.,* 1992; Maino *et al.,* 1993; Weldu, 1992) or regional-level (see for instance; Bouzaher and Mendoza, 1987; Cocklin *et al.,* 1988; Nijkamp *et al.,* 1989; van Huhlenbtroek and Martens, 1989; van Pelt *et al.,* 1990; Dent & McGregor, 1993) and at both levels (see for instance; Veloso *et al.,* 1992; Nkowani *et al.,* 1995a). A detailed discussion on the subject can be seen in the work done by Dent & McGregor (1993). While the present study's choice of approach is discussed in Chapter 7.

4.3 **Goal programming (GP)**

GP is perhaps the oldest approach within the Multiple Criteria Decision Making (MCDM)[10] techniques (Romero, 1991) (see an expository categorisation of the various MCDM techniques presented in Appendix 1). Goal as a planning method was first developed by Charnes *et al.,* (1955) and extended by Lee (1972), Ignizio (1978), and Romero & Rehman (1985). The application of GP in decision making processes associated with resource allocation in agriculture and natural resource systems at both the farm-level and also in the wider area of land-use at the regional-level has become widespread (McGregor *et al.,* 1994; Veloso *et al.,* 1992; Dent & McGregor, 1993). It has been found to correspond well with the usual conceptions of the resource manager's decision-making process: those of goal setting and goal ranking.

GP deals with problems involving multiple goals. Goals are included in the model in a form of equalities. The right-hand side values of these equalities which are called targets[11] or aspiration levels-are desirable values to which the decision maker wishes to aspire; they may or may not be satisfied. This MCDM technique is regarded as the method that operationalises the Simonian "satisficing" approach to the achievement of the decision maker's objectives (Romero, 1991; Romero & Rehman, 1993).

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[10] MCDM is an umbrella term for a variety of interrelated multi-criteria programming techniques. However, the term is sometimes used to describe not only programming models which specify decision variables as continuous, but also multiple attribute decision making models which involve choice among a small number of discrete alternatives.

[11] Targets are acceptable levels of achievement in the improvement of various attributes under consideration. On combining an attribute with target a goal is established (Romero and Rehman, 1993).

The purpose of the GP is to minimise the deviation between the achievement of goals and aspiration levels. This is achieved by transforming the objectives into constraint equations, each equation is set equal to desired goal level and through the addition of positive (P_i) and negative (N_i) deviation variables which symbolise over-achievement and under-achievement of each goal, respectively.

According to Steur (1986) and Ignizio (1994) GP models can be distinguished from other models by:

(i) The conceptualisation of objectives as goals.

(ii) The assignment of priorities and/or weights to the achievement of the goals.

(iii) Transformation of all 'rigid' constraints into top priority goals.

(iv) Transformation of all 'soft' constraints into lower priority goals.

(v) The establishment of an associated achievement function.

(vi) The minimisation of weighted-sums of deviation variables to find a solution that best satisfies the goals or in other words the utilisation of "satisficing philosophy" as a basis of multiple objective efficiency.

The minimisation of deviations from predetermined targets can be accomplished by several alternative methods, and of these the three most widely used ones are weighted or archimedian goal programming (WGP), pre-emptive or non archimedean goal programming (PGP) and the MINMAX GP (Romero, 1991).

4.3.1 **Weighted or archimedian goal programming (WGP)**

The linear weighted GP was first introduced by Charnes and Cooper in 1952. It was later applied by Charnes *et al.*, (1955).

This method considers all the goals simultaneously in a composite objective function which minimises the sum of all the deviations among the goals and their aspiration levels. The deviations are weighted according to the relative importance of each goal to the decision maker. A mathematical expression of this method is shown in Appendix 2.1. Because the objectives are incommensurable, the model must be structured so as to minimise the sum of relative, rather than absolute deviations from goal targets (Romero, 1991). The objective function specified in Appendix 2.1 reduces the problem to a scalar optimisation procedure. Mathematically, the problem becomes the same as conventional linear program and can be solved using the Simplex method.

Steur (1986) makes the following observations about WGP:

(i) The weights in the objective function are positive penalty weights.

(ii) Each goal gives rise to a goal constraint, except range goals that give rise to two.

(iii) Only deviational variables associated with undesirable deviations need be employed in the formulation.

(iv) The weighted objective function is the weighted-sum of the undesirable deviational variables.

(v) WGP can be solved using conventional LP software.

However, unlike PGP, relative weights are attached to the achievement of various goals instead of pre-emptive or absolute weights (Romero & Rehman, 1984; 1989; 1993; Romero, 1991; Cohon, 1978; Bouzaher & Mendoza, 1987; Zeleny, 1981).

The main shortcoming of the weighted GP technique relates to the extent of information which is required from the decision maker: both aspiration levels for each objective and weights of relative importance to the deviational variables must be specified. PGP was developed as a way of circumventing the latter requirement.

4.3.2 **Pre-emptive or non archimedean goal programming (PGP).**

PGP was developed by Ijiri (1965), extended by Lee (1972) and Ignizio (1976). In PGP, the model assumes that the decision maker can explicitly define all the goals that are relevant to a planning situation. Further, it assumes not only that priorities can be attached to these goals, but does so in a pre-emptive or absolute fashion. In other words, the fulfilment of the goals in a specific priority, Q_i, is immeasurably preferable to the fulfilment of any other set of goals situated in a lower priority Q_j. In solving the problem, the higher order priorities are solved first, and it is only then that the lower priorities are considered; hence the lexicographic order.

A large number of planning priorities can be explored, by carrying out sensitivity analysis on priorities and target levels. The structure of this PGP process is shown mathematically in Appendix 2.2.

Reviews of various algorithms for solving PGP with respect to accuracy and computational efficiency are given in Schuler and Meadows (1974), Ignizio (1976, 1978), Lee and Morre (1977), Olson (1984), Romero (1991), and Arthur and Ravindra (1980).

4.3.3 MINMAX GP.

In this variant instead of a pre-emptive (PGP) or non pre-emptive (WGP) minimisation of the sum of deviational variables the maximum of deviations is minimised. Obviously under computational point of view MIMAX GP is an LP problem and can be solved using the conventional Simplex. The mathematical structure of a MINMAX GP is given in Appendix 2.3.

4.4 The main attractions of GP.

The last few years have seen a somewhat heated debate in the literature about the pros and cons of GP (Ignizio, 1981a; Zeleny, 1981, Dyer *et al.,* 1983; McGregor, 1986; Ortmann, 1989; Ludwin & Chamberlain, 1989; Cornett & Williams, 1991; Romero, 1991; Romero & Rehman, 1984, 1987, 1989, 1993; Krawiec *et al.,* 1992; Dent & McGregor, 1993; Ignizio, 1994; McGregor *et al.,* 1994; Manning, 1994; Akatugba-Ogisi, 1994; Nkowani *et al.,* 1995a).

The main attractions of GP in relation to the problem defined in Section 4.2 lies in the following:

(a) The potential exists to mimic the resource manager's decision-making process: those of goal setting and goal ranking (Veloso *et al.,* 1992; Dent & McGregor, 1993; McGregor *et al.,* 1994; Nkowani *et al.,* 1995a; Winston, 1995).

(b) The "satisficing philosophy" (Romero, 1991) is properly operationalized.

(c) Computational efficiency is achieved in comparison to other techniques, particularly for solving WGP models for which an access to the standard Simplex model is sufficient (Steur, 1986; Romero, 1991).

(d) It is a logical, easily understood process of analysis which allows the analyst to proceed from goal definition to goal achievement in an orderly manner. Work is needed to prepare the model but in doing so, the analyst is forced to understand the model problem completely which leads to better definition of the interactions taking place which in-turn produces more reliable results (McGregor, 1986)

(e) Additional benefits relate to the inclusion of subjective estimates or desires as decision criteria and portrayal of several alternative potential solutions (Romero, 1991; Cornett & Williams, 1991). Trade-off relationships are captured and severe conflicts between certain goals that have an overriding influence on solutions are also identified through sensitivity analysis (Ludwin & Chaberlain, 1989; Howard, 1991).

(f) Qualitative information may be incorporated in the model without necessarily requiring financial considerations (Krawiec *et al.,* 1992; Cornett & Williams, 1991).

(g) Increased conceptual comprehensiveness is provided in evaluating alternative management scenarios (Ortmann, 1989; Ludwin & Chamberlain, 1989; Cornett & Williams, 1991; Romero & Rehman, 1989).

(h) A measure of risk can be incorporated in the programming routine (Berbel, 1993; Millan & Berbel, 1994).

(i) The introduction of deviational variables into equality constraints establishes greater flexibility, and allows targets or aspiration levels, desirable values to which the decision maker wishes to aspire to be over-achieved or under-achieved (Romero, 1991).

The above mentioned points indicate that GP can be a realistic and efficient tool for farm and regional planning with multiple goals. These positive points not withstanding, the advantage of GP over LP as an efficient planning tool has been questioned by some scholars (for instance; Barnett *et al.*, 1982; Debrea, 1959; Zeleny, 1981; Harrald *et al.,* 1978; Flinn *et al.*, 1980).

4.5 **Some identified or alleged problems with GP.**

There are, however, a number of aspects concerning the use of GP that have been mentioned by critics as underlying weakness such as:

(a) GP represents an fundamental shift from conventional mathematical programming. Ignizio (1994) on the other hand, believes that GP is simply an attempt to extend the mathematical modelling approach and it then uses the conventional algorithms (slightly modified) to solve the resultant model.

(b) PGP has been criticised as inflexible because higher priority levels brook no compromise with lower priority levels. One suggestion (for instance by Steur, 1986) proposed the use of relaxation quantities to alleviate this alleged inflexibility.

(c) GP requires 'too many' assumptions and simplifications (for instance; target values or aspiration level, ranking, weights to be attached to each unwanted deviation) which in most cases are subjectively applied (Harrald *et al.*, 1978). Not only is the decision maker expected to quantify targets and weights without information on trade-offs, but he or she is presumed to be in possession of a multi-attribute utility function which is separable, additive and stable over decision interactions. Further, the fact that both WGP and PGP provide a single solution has been seized by critics as being inadequate information for decision-making involving multiple criteria (i.e. for decision support).

Ignizio (1994) argues that the approach that imposes the highest degree of assumptions and simplifications is certainly not that of GP but that of conventional mathematical programming. While accepting that weighting is a problematic concept and usually subjectively applied, Romero and Rehman (1987, 1989, 1993), and Romero (1991) point out that there are methods available which help to mitigate the difficulties encountered in the use of GP. The use of sensitivity analysis and the interactive use of the GP is strongly recommended when the decision maker is not confident about any of the parameters of the model. In fact, the use of sensitivity analysis should be an integral part of the model implementation process so that the effects of setting different values of the targets, re-arrangements of the order of priorities, etc., can be explored in depth. Such an approach to the use of the GP makes it a robust tool for generating information that the decision maker requires for taking rational decisions.

(d) The minimisation of deviations from desired goals (objective function) with constraints is seen by critics (for instance; Zeleny, 1981) as being difficult to achieve. Literature elsewhere (for instance; Romero, 1991; Piech & Rehman, 1993) propose the use of the Simplex method to contain this problem. They argue that the solution is not the 'optimum' but that which 'satisfies' the stated policy levels set for goal attainment.

(e) Targets may not be truly representative of the aspiration levels of the decision maker(s). To overcome this problem, Piech and Rehman (1993) suggest that targets be derived from a conventional linear programming solution as the optimal values of the objective function for each goal, or can be set slightly higher.

(f) The incompatibility between the minimisation of an achievement function in PGP and the optimisation of the utility function[12] has been pointed out by several authors as a serious drawback to pre-emptive approach. Romero and Rehman (1984) are of the view that this problem is essentially theoretical, because in most planning and allocation decisions concerning resources with multiple goals, a hierarchical goal structure is an adequate objective function. In fact, it has been shown recently by Romero, (1991) that the incompatibility between PGP and utility optimisation is essentially due to the non-continuous system of preferences underlying the pre-emptive ordering. Romero and Rehman (1993) believe that the incompatibility between PGP and utility optimisation is less damaging to the applicability of PGP than it seems. Hence, to rule out the use of PGP from the tool-kit of analysis for this reason as some authors seem to suggest is unjustified.

(g) The allegedly inherent tendency of the GP technique to yield pareto inefficient solutions has been pointed out by critics as a serious disadvantage in its use. Rensi and Hrubes (1983) take a different view and argue that neither LP, GP or any other mathematical technique will necessarily provide pareto optimal solutions in the public domain as the conditions for pareto optimality rarely, if ever, are met in reality. This is so because markets are imperfect, price signals are often 'wrong' due to distortions and the representation of the true production possibility curve is extremely difficult, if not impossible. Hence, they felt it inappropriate to use the logic of welfare economics to judge the potential usefulness of GP.

[12] A utility function is just a device to assign numbers to a set of indifference's surfaces in a monotonic way. In other words, if the preference increases then the number assigned to the corresponding indifference surface also increases (Romero, 1991).

McGregor (1986), suggested the use of 'parametric analysis' of the aspiration levels in the model with the aim of verifying goal achievements. Romero (1991), on the other hand, points out that the GP was initially developed as a reliable methodology for finding acceptable solutions to real decision-making problems without worrying about their paretian efficiency. However, in the last few years some refinements of the GP techniques have been made to guarantee efficient solutions (for instance see; Hannan, 1980; Masud & Hwang, 1981; Romero, 1991). Therefore, the possibility of generating non-efficient solutions is no longer a serious problem associated with GP (Romero & Rehman, 1993).

There are also serious problems that can arise through a mechanistic and straight forward application of GP that can lead to the formulation of models which are not logically sound and/or misrepresent the reality analysed (Romero, 1991; Romero & Rehman, 1993). The problems fall under the following:

(h) The possible equivalence of solutions provided by GP and LP models. This can occur when the target for one goal is set very high, while others are set very low. Clearly, if this is a correct specification of the problem it would render GP superfluous.

(i) The lack of meaning and the misleading conclusions which can be obtained from a PGP model with an achievement function erroneously formulated as a scalar instead of as a vector.

(j) Generation of sub-optimal solutions due to either mistaken omission of a deviational variable or an unnecessary inclusion of a two sided goal.

(k) The naive setting of weights often implemented in the formulation of GP models, and which in many cases leads to wrong results.

(l) An excessive, and even absurd, prioritisation in PGP models leading to redundant goals.

The writing of Bouzaher and Mendoza (1987), Romero and Rehman (1984, 1987, 1989, 1993), Romero (1991), Steur (1986) and Ignizio (1994) report that these misleading results are not due to an inefficancy in GP methodology but in its superficial and careless application. The arguments presented show that in many cases these critics have exaggerated such difficulties into impossibilities. These, as has been pointed out, can be overcome or at least mitigated if GP is used properly. Reports about the weakness of GP, according to Ignizio (1994) are grossly exaggerated. GP is a useful and sound operational decision-making approach.

4.6 **GP modelling approaches at farm and regional-level.**

4.6.1 **A unified GP model.**

The unified GP model approach is advocated by McCarl (1992) to maximise the satisfaction of the regional developer but subject to a *notional* response of the farmer to regional policies. According to McCarl (1992), this approach is appropriate in the conceptualisation of the policy process but that it is difficult to solve due to the existence of many local optima. In addition, results have shown that a mix of good policies for farm on the one hand and region on the other could lead to an overall poor policy. It is against this background that this author calls for care in the application of such a unified model approach because results can be misleading.

4.6.2 **Multilevel GP model.**

The multilevel GP approach separates the modelling application between farmers (land users) and regional planners (policy makers) (Dent & McGregor, 1993). Broad constraints for the region are set out by the government against which the individual farm level representation takes place. The farm-level output provides a major source of data for the regional-level model. The advocates of this approach (for instance, Dent & McGregor, 1993; Veloso *et al.,* 1992; Nkowani *et al.,* 1995a) are of the view that micro, and regional-levels should be integrated in a multisystems concept to understand and model decisions and linkages at and between all levels.

The approach, however, is not without problems. Dent and McGregor, (1993) reported that the problem arises from certain assumptions that are considered at farm-level. For example, work at individual farm-level assumes that all farmers in the area act at the same time and in a unified manner. Farm families, on the other hand, are a unique group of people with a range of beliefs, motives, resources and objectives. Behaviour and decision making processes cannot be expected to be the same for all families. At regional-level, some of the goals need to be specified in terms of social benefits and social costs and these may not be generated directly from the farm-level model.

It might then be assumed that the most appropriate approach to integrating objectives between the land-users (farmers) and those concerned with regional development is to use a unified GP model. However, regional planning can hardly be successful unless the priorities, needs and aspirations of farmers are taken into consideration at an aggregate level, and this it is felt can be done by the use of a multilevel GP model approach. Detailed discussion about the use of multilevel approach are presented in Chapter 7.

4.7 **Summary.**

The rationale behind the use of Goal Programming (GP) in particular and Multiple Objective Decision-Making (MCDM) Techniques in general in the allocation of constrained land and associated resources between farmers (land users) and regional planners (policy-makers) has been discussed. Examples of the value of this technique to problems of a similar nature to the one in question had been provided. The main attractions and some identified or alleged problems associated with the use of GP have been presented. The choice of the modelling approach at farm and regional-level is discussed in detail in Chapter 7.

Base information required to set-up GP for application in the study area will be assessed in the light of existing quantitative and qualitative data held by Soil Productive Research Programme (SPRP), Adaptive Research Planning Team (ARPT), Misamfu Regional Research Station - Kasama, Regional Planning Unit (PPU) - Kasama, Government Institutions, Financial Institutions, UK Research Institutions, other Research Institutions and NGO's in the region.

In order to verify or clarify information on the structure and socio-economic conditions within the farming systems in the region from sources mentioned herein, there is need for survey to collect additional information related to current land-use and aspects of management. This information would be merged with the already available secondary data. Both sets of data will be used for the classification of representative farm type models of the region. It will be further used for input coefficients in the farm and region models.

The next chapter presents the study survey methodology. The chapter describes the sample selection method used followed by data representativeness of the surveyed area. The limitation to data collected is analysed and the analytical approach chosen described.

Chapter 5.

5.0 Survey Methodology.
5.1 Introduction.
5.2 Methods and data.
5.3 Research problem definition.
5.4 Survey.
5.4.1 Selection of villages.
5.4.2 Selection of households.
5.4.3 Household interviews.
5.5 Survey data limitations.
5.5.1 Definition of the household.
5.5.2 The concept of time.
5.5.3 The concept of area.
5.5.4 Production data.
5.5.5 Memory recall.
5.6 Data analysis.
5.7 Summary.

5.0 **Survey methodology**.

5.1 **Introduction**.

This chapter describes the approach and method[13] used to generate the information required to test the hypotheses outlined in Section 1.3 of Chapter 1. The aims of the 1993/94 field work were to verify and/or deny on information specific to the region, inorder to facilitate appraisal of analysing data sets concerning key issues about the farming systems and household economy. The Chapter begins with a description of the method used in data collection, then continues with an explaination of the research problem, purpose of data collection, and choice of the study area, data limitations, and finally, the management of data for analytical purposes.

5.2 **Methods and data**.

Research problems can be analysed by using primary and/or secondary data (Tull & Hawkins, 1990; Oppenhein, 1992). In this study, the farming systems of the Northern Region of Zambia were investigated in the household decision-making context and both secondary and primary data were used. The farming systems studied included chitemene, fundikila, ibala and agroforestry (as per discussion in Chapter 3). Data obtained were used to describe and compare representative farming systems in the region for the formulation of a logical framework for developing representative farm type models. The outcome of the models could be projected for devising appropriate farm and regional-level policies, research and extension strategies. In addition, the results of such an analysis are to be related to farm household objectives to develop multiple objective models for exploring land-use options open to smallholders in the region.

Secondary research data came in the form of literature of previously undertaken surveys on farming systems[14]. Quantitative variables related to physical farm characteristics; farm resources (such as: capital; family labour; hired labour; off-farm income and credit); household numbers; literacy and education level; crop and livestock production systems and input levels; fallow systems; area of grazing land; cultivation methods; system of crop rotation, input constraints, tenural arrangements,

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[13] A method is defined by Voorhees (1987) as: " a rational algorithm which prescribes a set of procedures whose implementation constitute a process resulting in specific imperial result." (pg 103)

[14] Sources of secondary data have been elaborated in detail in the same paragraph.

grain storage and loss; consumption patterns; household energy requirements; shelter and timber needs and expenses; and finally trading of crop products. Qualitative data related to smallholder's preferences and objectives on rural development policies. Both sets of data were derived from three main sources; on-station research (for instance see: Kamprath, 1980; Singh, 1984, 1987, 1989; Singh *et al.,* 1987; Goma & Singh, 1993; Holden, 1983, 1988, 1989, 1991; Lenvain, 1983; Steinshamn, 1984; Lungu, 1987; SPRP, 1987, 1988, 1989, 1990, 1991, 1992, 1993; Mathews *et al.*, 1992a, b, c; Dalland & Vaje), on-farm research (for instance see: Tveitnes, 1983, 1986; Gatter, 1993; Gatter & Sikana, 1989; Bolt & Holdsworth, 1987, 1988; Bolt & Kerven, 1988; Bolt *et al.*, 1987; Bolt & Silavwe, 1988; Kerven & Sikana, 1988; Holden, 1988, 1993; Holden & Otika, 1991; SPRP, 1988, 1989, 1990, 1991, 1992, 1993; ARPT, 1988; 1989, 1990, 1991, 1992, 1993; Otika, 1990; Matthews *et al.*, 1992a, b, c; Reid & Silavwe, 1986; Reid *et al.,* 1986; Reid, 1994), and follow-up surveys (see: Boyd, 1959; Woode, 1983; Trapnell, 1953; Watson, 1958; Richards, 1939; Schulz, 1976; McGrath, 1987; Mansfield, 1973, 1974; Mansfield *et al.,* 1975; Stromgaard, 1984, 18985, 1988, 1989, 1990, 1991; Haug, 1981; Uprichard, 1991; Eklund, 1990; Geisler *et al.*, 1985; Kakeya, 1976; Kakeya & Sugiyama, 1987; Kirscher *et al.,* 1984; Pottier, 1986, 1988, 1992, 1993; Vogtmann, 1981; Svads, 1983, 1986; Tveitnes, 1983, 1986; Lungu & Chinene, 1993; Huxley, 1986; Huxley *et al.,* 1986; Conway, 1987; Mattson, 1989; Sharp, 1987; Sano, 1989; Nkowani *et al.,* 1995a, b). These sources provided a detailed picture of changes in land-use and socio-economic conditions in the Northern Region of Zambia from the 1930s to early 1990s.

In order to verify and/or deny information on the structure and socio-economic conditions within the farming systems from past formal and informal surveys, some primary data were collected from a detailed study of 60 farmers in 1993/94. Once analysed, this information was ‘superimposed’ on the already available secondary data.

5.3 **Research problem definition**.

Two main questions arise from a wider study of the farming systems and the household economy in the study area.

(1) Planning for sustainable agriculture is not being realised in the Northern Region of Zambia (see Chapter 4, sub Section 4.1.2). The challenge has been how to raise smallholder productivity at farm-level without long-term resource depletion while at

the same time recognising the endemic poverty, wide spread food shortages and disease, poor soil fertility and seasonal labour shortages already present.

(2) Agricultural development policies and practices are not sufficient to address the perceived needs of smallholder farmers, in particular:

(a) For any technology to be acceptable, it must be at least be as productive as existing technologies in relation to the resource constraints and preferences of smallholder farmers in the area.

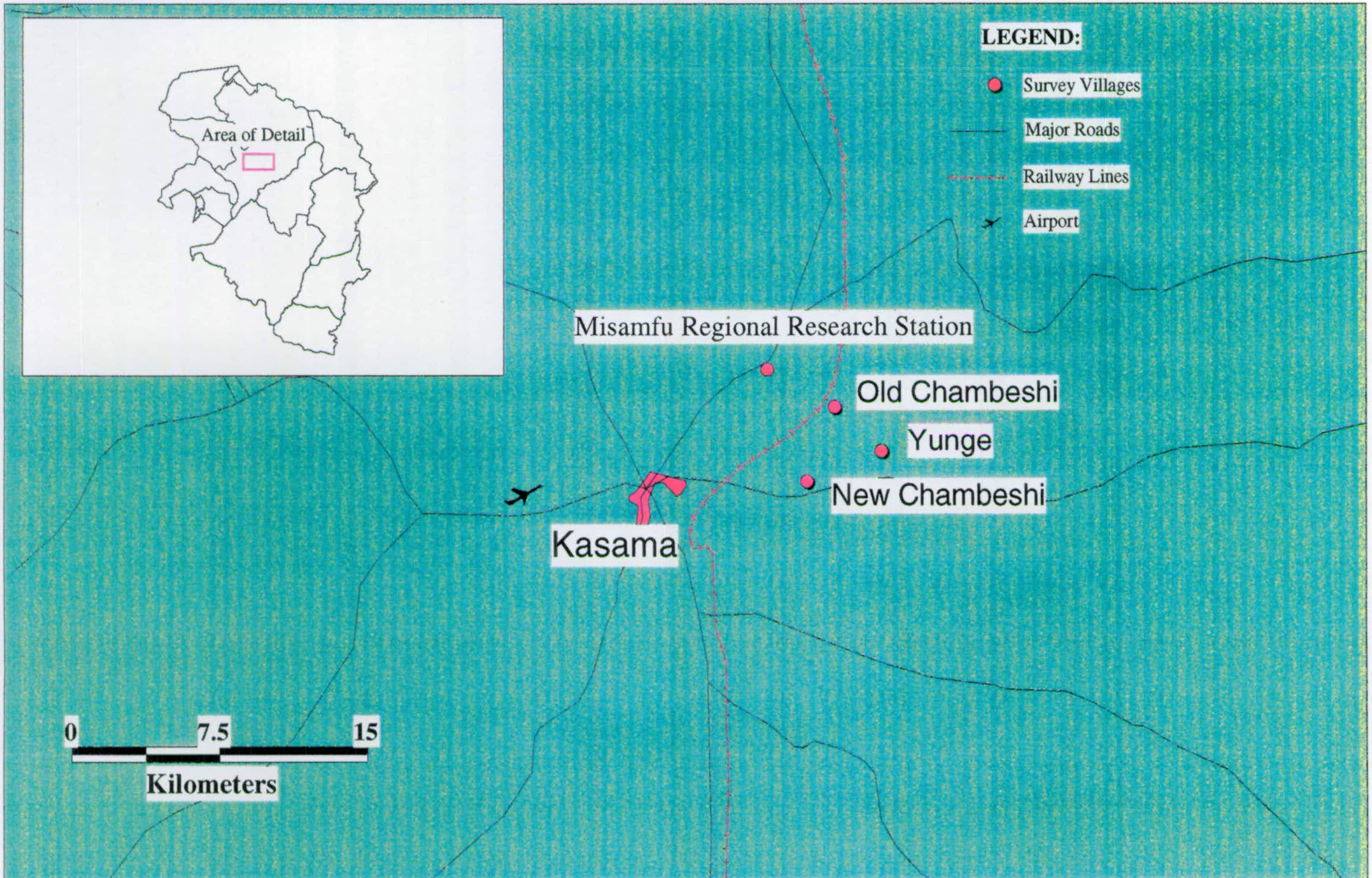
(b) Smallholder farmer's concern is to strive to find an ideal compromise over a set of farming objectives based on individual and/or community value systems rather pursuing maximisation of profit.

This study forms a significant attempt to seek for solutions which could aid conflict resolutions over the use of constrained resources between land-users (farmers) and those concerned with regional development (planners) in a sustainable development perspective.

5.4 **Survey**.

5.4.1 **Selection of villages**.

The appropriateness of any sampling framework has to be evaluated in terms of particular needs of the study at hand (Henry, 1990). In this study, a systematic sampling procedure based on the sampling frame of SPRP (1986) and Holden and Otika, (1991) was used to draw the samples. In order to represent the main farming systems (chitemene, fundikila, ibala and agroforestry) of northern region, three villages namely: Yunge, Old Chambeshi and New Chambeshi in Kasama district were chosen purposively (see Figure 5.1). As indicated in Section 5.2, classification of main farming systems would provide a logical framework for developing representative farm type models, whose outcome could be projected for devising appropriate farm and regional-level policies, research and extension strategies. These villages had representative soils and vegetation and were within the limits of logistical constraints: especially, supportive staff and transport from research teams of SPRP and ARPT - Misamfu Regional Research Station, Kasama. The three sample villages represented typical villages of the region, and consequently that the events noted here


LEGEND:
Survey Villages
Major Roads
Railway Lines
Airport
Area of Detail
Misamfu Regional Research Station
Old Chambeshi
Yunge
New Chambeshi
Kasama
0
7.5
15
Kilometers

may well apply elsewhere in the region and it was known that, the four main farming systems were practiced in the location.

5.4.2 **Selection of households.**

Regular meetings were held with the staff from SPRP, ARPT, PPU, the Regional Agriculture and Forestry offices, the Village Participatory Research Groups (VPRG) and the village headmen. A large amount of informal, qualitative information was gathered at these meetings, and this formed the backdrop around which the selection of households was conducted, and opinions formed. A list of farmers in the sample villages (46 in Yunge, 51 in New Chambeshi and 34 in Old Chambeshi), of which 126 were directly involved in agricultural activities was compiled.

Statistical inference implies that, up to a certain point a large sample will give a better estimate of population parameters. After this sample size, small gains in precision about population information will be relatively costly to achieve. Sampling size, therefore, requires a compromise between theoretical sampling requirements and practical limitations such as time and costs (Henry, 1990). According to Oppenhein (1992), the size of the sample is, of itself, not very important. Information requirements were specific and needed to be directed at particular respondents. To test the hypothesis, it required that information was collected from households that represented the main farming systems in the region. It was envisaged that analysis of survey results would be related to these farming systems. But due to lack of base line data it was impossible to stratify the sample in advance to aid such analysis. Consequently, a rather larger than expected random sample was taken of 60 farm households (48 %) to ensure that sufficient farms running each system were selected.

5.4.3 **Household interviews.**

A formal questionnaire (see Appendix 3.0) was used to interview farmers in the sample villages at household level[15] since this is the basic farming unit. The questionnaire content was designed taking into account two main issues as suggested by Converse and Stanley (1988):

(a) Questions will generate the right kind of information.

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[15] Households was defined as all who stayed, worked and ate in the group. Dependent children who stayed outside the household, but usually came back for weekends and holidays and belonged to the same consumption unit were also included. Absentees who pooled their income with the rest of the household or provided labour and received products from the farm were also included.

(b) The respondent will be able to answer the questions correctly.

In this survey, questions were kept as straight forward and unambiguous as possible to meet different objectives and procure accurate information.

Prior to the household interviews, the questionnaire was subjected to a thorough pre-testing of respondents similar to those included in the final survey for length, relevance and complexity. Pre-testing the questionnaire had two advantages: firstly, it became a training exercise for the enumerators; secondly, it became an opportunity to inform and organise the households selected for interviews. A week was spent on pre-testing and a certain amount of revision was made following the pre-test.

Five enumerators comprising four staff from the SPRP and ARPT and the researcher administered the questionnaires. Interviews were done individually by enumerators during visits to households. Usually each interview took two and a half hours to complete.

In conducting household interviews, the person making the majority of decisions on the farm was selected and in every instance was available. It was understood that the attitudes and perceptions of this individual were most likely to have an impact on organisations which dealt with the farm and therefore was considered to be the most suitable person.

Financial institutions identified by farmers as important such as the Northern Co-operative Union (NCU), Zambia Co-operative Federation (ZCF), Lima Bank (LB) and Credit Union and Savings Association (CUSA) were visited to get clarifications on their lending policies, as well as to gain from their past and present experiences with the farmers in the study area. Likewise, government institutions involved in rural development activities such as Agriculture, Fisheries, Forestry and Natural Resources Regional Offices, the District Council and the PPU were also visited to get more information to supplement the data gathered by the survey.

In order to have a better understanding on alley cropping research work being carried out elsewhere in the country, two further research stations were visited namely; Chalimbana located on the outskirts of Lusaka and Musekela located in the Eastern Region.

5.5 **Survey data limitations.**

5.5.1 **Definition of the household.**

One of the most difficult tasks in the data collection proved to be that of defining the household. Several nuclear families in the sample villages fulfilled all these criteria. There were however, some cases where the sleeping-household, the cash spending-household, the eating-household and the producing-household represented different combinations of individuals within a wide group of relatives. Three examples are given for illustration.

Residence.
A household would comprise usually of people living in a cluster of several huts around a common yard and with a common cooking shelter. There would typically be one hut for the wife and the youngest children, and one or more huts for the older children; for the wife's old parents or parents in-law; for the divorced, widowed or unmarried sisters; or for other relatives. The latter groups particularly represented difficult borderline cases as to whether they should be counted as separate household or not?

Production or working units.
In many cases members of the nuclear or extended family had jointly-owned plots where they worked together and shared the produce. However, cases of individually owned plots were perhaps even more common.

The wife, husband and their adolescent children might each have their individual plots where they worked alone. On the other hand, they could work together on each other's plots for certain operations while the rest of the operations were done individually.

Consumption units.
It was difficult to calculate incomes that are pooled within the household. Especially when on occasions, incomes from private plots of cash crops may be retained by the owner of the plot. In addition, the wife may be able to retain incomes from her beer sales without the knowledge of the husband so that the money was not taken away from her.

It was against this background that Mansfield (1974) wrote the following concerning the definition of the household:

"The ideal household for accounting purposes is the group of persons eating and sleeping together and pooling their income. In most villages, however, one has to deal with a considerable number of persons who are attached to more than one household and whose economic rights and obligations are ill defined. It is usually necessary to place these persons in households for the purpose of analysis on the basis of arbitrary decisions. The decisions will depend largely on the form of analysis".

The definition of the household membership was primarily therefore based on whether people were living in the same hut cluster. The judgement was based on discussions with and information from the informants and village headmen.

5.5.2 **The concept of time.**

In the interviews an attempt was made to obtain precise data on labour input under various farming systems and other activities. This proved to be difficult. Culturally, the people in the area are task-oriented, and not time-oriented. They do not have the same abstract concept of time as in the western culture; as work is measured not by the time it takes, but the tasks performed. The farmers, therefore found it quite difficult to answer questions regarding time use for various activities.

The conceptual differences mentioned are, however, not of such a nature that it was impossible to obtain information on the time used for different activities. It was possible to 'translate' concepts of time by further questioning farmers about the time they left home for the farm, when they leave the farm, when they rested, on what days did they work on the farm, what they did during their spare time, and so on.

5.5.3 **The concept of area.**

Most households have several plots. A lot of probing was therefore required to determine the correct number of plots and area cultivated by the household and these plots were field verified.

5.5.4 **Production data.**

A number of farmers could not provide accurate figures on what was harvested, stored, consumed, sold or what was purchased to make up for the short fall. In some cases the production and sales figures were given as a number of baskets, calabashes etc. The same problem arose for quantities given in number of bags, without information on the size of the bags or whether they were full or only half full. Estimations were made in such cases and in other cases information gathered by researchers and extension officers were used.

5.5.5 **Memory recall.**

Most farmers did not possess records of their day-to-day transactions. However, most of the data that were being asked related to figures for prices, yield, sales, time element, expenditures etc.,. In order to calculate household incomes, expenditures etc., for the whole year cycle, transactions that had taken place since the end of last year's rains were of paramount importance. When they had a more or less fixed date to relate events to, it was obviously easy for the informants to remember transactions. But a whole year was still a long time to remember all activities that took place. There were some cases where the informants obviously mixed up one year's figures with another year's figures.

It is therefore against this background that any conclusions drawn should be assessed.

5.6 **Data analysis.**

Survey data were transferred to computer spread sheets and analysed where appropriate using SPSS statistical package. Data analysis comprised two elements which complemented each other. Firstly, statistical analysis of data from the survey were used to describe and compare the various farming systems under consideration. Secondly, the results of the survey were used as background information to construct representative farm type linear programme and to set-up for multiple objective models in the study area (see Chapter 7). In addition, the survey results, apart from secondary data were used to derive coefficients for the linear programming and multiple objective models at both farm and regional-levels.

5.7 **Summary.**

In this Chapter, data and the approach and method used in order to generate data required to test the hypotheses outlined in Chapter 1.0 is presented. Paucity of specific information relating to the study area is also described. The aim of the field work were to verify and/or deny information specific to the region, inorder to facilitate apparaisal of analysing data sets concerning key issues about the farming systems and household economy.

In the next Chapter, statistical results obtained from the survey are presented. The primary objective of this part of research is to provide quantitative information on the structure and socio-economic parameters within the farming systems and the household economy emphasising the relationships and the influence of components to each other.This output along with secondary data and other sources of information are used as input data for the formulation of a logical framework for developing representative farm type linear programming and multiple objective models (see Chapter 7.0).

Chapter 6.

6.0 **Survey results.**

6.1 **Introduction.**

This chapter presents results from the 1993/94 survey carried out in the Northern Region of Zambia which lies in Natural Region III. Statistical analysis of data was done at household level, and for a few variables at farming systems level within the study area by using the SPSS package. The farming systems studied included; chitemene, fundikila, ibala and agroforestry. The primary objective of this part of research was to provide quantitative information on the structure and socio-economic parameters within the farming systems and the household economy emphasising the relationships and the influence of components to each other. The data are presented by means of discrete groupings which are some cases not scale specific of the systems under review. This approach facilitates understanding the features of particular groups in relation to each other for example, their resource position, production orientation and potential (Low, 1986).

In the next part of this thesis, the survey results together with secondary research data, scientific information and other sources of information form the basis for developing a logical mathematical framework for representative farm type linear programming and multiple objective models at farm-level which are later aggregated into a regional-level model.

6.2 **Household characteristics.**

6.2.1 **Household size.**

The average number of persons in a household were 7.5 (s.d* 1.25), ranging from 1 to 11 persons per household. The average number of persons per household did not vary significantly ($P > 0.05$)[16] among the farming systems (see Table 6.1).

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[16] This probability is called the observed significance level. If the observed significance level is small enough (usually less than 0.05, or 0.01), the hypothesis that the sample means between farm system types are equal is rejected.

Table 6.1: **The average household size by farm system type**

Farm system type.	Average size (persons).
Chitemene.	7
Fundikila.	8
Ibala.	7
Agroforestry.	8
Total.	7.5 (s.d* 1.25).

* Standard deviation.

6.2.2 **Gender of head of household.**

The survey sample included 53 male-headed households and 7 female headed households (88.3 % and 11.7 % respectively of the surveyed households). The average household size for male-headed households across the farm system types was found to be significantly higher ($P < 0.05$) than that for female-headed households (see Table 6.2). However, this observation may be misleading because the numbers in each group were too small to give population estimates.

Table 6.2: **Gender of head of household and household size by farm system type.**

	Number of households.		Mean household size (persons).			Total no. (persons).
Farm system type	Male headed.	Female headed.		Male headed.	Female headed.	
Chitemene.	12	3		7	6	107
Fundikila.	13	2		8	6	115
Ibala.	13	2		7	7	106
Agroforestry	15	0		8	0	117
	53 (88.3%)	7 (11.7%)		7.5	4.75	445

6.2.3 **Age and sex distribution.**

The family age and sex distributions of the sample were compared across the farm system types and were found to be significantly different ($P < 0.05$) (see Table 6.3). The table shows that over 50 per cent of the sample population by age and sex is below the age of twenty six. But a significantly higher proportion ($P < 0.05$) (see Table 6.3) of males and females above the age of 39 were observed in agroforestry household type.

Table 6.3: **Population percentage by gender and age.**

Age.	Chitemene.		Fundikila.		Ibala.		Agroforestry.	
	Male (%)	Female (%)	Male (%)	Female (%)	Male (%)	Female (%)	Male (%)	Female (%)
0-12	38.3	41.4	45.7	31.5	33.3	41.8	33.3	36.9
13-25	36.2	37.5	27.4	38.9	41.2	29.1	36.9	38.1
26-38	11.8	13.6	11.6	17.7	7.8	14.2	7.0	6.3
39-51	11.6	5.6	13.1	7.9	15.1	10.9	14.8	15.0
52 +	2.2	2.5	2.4	3.1	2.5	4.0	6.0	5.6

6.2.4 **Literacy level.**

Distinct differences in literacy level in the sample survey were observed to be significant ($P<0.05$) at farming system level and between men and women (see Table 6.4). Most of the people who had received no formal education were still young (under 12 years old) so it is possible that they would perhaps receive a few years of education before reaching adulthood. It is obvious that most people apart from the young ones should be able to operate in the local language. According to Table 6.4, the same could not be said to be true when reading and writing is brought into the picture. The statistics show, as would be expected, less literacy levels in households under chitemene and fundikila systems.

Table 6.4: **Literacy percentage by farm system type and gender.**

Farm system type	Local language. (Speak, read and write).		English. (Speak, read and write).	
	Males (%).	Females (%).	Males (%).	Females (%).
Chitemene.	29.4	13	21.2	8.3
Fundikila.	26.6	16	20.8	9
Ibala.	53.7	22.2	38.6	13
Agroforestry	52.9	21	36.7	15

6.3 **Farm characteristics.**

Farms were highly fragmented, with farmers cultivating a number of small plots. The maximum number of plots across the farm system types was 8, the least was 1, and the most frequent was 5. The average farm plot sizes between farms were significantly

(P < 0.05) different (see Table 6.5). The total average size of the plots was 0.86 ha, with the largest plot recorded at 3.6 ha (an ibala field), and the smallest a chitemene at 0.16 ha (see Table 6.5). The most common overall farm size (including all plots being farmed by the household) was between 2 to 3 hectares with over 30 per cent of the sample falling within this range. The largest farm was 5.5 ha, the smallest 1.72 ha. Plots were scattered, with separate plots used for specific purposes, and local knowledge largely determining where specific crops may be best suited. The actual choice about what kind of system to adopt and where to use the respective system appears to depend on farmers perceptions of land and soil suitability (Kerven & Sikana, 1988). There is no permanent system of land tenure; the chief holds the land in trust and an individual maintains rights to a field as long as he or she has it under cultivation.

Table 6.5: **Farm plot size between farm system types.**

Farm system type.	Farm plot size.		
	Minimum.	Maximum	Mean
Chitemene.	0.16	1.0	0.37
Fundikila.	0.20	1.85	0.77
Ibala.	0.22	3.62	1.19
Agroforestry	0.25	3.0	1.12
		Total mean.	0.86

As described in Chapter 3 Section 3.5.1, the average farm holding in Kasama District and surrounding region during the early part of the century (Richards, 1939; Trapnell, 1953) was 1 ha, and rarely as large as 2; farm size would therefore appear to have increased. This would seem to be accounted for by the increase in cultivation area and through the introduction of more semi-permanent and permanent farming systems in the area, neither of which were recorded at that time. Studies carried in Chinsali District within the Region (for instance; Reid, 1994) reported the maximum number of plots across all farm system types observed per farmer were 15, the least were 1, and the most frequent was 10; slightly less than half of the households fell within the range of 9 to 12 plots each. The largest farm, on the other hand, was 6.0 ha (an ibala field) and the smallest a chitemene at 0.20 ha. These findings show some significant differences in the average number of plots a household is able to cultivate but seems to be quite consistent with observations made by Reid (1994) where farm size is concerned although, this study was carried out in Kasama District.

6.4 **Farm household food pattern**.

A number of questions, aimed at establishing household aspirations, constraints, and strategies in relation to food security issues were asked during the survey. Firstly, farmers were asked to indicate their most important concern with respect to food security. A total of 51 per cent of the households aimed at producing nearly all of its staple food and usually succeeded in doing so. Households who did not plan to produce all their staple food coped with food production shortfalls by doing the following:

(a) "Insurance" crops were grown as alternatives such as millet and cassava.

(b) Labour was sold to obtain food known as 'food for work'.

(c) Food was purchased from the market using money obtained from selling livestock, charcoal, firewood etc.

(d) Food aid was received from the government, and NGO's.

However, food security strategies varied significantly ($P < 0.05$) between farm system types. Ibala and agroforestry farm households produced nearly all their staple food requirements unlike chitemene and fundikila farm households.

Secondly, farmers were asked to identify the main causes of food production shortfalls. The majority of farm households (57 %) interviewed gave lack of resources (capital and labour), and/or low soil fertility as the main constraints behind food production shortfalls.

6.5 **Farm resources**.

6.5.1 **Income**

About 88 per cent of the farm family households revealed that cash income in the household economy was generally low and mainly used to buy basic food needs. Twelve per cent, on the other hand, showed that they had more than adequate cash income to meet basic needs and that a moderate 'surplus' was left over for farm inputs. Cash income, however, was observed to vary significantly ($P < 0.05$) between farm types (see Table 6.6). This could be attributed due to high external input costs demanded by ibala and agroforestry systems in comparison to chitemene and fundikila systems in crop production.

Table 6.6: **Estimated annual farm household income by farm system type**.

Farm system type	Amount in (Zk)		
	Minimum.	Maximum.	Mean.
Chitemene.	1000	242500	120750
Fundikila.	2500	847928	177408
Ibala.	4500	1600000	435018
Agroforestry	6800	1567940	566733

The main sources of income identified for all farm system types were; sales of crops (23 %), livestock and livestock products (22 %), off-farm income (19.2 %), gifts and remittances (17.8 %), and credit (18 %). The majority of the farmers (over 54 per cent) gave lack of positive government support and poor soils as the main causal factors responsible for the low cash income in the household economy.

6.5.2 **Household labour.**

In the questionnaire (see Appendix 3.0), unlike Low (1986), a distinction between household production activities and household maintenance activities was attempted. Household maintenance activities were defined as those giving 'relatively immediate utility' such as; cooking, water collection, maintenance of construction, and household cleaning. The main production activities were defined to include land clearing, ploughing or cultivation (October to November), sowing, weeding, pruning (December to February), and harvesting and lopping of trees (April to June). Within the farm household across all farm types an adult female significantly ($P < 0.05$) contributed more family labour than an adult male and/or child. These findings are consistent with those observed by Bolt and Kerven (1988).

6.5.3 **Hired labour.**

The amount of hired labour from households varied significantly ($P < 0.05$) between farm system types with chitemene (52 %) and fundikila (46 %) providing most of the labour for hire, and ibala providing (2 %) and alley cropping (0 %). This estimate supports the growing evidence (see Chapter 3) that agroforestry demands increased labour needed for the establishment, prunings and fire protection of the agroforestry plots hence, the failure to contribute to hired labour. Most of the hired labour (60 %)

was mainly employed in weeding and harvesting hybrid maize and agroforestry plots. Hired labour was mainly paid in cash (60 %) followed by food (25 %) and household commodities such as salt, sugar, cooking oil, soap, clothing etc. Households did at times provide labour on an exchange basis during peak labour requirement (during weeding and harvesting time), with beer and munkoyo beverage as a token of appreciation. This community-based support mechanism is on the decline due to broad organisation changes such as the transition from large community groupings to nuclear households (Pottier, 1993).

6.5.4 **Off-farm income**.

There has been a tendency in the past to regard peasants as farmers confined only to their farm, thus overlooking their engagement in off-farm activities. Evidence elsewhere (for instance; Reardon, 1989; Low, 1986) suggests that off-farm income opportunities are widespread. The sources of off-farm income in the farm households in this study included; brewing beer, fishing, collection of caterpillars, ichikanda roots and mushrooms, charcoal burning, wood carving, and hand craft. However, over 20 per cent of the total revenue (off-farm) in most of the households emanated from beer sales. The average off-farm income raised by farm households constituted 19.2 per cent of the total income. While studies carried out by Bolt and Silavwe (1988) showed that on average off-farm income constituted 43 per cent of total income in the region, the large disparity in observations may be due to a number of reasons which may included; the definition of off-farm activities or the sampling procedure used.

According to Low (1986), the availability of off-farm income influences farm household decisions and may even cause stagnation or decline in per-capita food production (see discussion postulated in Chapter 3 Section 3.4.3).

6.5.5 **Credit.**

Two types of credit were identified: formal and informal. Most farmers (77 %) across all farm system types received formal credit while (23 %) of the farmers got informal credit. The cost of formal credit amounted to 80 per cent per year of the principal loan. However, interest was not charged for cash advances in the informal situation. This kind of credit as pointed out by Nkowani *et al.,* (1995b) results mainly from the personalised nature of the relationship in which the loan is made. Over 55 per cent of households obtained credit for two main purposes namely; crop inputs and school requirements for their children. The main sources of formal credit by percentage proportion comprised; Northern Co-operative Union (32.8 %), Lima Bank (11.5 %), Zambia Co-operative Federation (25 %), Credit Union and Savings Association (7.7 %), and others (23 %).

The amount of credit acquired from these sources varied significant (P < 0.05) between farm system types (see Table 6.7).

Table 6.7: **Estimated annual farm household amount of credit by farm system type.**

Farm system type	Amount of credit in (Zk)		
	Minimum.	Maximum.	Mean.
Chitemene.	5000	30000	16000
Fundikila.	34000	351375	229647
Ibala.	420445	865815	621903
Agroforestry	693906	1079738	846512

Households with intensive farming practices such as that of ibala and agroforestry received significantly higher amounts of credit when compared with chitemene and fundikila households. It was also observed that farmers under ibala were both willing and capable of self-financing input purchases in the absence of credit. This observation is in agreement with the farming systems and household economy study carried out by Bolt and Silavwe (1988). The access to credit was observed to be poor among small farmers who are the majority (mostly practising chitemene and fundikila), thereby inhibiting the purchase of seed and fertiliser or hiring labour.

6.6 **Household expenses.**

Cash expenditures for a typical farm household included: purchases of staple and minor foods, sundries, fuelwood, building materials, crop inputs, hired labour, farm equipment, livestock, veterinary services, raw material for home industry, school fees and other requirements, social expenses and other needs. The amount of expenditure by farm households varied significantly (P < 0.05) between the farm system types (see Table 6.8). It would appear that agroforestry and ibala households incur more expenses than either fundikila or chitemene may be because these households are wealthy.

Table 6.8: **Estimated annual farm households expenses by farm system type.**

Farm system type	Expenses by farm type in (Zk)		
	Minimum.	Maximum.	Mean.
Chitemene.	500	70388	10842
Fundikila.	2000	351375	38718
Ibala.	2400	865815	70134
Agroforestry	2500	1036738	87505

6.7 Land preparation methods.

Land preparation methods in the sample survey area involved the use of the following; manual or family labour, hired manual labour, owner operated animal drawn, hired animal drawn, owner operated tractor, rented tractor and other. The main ones were; manual labour (62 %), hired manual labour (27 %) owner operated animal drawn (9.2 %) and hired animal drawn (0.8 %). Bolt and Holdsworth (1988) reported that the ability of ibala and agroforestry households to mobilise extra-household labour through hiring rather than the availability of intra-household labour was central for the expansion of the systems under hoe cultivation. Outside labour was mainly used for land preparation and for follow-up practices such as weeding and harvesting. Intra-household labour availability were, however, seen to be central to food production for chitemene and fundikila households.

6.8 Crop production.

The main crops grown were millet, maize, cassava, groundnuts and beans. Over 80 per cent of ibala household types grew maize as the main crop while over 70 per cent of chitemene grew millet, cassava, groundnuts and beans, with over 60 per cent of fundikila households growing millet, maize, cassava and beans. Agroforestry household types on the other hand multi-cropped their farms. In chitemene farms, little use of external inputs such as the use of hybrid seed and fertilisers was recorded. In fundikila farms, some cash rich households used hybrid seed and fertilisers while the cash poor households did not. All ibala household types used hybrid seed and fertilisers while agroforestry farms mainly used local seed coupled with the use of fertilisers and lime. Lime was used to ameliorate the highly acidic soils.

The average labour (mandays) used per ha by farm system type for the main crops was observed to be significantly higher ($P < 0.05$) in agroforestry farms when compared with the rest of the systems (see Table 6.9).

Table 6.9: **The average farm household mandays used per ha by crop and by farm system type.**

Crop.	Chitemene.	Fundikila.	Ibala.	Agroforestry.
	Mandays/ha.	Mandays/ha.	Mandays/ha.	Mandays/ha.
Millet.	15.2	18.97	19.68	52.9
Maize.	17.5	21.86	22.2	55
Cassava.	10.5	12.7	14.4	48.5
G.nuts.	14.4	17.28	19.9	53
Beans.	13.5	16.2	18.96	52.3

The cost of production inclusive of labour supplied from farm family households by crop per ha were too observed to be significantly higher in agroforestry household types when compared with the other household types (see Table 6.10). This could be attributed to extra labour needed for the establishment, maintenance and protection of agroforestry plots apart from the cost of fertilisers, seed, and lime.

Table 6.10: **The average cost of production per ha by crop and between farm system types.**

Crop.	Chitemene.	Fundikila.	Ibala.	Agroforestry
	Cost/ha (Zk).	Cost/ha (Zk).	Cost/ha (Zk).	Cost/ha (Zk).
Millet.	22800	28200	85800	153350
Maize.	26250	31500	119350	194500
Cassava.	15750	19050	59600	146750
G.nuts.	21600	25920	87700	153600
Beans.	20250	24300	66440	152450

The average yields per ha by crop by farm household were observed to vary significantly ($P < 0.05$) between farm system types (see Table 6.11). Yields apart from maize are poor in agroforestry plots when compared to ibala or even fundikila and could be attributed to reasons discussed in Chapter 3 Section 3.7.

Table 6.11: **The average farm household yields per ha by crop and between farm system types.**

Crop.	Chitemene.	Fundikila.	Ibala.	Agroforestry
	Yield Kg/ha.	Yield Kg/ha.	Yield Kg/ha.	Yield Kg/ha.
Millet.	700	520	1200	900
Maize.	1200	1200	2560	2600
Cassava.	5500	4200	4600	3100
G.nuts.	800	800	900	400
Beans.	800	600	1100	500

6.9 **Livestock.**

Livestock husbandry as reported in Chapter 3 has never been the major part of agriculture in the Northern Region of Zambia due to the non-pastoral tradition among many of the indigenous tribes apart from the Namwanga tribe. Other reasons relate to lack of dry season grazing, incidence of livestock epidemics such as East Coast Fever and Foot and Mouth Disease and generally lack of veterinary services.

In the sample survey area, across all farm system types, livestock comprised cattle, goats, and sheep in the grazing animals group, pigs and poultry in the group of animals normally hand fed in enclosures. Both groups were mainly dependent on rangeland for feed. The largest portion (about 50 %) of the total livestock grazing units per farm household was made up of goats. Over 70 per cent of the farm households owned poultry. The first four most important products from cattle were given by most cattle owners (80 %) as meat, milk, draught power and manure. Few farmers identified sales (meat) as the only objective of raising cattle. The structure of the cattle herd in the area studied, suggest that the community attach considerable importance to breeding (as evidenced by a large proportion of breeding females in the herd). Births alone contributed between 85 to 90 per cent of the total number of animals in the herd. The other contributions came in form of gifts or remittances from friends, relatives and in the form of dowry in marriage. Farmers, however, revealed that receiving animals as gifts were now rare.

The majority of the cattle in the study area, phenotypically appeared to be of indigenous breeds or crosses among themselves. The main indigenous breed, the Angoni, formed the majority of the cattle stock. In a way, the presence of crossbreeds indicated the level of improvement currently in the herds in terms of capital stock. However, it was also clear that no planned breeding policy existed.

Labour was a major input in livestock production. The main activities in which labour was used in relation to livestock production were herding and crop residue (stover) collection and feeding. Livestock were used as inputs in production of livestock themselves (breeding) and crop production (draught power). Quantified information concerning herding, collection of stover and feeding activities could neither be obtained from the study area nor elsewhere. However, over 80 per cent households with animals interviewed stated that herding was done throughout the year. Crop stover was collected during or immediately after harvest in May and June, and fed to livestock during the dry season between August and September to supplement their feed.

The Cold Storage Board (CSB), local butchers and private buyers were named as the common buying agents in the area. The main customers were the local butchers (52 %) and CSB (28 %). The private buyers shared the remaining 20 per cent. It would seem the local butchers provided better prices to cattle owners in comparison to CSB and private buyers.

6.10 **Grazing land**.

None of the farmers interviewed in the sample survey could quantify the extent of grazing land under their respective enterprises. Neither could such information be obtained from other sources. However, information of total land area, land allowed for service centres (schools, hospitals and business enterprises), and the residential area in each village studied was obtained from the Provincial Planning Unit (PPU) and the District Council.

Grazing is carried out in communal areas and the herding of these animals is mainly done by young males. Grazing of range land was the main source of feed for about 8 months in a year. Arable lands were grazed by livestock for approximately 4 months of the year, during the dry season. However, grazing of fallow land or valleys within the arable land during the cropping season was not found to be a common practice in the area studied.

6.11 **Household energy, shelter and timber needs.**

6.11.1 **Energy.**

The main fuel types identified in the sample survey were firewood and charcoal. Eighty six per cent of the farm households across all farm system types used firewood as their main source of energy while 14 % apart from firewood, also used charcoal. Over 70 % of the households collected the fuels from the nearby forests with less than 30 % supplementing their fuel needs by purchases. Quantifiable information on the consumption pattern for fuels, stakes and timber could not be obtained from the survey area and neither could such information be obtained from other sources.

Most of the households (95 %) interviewed identified more than one main end-use for fuelwood and charcoal. The four most important uses of the fuels were cooking, heating, lighting and brewing beer. Few farmers (5 %) identified sales of fuels as the main objective.

6.11.2 **Shelter.**

Most households (98 %) across all farm system types collected shelter poles from the nearby forests. Households interviewed, identified more than one primary use for poles. The three most important uses for the poles were house building, fencing and construction of storage bins.

6.11.3 **Timber.**

Most households (69.8 %) interviewed across all farm system types revealed that they purchased timber from either the Pit Sawyers or the Forestry Department Depot. The main end use for timber purchased for most households (82 %) were for construction and maintenance of homes and construction of furniture.

6.12 **Tree planting and agroforestry.**

6.12.1 **Tree and tree products.**

A number of questions, aimed at establishing the availability and general knowledge associated with tree and tree products were asked during the survey across all farm types. First of all, farmers were asked to indicate how available were tree and tree products. Forty nine per cent stated that tree and tree products were scarce, 41 per cent indicated that there were sufficient, while 10 % indicated that they had plenty. Secondly, farmers were asked to state whether they knew about tree planting on farms for food, fodder, poles, fuelwood, soil fertility and prevention of soil erosion. About 60 per cent of the farmers showed no knowledge while 40 per cent revealed that they had an idea about the beneficial effects of tree planting. Thirdly, farmers were asked to indicate the main species of trees they liked most and provide reasons for their choice. Most households (70 %) identified more than one specie: the six most important were oranges, paw paws, mangoes, *Leuceana leucocephala, Cassia spectabilis, Glicidia sepium* and *Sesbania seban.* The main reasons behind these selected species were given as; food (55 %), fuelwood (20 %), poles (15 %) and soil fertility (10 %).

6.12.2 **Agroforestry systems.**

Questions asked in this section were aimed at establishing the main agroforestry systems preferred by the farmers and at the same time recorded the perceived problems associated with agroforestry as an alternative land-use system. Farmers were asked to indicate the most preferred agroforestry system being promoted by various extension services. About 40 per cent farmers identified more than one system among the agroforestry systems. The most important ones, in decreasing order were intercropping, alley cropping and boundary planting. The majority (65 %) of farmers gave having more food produced from one piece of land and the demarcation of land as the main reasons behind their preferred choice. The main problems associated with tree planting were given as; having no exclusive rights (38 %), high labour demands (25 %), high input costs (20 %), high land demand (15 %) and poor markets (2 %).

6.13 **Summary.**

The primary objective of this part of analysis was to provide quantitative information on the structure and socio-economic parameters within the farming systems and the household economy emphasising the relationships and the influence of components to each other. The data were presented by means of discrete groupings of the systems under review. This approach facilitated understanding the features of particular groups in relation to each other. In addition, the data analysis about the household economy and the farming systems enabled the researcher to identify farmers' priorities, production capabilities and potential.

In the next part of this research, these findings together with the secondary research data, scientific information and other sources of information form the basis for developing a logical mathematical framework for representative linear programming and multiple objective models at farm-level which are latter aggregated into a regional model. The development of a computer models backed by a series of spread sheets are aimed at analysing land/resource use options open to decision makers and at developing an understanding of the trade-offs that are available between land-users (farmers) and those concerned with regional development. In addition, the models attempt to explore an approach which takes preferences from the farm-level through to regional-level planning and decision-making.

Chapter 7.

7.0 **Development of a multilevel mathematical modelling framework.**

7.1 **Introduction.**

In this chapter, the four farm system types described and analysed in Chapter 6 are explored along with other options in the context of farm family resource structures (ARPT, 1987). The rationale for this approach is two fold: (a) information available for farm family models is usually based on surveys of randomly selected families in a village, a district or region. To measure the impact of future changes and comparisons, a more realistic and specific classification of farm families into relatively homogeneous[17] groups is needed (Marz, 1990); (b) households with different resource levels will have different priorities and production objectives; use their resource differently; be capable of producing more or less in terms of total output; and have different standards of management (see Low, 1986).

The section further describes an multilevel approach which includes aggregating individual farm-level decision models into a regional resource planning model. The models are used to investigate land/resource use options open to smallholder farmers in the Northern Region of Zambia. In addition, the models attempt to explore an approach which takes preferences from the farm-level through to regional-level planning and decision-making. The main attraction in the mathematical modelling approach according to Moxey *et al.,* (1995) is that production activities can be described using minimal data from a variety of sources, thereby allowing exploration beyond historically observed activities. Moreover, activities may be differentiated subtly by altering input-output coefficients to reflect for example, variation in management regimes or environmental conditions, allowing an exploration of a range of planning options available.

Additionally, the structure of the programming models allows the specification of a wide range of price and non-price decision criteria. Given that decision-making in agriculture is characterised by the need to resolve conflicts, multiple goals and objectives, this is a desirable trait. The structure of programming models also allows links between separate activities to be expressed explicitly. For example, the fact that individual arable crops are often grown in a rotation. This is potentially important if 'knock-on' effects in one land use on other land uses are to be identified.

[17] Refers to the physical characteristics of the farm and the socio-economic characteristics of the farm.

However, it remains an elusive goal to integrate economic and productive uses of land whilst avoiding biophysical and environmental risks as well as being sensitive to the wishes of immediate stakeholders and broader society (Nkowani *et al.*, 1995a). Nevertheless, the ability of models to provide insight and understanding of the interactions between competing planning objectives, particularly trading-off between economic, social and environmental imperatives (Cocklin *et al.*, 1988), make them appropriate tools to explore constrained resource use options.

7.2 The need for a multilevel systems approach to conflict resolution in resource management in the Northern Region of Zambia.

It might be assumed that the most appropriate approach to integrating objectives between the land-users (farmers) and those concerned with regional or national development is to create a unified programming model. Such a model is specified by McCarl (1992) to maximise the satisfaction of a regional developer but subject to a *notional* response of the farmer to regional policies. McCarl (1992) argues that such a model is an appropriate conceptualisation of the policy process but that it is difficult to solve due to the existence of many local optima. In addition, this author calls for care in the application of such a unified model approach because results can be misleading. Moxey *et al.*, (1995), in support of the approach, argued that although such an approach may overstate flexibility and co-ordination of agricultural production, it is a widely accepted means of modelling large areas, a statement which is also backed by Norton and Schiefer (1980).

The development of a region is, however, determined by decisions at micro (family), (village), and regional-levels (Werner, 1994). Decisions are made according to the needs and objectives of the decision makers, availability of resources, and constraints. Micro, and regional-levels should be integrated in a multisystems concept to understand and model decisions and linkages at and between levels. The unified (partial) approach can be corrected by using a multilevel model which separates the modelling applications between farmers and regional (national) planners as demonstrated in the work by Dent & McGregor (1993). The conceptual development of the multilevel approach is illustrated in Figure 7.1.

For ease of interpretation Figure 7.1 can be divided into three linked parts:

(a) Part A is a generalised goal format for a single farm. The model would run for each defined representative farm within the region (F_1 to F_n) with provision for the objectives, goals levels, priorities and weights to be included.

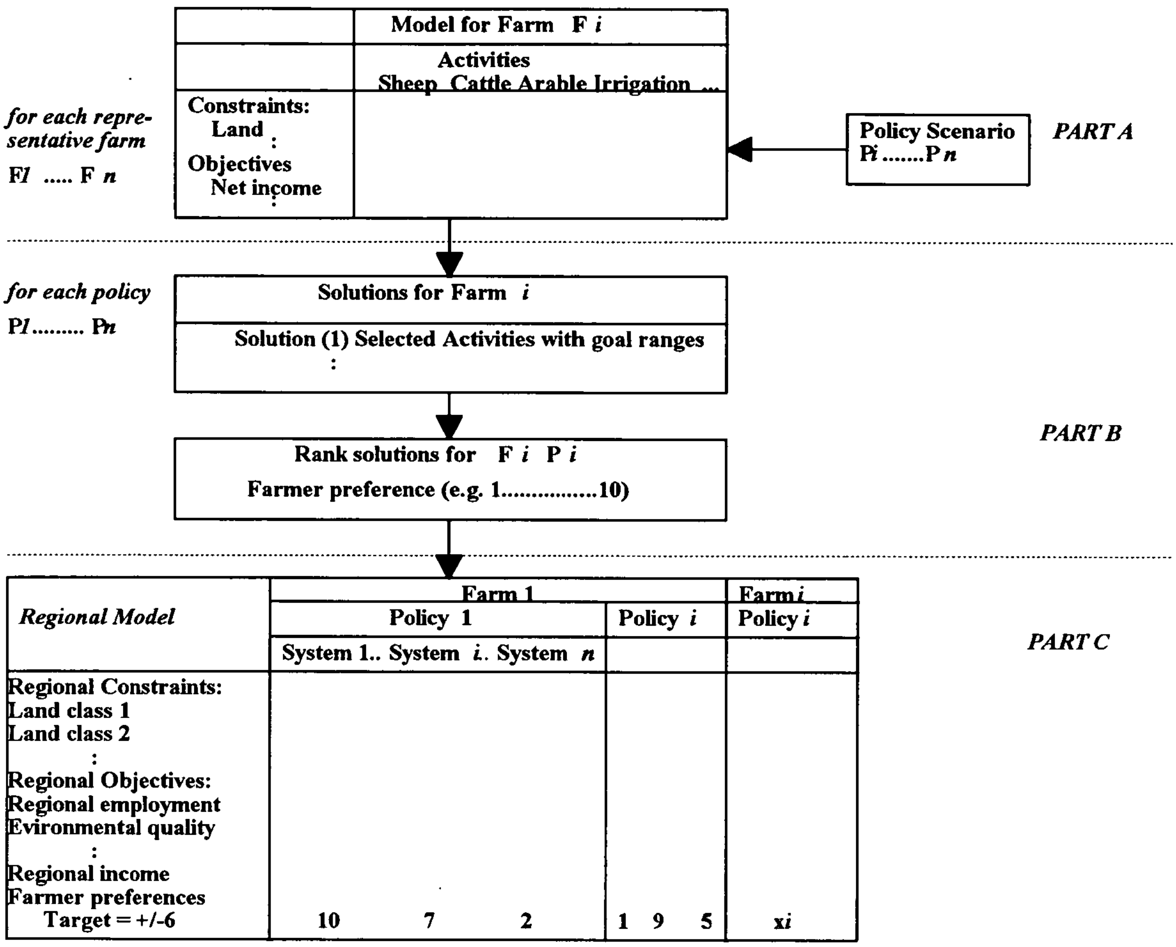

Figure 7.1: The Conceptual Development Framework of a Multilevel Model

(b) For each representative farm, the above procedure would be repeated for each potential regional policy (P_1 to P_n). Part B of Figure 7.1 first shows that a set of solutions for F_i and P_i will be generated.

The goal programming model solutions for F_i P_i will provide a set of solutions with different characteristics but all meet the goal ranges and are feasible within the constraints specified. These may be ranked by farmers to reflect their preferences using for instance a simple scale (say 1 to 10).

Solution sets for all (F_n) farm household types each operating under all potential (foreseeable) policies (P_n) may now be transferred to Part C of Figure 7.1 along with the relevant farmer preferences. Some culling of solutions may take place at this stage but it would be desirable to retain all options until it is obvious which solutions are dominated

Part C provides the format of the regional-level model. Constraints may refer, for example, to total regional area available of different land classes and development expenditure. The regional objectives may relate to overall or district employment levels, local or environment quality. The activities represent each of the solutions for F_i P_i (generated in Part B). Hence, for farm household type 1 and policy 1 there will be a range of possible systems (S_1 to S_n) as shown in Part C. This would be repeated for each policy over all farm household types. The Land Class 1 coefficient for activity S_i will be for the total area in the region required for this type of farm operated under Policy P_i.

An additional objective is defined in the example - farmer preferences. This will indicate the subjective level of preferences which farmers of this type have for this policy and system. The target level can be varied to reflect the speed of uptake or level of acceptance (high target values indicating greater and faster acceptance).

An important feature of the representation is that policy options must be made mutually exclusive but this constraint could be partially relaxed if it was appropriate for different spatial areas to have individual policy specifications.

The successful adoption of this approach, which is conceptually tidy and appealing, is dependent on elicitation of appropriate preference functions from farmers for each policy/system combination once the individual farm models have been developed and run.

7.3 **Model framework.**

The model framework used in this study and given in Figure 7.2 was formulated based on the conceptual framework developed by Dent and McGregor (1993) and shown in Figure 7.1. The following sub-sections provide a general discussion of work carried out under each stage of the modelling effort.

7.3.1 **Data.**

The models at both farm and regional-level were specified on the basis of primary and secondary data sources (Figure 7.2 Part A). Primary data were collected from 60 farm households in 1993/94 to establish the structure and the socio-economic conditions within the farming systems and the household economy (see Chapter 5 Section 5.2 for details). The farming systems studied in the region included chitemene, fundikila, ibala and agroforestry.

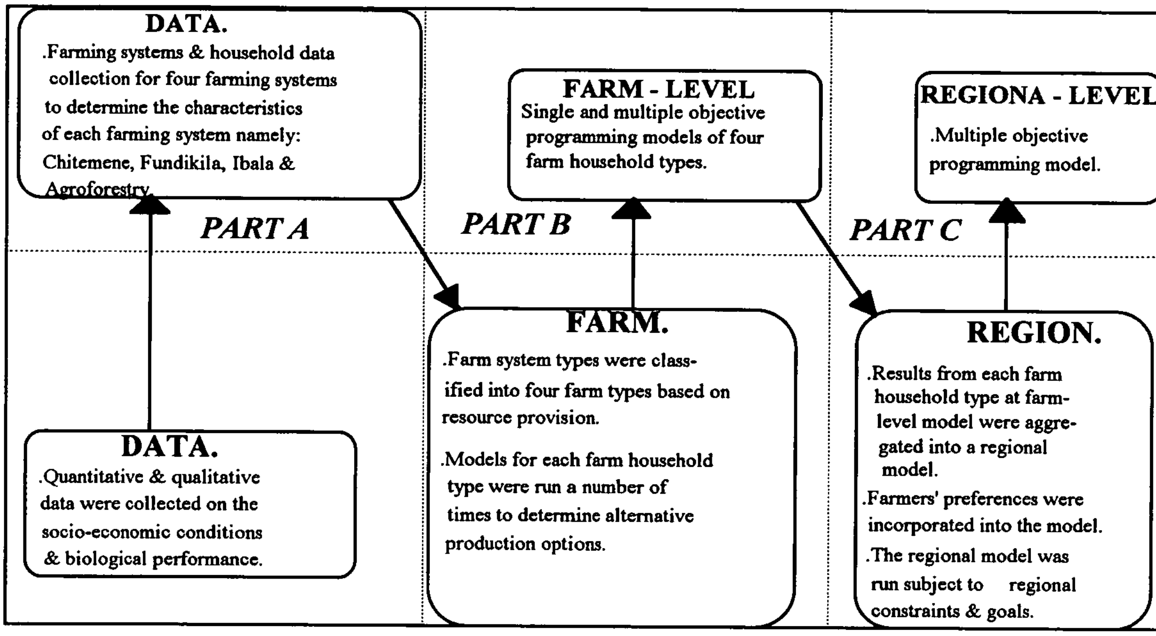

Figure 7.2. The Integration of Farm-level models into the Regional-level model.

The main variables were quantitative and qualitative in nature. Quantitative variables related to physical farm characteristics, farm resources (such as: capital; family labour; hired labour; off-farm income and credit); household numbers; literacy and education level; crop and livestock production systems and input levels; area of grazing land; cultivation methods; systems of crop rotation; fallow system; input constraints; tenural arrangements; grain storage and loss; consumption patterns; household energy requirements; shelter, and timber needs and expenses; and finally trading of crop products. Qualitative data related to smallholders' preferences and objectives on rural development policies and land-use options

Quantitative and qualitative sets of data provided information on the structure and socio-economic parameters within the farming systems and the household economy emphasising the relationships and the influence of components to each other. This information was then merged with existing secondary data. These sources provided a detailed picture of changes in land-use and socio-economic conditions in the Northern Region of Zambia from the 1930s to the early 1990s. The data were used for the classification of a logial framework for representative linear programming and multiple objective models at farm-level which were latter aggregated into a regional model. It was further used for input coefficients in the farm and regional models.

7.3.2 **Farm-level.**

At farm-level two sequential methodologies were used (see Figure 7.2 Part B). The data from the farm survey were classified into four farm household types (as distinct from farm system types) by use of a simple cluster analysis based on resource provisions according to the criteria and categories specified by ARPT (1987) (see Appendix 4.0).

The criteria used for classification of farm household types were based mainly on features identified in informal surveys and community studies conducted by ARPT. These included the number of resident family members, amount spent in purchased inputs, and crop income from the previous season. Details are given in Appendix 5.0. This approach according to ARPT (1987) was used because of the need for a classification which would permit a more sensitive analysis and comparison of smallholder farmers. The four indentified by the cluster analysis are:

Farm household type 1: *Labour poor/cash poor.*
Households in this farm type are comprised of a small number of family members available to work on farm activities. They receive low income in cash (≤ Zk 352,000) or kind both from farm and off-farm sources, and have poor access to extra-household labour and inputs. This category includes families which are early or late in the life cycle, many female-headed households, and older wives of polygamous marriages.

Farm household type 2: *Labour poor/cash rich.*
Households in this farm type comprised of a small number of family members available to work on farm activities. They receive higher income (≤ Zk 1,080,000) from sales of cash crops permitting greater access to extra-household labour and inputs for crop production. This category also included the following; (1) small families with the husband having good income-earning prospects off-farm, leaving the wife to maintain production at least at subsistence level often using purchased inputs, (2) returned migrants workers with small families who have brought savings for investment in agriculture, (3) wealthier female headed households.

Farm household type 3: *Labour rich/cash poor.*

Households in this category have a large number of resident family members able to work on farm activities: they therefore have the potential to cultivate larger areas. They receive low income (≤ Zk 80,000) from on-farm and off-farm activities and have poor access to purchased inputs. This category of household includes many mature households who have low prospects for off-farm income-earning possibilities.

Farm household type 4: *Labour rich/ cash rich.*

Households in this category have a large number of resident family available for work on-farm activities and thus have a potential to cultivate large areas which provide surplus food production for sale. They receive higher income (≤ Zk 1,080,000) from sales of cash crops and off-farm income permitting greater access to extra-household labour at times of high labour demand, and purchase of inputs for crop production. This category of household includes mature households with an established farm income (i.e. emergent) and good off-farm income earning possibilities.

A summary of farm household type categories based on household resource levels is presented in Table 7.1. The four farm household type categories formed the basis for the development of representative single and multiple objective farm-level models. LINDO Software[18] was used to run the models. The single objective function for the LP at farm-level related to maximisation of profit with no cognisance of the other non-profit related goals of the decision maker. While that of multiple objective programming models at farm-level related to be the achievement of food production needs, net income and limiting the cost of production.

Table 7.1: **Summary of the characteristics of the four farm household type categories.**

Farm Household Type Categories	Labour poor & cash poor	Labour poor & cash rich	Labour rich & cash poor	Labour rich & cash rich
Management regimes:	(11)*	(22)	(9)	(18)
Local seed and no fertiliser	√		√	
Local seed and fertiliser	√			
Hybrid and no fertiliser	√			
Hybrid/local and no fertiliser	√			
Hybrid and fertiliser		√		√
Hybrid/local and fertiliser		√		√
Hybrid/local, fertiliser and lime		√		√

* numerals in parentheses refer to number of households falling under prescribed categories.

[18] LINDO (Linear, Interactive, and Discrete Optimizer) was developed by Linus Schrage in 1986. It is a user-friendly computer package that can be used to solve linear, integer, quadratic and goal programming problems (Winston, 1995).

Representative single and multiple objective farm-level models were used to investigate land/resource use options open to smallholder households in each class. The modelled farm-level output: land and other resource use and patterns of crop output of crop produce which define the results of the decisions taken by the farmers in their daily lives provided a major source of data for the regional-level model.

The farm household level models incorporated production possibilities in the form of a wide range of activities and in terms of input-output relationships subject to constraints imposed by resource availability (see Table 7.2). The activities were related to typical farm family unit, production, supply of seed, fertiliser and lime, storage and loss, consumption, trading, quality substitution of labour, exchange labour, and hired labour, capital transfer and credit. The cropping activities were regulated by a set of constraints to simulate typical cropping systems, crop rotation and agroforestry systems, observed in the region.

7.3.3 **Regional-level.**

A Multiple Objective Programming Model was developed to represent opportunities for change at the regional-level. The model developed at regional-level, was used to analyse a range of solution sets for all (F_n) farm household types each operating under all potential (foreseeable) policies (P_n) along with relevant farmer preferences with the aim to selecting management options which satisfy the set of regional objectives (see Figure 7.2 Part C). The adoption of these management strategies would lead to an improvement in the utilisation of land and associated resources resulting in an enhancement in the welfare and improved lifestyle of the people within the region.

The multiple objectives here included an increase in the amount of food surplus coming forward for sale to non-rural areas, increased regional income, incorporation of farmer preferences into regional planning, reduced cost of production, limiting the use of hired labour in crop production and input purchases. The activities included comprised of household production, supply of seed, fertiliser and lime, storage, consumption, trading, total hired labour, total capital transfer and credit. The regional cropping activities were regulated by a set of constraints which included; land area, family and hired labour on a monthly basis, quarterly crop production and energy requirements, seed, fertiliser, lime demands, and quarterly capital and credit requirements.

At regional-level farmer preferences were subjectively built into the model based on information obtained from research and technical reports, discussions with scientists and farm advisors, and considerable personal experience with farmers. These set of preferences ranked from 1 to 9 defined the level of preference for each management plan selected by the LP and pre-emptive goal programming models.

The development of computer models was aimed at analysing land/resource use options open to decision makers and at developing an understanding of the trade-offs that were available between land-users (farmers) and those concerned with regional development. In addition, the model attempts to explore an approach which takes preferences from the farm-level through to regional-level planning and decision-making.

7.4 Description of farm-level models.

Four individual farm household type models were developed to represent the range of resource endowments outlined in Section 7.3.2. The models include a wide range of farm activities which represent the major management options for northern Zambia. In total the farm household type LP level models includes 770 activities and 106 constraints. While the multiple objective farm household type level models includes 770 activities, 106 constraints and 3 categories of goals. The time step used in the model is quarterly within a single year, rather than a multiyear model. The seasonal or climatic assumptions are those for an average year. Sensitivity analysis was carried out to explain the impacts of 'low' and 'high' developed scenarios[19] on prices of crop products.

Table 7.2 and 7.5 show simplified representations of a single and multiple objective model structures at farm-level. Each row or column represents a number (indicated in brackets) of activities or constraints included in the matrix. The tables provide an overview of the model structures and the relationships between their various components. Greater detail is given in the following sections[20].

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[19] In the high price scenario, it was anticipated that output prices would be a 20 per cent increase over the mean. In the low price scenario, a decrease of 20 per cent from the mean was assumed. These scenarios were judged appropriate based on documented Bank of Zambia (BoZ) Quarterly Financial and Statistical Reviews on the Zambian Economy.

[20] The reader will be referred back to Tables 7.2 and 7.5 to maintain a perspective on the models.

7.4.1 **Goal(s) and Objective function(s).**

An objective represents directions of improvement of one or more of the attributes[21] (Rehman & Romero, 1993). When the direction of improvement implies that 'more is better' then an objective is being maximised; on other hand if the implication is that 'less is better' minimisation is being pursued. Goals differ from objectives in that they state a specific attribute level, or target, to be achieved (Rae, 1994).

Single vs Multiple objectives.

Single objective (LP) programming is recognised as a powerful and versatile computer-based aid to decision-making at farm planning because it can provide valuable insights into the nature of resource allocation decisions (Dent *et al.*, 1986; Piech & Rehman, 1993). Major limitations of this modelling technique are the restriction to solving a single objective function (such as maximisation of profit or minimisation of cost) which has limited application to multilevel or integrated land use planning. Other problems include the assumption that all the underlying relationships are linear, and parameters have single value expectations (Romero & Rehman, 1984). The mathematical basis of a single objective decision-making problem is as follows:

$$Max\ Z= \sum_{j=1}^{n} c_j x_j \qquad (1)$$

$$\text{subject to: } \sum_{j=1}^{n} a_{ij} x_j \le bi \qquad \text{all } i = 1 \text{ to } m \qquad (2)$$

$$\text{and } x_j \ge 0 \qquad \text{all } j = 1 \text{ to } n \qquad (3)$$

where x_j is the level of the *jth* activity, and *n* denotes the number of activities; c_j is the forcasted net revenue of a unit of the *jth* activity; *aij* is the quantity of the resource required and *m* denotes the number of resources; b_i is the amount of the *ith* resource available; (3) is the set of non negativity conditions.

In Chapter 4 Section 4.1 it was argued that decision makers are not interested in ordering the feasible activity set according to just a single criterion but strive to find an ideal compromise amongst several objectives, or seek to achieve 'satisficing' levels of

[21] Attribute can be defined as the a decision maker's values related to an objective reality (e.g. gross margin, seasonal cash exposure, indebtedness, etc) (Romero & Rehman, 1989).

their goals. Bearing this point in mind, the LP's solution would not satisfy all objectives without the imposition of numerous simplifying and questionable assumptions (Cohon, 1978).

Several approaches have been developed in systems analysis or management science to deal with multiple objectives decision-making problems (Romero & Rehman, 1989). The mathematical basis of the general multiple objective (vector optimisation) decision-making problem is as follows:

$$\text{Max } Z(x) = \left[z_1(x), z_2(x), \ldots\ldots, z_k(x)\right] \tag{1}$$

$$\text{subject to:} \quad f_i(x) \leq 0 \tag{2}$$

$$\text{and} \quad x_j \geq 0 \tag{3}$$

where $z(x)$ is the k-dimensional objective function: i.e., there are k objectives; x is an n-dimensional vector of decision variables; the $fi(x)$ represent the constraints associated with the problem; and (3) is the set of non-negativity conditions. The region defined by the constraint set (2) and (3) in n-dimensional Euclidean vector space:

$$\mathbf{X} = \begin{Bmatrix} x \setminus f_i(x) \leq 0, \forall_i \\ x_j \geq 0, \forall_j \end{Bmatrix} \tag{4}$$

X is referred to here as the feasible region in decision space. Each feasible solution to the problem (1), i.e., all $x \; \varepsilon \; \mathbf{x}$, implies a value for each objective [z_i (x), i = 1,2, ...,k]. The k-dimensional objective function maps the feasible region in decision space **x** into the feasible region in objective space z(**x**), which is defined in the k-dimensional Euclidean vector space.

The term 'vector optimisation' is a contradition in terms, since one cannot in general optimise a vector (Mendoza *et al.*, 1986; Manning, 1994). In the absence of information about preferences which provide some rule for combining and ordering the objectives of the decision maker(s), a satisficing solution to problem (1) - (3) cannot be found, since all feasible solutions are not comparable. A complete ordering which is characteristic of scalar (single objective) optimisation problems, can be obtained for a vector optimisation only by introducing value judgements, i.e. preference information, into the model. Pre-emptive Goal Programming, an advanced extension of an LP designed to handle several incompatible and incommensurable objectives, linear and non-linear objectives and/or constraints and large land-use problems has proven to be a useful tool to aid decision-making at both farm and regional-level (Winston, 1995). The achievement function replaces the objective function in the conventional LP model. The mathematical representation of PGP as shown in Chapter 4 is as follows:

$$\text{Minimise } a = \left[h_1(n,p), h_2(n,p), \ldots h_k(n,p)\right] \quad (1)$$

$$\text{Subject to: } f_i(X) + n_i - p_i = b_i \qquad (i = 1,2,\ldots,k) \quad (2)$$

$$X \in F \quad (3)$$

Where Min. a is a lexicographic optimisation process; h_k is *k-th* priority involving a given combination of elements for the n and p vectors; n_i is a negative deviational variable attached to the *i-th* attribute; p_i is a positive deviational variable attached to the *i-th* attribute; f_i (**x**) is an objective function - mathematical expression for the *i-th* attribute; b_i is target set/goal attainment desired for *i-th* attribute; **x** is the vector of decision variables; and F is the feasible set or region satisfying the rigid restraints.

Farm-level single objective LP.

The single objective models developed at farm household level recognised the basic needs of stakeholders as they themselves perceived them, based on their observed behaviour in relation to their allocation of scarce resources to meet their needs. But the aim of the study was to develop operational models capable of providing insights into certain aspects of household behaviour and their production systems, and the consequences this behaviour may have for the use of land and associated resources in a sustainable development perspective. The objective function, therefore, was set deliberately at maximising cash income with no cognisance of the other non-profit goals of the decision maker. Sensitivity analysis was carried out to explain the impacts of 'low' and 'high scenarios' on price.

Table 7.2: **Simplified single objective model structure for farm-level.**

		Grow crop (552)*	Farm household equivalent (3)	Seed supply (2)	Fertiliser supply (1)	Lime supply (1)	Storage & losses (20)	Consum-ption (family) (20)	Sell (20)	Purc-hases (20)	Quality substitution of labour (48)	Exchan-ge labour (36)	Hired labour (36)	Capital transfer (4)	Credit (6)	Final balance (1)	Limit
Objective:																	
Net income (max)		S					S		D	S				D	S	D	
Total area	(1)	D															≤ A
Labour requirement	(36)	D	S								D/S	S	S				≤ 0
Hired labour rec	(12)												D				≤ A
Production rec	(20)	S					D/S	D	D	S							≤ 0
Energy output rec	(4)		D					S									≤ 0
Protein rec	(4)		D					S									≤ 0
Seed rec	(2)	D		S													≤ 0
Fertiliser rec	(1)	D			S												≤ 0
Lime rec	(1)	D				S											≤ 0
Household size rec	(3)		D														≤ A
Exchange labour rec	(1)		S									D					≤ 0
Crop rotation	(10)	S/D															≤ 0
Capital rec	(4)	D							S	D					D/S	S/D	≤ 0
Credit rec	(6)															D	≤ A
Final balance	(1)													S	D	D	≤ 0

D = an activity demanding for resources having a positive coefficient.
S = an activity supplying resources having a negative coefficient.
D/S = an activity having both positive and negative coefficients.
A = target limit.
* = numerals in parentheses refer to numbers of columns (activities) and rows (constraints) in the matrix.
Rec = reconciliation.

Farm-level multiple objective programming.

The initial steps at farm household level were to identify the competing objectives which would allow an objective function to be specified. The purpose of the pre-emptive goal programming is to minimise the deviations of the multiple objectives from the desired goal levels (shown in Table 7.3). The solution generated is not the optimum but that which satisfies the stated policy levels for goal attainment.

Pre-emptive goal programming algorithm requires that goal priority levels (shown in Table 7.4) be assigned to goals. The approach according to Winston (1995) assumes that the weight for goal 1 is much larger than the weight for goal 2 up to the least important goal n:

$$P1 >>> P2 >>> P3 >>> ..... >>> Pn$$

Thus, the algorithm satisfies the highest priority goals first then considers lower priority goals subsequently. Mathematically, to go from step $i + 1$, the analyst simply had to modify the objective function to minimise the deviation from the $i + 1$ highest-priority goal and add a constraint that ensures that the deviation from the *i th* highest-priority goal remains at its current level (shown in Appendix 6.0).

Table 7.3: **Summary of goals and goal attributes at farm -level.**

Goal description	Minimise	Deviation variable	Target level farm household type 1	Target level farm household type 2	Target level farm household type 3	Target level farm household type 4
Food output (Kcal)	Over	*p (+ve)*	5.79×10^6	5.79×10^6	5.79×10^6	5.79×10^6
Net income (Zk)	Over	*p (+ve)*	3000000	10000000	3000000	10000000
Total budget (Zk)	Under & Over	*n (-ve) & p (+ve)*	800000	3000000	800000	3000000

The goals g_i (i = 1, ..., 3) were incorporated within a pe-emptive goal programming model in the form of equalities. In pre-emptive goal programming, if the goal is of the type $f_i(x) \le g_i$, the positive deviation variable (g_i) which minimises over-achievement of the target is minimised. If the goal is of the type $fi(x) \ge g_i$, the negative deviation variable (n_i) which minimises under-achievement of the target level is minimised. If the target is to be exactly achieved, $f_i(x) = g_i$, then $n_i + p_i$ are minimised (*minisum*) (Ignizio, 1985; Romero, 1991). For that purpose the right-hand sides of the goals are the targets aspired by the decision maker. The difficulty of choosing targets as being representative of the true aspirations of the decision maker for each farm type were overcome by setting slightly higher target levels as suggested by Romero (1991), Piech and Rehman (1993) and McGregor and Dent (1993).

The setting of goal levels at artificially high levels shown in Table 7.3 were necessary to maximise food output and net income levels, and the minimisation of over-achievement allows for lesser values to be accepted. This would also allow trade-offs to occur with the total budget objetive. In order to reflect the objective of minimum total budget for maximum food output and net income the goal level for the budget was given a low target level, and both under and over-achievement of the goal was minimised.

Table 7.4: **Goal priority levels used in the farm household model runs.**

Goal description	Goal priority levels for run			
	A	*B*	*C*	*D*
Food output	1	3	1	2
Net income	2	1	3	1
Total budget	3	2	2	3

A number of solutions were generated for each farm household type by reordering (sensitivity analysis) the priorities assigned to the goals which provides the decision-maker(s) with a range of solutions from which to choose from depending on their priorities and needs (shown in Table 7.4).

7.4.2 **Specification of activities.**

Grow crop.

The crop growing activities are 'intermediate activities'. They supply resources to three alternative activities; storage, consumption and selling of crop produce. This group of activities are constrained by their demand for land, labour, capital, seed, fertiliser, lime and crop rotation. In turn they supply produce for a range of crop options (such as maize, millet, cassava, ground nuts and beans) under various management regimes observed in the region.

Table 7.5: **Simplified multiple objective model structure for farm-level.**

		Grow crop (552)*	Household equivalent (3)	Seed supply (2)	Fertiliser supply (1)	Lime supply (1)	Storage & losses (20)	Househ-old consu-mption (20)	Sell (20)	Purcha-ses (20)	Quality substitution of labour (48)	Exchange labour (36)	Hired labour (36)	Capital transfer (4)	Credit (6)	Final balance (1)	d_i^- (3)	d_i^+ (3)	Limit
Objective: minimise																	d_i^-	d_i^+	
Total area	(1)	D																	≤ A
Labour requirement	(36)	D	S								D/S	S	S						≤ 0
Hired labour rec	(12)												D						≤ A
Production rec	(20)	S					D/S	D	D	S									≤ 0
Energy output rec	(4)		D					S											≤ 0
Protein rec	(4)		D					S											≤ 0
Seed rec	(2)	D		S															≤ 0
Fertiliser rec	(1)	D			S														≤ 0
Lime rec	(1)	D				S													≤ 0
Household size rec	(3)		D																≤ A
Exchange labour rec	(1)		S									D							≤ 0
Crop rotation	(10)	S/D																	≤ 0
Capital rec	(4)	D							S	D					D/S	S/D			≤ 0
Credit rec	(6)															D			≤ A
Final balance	(1)													S	D	D			≤ 0
Farm level goals:																			
Net income (max)	(1)	D					D		S	D				S	D	D	D	S	≤ A
Food energy (max)	(1)		D					S						S	D	D	D	S	≤ A
Costs (min)	(1)	D					D			D				S	D	D	D	S	= A

D = an activity demanding for resources having a positive coefficient.

S = an activity supplying resources having a negative coefficient.

D/S = an activity having both positive and negative coefficients.

A = target limit.

* = numerals in parentheses refer to numbers of columns (activities) and rows (constraints) in the matrix.

Rec = reconciliation.

Production agriculture.

In total 552 crop growing activities were included in the farm household level models. These comprised two broad categories of land use - agriculture through sole cropping and agroforestry including hedgerows, intercropping and boundary planting.

The assumption incorporated in the models is that farm households have the opportunity to use both local and hybrid varieties depending on their preferences and the availability of capital.

Traditional crops are grown from home-saved stock: cassava from cuttings, and millet, maize, groundnuts and beans from saved seed. Groundnuts and beans can also be purchased on the local market. Hybrid seed of maize, groundnuts, millet, and beans can be purchased or obtained on credit from financial institutions such as the Northern Co-operative Union (NPU), Lima Bank, Zambia Co-operative Federation (ZCF) and Credit Union and Savings Association (CUSA). Fertiliser prices were obtained from the financial institutions in the region. Flexibility in the use of fertiliser was incorporated in the models so that farm households would 'Grow crops' with or without fertiliser depending on resource endowments and prospective yields. The input prices assumed for crop growing activities are shown in Appendix 5.0.

The annual rainfall in this part of the country (Natural Region III) is fairly stable (1000-1600 mm year^{-1}. It was therefore, anticipated that crop yields would not vary significantly from one year to another since the climate is reliable. It was therefore, assumed that the average crop yields as documented by previously conducted surveys (see Bolt & Silavwe, 1988; Holden, 1993, Reid, 1994; SPRP (1987-94) represent adequately the actual situation. The analysis does, however, take into consideration the effects of crop management, crop rotation and price fluctuations (uncertainty).

The range of crops grown under sole cropping systems (refer Table 7.2) included; maize, millet, cassava, groundnuts and beans. The management regimes under which these crops could be grown included the following:

(1) local seed and no fertiliser;
(2) local seed and fertiliser;
(3) hybrid seed and no fertiliser;
(4) hybrid/local seed and no fertiliser;
(5) hybrid seed and fertiliser; and
(6) hybrid/local seed and fertiliser

Agroforestry.

Technologies which have some degree of proven success under Northern Zambian conditions are incorporated into the models. In some cases prototype technologies were specified on the basis of the present limited experience. This experience was, however, based upon on-station and on-farm research. Some relatively short-term benefits in the form of food and/or cash, and fuelwood were assumed since farmers are unwilling to invest in something which would benefit only the next generation. The models also incorporated the application of local/hybrid seed, use of fertiliser and lime as a necessity for the establishment of agroforestry tree species on the acid soils (majority soils) in the region. The agroforestry technologies considered were as follows:

(1) Hedgerow crop, legume crop and agriculture crop.
(2) Hedgerow crop and agriculture crop.
(3) Legume crop and agriculture crop.
(4) Boundary crop, legume crop and agriculture crop.
(5) Boundary crop and agriculture crop.

It should be stressed that the prototype technologies specified here have in most cases not yet been tested under realistic on-farm conditions. However, it was possible to generate coefficients on the basis of several years of research and interaction with farmers in the area using a *Farming Systems* and *User Perspective Approach*. The specification may appear strict in relation to the complexity and flexibility that exists in the formulation of agroforestry technologies but it leaves some possibilities for flexibility in tree species choice and spatial arrangements between the agriculture and tree crop.

The technology specified assumes proper management by the farmer in terms of the timing and execution of operations such as establishment, protection and pruning of the tree hedgerows and the use of biomass as green manure. This requires additional skills and perhaps tools. The full potential of the established technology is analysed, assuming that the technology is renewed by establishing an area with new agroforestry options every year. Long-term benefits emanating from the tree crops were not considered in the models because as stated earlier on, farmers are unwilling to invest in ventures which could only benefit the next generation. It was also argued by Nkowani *et al.*, (1995b) that since farmers have no secure and enforceable property rights over land in the region, conditions for a farmer to take a long-term view and invest in good husbandry were therefore constrained.

Crop storage.

This group of activities is included in the model to allow crop outputs to be stored prior to use or sale. Crop storage implies losses and the magnitude of grain losses from one quarter to another during the year has been incorporated in the model on the basis of 5 per cent per quarter (as shown in Table 7.8).

Human consumption.

This group of twenty activities specifies quarterly household energy (Kcal) and protein (gm) requirements. The household consumption of crop production is examined only in terms of fulfilment of annual household calorific and protein requirements. The annual Kcal and protein requirements in the Northern Region of Zambia are set on F.A.O. figures (F.A.O., 1989) (as shown in Table 7.6). While the edible calorific and protein values of crops are specified in Table 7.7 and the general food links within the matrix are shown in Table 7.8.

Table 7.6: **Annual Kcal and protein needs of a typical farm household in Northern Region of Zambia.**

	Kcal	Protein (gm)
Men	1095000	20075
Women	912500	18250
Children	620500	13870

Source: F.A.O. (1989)

Households have a choice between producing food or purchasing it from the market. The choice depends on the relative scarcity of cash and labour within the household, the yields of crops grown, and the cost of obtaining the food from the market.

Table 7.7: **Crop nutritional value.**

	Calorific value (Kcal/kg)	Protein (gm/kg)
Maize	3600	90
Millet	3500	90
Cassava (fresh)	1090	25
Ground nuts	5460	240
Beans	4000	240

Source: F.A.O. (1989).

Table 7.8: **Food links represented within a period.**

		Household calorific equivalent			Crop storage				Human consumption				Sell				Purchases				
		Female (1)	Male (1)	Child (1)	Maize1 (1)	Maize2 (1)	Maize3 (1)	Maize4 (1)	Maize1 (1)	Maize2 (1)	Maize3 (1)	Maize4 (1)	Maize1 (1)	Maize2 (1)	Maize3 (1)	Maize4 (1)	Maize1 (1)	Maize2 (1)	Maize3 (1)	Maize4 (1)	Limit
Production rec																					
Maize 1	(1)				1				1				1				-1				≤0
Maize 2	(1)				-0.95	1				1				1				-1			≤0
Maize 3	(1)					-0.95	1				1				1				-1		≤0
Maize 4	(1)						-0.95	1				1				1				-1	≤0
Energy output																					
Maize 1	(1)	xkcal	ykcal	zkcal					-kcal												≤0
Maize 2	(1)	xkcal	ykcal	zkcal						-kcal											≤0
Maize 3	(1)	xkcal	ykcal	zkcal							-kcal										≤0
Maize 4	(1)	xkcal	ykcal	zkcal								-kcal									≤0

* = numerals in parentheses refer to numbers of columns (activities) and rows (constraints) in the matrix dealing with one crop.

Rec = reconciliation

Ist quarter = January-March; 2nd quarter = April-June; 3rd quarter = July-September; 4th quarter = October-December.

The fat, vitamin and mineral components of the diet are not examined, neither is crop quality due to lack of documented information. It is possible that because of the exclusion of these aspects, there could be under provision of food provided for farm households. But it is anticipated that the non inclusion of the above would not have any significant impacts on the choice of land-use options open to them because production decisions at the traditional sector have been observed to be dominated by social and cultural norms (Barnett *et al.*, 1982; Holden, 1993). In addition, it has been argued elsewhere (for instance; Henson, 1991) that results produced from models with detailed nutrition information have no practical application without the inclusion of palatability details of the diets consumed.

Sources of food outside domestic consumption crop production e.g. hunting, fishing, gathering and gifts are not considered too in the models because of absence of data. The effects of food preparation methods on nutritional quality and palatability are also excluded, for example the brewing of beer from millet (unfiltered) represents added value (Kcal) but only for certain household members who consume the beer.

Sell crop.

The average quarterly sale prices per kg for each crop during the year are shown in Table 7.9. The returns from sales of crop products (in Zk) supply the cash required for the purchase of inputs and other necessities for the household. The farm-level models assumed the price relationships in place for 1993/94 although later sensitivity analyses explained the impacts of 'low' and 'high scenarios' on price.

Table 7.9: **Average quarterly sale prices per kg of crop produce during the 1993/94 period.**

	Maize Zk/kg	Millet Zk/kg	Cassava Zk/kg	Ground nuts Zk/kg	Beans Zk/kg
1st Quarter	120	275	85	460	360
2nd Quarter	116	275	72	460	350
3rd Quarter	116	266	72	444	350
4th Quarter	120	266	85	444	360

Ist quarter = January-March; 2nd quarter = April-June; 3rd quarter = July-September; 4th quarter = October-December

Source: The Post (Various Issues).

Purchase crop.

The twenty activities in this group provide a potential for the purchase of crop produce for the household during the time of need. The average purchase prices per kg for each crop during the year were much higher (by 10%) compared to the sales price per kg during the same period (seen in Table 7.10). This is due to sellers margins (mark-ups) and transport costs.

Table 7.10: **Average quarterly purchase prices per kg of crop produce during the 1993/94 period.**

	Maize Zk/kg	Millet Zk/kg	Cassava Zk/kg	Ground nuts Zk/kg	Beans Zk/kg
1st Quarter	130	300	90	480	370
2nd Quarter	125	290	85	480	365
3rd Quarter	125	290	85	470	365
4th Quarter	130	300	90	470	360

Ist quarter = January-March; 2nd quarter = April-June; 3rd quarter = July-September; 4th quarter = October-December

Labour.

Data on family labour were collected using the questionnaire shown in Appendix 3.0 which included information about number of family members, age, sex, type of employment they were engaged in, the usual hours available for farm work and the hours actually worked each day. However, gender specific activities within the farm household were not fully examined due to absence of data.

Family labour is provided by all members of the household but labour provided by a child or an adult male is not equivalent to a mature female in the amount of work that may be achieved because of the differences in labour efficiency observed in time inputs (Pottier, 1988). To account for this, the time requirements for various activities are specified in female labour hours on a monthly basis (see Table 7.11). A female is assumed to be equivalent to 1.0 physical unit of labour; a male is equivalent to 0.75 female labour, and a child is equivalent to 0.40 female labour. The assumption is that, labour can be substituted from a female to a male, a female to a child and a male to a female. However, child labour can not be substituted to either a male or a female. In the absence of child labour, work has to be done by either a male or female. The woman equivalent-days of the family labour available per month is obtained by the following formula;

$$WD = \sum_{i=1}^{n} WE_i \cdot D_i$$

Where:

WD is woman equivalent-days of family labour per month.

WE is the woman equivalent factor.

D is the net work days available per month, and *n* is number of persons per household.

The net number of days on which farm work takes place (net days) per month are computed from the total number of days in a calendar month less adjustments for rainy days (historical average), Sundays and time spent on house work. Public holidays are disregarded because this has limited effect on farmers who live in rural areas.

In addition to family labour, the models also incorporated other assumptions which included the following:

Exchange labour.

This activity was formulated to take into account community-based or mutual support mechanisms, often practised by smallholders in the region for activities such as land preparation and harvesting where exchange of labour among farm households plays a very important role in the crop production (see Table 7.11).

Hired labour.

Labour hiring activities were formulated on a monthly basis and are expressed in woman-equivalent hours (see Table 7.11). The average cost of hiring farm labour is Zk 1500 woman equivalent day^{-1}. Farmers indicated that the use of hired labour is constrained by the inability to pay rather than availability.

Table 7.11: **Labour interactions represented within a period.**

		Production	**Household equivalent (People)**			**Quality substitution of labour**				**Exchange labour (Hours)**			**Hired labour (Hours)**			
		Grow crop	Female	Male	Child	Female to Male	Female to child	Male to female	Male to child	Female	Male	Child	Female	Male	Child	Limit
		(552)*	(1)	(1)	(1)	(12)	(12)	(12)	(12)	(12)	(12)	(12)	(12)	(12)	(12)	
labour:																
Female	(12)	x	-x			1	1	-0.75		-1			-1			≤ 0
Male	(12)	y		-y		-1.25[1]		1	1		-1			-1		≤ 0
Child	(12)	z			-z		-2.5		-0.53			-1			-1	≤ 0
Hired labour rec	(12)												1	1	1	≤ A
House hold size:																
Female	(1)		x													= A
Male	(1)			y												= A
Child	(1)				z											= A
Exchange labour rec	(1)									1	1	1				≤ 0

* = Numerals in parentheses refer to numbers of columns (activities) and rows (constraints) in the matrix.

A = Target limit.

[1] = Adjusted for labour efficiency.

Cash transfer.

Four cash transfer activities which permit the transfer of cash from one quarter to another in the models are included in the models (see Table 7.12). A market rate of 40 per cent per prescribed period is assumed for all borrowings and 26 per cent (quarterly 6.5 %) for savings. At the end of the year cash is transferred into the final balance activity.

The transfer activities are necessary because cash is required for farm operations and food purchase in each of the periods in the production year and is also generated through the sale of crops and the credit support system. However, in this study it was assumed that farm households operate on a subsistence basis and as such they do not have significant cash surpluses at the end of the year (see Table 7.12). In more capital intensive cases, surpluses can be used to pay for investment.

Credit.

Cash borrowing is permitted in each quarter as shown in Table 7.12. Credit is divided into formal and informal credit. Interest is not paid on informal credit due to the personalised way in which it is obtained (Nkowani *et al.,* 1995b). However, Pottier (1993) revealed that this is not the case with some smallholder farmers in developing countries. Private traders make cash advances which allow the farmers to buy tools, seeds and other inputs, and to maintain their families. However, they tie farmers to particular traders and offer prices which are set low, thereby transferring all risk to the borrower while at the same time price fluctuations operate to the advantage of the lender.

This means securities such as standing crops are grossly undervalued in relation to what the lender expects to be their market value. This undervaluation results from the monopoly power of the lender. Forty percent interest rate per prescribed period is used on formal credit in the models. It is required in the models that formal credit must be paid back with interest. Formal credit can only be drawn in the first quarter that is at the beginning of the growing period and repaid after harvest of the crop which is in the third quarter of the year. After repayment of the credit at this stage the farmer qualifies to secure another credit which would be paid back at the beginning of another season (see Table 7.12).

Table 7.12: **Seasonal cash transfer activities**

											Credit						
						Cash transfer			**Formal**			**Informal**					
		Grow crop (552)*	Sales (20)	Purchases (20)	Cash 1-2 (1)	Cash 2-3 (1)	Cash 3-4 (1)	Cash 4-f (1)	Cref1 (1)	Cref3 (1)	Crei1 (1)	Crei2 (1)	Crei3 (1)	Crei4 (1)	Final balance (1)	Limit
Working capital rec																
1st quarter	(1)	x(zk/ha)	-y(zk/kg)	z(zk/kg)	1				-1		-1					≤ 0
2nd quarter	(1)				-1.065	1					1	-1				≤ 0
3rd quarter	(1)					-1.065	1		1.40	-1		1	-1			≤ 0
4th quarter	(1)						-1.065	1					1	-1		≤ 0
Credit rec																
Formal limits																
1st quarter	(1)								1							≤ A
3rd quarter	(1)									1						≤ A
Informal limits																
1st quarter	(1)										1					≤ A
2nd quarter	(1)											1				≤ A
3rd quarter	(1)												1			≤ A
4th quarter	(1)													1		≤ A
Final balance	(1)							-1.065		1.40				1	1	= 0

A = Target limits.

* = Numerals in parentheses refer to numbers of columns (activities) and rows (constraints) in the matrix.

Rec = Reconciliation.

Cref = Formal credit.

Crei = Informal credit.

Ist quarter = January-March; 2nd quarter = April-June; 3rd quarter = July-September; 4th quarter = October-December.

7.4.3 **Specification of constraints.**

Constraints on resource availability are fundamental in every decision-making situation and this also applies in this study. The assumptions used in specifying the constraints on resources in the study are examined in this sub-section.

Land.

Land was considered to be on average equally distributed between households within the region. Land type was assumed to be uniform in the study area on the basis of homogeneity of soils, the majority of which are acidic. Total land used in the production process must be less than or equal to the total land available to the farm in the same period.

Labour.

Labour is a limiting factor especially during land preparation, weeding and harvesting periods. However, the models have been formulated in such a way (see Table 7.11) that alternative labour sources can be explored during the time of labour short fall. The total labour required for production activities is less than or equal to the sum of family, exchange and hired labour minus any excess for the same period.

Production.

Crop outputs are average yields as given in published figures for the district from trials and surveys. The effects of planting dates on yield are not well documented and neither is the performance of alternative varieties (SPRP, 1993). These effects are therefore not included in the models but these factors could be easily incorporated in the model at a later date.

Family food output.

This constraint is concerned with quarterly household food consumption demands. The household, as stated earlier, has a choice between producing food itself or purchasing it from the market depending on the relative scarcity of cash and labour within the household, the productivity of self production and the cost of obtaining the food from the market.

Household size.

The household size incorporated in the models varied with each farm household type. The main basic concerns of a rural household, based on survey information, related to improving food security, minimisation of total labour use, cost, and credit input, involvement in community, fulfilling cultural obligations and concerns about income. It was assumed that inter-household relationships serve as an assurance against crop failure and that households do not undertake additional measures to reduce risk.

Rotation.

The rotation that a farmer adopts has important implications on the farming objectives and to the soil types and conditions found on the farm (Dent *et al.,* 1986). Suitable rotations are the basis of a suitable farming system. In order to assess the implications of alternative crop rotations, it is necessary to have an understanding of the sequence that crops are planted in the field. Dent *et al.*, (1986) demonstrated an efficient method to constrain rotations under short-term and long-term plans; a difficulty with Dent's approach, however, is that while details are supplied about the proportion of the farm planted to different crops, this information is not sufficient to uniquely identify (except in very restricted cases), the actual sequence that crops are planted in the ground, and hence the influence that a crop exerts on subsequent crops in the rotation (Finlayson & McGregor, 1994).

In this study, a tightly prescribed rotational sequence which overcomes the shortcomings of the previous approach is used based on the approach adopted by Finlayson and McGregor (1994) (see Table 7.13). The method is suitable for constraining crops such as groundnuts and beans which are widely grown and economically important crops, which for nutrient enrichment reasons, had to follow maize, millet or cassava. Similar but separate rotational sequences were constructed for each representative farm household type model which considered extended fallows (eg. chitemene), short rotations (eg. fundikila), continuous cropping (eg. ibala and agroforestry).

Essentially, activities (nodes) were defined to represent linkages between crops planted in subsequent years, so that the rotational activities contained a pair of unitary coefficients, which specified the crops that preceded and followed the current crop(s) (see Table 7.13).

When the model was solved, the nodes chained together to form rotations, that could be of any length, giving an optimum solution. The rotational nodes were defined in terms of the following:

(1) The crop that was to be planted after fallow.
(2) The number of years since a crop.

Table 7.13: **Interactions represented in rotation activities.**

Crop		Fallow	Maize	Millet	Cassava	Beans	Cassava	Groundnuts	Maize	Millet	Groundnuts	Cassava	Beans	
Sequence (Year)		B	1	2	2	3	3	3	3	4	4	4	4	Limit
		(46)*	(46)	(46)	(46)	(46)	(46)	(46)	(46)	(46)	(46)	(46)	(46)	
Land	(1)	1	1	1	1	1	1	1	1	1	1	1	1	≤ A
Maize after fallow	(1)	-1	1											≤ 0
Millet and cassava following maize	(1)		-1	1	1									≤ 0
Beans, cassava, groundnuts, maize following millet and cassava	(1)			-1	-1	1	1	1	1					≤ 0
Cassava and maize following millet	(1)			-1			1		1					≤ 0
Beans and groundnuts following cassava	(1)				-1	1		1						≤ 0
Millet, groundnuts, cassava, beans following beans, cassava groundnuts and maize	(1)					-1	-1	-1	-1	1	1	1	1	≤ 0
Millet following beans, cassava and groundnuts	(1)					-1	-1	-1		1				≤ 0
Groundnuts following beans cassava and maize	(1)					-1	-1		-1		1			≤ 0
Cassava following beans, cassava and maize	(1)					-1		-1	-1			1		≤ 0
Beans following cassava, groundnuts and maize	(1)						-1	-1	-1				1	≤ 0

A= Target limit.

B = Number of years.

* = Numerals in parentheses refer to numbers of columns (activities) and rows (constraints) in the matrix.

(3) The preceding crop(s) if a crop planted more that a year previously has implications for the current crop(s).
(4) The number of fallow years.

Nodes were only included for acceptable sequences of crops, so that if a crop was not able to enter a rotation after a particular crop, then the node was not defined for the combination.

In Table 7.13, five possible crops; maize, millet, cassava, ground nuts and beans, were constrained by a requirement for land. Maize was grown after fallow in the first year.

In the second year of the rotation, either millet or cassava could be grown. In the third year, if millet was grown, then , cassava or maize would be grown. But, if cassava was grown, then beans or ground nuts could be grown. In the fourth year of the rotation, a combination of beans, cassava, and ground nuts give permission for millet to grow in the next year. Beans, cassava and maize give permission for ground nuts to grow, where as beans, groundnuts and maize give permission for cassava to grow. Finally, cassava, ground nuts and maize give permission for beans to grow.

This approach is very flexible and capable of addressing smallholders problems at reasonable costs in terms of the number of activities that are required to represent problems in matrix form. In this study, 12 activities were necessary to specify all possible rotations for any length of time horizon. In relation to Dent *et al.'s* (1986) method, maize could be constrained to be planted on less than a third of the total land, but there is no facility to constrain the sequence of crop planting, so that the requirement that maize is not planted any more than once in two years to the same ground, can not be enforced.

Working capital.

Working capital is sub-divided into four quarterly periods (see Table 7.12). The division is based on the reasoning that working capital is invested at different periods in the production year. In a similar fashion, crops mature at different times and are sold. Part of the revenue is used to finance further production and repayment of credit accrued in the same year. The maximum cash required at the beginning of the production year by each farm type is obtained by determining the households expenditure on farm inputs. Cash used must be less than or equal to the sum of cash borrowed and cash from sales of crops.

Credit.

Credit is considered on a quarterly basis in a similar way to working capital. Cash recovery on credit secured is treated as a constraint. This constraint ensures that cash borrowed for production of crops must be paid at the prevailing interest rate during the year, and a balance not less than own cash recovered as a source of own cash for the next production year (see Table 7.12).

7.5 Description of the regional-level model.

This section describes a multiple objective programming model using the pre-emptive goal programming approach adopted by Winston (1995). The regional-level model includes 182 activities, 90 constraints and 8 categories of goals. Table 7.14 shows a generalised view of the model structure, the relationships between its various components corresponds to Section C of Figure 7.1.

Each row or column represents a number (indicated in brackets) of activities or constraints included in the matrix. The model is used to analyse a range of alternative land-use management scenarios and selects management options which best satisfy multiple objectives. The enhanced sustainability of the land resource through improved rotations and the incorporation of farmer preferences would lead to enhanced welfare and improved lifestyle of people within the region. The following discussion summarises the main features of the model.

7.5.1 Goal(s) and Objective(s)

Given the conflicts over objectives between land users (farmers) and those concerned with regional development (policy makers), a trade-off process through which the use of land and other resources could be judged was needed. The initial steps in the regional model development were to identify the competing objectives which would allow an objective function to be specified. The objective function in the regional model was to minimise the deviations between the achievement of the goals and their aspiration levels (shown in Table 7.15). The goals were included in the model through the addition of positive (p_i) and negative (n_i) deviations which symbolize over-achievement and under-achievement of each goal, respectively. The right-hand side values of these equations - which are called target or aspiration levels - were desirable values to which the decision maker aspired: they may or may not be satisfied. Obviously, there were difficulties of choosing target levels as being representative of the true aspirations of the decision maker. To overcome this difficulty, targets were set

Table 7.14: **Overview of the multiple objective model at regional-level.**

		Grow crop $F_1 0_1$ - $F_4 0_n$	Household equivalent	Seed supply	Fertiliser supply	Lime supply	Total storage	Total consum-ption	Total sales	Total purch-ases	Total hired labour	Total capital transfer	Total credit	d_i^-	d_i^+	Limit
		(33)*	(3)	(2)	(1)	(1)	(20)	(20)	(20)	(20)	(36)	(4)	(6)	(8)	(8)	
Objective: Minimise														d_i^-	d_i^+	
Regional constraints:																
Total land area	(4)	D														≤ A
Labour requirement	(36)	D	S								S					≤ 0
Hired labour rec	(12)										D					≤ A
Production rec	(20)	S					D	D	D	S						≤ 0
Energy output rec	(4)		D					S								≤ 0
Seed rec	(2)	D		S												≤ 0
Fertiliser rec	(1)	D			S											≤ 0
Lime rec	(1)	D				S										≤ 0
Capital rec	(4)	D							S	D		D	S			≤ 0
Credit rec	(6)												D			≤ A
Regional goals:																
Net income	(1)	D					D		S	D				D	S	≤ A
Energy output	(1)		D					S						D	S	≤ A
Total costs	(1)	D					D			D				D	S	= A
Farmer preferences	(1)	D												D	S	≤ A
Total credit	(1)												D	D	S	= A
Total sales	(1)								S					D	S	≤ A
Total purchases	(1)									D				D	S	= A
Total hired labour	(1)										S			D	S	= A

D = an activity demanding resources having a positive coefficient.

S = an activity supplying resources having a negative coefficient.

A = target limit.

* = numerals in parentheses refer to numbers of columns (activities) and rows (constraints) in the matrix.

Rec = reconciliation.

slightly higher.

The solutions generated were those which best satisfied the stated policy levels set for goal attainment. The pre-emptive goal programming used in this study required that goal priority levels (shown in Table 7.16) be assigned to the goals. The algorithm satisfies the highest priority goals first then considers the lower priority goals subsequently.

The goals and goal attributes used in the regional model are shown in Table 7.15. Maximisation of food output goal is achieved by setting the goal levels at artificially high levels (5.79 x 10^6 Kcal) so that over-achievement of their target levels was minimised. In other words, allowing for under-achievement of the goal. The initial high priority level given to food output goal attainment according to Winston (1995) assumes that the weight for goal 1 is much larger than the weight for goal 2 up to the least important goal *n*. The positive deviation variable minimised over-achievement of the target level to allow a lesser value to be accepted and also to allow trade-offs to occur with other objectives.

Table 7.15: **Summary of goals and goal attributes at regional-level.**

Goal description	Minimise	Deviation variable	Target level
Food output	Over	*p (+ve)*	5.79x10^6 Kcal
Net income	Over	*p (+ve)*	Zk 10000000
Total budget	Under & Over	*n (-ve) & p (+ve)*	Zk 6000000
Farmer preferences	Over	*p (+ve)*	9
Total credit	Under & Over	*n (-ve) & p (+ve)*	Zk 8000000
Sales	Over	*p (+ve)*	Zk 12000000
Purchases	Under & Over	*n (-ve) & p (+ve)*	Zk 1000000
Hired labour	Under &Over	*n (-ve) & p (+ve)*	1955 Hours

Other goals which had positive deviation variables included net income, farmer preferences and sales of crop products. In order to reflect the objectives of minimum total budget, credit, food purchases and use of hired labour for maximum food output, net income, farmer preferences and sales of crop products, the goal levels were given low target levels, and both under and over-achievemnet of the goals were minimised.

A number of solutions were generated by reordering (sensitivity analysis) the priorities assigned to the goals which provides the decision-maker(s) with a range of solutions from which to choose from depending on their priorities and needs (shown in Table 7.16).

Table 7.16: **Goal priority levels used in the region model runs.**

Goal description	Goal priority levels for run					
	A	*B*	*C*	*D*	*E*	*F*
Food output	1	3	1	1	2	3
Net income	2	1	2	3	3	2
Total budget	3	4	4	8	4	4
Farmer preferences	4	2	3	2	1	1
Total credit	5	5	8	4	7	5
Sales	6	6	5	5	5	6
Purchases	7	8	6	6	6	8
Hired labour	8	7	7	7	8	7

7.5.2 **Decision variables.**

The model includes 33 crop production activities, 3 household equivalent activities, a total of 4 input supply actvities, 20 storage activities, 20 sales activities, 20 purchase activities, 36 hired labour activities, 4 capital activities, 4 credit activities, and 8 negative and 8 positive deviation activities (shown in Table 7.14). To reflect variation in management, activities are distinguished not only by farm type or product, but also production intensity. These decision variables were derived from the LP and multiple objective farm-level models (shown in Table 7.2 and 7.5) and provided the major source of data for the regional-level model. Additional land uses may be envisaged and incorporated into the range of available activities with relative ease. This is important since users of the model may wish to explore land use scenarios involving activities not anticipated by the modeller.

7.5.3 **Constraints.**

The regional-level model is subject to constraints on land, labour, household food consumption requirements, seed, fertiliser, lime, capital and credit needs (shown in Table 7.14). There is land constraint for each farm type ($F_1 0_1$-$F_4 0_n$). The number of hectares of crops cultivated at the end of the growing season may not exceed the available land area for each farm type in the region.

There is one labour constraint for an adult female, adult male and a child for each month of the year. These constraints restrict the amount of labour by the alternative farm types in the basis. The amount of labour required to cultivate 1 ha of crop i is represented by labour coefficients derived from the farm-level models. This gives a measure of total labour used in crop production and its distribution among the household members.

The human food needs constraint places a higher bound on the amount of food output that must be produced for home consumption (shown in Table 7.15). This allows for a lesser value to be accepted.

Capital and credit constraints relate to the farmers initial capital and credit required for crop production within a given period.

Eight goal categories (g_i *to* g_8) are specified in the goal summary of Table 7.15.

7.6 **Summary**.

A multilevel methodology in this research where individual farm-level models are aggregated into the regional model is described and the resulting model structure presented. The models are used to investigate land/resource-use options open to smallholder farmers in the Northern Region of Zambia. In addition, the models attempt to explore an approach which takes preferences from the farm-level through to regional-level planning and decision-making.

The steps taken in specifying activities and constraints for LP and the pre-emptive goal programming models at farm and regional-level are also outlined. The single and multiple objectives at both farm and regional-level are considered. While priorities, target levels and the goals and objective function(s) of the pre-emptive goal programming are ascribed too. The methodology used in running the pre-emptive goal programming is illustrated.

The modelling results are presented in Chapter 8. The results show an assessment of the applicability of linear programming and multiple objective models in the allocation of finite resources among competiting stakeholders at both farm and regional planning level. Perhaps, the greatest value of the planning framework used is that the application highlights the key relationships that exist between technologies, productive activities, constraints and smallholder farmer's preferences in meeting specified goals and in determining the conflicts and trade-offs that would occur if certain decisions were made.

Chapter 8.

8.0 Results and Discussion of Single (LP) and Multiple Objective (PGP) Models.
8.1 Introduction.
8.2 Assumptions of the planning framework.
8.3 Validation
8.4 The LP models at farm-level.
8.4.1 Results and discussion of the LP models.
8.4.2 Sensitivity analysis of the LP results
8.4.3 Implications of the farm-level LP model results.
8.5 Results and discussion of the Pre-emptive Goal Programming models at farm-level.
8.5.1 Implications of the farm-level multiple objective model results.
8.6 Results and discussion of the Pre-emptive Goal Programming model at regional-level.
8.6.1 Implications of the regional-level multiple objective model results.
8.7 Strengths and weaknesses of the model results.
8.8. Summary.

8.0 **Results and discussion of Single and Multiple Objective models.**

8.1 **Introduction.**

In this chapter the assumptions used in the multilevel systems planning framework are re-emphasised and the limits on its performance identified. The results of the LP and pre-emptive goal programming models both at farm and regional-level are presented and discussed. The results of the LP farm models are examined in Section 8.4. While in Section 8.5 results of the pre-emptive goal programming models at farm-level are discussed. Section 8.6 examines results of the pre-emptive programming model at regional-level. The strengths and weaknesses of the modelling effort are briefly analysed in Section 8.7. The summary of the chapter is, essentially, a brief assessment of the applicability of the models in the allocation of finite resources among competing stakeholders at both farm and regional planning, is given in Section 8.8.

8.2 **The assumptions of the planning framework.**

The planning framework used in this study was designed in such a way to accommodate agro-ecological and socio-economic realms, encompassing two levels of integration: farm and regional-level as illustrated in Figure 7.1 of Chapter 7. The behaviour of the actors at each level of modelling was of interest, especially to decision-making which has an impact on the stock and potential use of the available resource in the Northern Region of Zambia.

The farmers' land-use decision-making process were assumed to be more specific and were driven by a number of objectives which include improving food security, concerns about income and cost of production, minimising risk, involvement in community and fulfilling cultural obligations. Decision-making by farm households is complex. However, this complexity was represented in model formats by specifying a wide range of possible production activities into the socio-economic framework established at farm-level which set out the farm family resource structures and constraints under which smallholder farmers operate. Representative single and multiple objective farm-level models were used to investigate land/resource-use options open to smallholder farmers. The aim, therefore, was to design operational models capable of providing insight into certain aspects of household behaviour, and the consequences this behaviour may have for land/resource-use options in a sustainable development perspective. In addition, the models attempted to explore an approach which takes preferences from the farm-level through to the regional-level planning and decision-making. The modelled farm-level outputs which define the results of decisions taken by farmers provided the major source of data for the regional-level model.

At regional-level, planners or decision-makers were assumed to have wider aims which include having food surpluses, concerns about income, expenditure, credit, labour and employment and the environment. Policy is therefore directed at influencing the allocation decisions of individuals to improve the degree of attainment of goals and aspirations of society as a whole. Therefore, at both farm and regional-level, competition for scarce resources was assumed to be a major consideration and often the root-cause of conflict. Perhaps, the greatest value of the planning framework used is that the application highlights the key relationships that exist between technologies, productive activities, constraints and smallholder farmers' preferences in meeting specified goals and in determining the conflicts and trade-offs that would occur if certain decisions were made.

8.3 **Validation.**

If the study is to provide support to potential users, the models that underlie it must be demonstrably reliable. This means that the land/resource-use planning models have to be validated and limits on performance identified. Unfortunately, rigorous validation is hindered by a lack of suitable benchmark data. In particular, data on past land-use is incomplete: agricultural census data on land quality and management is not well documented.

Nevertheless, some validation was possible, (see below) albeit not as comprehensive as might be hoped (see McCarl, 1984; Hazell & Norton, 1986; Jakeman *et al.*, 1995). In this study some individual elements of the models developed both at farm and regional-level were therefore examined.

Data reconciliation.

The development of representative models, each characterised by a range of production activities, and links between activities for the various constrained resources plus the need to tie activities from one quarter in the year to activities in another quarter within the planning period, required a matrix of coefficients for each model exceeding 12,000 elements. In principle, each of these elements should be validated individually. In practice, this was found impossible to achieve since the number of coefficients was simply too large and, perhaps more importantly, there were few 'hard' data against which to compare them. Information related to working capital requirement, labour use, nutrition and average crop yields were carefully reconciled with available secondary information following the work of Hazel and Norton (1986). However, this was not true for coefficients related to land-use and input/ output prices which were obtained from research reports, past surveys, recent field surveys and literature held by government and private institutions.

In the absence of any obvious logical inconsistencies or gross inaccuracies of the production relationships embedded within the single and multiple objective planning frameworks, the models were then debugged for clerical or coding errors. Then, the real test of the model that remained was whether all of the individual elements combined to give acceptable predictions of land and resource-use options open to smallholder farmers in the Northern Region of Zambia.

Model validation.

Detailed data relating to current land-use were surprisingly scarce. Land management agricultural census data such as data on aspects of management (seed, fertiliser and lime usage) by smallholder farmers in the region had to be inferred from other technical and research reports (often incomplete sources). But as Dent (1995) confessed, "models are definable systems developed from understanding basic processes and operationalised by coupling with a limited amount of information". Accordingly, Dent (1991) argues that the development of models that mimic the decision-making processes of the farm-level decision-making unit can help planning for change at regional-level in two ways. The first is that such models provide useful mechanisms to pre-screen the ways in which farm households would react to new circumstances (such as a new policy instrument) or would permit a comparison of a possible policy scenario with another in terms of its economic and social benefits and costs. Second, these models are also useful for pre-screening potential land-use options prior to expensive research, development and extension programmes being committed. This gives an opportunity to decision makers to judge the relative merits of one research development and extension programme against another (Edwards-Jones & McGregor, 1994).

Some validation as pointed out in Section 8.3 was possible, albeit not as satisfactorily as might be hoped (McCarl, 1984; Hazel & Norton, 1986; Jakeman *et al.*, 1995). The output from single and multiple objective models in this study were intuitively judged against presently observed farm production systems in the region. The LP and PGP models are in broad terms mathematically similar in structure (see Tables 7.2, 7.5 and

7.15 in Chapter 7.0), although they are driven by different criteria. The solutions from LP models, although risky and unlikely, are technically feasible and potentially would be workable. They offer stable solutions since they do not vary significantly under sensitivity analysis. When considering the multiple objective models the model results signified a change in crop activity mix. The answers, although perhaps risky too, show a closer representation of actual decision-making at farm and at regional-level in northern Zambia.

The farmers in the region are not entrepreneurial above everything else. Results should be seen within the realms and limits of knowledge and data collection efforts. Perhaps, the greatest value to this type of research is that the modelling effort highlights the potential use of explorative land/resource-use studies to make consequences of and trade-offs between different aims and perceptions explicit.

8.4 **The LP models at farm-level.**

The results of the LP models are presented under each farm type whose model framework and variants were described in Chapter 7. These LP models maximise profit subject to the production constraints with no cognisance of the other non-profit goals of the decision maker(s). The levels of the real activities that came into plan were read off and the amounts of resources fully used and their marginal value product were identified. The total net income for the optimal plan was noted. The LP models also provided information concerning the stability of the optimal plan in relation to data input assumptions and how it would vary in response to a change in the resource base.

8.4.1 **Results and discussion of the LP models.**

The optimum solutions for the LP Models are presented in Table 8.1. For each farm household type the optimum rotation is a sequence of 4 crops. For farm household types 1 and 3 where land is a seriously limiting constraint, the rotation involves millet followed by cassava, followed by ground nuts and finally a further cassava crop. In farm household type 1 all crop activities included in the basis belonged to the Chitemene farming system which used 46 kg of local seed and 400 kg of fertiliser/ha/year. In farm household type 3, the crop activities were also of the Chitemene farming system but here no fertiliser was applied and only 36 kg of local seed was used per hectare/year. All the year crops produced were in fact similar and maize was purchased as required throughout the year to provide for the dietary requirements of the families.

Table 8.1: **Optimum solutions for LP models.**

Farm household type 1		**Farm household type 2**		**Farm household type 3**		**Farm household type 4**	
Activity	Quantity	Activity	Quantity	Activity	Quantity	Activity	Quantity
Crop	2.0 ha	Crop	4.5 ha	Crop	1.8 ha	Crop	4.5 ha
rotation:		rotation:		rotation:		rotation:	
millet	0.5	maize	1.125	millet	0.45	maize	1.125
cassava	0.5	cassava	1.125	cassava	0.45	cassava	1.125
groundnuts	0.5	groundnuts	1.125	groundnuts	0.45	groundnuts	1.125
cassava	0.5	cassava	1.125	cassava	0.45	cassava	1.125
Consume		consume		Consume		Consume	
(periods):	(kgs)	(periods):	(kgs)	(periods):	(kgs)	(periods):	(kgs)
maize1	498	maize1	498	maize1	540	maize1	540
maize2	498	maize2	498	maize2	540	maize2	540
maize3	498	maize3	498	maize3	540	maize3	540
maize4	498	maize4	498	maize4	540	maize4	540
Sale		Sales		Sales		Sales	
(periods):	(kgs)	periods):	(kgs)	(periods):	(kgs)	(periods)	(kgs)
millet1	450	maize1	2990	millet1	315	maize1	2947
cassava1	6200	cassava1	10463	cassava1	4725	cassava1	10462
groundnuts1	475	groundnuts	1068	groundnuts1	360	groundnuts1	1068
Purchase		Purchase		Purchase		Purchases	
(periods):	(kgs)	(periods):	(kgs)	(periods):	(kgs)	(periods):	(kgs)
maize1	498	maize1	0	maize1	540	maize1	0
maize2	498	maize2	498	maize2	540	maize2	540
maize3	498	maize3	498	maize3	540	maize3	540
maize4	498	maize4	498	maize4	540	maize4	540
Working		Working		Working		Working	
capital used:	(zk)	capital used	(zk)	capital used:	(zk)	capital used	(zk)
capital		capital		capital		capital	
period 1	30856	period 1	86008	period 1	27366	period 1	84489
capital		capital		capital		capital	
period 2	16905	period 2	30202	period 2	31673	period 2	24558
capital		capital		capital		capital	
period 3	18005	period 3	32165	period 3	33731	period 3	26154
capital		capital		capital		capital	
period 4	21662	period 4	31768	period 4	38623	period 4	25154
Credit:	(zk)	Credit:		Credit:	(zk)	Credit:	(zk)
informal1	10750	informal1	12500	informal1	1700	informal1	12500
informal2	10750	informal2	12500	informal2	1700	informal2	12500
informal3	10750	informal3	12500	informal3	1700	informal3	12500
informal4	10750	informal4	12500	informal4	1700	informal4	12500
Household		Household		Household		House	
size:	(number)	size:	(number)	size:	(number)	size:	(number)
female	3	female	3	female	3	female	3
male	3	male	3	male	3	male	3
child	2	child	2	child	3	child	3
Worked days		Worked days		Worked		Worked	
female equi-		female		days female		days female	
valent:	170	equivalent:	239	equivalent:	194	equivalent:	248
Seed &		Seed &		Seed &		Seed &	
fertiliser:	(kgs)	fertiliser:	(kgs)	fertiliser:	(kgs)	fertiliser	(kgs)
local seed	46	hybrid seed	90	local seed	36	hybrid seed	90
fertiliser	400	fertiliser	900	fertiliser	0	fertiliser	900

This crop activity mix is technically functional but a somewhat unlikely strategy. A smallholder farmer would almost certainly grow some maize in his/her rotation and would not necessarily sell all the millet, cassava and ground nuts that has been produced. However, the solutions illustrated in Table 8.1 are similar to those derived by Bakker (1994) in their work in Mali. The solution in these cases is driven by the single criterion for the linear programme of maximising net income: in this light it is a reasonable answer. However, as farm family preferences beyond a maximisation of net income are expressed, in the multiple objective level at regional level, the solutions will be seen to change to become more in line with the observed range of land-use strategies in the region.

The total labour used and expressed in female equivalent-days of the family labour available in a year bear no significant differences between farm household type 1 and 3. This as would be expected in a rural household is attributed to the fact that labour interactions represented within the planning period (as shown in Table 7.11 Chapter 7) balance out.

The marginal value product (MVP) of land is respectively Zk 1340877 for farm household type 1 and Zk 1230072 for farm household type 3. These indicate similar levels of productivity of the scarce resource land, but the slightly lower value for farm household type 3 reflects the lower level of informal credit provided into the system. The marginal value product for informal credit for both farm household types is somewhat similar and is in the range of 13-16% per quarter for each farm household type. The working capital requirement for farm household type 1 optimal solution is somewhat higher than for farm household type 3, as would be expected, reflecting the higher levels of input provided.

The optimal solutions for farm household type 2 and 4 also reflect a four course rotation and in both household types exactly the same amount of land is available. Land is still however clearly a constraint on the farm system type with high marginal value products though the values, as would be expected, are somewhat lower than in solutions for farm household type 1 and 3. For both farm household types 2 and 4, the crop activities shown in the optimum plan belong to the Ibala farm system type and on both farm household types 90 kg of hybrid seed were used per hectare and 900 kg of fertiliser. The quantities of grain consumed on the farm by the farm household for farm household type 2 was just less than 500 kg during each quarter of the year while for farm household type 4 was just over 500 kg. Unlike farm household type 1 and farm household type 3, however, maize is grown in the rotation and purchases were therefore restricted to the 2nd, 3rd and 4th periods of the year.

The solutions for these farm household types are similar and technically feasible. They are, however, rather risky strategies since a smallholder farmer is likely to sell maize only after satisfying basic consumption needs at the household for the year. It is also very unlikely that the farmer would sell all the cassava and the ground nuts harvested. In these cases the linear programming objective is again to maximise the net cash income in each quarter of the planning period without cognisance of the other goals and aspirations of the individual farmers. Informal credit is used to the maximum available and has a high marginal value product of between 13-16 per cent per quarter for each farm household type. This high value of extra credit at the margin reflects the severe constraint for provision of informal credit. Formal credit is not used in either optimal solution because of the high cost - 40 per cent per half year.

The total labour used in farm household types 2 and 4 are similar but much higher than for farm household types 1 and 3, indicating the slightly higher levels of input into the production systems.

For both farm household types all the land available is completely used and the marginal value products are similar but slightly lower than for farm household types 1 and 3, reflecting the somewhat larger areas of land available to these farmers.

8.4.2 **Sensitivity analysis of the LP models at farm-level.**

Further analysis was carried out to examine the sensitivity of solutions presented in Section 8.4.1 to price variability of commodities. This analysis is important since it allows some measure of the stability of solutions to feasible price ranges (Rae, 1994). The prices were altered from the mean to represent both high and low scenarios. In the high price scenario, it was anticipated that output prices would be a 20 per cent increase over the mean. In the low price scenario, a decrease of 20 per cent from the mean was assumed.

The variants to these scenarios was that the price for instance of maize would increase/decrease by 20 per cent while cassava by 5 per cent or vice-versa. This analysis was used on all crops specified in the models. All the scenarios developed were subjectively judged to be appropriate (see Chapter 7, Section 7.4). In all other respects the matrix were assumed to retain the same coefficients.

The analysis showed the solutions presented in Section 8.4.1 were stable to feasible price ranges. Meanwhile, in the work of de Janvry *et al.* (1991) on peasants household behaviour with missing markets, it had been shown that the elasticity of peasant household response to price incentives is an important condition for the successful economic development of agrarian societies. In support of de Janvry's work, the economic theory suggests that as relative prices of product change, then too would the profit maximising activity combination. This also applies to linear programming models (Rae, 1994). However, a range of relative prices will exist between which the optimum solution is invariable. Further, in this study, it was assumed that markets did exist.

It should also be borne in mind that the northern region does not operate in isolation of the other regions in the country. Despite the fact that this region itself has a very stable climate from year to year, the risk component originating from the stochastic nature of rainfall in other regions of Zambia could lead to price variability. The sensitivity analysis, which was undertaken to test the validity of the results of the LP models should be seen in this vein, that is, it is region specific.

8.4.3 **Implications of the farm-level LP model results.**

Choices for farmers depend on a number of factors which include household priorities and production objectives, the level of crop production, labour and land availability and cash resources. The LP results have provided an insight into certain aspects of household behaviour and their production systems, and the consequences which this behaviour may have for the use of land and other associated resources when maximising of net cash income is the main household objective function.

The model solution results in Section 8.4.1 indicate allocation of land to crops which guarantee household cash income subject to resource constraints. Under the existing cropping pattern, household food security is ensured by the production of millet, cassava, and beans. While household income is ensured by producing maize, millet, beans and groundnuts. Cash income in the models is guaranteed by the production of millet, cassava and groundnuts. While food security is ensured by the production of maize for sale. But smallholders simultaneously take into account consumption and production (Kruseman *et al.*, 1995). The human basic nutritional requirement which forms the main strategy of the smallholder farmers may be in conflict with the wish to maximise net cash flow in each quarter of the planning period. This conflict of interest has been shown in optimum solutions obtained in Section 8.4.1 which have been found technically feasible but risky and unlikely strategies. This could have been attributed partly to the restrictions of the modelling framework adopted, but it is also the case that LP modelling format has deficiencies in these circumstances because it assumes farm families have simple objective functions. Therefore, the farm family behavioural pattern cannot be adequately captured in the LP formulated models since profit maximisation ignores the non-profit goals in decision-making.

In all solutions obtained at farm-level, labour used was examined in female equivalents on a monthly basis and presented in the optimum solutions on an annual basis. Future research should attempt to examine labour in more detail; for example, using simulation models on biweekly intervals to see if there are points in time when labour is scarce and which could then render the labour balance over the three-month planning periods in a year irrelevant. Another option would be to define the periods of the year which will be considered in the models, according to the peaks and troughs of the actual availability of labour, and not according to fixed intervals.

Five types of agroforestry technologies specified in Section 7.4.2 did not come into the LP solutions in any given farm household type model result mainly because the reduced costs to the gross margins were very high (ranging between Zk 854742 - Zk 1969758). According to Ngambeki (1985) and Holden (1991), they argue that in a profit maximising strategy, the relative scarcity of cash as against labour in the household determines the choice of technology. The opportunity cost of labour may also influence the choice. The increased labour requirement needed for the establishment, prunings and fire protection of agroforestry trees would have the same effect. In addition, a lower yield response from the application of prunings to agricultural crops that have been specified in the models could make the agroforestry cropping technologies less attractive (refer to Chapter 3 Section 3.7). For these technologies to be broadly accepted in this region, there is need for government support in form of targeted subsidy on inputs to encourage smallholder farmers to incorporate trees in their farming systems.

8.5 Results and discussion of Pre-emptive goal programming (PGP) models at farm-level.

The models were solved using a sequential pre-emptive goal programming formulation as demonstrated by Winston (1995) for each farm type. The output from this modelling effort provided a significant amount of information, not all of it useful in the decision-making process. The results presented in this Section relate to experimentation with the models into the effects of varying the goal priorities in determining the impacts and trade-offs that would occur if certain decisions were made at farm-level.

The results show that the changes in priority levels assigned to each goal has no significant effects on the activity mix for each specific farm household type. This is illustrated by:

(1) No change in activity combination was observed in all farm household types when household food output, income and farm expenditure goals are interchanged (see Table 7.4, Chapter 7 for Runs A-D)

(2) The human basic requirement was guaranteed in all farm household types, but areas under production were substantially reduced (see Table 8.2).

Activity mix.

The solutions for the pre-emptive goal programming models runs at farm-level are presented in Table 8.2. The crop activities for all farm household types in the basis showed a substantial decrease in areas under production in comparison to the LP models. For each farm household type the activity mix involved a sequence of four crops. In farm household type 1 and 3, just as, in farm household type 2 and 4 similar amount of land was put under cultivation. Maize is grown in farm household type 1, 2 and 4 farms but not on farm household type 3 farms. For household type 1 and 3 farms, all crop activities included in the basis belonged to Chitemene farming system. While activities in type 2 and 4 farms belonged to Ibala farming system.

The type of crops consumed on the farm by type 1 and 3 farm households apart from maize included cassava as could be expected in this region. Purchases of maize were restricted to the 2nd, 3rd and 4th periods of the year for all types of farms as required to provide for the dietary requirement of the families.

The PGP solutions at farm-level are technically feasible, certainly likely strategies in particular for farm household type 1 and 3 where consumption of crop harvested is concerned. However, questions still arise concerning the trading decision behaviour of the farmers on the market. A small farmer would not necessarily sell all the cassava, millet and ground nuts grown as the solutions seem to suggest particularly so in household type 2 and 4 farms. This behavioural pattern could be attributed to the update of prices and costs and possibly due to the non incorporation into the models of farmer preference functions.

Table 8.2: **Overview of PGP solutions following runs A-D at farm-level.**

Farm household type 1		**Farm household type 2**		**Farm household type 3**		**Farm household type 4**	
Activity in solution		Activity in solution		Activity in solution		Activity in solution	
Activity	Quantity	Activity	Quantity	Activity	Quantity	Activity	Quantity
local seed &		*Hybrid seed*		*Local seed &*		*Hybrid seed*	
fertiliser.	2.0 (ha)	*& fertiliser*	4.5 (ha)	*no fertiliser*	1.8 (ha)	*& fertiliser*	4.5 (ha)
Rotation:		Rotation		Rotation		Rotation	
cassava	0.237	maize	0.171	millet	0.241	maize	0.186
local seed &		cassava	0.171	cassava	0.241	cassava	0.186
no fertiliser.	(ha)						
millet	0.237	ground nuts	0.171	ground nuts	0.241	ground nuts	0.186
ground nuts	0.237	cassava	0.171	cassava	0.241	cassava	0.186
maize	0.237						
Consume		Consume		Consume		Consume	
(periods):	(kgs)	(periods):	(ha)	(periods):	(kgs)	(periods):	(kgs)
maize1	285	maize1	498	cassava1	1783	maize1	540
cassava1	704	maize2	498	maize2	540	maize2	540
maize2	498	maize3	498	maize3	540	maize3	540
maize3	498	maize4	498	maize4	540	maize4	540
maize4	498						
Sales		Sales		Sales		Sales	
(periods):	(kgs)	(periods):	(kgs)	(periods):	(kgs)	(periods):	(kgs)
millet1	166	maize1	34	millet	169	maize1	37
cassava1	766	cassava1	1594	cassava1	750	cassava1	1731
groundnuts1	190	groundnuts1	163	groundnuts1	193	groundnuts1	177
Purchase		Purchase		Purchase		Purchase	
(periods):	(kgs)	(periods):	(kgs)	(periods):	(kgs)	(periods):	(kgs)
maize2	498	maize2	498	maize2	540	maize2	540
maize3	498	maize3	498	maize3	540	maize3	540
maize4	498	maize4	498	maize4	540	maize4	540

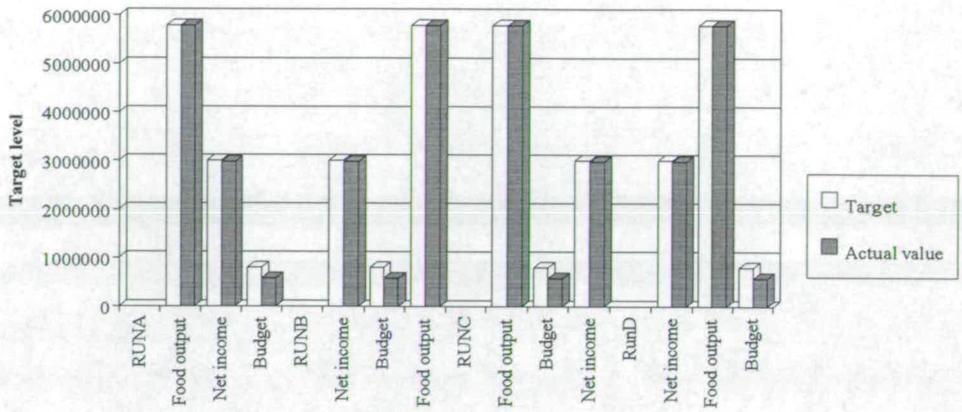
The effects of varying the goal priority levels at farm-level.

Four Runs (A-D) of each farm household type model were carried out using the goal levels shown in Table 7.3 and priority levels shown in Table 7.4 of Chapter 7. The priority levels were set on the basis of analysis of evidence given during data collection coupled with technical and research reports, literature and discussions with farm advisors.

Farm household type 1 model.

The effects of varying the goal priority levels in Runs A-D in farm household type 1 model is shown in Figure 8.1. The food output objective of 5790000 Kcal is fully satisfied in each run, while net income of Zk 3000000 and budget of Zk 800000 target levels are under achieved by Zk 24683 and Zk 222616 respectively in each run. The under achievements of both objectives is reasonable in this modelling approach since the goal levels were set at artificially high levels to allow for lesser values to be developed (see Table 7.3).

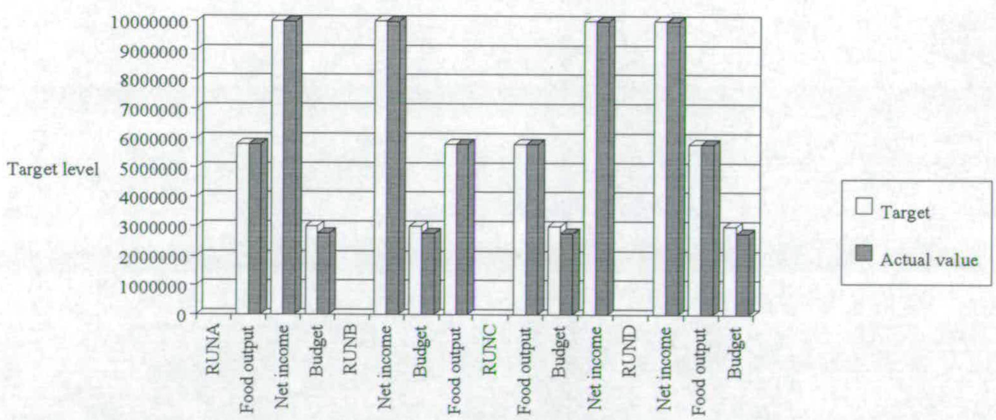
Figure 8.1. The effects of varying the goal priority levels in type 1 farms



Farm household type 2 model.

The effects of varying the goal priority levels in Runs A-D in farm household type 2 model is shown in Figure 8.2 The food output objective in every run is fully satisfied. Net income of Zk 10000000 and budget of Zk 3000000 target levels in each run are under achieved by Zk 25072 and Zk 239444 respectively. The under achievements of both objectives are acceptable since the goal levels were set deliberately at high levels to overcome the problem of choosing targets which were the true aspirations of individual farmers.

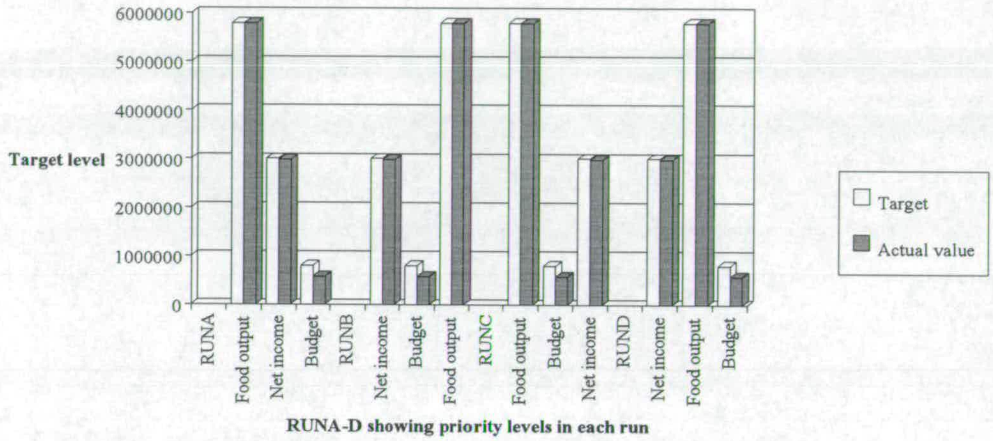
Figure 8.2. The effects of varying the goal prioirty levels in type 2 farms



Farm household type 3 model.

The effect of varying goal priority levels under Runs A-D in household type 3 farms is shown in Figure 8.3. Here the net income of Zk 3000000 and budget of Zk 800000 target levels are under achieved in each run by Zk 24572 and Zk 223511 respectively. Nutrition on the other hand is fully achieved. The under achievements of both objectives allow for high priority goals of the individual farmers to be satisfied.

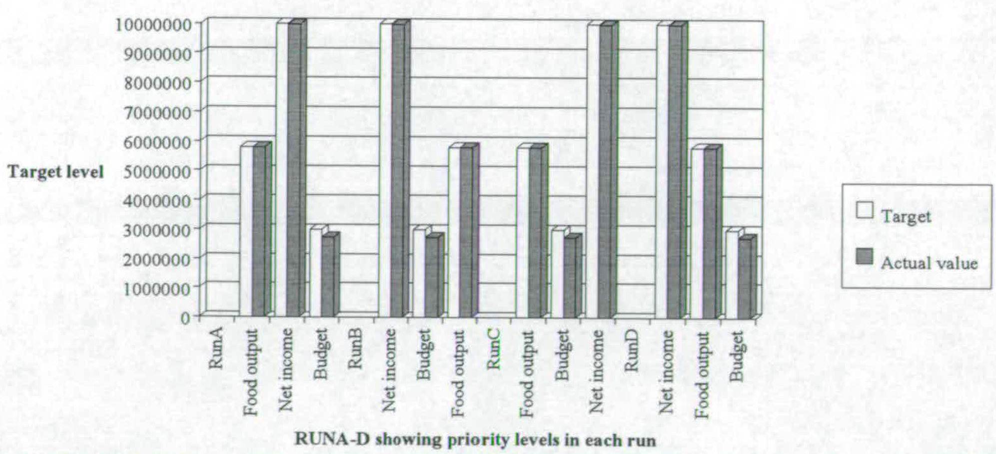
Figure 8.3. The effects of varying the goal priority levels in type 3 farms



Farm household type 4 model.

The effects of varying the goal priority levels in farm household type 4 model is shown in Figure 8.4. The food output objective, similarly to results shown in household type 1, 2 and 3 farms is fully achieved in each run. The net income of Zk 10000000 and budget of Zk 3000000 target levels are under achieved by Zk 26976 and Zk 259952 respectively in each run.

Figure 8.4. The effects of varying the goal priority levels in type 4 farms



8.5.1 **Implications of farm-level pre-emptive goal programming model results.**

The results show no significant effect as a result of varying the priorities assigned to goals in the all farm household types using the goal levels shown in Table 7.4 in Chapter 7. In the literature on smallholder farmers, explanations of farmer production systems and behaviour have often been sought in the specificity of their motives, postulating that peasants are not utility maximisers, by difference with other households, but are motivated instead by the satisfaction of needs or by the desire to ensure 'simple reproduction' of the family (Vergopoulus, 1978). The results show a low degree of conflict between maximising food output and income, and minimising the cost of the budget in all the runs. This could be attributed, as suggested in Romero (1991), to the small number of individual farmer goals specified at farm-level.

The human basic nutritional requirement which forms the main strategy of smallholder farmers was guaranteed in all the runs although it was observed that areas under production were substantially reduced and this also resulted in a decrease in crop sales to the market.

Agroforestry technologies specified in Section 7.4.2, do not enter into the pre-emptive goal programming models at farm-level. This problem has been raised in sub-Section 8.4.3 of this chapter and earlier highlighted in Chapter 3 Section 3.7. Model results have shown that the reduced cost to the gross margin is very high. From the literature, it has been established that most of the agroforestry species such as *Leucaena leucocephala*, *Gliricidia sepium*, *Sesbania sesban*, *Cacia spectabilis*, *Flemingia congesta,* and *Albizia falcataria* specified in the models have been found to perform very poorly on acid soils of the region (Matthew's *et al.*, 1992b). Their relatively low biomass production (0.5 - 1.1 t ha $^{-1}$ year $^{-1}$) has been reported to have serious limitations as to their usefulness as agroforestry species in the study area. These observations illustrate the concern raised by Ngambeki (1985) that the introduction of a technology for example, alley cropping which can require up to 50 per cent more labour is unlikely to succeed unless substantial benefits to crop yields can be demonstrated. Where there is adequate land, the return to labour is likely to be greater from expanding the cropped area, rather than intensifying an existing area (Stromgaard, 1984; Eklund, 1990; Holden, 1991).

However, the rapid population expansion in the region may soon reverse this, and it is essential, therefore, research should continue into lower input systems of sustainable cultivation; the partial success of *Leucaena leucocephala* grown with maize or cassava when agroforestry techniques are forced into the plan provides a focus for optimism. Future work should concentrate on developing approaches not requiring the input of lime by screening a wider range of *Leucaena* and other tree species for higher biomass production on the acid soils of the region. Care should be taken, however, as higher tree biomass production may mean greater competition with the crop for already scarce soil nutrients; it may be necessary to add those nutrients which are limiting to avoid this.

According to Lundgren (1982) agroforestry may be seen as a 'tool' to serve man, a tool, as good or as bad as others, depending on the qualification and good will of those who use it. Agroforestry, as a land-use option may well be the best answer to solving problems of rural development in specific sites or regions. For others, as it has been demonstrated by the single and multiple objective models at farm-level in this case, it may be just as good as any other land-use or even less suitable given the current production parameters.

In a maximising situation, the optimum solutions of the LP models would be chosen in terms of the high profit margins realised in all farm types (Section 8.4.1). But because individual farmers have other goals - which are incorporated into the models, the decision on the suitability of the farm planning models has to be considered within the frame work. In the LP solutions, more capital was used which implies higher expenditure on the part of the individual farmer. This can be in conflict with 'minimum cost' of production. In addition to this, the household nutrition requirement cannot be guaranteed in the LP. Therefore, in the light of satisfying the multiple and perhaps conflicting goals of the farmers and the level of resource use, the pre-emptive goal programming models at farm-level are considered more suitable in this situation.

8.6 **Results and discussion of pre-emptive goal programming model at regional-level.**

The aggregated model at regional-level was solved in a similar fashion as that of farm-level described in Section 8.5. The goal and goal attributes used at this level of modelling are shown in Table 7.15. Goal priority levels assigned to the goals for Runs A-F are shown in Table 7.16. The output from the regional model provided a significant amount of information to allow for the exploration of the relationships between the more specific objectives of individual farmers and the wider held objectives of the regional planners. Here, at the regional-level, two main modifications were made to the model vis-à-vis: individual farmer preferences were subjectively incorporated into the model, and area hectarage for each farm type was aggregated as shown in Table 7.14 of Chapter 7. However, not all the information was useful in the decision-making process. The results presented in this Section show the effects of varying the goal priorities in determining the conflicts and trade-offs that would occur if certain decisions were made at regional-level. These conflicts and trade-offs are reflected in the form of activity mix in the basis in relation to the satisfactory achievement of the various regional goals (the generalised views are illustrated in Figures 8.5-8.10) of this section.

The results show that the changes in priority levels assigned to each goal has no significant effects on human basic consumption requirements. This is illustrated by:

(1) No change in nutrition when regional expenditure, income goals and food output goals are interchanged (Runs A, B and E). This could be due to the fact that the human basic nutritional requirement activity is highly constrained (see Table 7.14) of Chapter 7.

(2) When farmer preferences was assigned first priority, all other goals under it were not considered in the basis (Runs E and F).

(3) Further analysis outside Runs A-F showed that regional goals like maximisation of hired labour (employment), sales, credit and purchases could only be fully satisfied by assigning the lowest priorities to regional expenditure and farmer preference goals. This suggests that assigning high priority to farmer preferences and regional expenditure goals was the reason for excluding most of the regional goals in the solutions.

(4) By varying the priorities assigned to goals, it was possible to represent opportunities for change at regional-level with an aim of selecting management options which satisfy the set of regional objectives. The results of the various regional runs have demonstrated that the activity mix shown in Runs D and F, more likely than most, represent the observed range of land-use strategies in the region.

The effects of varying the goal priority levels.

Six runs (A-F) of the model were carried out using the goal levels shown in Table 7.15 and priority levels shown in Table 7.16 of Chapter 7. The goal priority levels as in Section 8.6 were reordered in an effort to generate alternative opportunities from which regional planners would consider. Farmers for instance would want to maximise their preference objective function. While the regional planners would want to maximise the amount of food surplus coming forward for sale to non-rural areas. By varying the priorities it was possible to determine the trade-offs that would occur if certain decisions were put in place. It was also possible to select management options which satisfy the set of regional objectives at this level of planning. Details of the various runs are discussed below.

Regional Run A

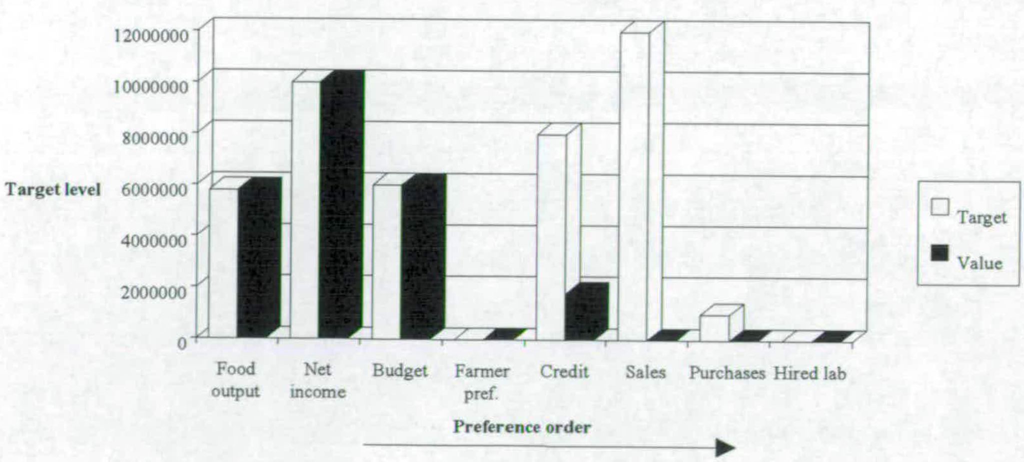
In run A the highest priority was assigned to food output followed by net cash income with the least goal being the minimising of the deviations on hired labour as shown in Figure 8.5. The solution generated showed that the region would grow 51695 ha of groundnuts from local seed and no fertiliser; 13806 ha of cassava from hybrid cuttings and fertiliser; 77543 ha of cassava from local cuttings and no fertiliser.

A total of 253411 kgs of groundnuts is stored with a consumption of 186504 kgs of purchased millet and 1473441 kgs of groundnuts during the planning period. Quantities of crops sold involved 8808645 kgs of groundnuts.

The solution generated in Run A is technically feasible but an unlikely strategy because millet is not grown in the plan.

Figure 8.5 shows that if goals 1 and 2 are met the best the decision-maker could do is to come within Zk 0.40 of meeting goal 3. Goals 4, 5, 6, 7 and 8 shown in Figure 8.5 are not considered. The only way the basis can come closer to goals 4, 5, 6, 7 and 8 is to violate the higher priority goals stipulated in Table 7.16 (Run A) of Chapter 7.

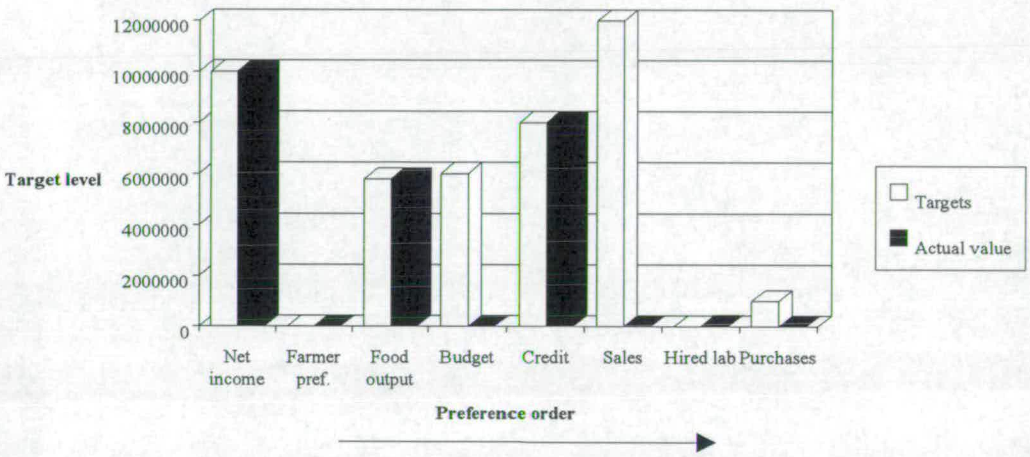
Figure 8. 5. PGP Regional results in run A



Regional Run B

In run B the highest priority was assigned to net cash income followed by farm households preferences with the least goal being the minimising of the deviations on `purchases as shown in Figure 8.6. The solution generated showed that the region would grow 51695 ha of millet from local seed and no fertiliser; 11302 ha of cassava from hybrid cuttings and fertiliser and 3561 ha of beans from hybrid seed and fertiliser; 6505 ha of groundnuts and 71038 ha of cassava from local seed and no fertiliser.

Figure 8.6. PGP Regional results for run B



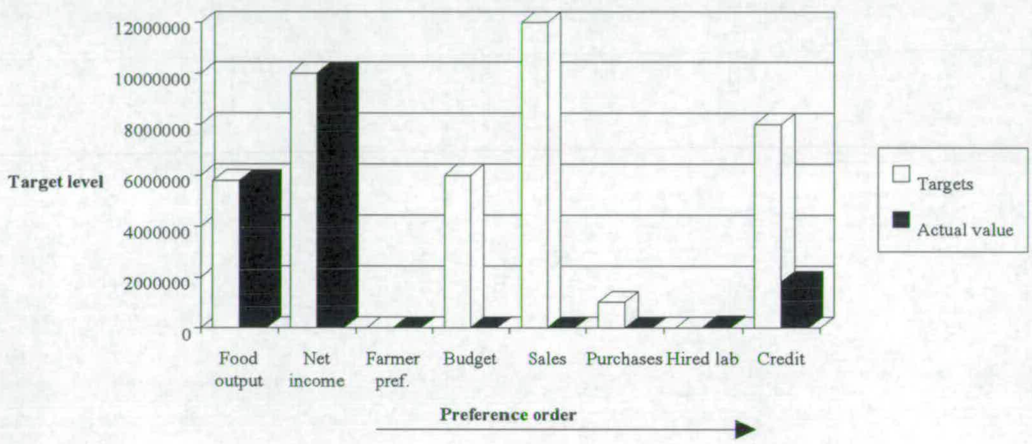
A total of 921239 kgs of purchased maize and 13891820 kgs of own grown groundnuts is stored. The quantities of crops consumed were 2625531 kgs of purchased maize, 183 kgs of grown millet, and 898345 kgs of grown beans. The quantities of crops sold are 480482272 kgs of cassava, 4509095 kgs of groundnuts, and 2698788 kgs of beans. The solution is feasible and likely strategy for the region. However, a small farmer is very likely to grow some maize too.

Figure 8.6 on the other hand, shows that if goal 1 is met the best the regional planner could do is to come within smallholders' preference function of 2 (which involves growing local/hybrid seed and no fertiliser) of meeting goal 2. Goal 4, 5, 6, 7 and 8 are made redundant. The only way the basis can come closer to meeting these goals is to violate the higher priority goals.

Regional Run C

In run C the highest priority was assigned to food output followed by net cash income with the least goal being the minimising of the deviations on total credit as shown in Figure 8.7. The solution generated showed that the region would grow 79957 ha of groundnuts, 6124 ha of maize, and 19845 ha of beans from local seed and no fertiliser; 23310 ha of cassava from local cuttings and no fertiliser; 12749 ha of cassava from hybrid cuttings and fertiliser; and 2115 ha of beans from hybrid seed and fertiliser.

Figure 8.7. PGP Regional results for run C.



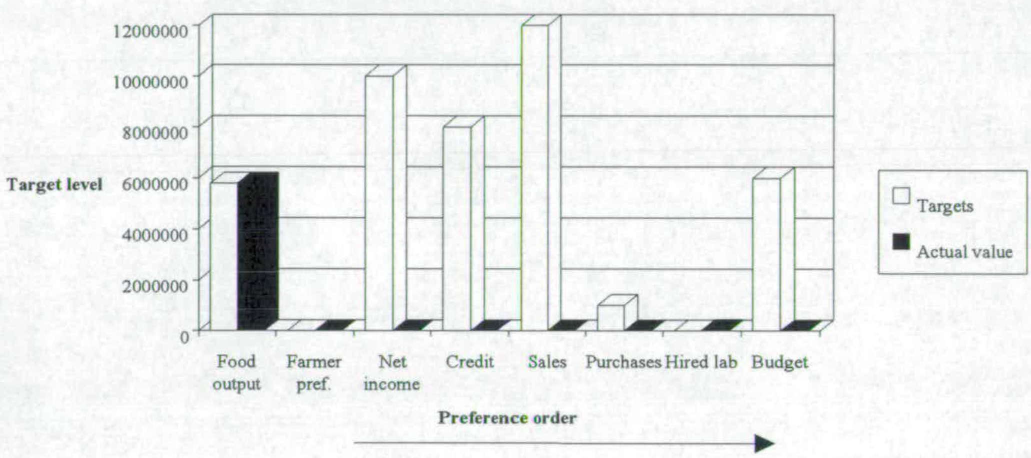
A total of 7349694 kgs of maize, 193 kgs of purchased millet, 1003126 kgs of groundnuts and 669813 kgs of beans is stored during the planning period. The quantities of crops consumed include 620434 kgs of maize, 183 kgs of purchased millet, 409077 kgs of groundnuts and 1274484 kgs of beans. The quantities of crops sold include 4150436 kgs of maize, 63506754 kgs of groundnuts, and 16704439 kgs of beans. The solution obtained in Run C is as would be expected in a region under review with one exception: a small farmer would be expected to grow some millet.

The diagram in Figure 8.7 shows that if goals 1 and 2 are met the best the regional planner could do is to come within the smallholders' preference function of 2 of growing local/hybrid seed and no fertiliser in meeting goal 3. Goals 4, 5, 6, 7 and 8 are made redundant in this basis which suggests that these goals were not considered in arriving at the basis. The only way the basis can come closer to goals 4, 5, 6, 7 and 8 is to violate the higher priority goals shown in Table 7.16.

Regional Run D

In run D the highest priority was assigned to food output followed by farmers' preference function with the least goal being the minimising of the deviations on the total budget as shown in Figure 8.8. The solution generated showed that the region would grow 54586 ha of groundnuts from local seed with no fertiliser; 13403 ha of cassava from hybrid cuttings with fertiliser; 74651 ha of cassava from local cuttings with no fertiliser; and 805 ha of beans from hybrid/local seed with fertiliser.

Figure 8.8. PGP Regional results for run D



A total of 8803411 kgs of cassava and 172910 kgs of beans is stored during the planning period. The quantities of crops consumed include 62402 kgs of purchased millet, 6254015 kgs of own grown cassava and 624029 kgs of own grown beans. The quantities of crops sold are 433784928 kgs of cassava and 51863 kgs of beans.

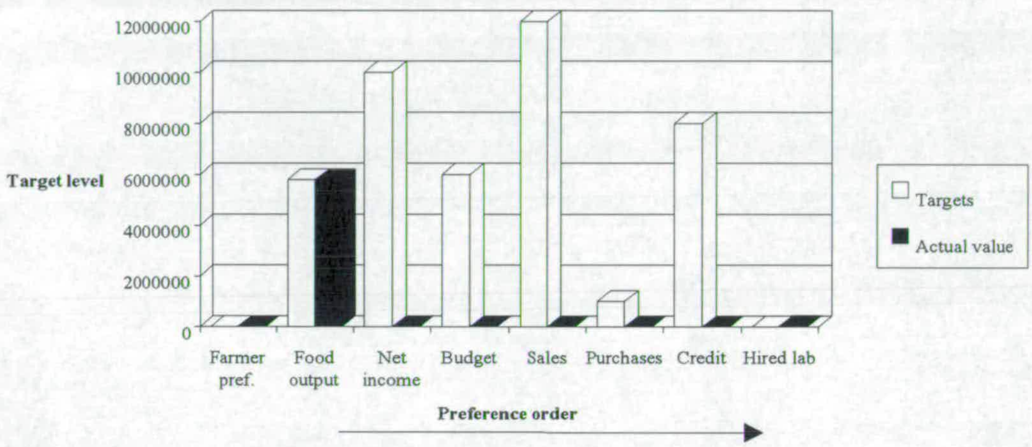
The strategy adopted in this basis is feasible but unlikely. Some millet and maize are very likely to be grown by the small farmer.

The diagram in Figure 8.8 shows that if goals 1 is met the best the regional planner could do is to come within the smallholders' preference function of 2 of growing local/hybrid seed with no fertiliser in meeting goal 2. Goals 3, 4, 5, 6, 7 and 8 are made redundant in this basis. The only way the basis can come closer to goals 3, 4, 5, 6, 7 and 8 is to violate the higher priority goals.

Regional Run E

In run E the highest priority was assigned to farmer preference function followed by food output with the least goal being the minimising of the deviations on the hired labour as shown in Figure 8.9 The solution generated showed that the region would grow 44231 ha of groundnuts and 7463 ha of maize from local seed with no fertiliser; 13806 ha of cassava from hybrid cuttings with fertiliser; 32046 ha of beans from local seed and fertiliser and 45496 ha of cassava from local cuttings with no fertiliser.

Figure 8.9. PGP Regional results for run E



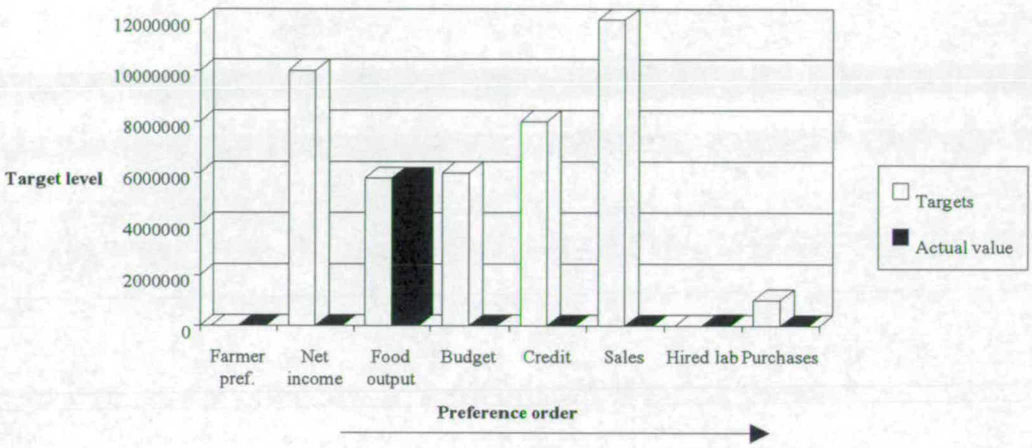
Quantities of crops stored amounted to 6872810 kgs of own grown maize, 122204 kgs of purchased millet and 50710 kgs of own grown beans during the planning period. The quantities of crops consumed are 173928 kgs of purchased millet and 2083926 kgs of own grown maize. The quantities of crops sold include 343904256 kgs of cassava, 6529169 kgs of maize, and 48174 kgs of beans. The basis is unlikely strategy by opting to purchase the millet in the second and fourth period of the plan instead of growing the crop.

Figure 8.9 shows that if goal 1 is to be met the best the regional planner could do is to come within the smallholders' preference function of 2 (ie of growing local seed with no fertiliser) in meeting goal 1. Goals 2, 3, 4, 5, 6, 7 and 8 in this basis are therefore not considered. The only way the basis can come closer to goals 2, 3, 4, 5, 6, 7 and 8 is to violate the higher priority goal.

Regional Run F

In run F the highest priority was assigned to farmers preference function followed by net cash income with the least goal being the minimising of the deviations on the total purchases as shown in Figure 8.10. The solution generated showed that the region would grow 1354 ha of millet, 1609 ha of groundnuts, 48731 ha of maize, and 13473 ha of beans from local seed with no fertiliser; 14864 ha of beans from hybrid seed with fertiliser; and 64069 ha of cassava from local cuttings with no fertiliser.

Figure 8.10. PGP Regional results for run F



Quantities of crops stored amounted to 948022 kgs of own grown millet and 3641298 kgs of own grown groundnuts during the planning period. The quantities of crops consumed are 184 kgs of millet, 5945298 kgs of maize and 2036549 kgs of beans. The quantities of crops sold are 52532358 kgs of maize, 900620 kgs of millet and 23754976 kgs of beans. The solution is functional and very likely strategy apart from the fact that all the cassava and groundnuts grown by the farmers is neither consumed nor sold in this basis.

The diagram in Figure 8.10 shows that if goal 1 is to be met the best the regional planner could do is to come within the smallholders' preference function of 2 (ie. of growing local seed and no fertiliser) in meeting goal 1. Goals 2, 3, 4, 5, 6, 7 and 8 are not considered in this basis. The only way the basis can come closer to goals 2, 3, 4, 5, 6,7 and 8 is to violate the higher priority goal.

8.6.1 **Implications of the multiple objective regional model results**.

Pre-emptive goal programming is an advanced extension of LP designed to handle several incommensurable objectives and constraints (see Chapter 4 Section 4.3) has shown to be a valuable tool to aid smallholder decision-making processes at both individual farm (see Section 8.5) and regional-level (see Section 8.6). Examples of the value of this technique have been provided for example by Romero (1991). The degree of conflict was observed to be very highly correlated to the number of goal levels not attained. The regional-level model (Table 7.15) unlike farm-level models (Table 7.3) consisted of 8 categories of goals. At both levels of approach, the PGP model results showed a closer representation which fit broadly with the actual decision-making processes of smallholder farmers in the region.

The multilevel PGP framework, on the other hand, has highlighted that much can be learned from analysing farmers (land-users) and regional (national) planners behaviour, and the consequences this behaviour may have for the use of land and associated resources in a sustainable development perspective. This knowledge, where possible, should be taken into consideration when making policy decisions related to rural development. For example, the incorporation of farmer preference function in the regional model (Chapter 8 Section 8.6) has demonstrated that land-use options with lower and more realistic quantities of resource material would suffice under current smallholder behavioural patterns. This is consistent with regional expectations where poverty significantly constrains behaviour and survival seems to be the overriding objective.

However, in view of the necessity to improve grain yields to feed the fast growing population in the region, the future research and policy agenda cannot exclude innovations such as hybrid seed, fertiliser and lime use, uptake of credit and regional adoption of agroforestry systems. These items represent an important component in the present farming systems to satisfy increasing food demands. However, fertiliser, hybrid seed and lime are expensive and difficult to transfer from main centres to outlying areas in the quantities required. Furthermore, results in Section 8.4.1 have shown that the cost of formal credit (40 %) per prescribed period severely constrains its uptake. Sensitivity analysis shows that farmers would be prepared to take up formal credit at the rate at and below 20 percent. The biomass from tree prunings should therefore have the potential to substitute for most of the top dressing and part of basal fertiliser requirements in the region which would be compensated by increasing the labour input for the establishment, pruning, and fire protection of agroforestry trees. But for the adoption to occur, institutional and structure problems which are exacerbated by conflicts documented in the work of Nkowani *et al.*, (1995b) will have to be addressed if smallholders are to fully play a role in a sustainable development perspective of the region.

8.7 Strengths and weaknesses of the mathematical modelling results.

Agricultural and natural resource systems are modelled at many different levels, from micro (family), (village), and regional or national levels (Werner, 1994; McCarl, 1992; Moxey *et al.*, 1995; Dent & McGregor, 1993; Nkowani *et al.*, 1995a). The most appropriate level at which to model the system depends on the issues to be addressed (Morrison *et al.*, 1986). This study was aimed at developing a multilevel systems approach in the allocation of constrained land and associated resources in the Northern Region of Zambia and was structured accordingly following the arguments specified in Section 7.2 of Chapter 7.

Modelling any given system is an elaborate task and requires careful quantification and calibration of many relationships. Choosing an appropriate level of approximation involves making the difficult trade-off between expense of a larger, more complex, models and the benefit of greater precision. The cost of increased size and complexity include not only man hours and computer time but mainly difficulties of understanding the models. Benefits from increased detail are in the dependability of results, although it has been observed that improvements in the accuracy from increased detail are subject to the law of diminishing returns (Morrison *et al.*, 1986). Additionally, for many aspects of the production systems and the socio-economic conditions being modelled, there are gaps in understanding or uncertainties regarding the values of particular parameters, so that very detailed representation of these aspects is not warranted (Rae, 1994).

Consequently, the LP and pre-emptive goal programming models involve a greater approximation of land/resource-use options open to smallholder farmers in the Northern Region of Zambia than most enterprise-level models (for instance; Holden, 1991,1993). However, it should not be seen as competitive with such models, but rather as complementary, providing a vehicle to search for an ideal compromise in the use of land and associated resources in the region.

8.8 Summary.

The model results of the LP and pre-emptive goal programming farm planning models and the aggregated pre-emptive goal programming model at regional-level are presented for the study area. The LP farm household type models, unlike the pre-emptive goal programming models, maximise net cash income subject to the traditional production constraints without taking into account of the other goals of the decision maker.

In a clear maximising situation, the optimising solutions of the LP models would be chosen in terms of the high profits realised in the basis. But in more complex farm family, subsistence nutrition levels for the family and perhaps cultural objectives seem to be paramount. In such a situation, farm family behavioural patterns can not be adequately captured in the LP framework. Since smallholder farmers have other goals - which are incorporated into the models, the decision on the suitability of the farm planning models has to be considered within the framework in which smallholder farmers operate. In addition, although possible within such models, it is not usual specifically to illustrate the impact of trade-offs between many different objectives within the farm households.

In the light of satisfying the multiple objectives of smallholder household and perhaps conflicting and incommensurable goals of the small farmers and the level of resource-use, the pre-emptive goal programming models are considered more suitable in a multilevel systems planning and decison-making in this situation. It is also been shown in this study that where researchers do not have access to a computer program that could solve pre-emptive goal programming problems, LINDO (or any other LP package) may still be used to solve them

The multiple objective approach used within the multilevel systems framework in the presentation of results was developed to support decision makers in choosing appropriate policy objectives to induce changes at farm-level, in order to realise aims at aggregate, regional-level.

In the next Chapter, conclusions and implications of the study findings are presented. The discussion mainly focusses on the applicability of linear programming and multiple objective models in the allocation of land and associated resources among competing stakeholders at both farm and regional-level. Limitations of the present study are described and suggestions for further research work provided.

Chapter 9.

1.0 **Introduction**

The farming systems of the Northern Region of Zambia have been analysed along with other options in the context of farm family resource structures by use of a Single and Multiple Objective Mathematical Programming Models. Paucity of specific data relating to the area made estimation of good technical coefficients difficult. Production activities were therefore described using data from a variety of sources thereby allowing exploration beyond historically observed activities.

The multilevel systems approach used in this study where individual farm-level decision models are aggregated into a regional resource planning model were presented and the resulting model structures described. The specific objective of the models were to investigate land/resource-use options open to smallholder farmers in the Northern Region of Zambia. In addition, the models attempted to explore an approach which takes preferences from the farm-level through to regional-level planning and decision-making.

The general objectives of the study were to:

(1) To identify and understand the technical, social and economic factors, and their relative importance and their complex interactions, that dictate the smallholders decisions in the uptake of any specific land-use option.

(2) To identify major features or characteristics of each farming system.

(3) Attempt to mimic smallholder farmer (land-user) production behaviour by using LP and PGP. The comparison of both techniques was not emphasied in this study.

(4) Provide a tool which can be used by decision makers in choosing appropriate policy objectives to induce changes at farm-level, in order to realise wider aims at aggregate level (regional-level).

(5) Consider policy implications of the findings in designing technologies for sustainable development.

The methods used in achieving the objectives of the study were discussed in Chapters 4, 5 and 7 and, the results were presented in Chapters 6 and 8. In this Chapter, the conclusion and implications of the study findings are attempted in Section 9.2, limitation of the present study are presented in Section 9.3 and, suggestions for further research are given in Section 9.4.

9.2 **Conclusion and implications of the study findings.**

A number of conclusions and implications of findings have already been made in different sections of the thesis. This section focuses on the overall conclusion but where relevant, a restatement of some of the earlier conclusions are made.

The conclusions reached from the literature reviewed and the results of the study are:

The major issue in agricultural and natural resource management in the study area has been declining agricultural production and environmental degradation leading to the subsequent weakening of the economic development potential. Several factors (see Nkowani *et al.,* 1995b; Chapters 2, 3, 4) combine to cause significant constraints to agricultural development in particular and management of the natural resource systems in general. These constraints have coincided with the flagging national economy reliant on the dwindling income from copper, with increasing dependence on donor aid support, and lack of positive, cohesive national directive in agriculture and natural resource development. Competition for scarce resources due to differences in priority setting between land users (farmers) and those concerned with regional development (planners) was also noted to be a source of concern.

At farm-level, the land-use decision-making processes of farmers were assumed to be more specific and were driven by a number of objectives based on individual and community values. Objectives included improving food security, concerns about income and cost of production, involvement in community and fulfilling cultural obligations. To reflect variation in management, model activities were distinguished not only by farm type or product, but also production intensity. Additional land-uses could also be envisaged and incorporated into the range of model activities with relative ease. This is important since users of the model may wish to explore land-use scenarios involving activities not anticipated by the modeller.

The use of the LP served two purposes:

(i) to examine options for development or change on typical representative farms,

(ii) the output provided, in multiple runs, set-up input data for the formulation of a regional model. In other words, it provided data to focus discussion at the interface between farmers (land-users) and the wider community (Brossier *et al.*, 1990). This is a useful device to create dialogue about:

(a) the relationship of the farm systems with the outside community in order to attempt a balance between technology, infrastructure inputs and socio-economic elements.

(b) Policy agenda, research and extension priorities which are set within the wider systems boundary

The LP models failed to capture the reality of decision-making at farm-level in the region. The LP solutions adopted strategies which, although, functional were risky and unlikely (see Section 8.4.1 & Table 8.1). This could have been attributed partly to the restrictions of the modelling framework adopted, but it is also the case that LP modelling format has deficiencies in these circumstances because it assumes farm families have simple objective functions. In addition, although possible within such models, it is not usual, specifically to illustrate the impact of trade-offs between many and different objectives within the farm households. In highly capitalised and intensive farm systems or in a clear traditional profit entrepreneurial situation, the optimum solution of the LP models would be chosen in terms of high profit margins realised (Section 8.4.1). But in more complex farm family situations, subsistence nutritional levels for the family and perhaps cultural objectives seem to be paramount. Smallholders seem simultaneously to take into account consumption and production which is consistent with the rules of the traditional theory of the firm (Becker, 1965). In such a situation, farm family behavioural patterns can not be adequately captured in the LP since profit maximisation ignores the non-profit goals in decision-making process. The hypotheses about the inadequacy of the existing decision-making methodologies for technical, social, economic and environmental planning in the region can not be rejected.

The role of incorporating smallholder preferences at regional-level which define their allocation decisions on land/resource-use options available to them was attempted. Farmer preference functions were subjectively built into the regional model, based on information obtained from research and technical reports, discussions with scientists and farm advisors, and considerable personal experience with farmers. The planners' land-use decision-making process at this level were assumed to be based on wide held views and were directed at influencing the allocation decisions of individual farmers to improve the degree of attainment of goals and aspirations of the wider society. The multiple objectives here included an increase in the amount of food coming forward for sale to non-rural areas, increased regional income, reduced cost of production, and limiting the amount of hired labour and input purchases. The modelling effort here was directed to achieve three main goals:

(i) to explore an approach which takes preferences from the farm-level through to regional-level planning and decision-making.

(ii) to examine options for development or change with a view to selecting and promoting management options which satisfy the set of regional constraints.

(iii) to aid in conflict resolution over the use of constrained land and associated resources between land-users (farmers) and those concerned with regional development (planners) in a sustainable development perspective.

Pre-emptive goal programming (PGP) capable of handling several incommensurable objectives and constraints was used. Examples of the value of this technique have been provided for example by Romero (1991) and Dent and McGregor (1993). The PGP model results showed a closer representation which fit broadly with the actual decision-making processes at farm-level (Section 8.5 Runs A-D) and regional-level (see Section 8.6 Runs A-F).

The overall implication of the findings of this study seem to suggest that land-use options with lower and more realistic quantities of resource material would surfice under current smallholder behavioural patterns. This is consistent with regional expectations where poverty significantly constrains behaviour and survival seems to be the overriding objective. Intensive farming systems such as alley cropping never came into the basis at either level of modelling. It is concluded that for these technologies to get wide acceptance in the rural sector, there is need for targeted subsidy from government in form of price support for inputs costs and marketing of surplus crop. Hence, the hypotheses that for new technologies to be accepted, they must be at least as productive as existing technologies in relation to resource constraints and preferences of smallholder farmers can not be rejected.

10.3 **Limitations of the present study.**

Paucity of specific data relating to the area made estimation of good technical coefficients difficult. Detailed data relating to current land-use were surprisingly scarce. Land management agricultural census data such as data on aspects of management (seed, fertiliser and lime usage) by smallholder farmers in the region had to be inferred from other technical reports (often incomplete sources). But as Dent (1995) confessed, "models are definable systems developed from understanding basic processes and operationalised by coupling with a limited amount of information." Accordingly, Dent (1991) argues that the development of models that mimic the decision-making processes of the farm-level decision-making unit can help planning for change at region-level in two ways. The first is that such models provide useful mechanisms to pre-screen the ways in which farm households would react to new circumstances (such as a new policy instrument) or would permit a comparison of a possible policy scenario with another in terms of its economic and social benefits and costs. Second, these models are also useful for pre-screening potential land-use options prior to expensive research, development and extension programmes being committed. This gives an opportunity to decision makers to judge the relative merits of one research, development and extension programme against another (Edwards-Jones & McGregor, 1994).

Some validation against available data was possible, albeit not as satisfactorily as might be hoped (McCarl, 1984; Hazel & Norton, 1986; Jakeman *et al.,* 1995). The output from single and multiple objective models in this study were intuitively judged against presently observed farm production systems in the region. The LP and PGP models are in broad terms mathematically similar in structure (see Table 8.2, 8.5 and 8.15 in Chapter 8.0), although they are driven by different criteria. The solutions from LP models, although risky and unlikely, were technically feasible and potentially workable. The modelling output at this level served as a step forward and/or a source of data input towards the development of a multiple objective farm and regional-level planning models. When considering the PGP models, the model results signified a change in crop activity mix. The answers, although perhaps risky too, showed a closer representation of actual land allocation at farm and regional-level in northern Zambia.

The farmers in the region are not entrepreneurial above everything else. Results should be seen within the realms and limits of knowledge and data collection efforts. Perhaps, the greatest value to this type of research is that the modelling effort highlights the potential use of explorative land/resource-use studies to make consequences of and trade-offs between different aims and perceptions explicit.

9.4 Suggestions for further research work.

As previously stated, farmers' land-use decision-making processes are driven by a number of objectives which include minimising risk, improving food security, involvement in community, fulfilling cultural obligations and concerns about income and cost of production. In this study, smallholder farmer preference functions were subjectively built into the regional model based on information elicited from research and technical reports, discussions with scientists and farm advisors, and considerable experience with the farmers. The incorporation of this information into the models can provide mechanisms for rejecting options at the systems design stage where conflicts with family seasonal labour supply, life style, gender issues, tastes and preferences are significant.

The compatibility of any innovation is influenced not only by its overall labour requirement, but also by seasonal and annual variations and by gender division of the required labour input. An innovation will stand more chance of adoption if it exploits slack periods and places no extra labour burden during busy periods. The models have shown that chitemene farming system still remains in contention in the region because of the reasons discussed in Chapter 3. In this study, labour was defined in female equivalents on a monthly basis and presented in optimum solutions on an annual basis. Future investigation should be attempted to examine labour demands in more detail; for example, one option would be to define the periods of the year which will be considered in the models, according to the peaks and troughs of the actual availability of labour, and not according to fixed intervals.

The amount of the labour available in a household is largely determined by the size and composition of the working family, the number of its members capable of work, then by the productivity of the labour unit. Therefore a family circle is an important factor as in the course of the cycle, the ratio of producers to dependants (workers to consumers) will vary. Further research is suggested to examine these relationships as well as explore the relationship between marginal productivity of labour and marginal valuation of farm family labour.

At both levels of modelling, the marginal value product for informal credit (13-16 %) per quarter is seen to be very high for smallholder farmers. This high value of extra credit at the margin reflects the severe constraint for provision of credit. Formal credit too is not used in the plans because of the high cost (40 %) per half year. Expensive credit inhibits smallholder farmers (who are the majority) from purchasing tools, seed and fertiliser or, more importantly, from hiring labour for crop production. Serious consideration should be given by government in order to develop agriculture and improve the management of the natural resources in the region. Policy options would relate to providing subsidised credit, subsidised inputs and/or provide government credit to smallholder farmers to enhance their welfare and life style. The government has to face-up to hard choices in identifying policy measures that would be sympathetic to smallholder farmers and at the same time be consistent with the general thrust of market liberalisation.

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Appendix 1.0
Categorisation of MCDM techniques in relation to their attributes.

Attributes	Techniques																		
	Multiobjectives														Meth-ods that gener-ate altern atives	Multiple decision maker methods.			
	Weight-ing	Constr-aint	Non-inferior set estimate	Multiob-jective simplex	Various geometri cal notions of best-	Goal program-ming	Surrogat-e worth trade-off method	Compro mise program ming	Electre metho-d.	Multi-attribute Utility	Step method	Trade-off develop ment method	Zionts and Waleniu-s	Interacti-ve multiple goal program ming	Hop, skip and jump method	Multiobj-ective multiple decision maker	Paretian analysis method	Element-ary game theory: Two person zero sum games	Logrolli-ng modles: multiple person & cooperat ive games
Generating.	√	√	√	√	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Non-interactive.	X	X	X	X	√	√	√	√	√	√	X	X	X	X	X	X	X	X	X
Interactive.	X	X	X	X	X	X	X	X	X	X	√	√	√	√	X	X	X	X	X
Generating of alternatives.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	√	X	X	X	X
Multiple decisions.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	√	√	√	√

Source: Modified from Mendoza *et al.*, (1986)

Appendix 2.0
Mathematical representation of Goal Programming Methods.

Appendix 2.1: Weighted Goal Programming (WGP).

The weighted goal programming problem is formulated as follows:

$$Min \quad \sum_{i=1}^{k} (\alpha_i n_i + \beta_i p_i) \tag{1}$$

Subject to: $\quad f_i(X) + n_i - p_i = b_i \qquad (i = 1,2, \ldots\ldots, k) \quad (2)$

and $\quad X \in F \quad (3)$

Where:

n_i = negative deviational variable attached to the *i -th* attribute.

p_i = positive deviational variable attached to the *i -th* attribute.

α_i = relative weight attached to *ni* and $\alpha\, i = 0$ when n_i is unwanted.

β_i = relative weight attached to *pi* and $\beta\, i = 0$ when p_i is unwanted.

$f_i(X)$ = an objective function - mathematical expression for the *i -th* attribute.

b_i = target set / goal attainment desired for *i -th* attribute.

X = is the vector of decision variables; and

F = is the feasible set or region satisfying the rigid restraints.

Appendix 2.2: Pre-emptive Goal Programming (PGP).

The mathematical representation of PGP is as follows:

$$Pre\ Min.\ a = [h_1(n,p), h_2(n,p), \ldots h_k(n,p)] \quad (1)$$

$$Subject\ to: \quad f_i(X) + n_i - p_i = b_i \quad (i = 1,2, \ldots\ldots, K) \quad (2)$$

and $X \in F$ (3)

Where:

Pre Min = a pre-emptive optimisation process.

h_k = *k-th* priority involving a given combination of elements for the n and p vectors.

The explanation of the rest of the model structure is the same as for Appendix 2.1

Appendix 2.3: MINMAX GP.

The mathematical structure of a MINIMAX GP model would be given as follows:

Minimise d (1)

subject to $\alpha i n i + \beta i p i - d \leq 0$ (2)

$f i(x) + n i - p i = b i$ (3)

and $X \in F$ (4)

$x \geq 0 \; n \geq 0 \; p \geq 0$ (5)

Where:

d is the minimum deviation.

The explanation of the rest of the model structure is the same as for Appendix 2.1.

Obviously from a computational point of view, model in Appendix 2.3 is an LP problem and can be solved by using the conventional Simplex Method.

Appendix 3.0
Farming Systems and Household Economy Survey Questionnaire.

THE UNIVERSITY OF EDINBURGH,
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FARMING SYSTEMS & HOUSEHOLD ECONOMY SURVEY - NORTHERN REGION OF ZAMBIA.

KENNETH NKOWANI.
1993/94.

A. FARMER IDENTIFICATION.

1. Village:...[ ]

Codes:
Old chambeshi = 1; New chambeshi = 2; Yunge = 3; Other = 4.

2. Name of the head of the household:..

3. Sex: [ ]

Codes:
Male = 1; Female = 2.

4. Marital status: [ ]

Codes:
Single = 1; Married = 2; Separated = 3; Divorced = 4; Widowed = 5.

5. Number of wives:...[ ]

6. Tribe: [ ]

Codes:
Bemba = 1; Namwanga = 2; Mambwe = 3; Lungu = 4; Other = 5.

7. Religious affiliation:..[ ]

Codes:
Catholic = 1; United church of Zambia = 2; Protestant = 3; Other = 4.

Farming system in use:..[ ]

Codes:
Chitemene = 1; Fundikila = 2; Ibala = 3; Agroforestry = 4; Other = 5.

B. DETAILS OF HOUSEHOLD MEMBERS.

No	Full name.	Sex.	Age	RHH	Working on farm.	Off-farm.	Non-working	Absentee
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								

Codes:
Sex: [ ] Male = 1; Female = 2.

RRH (Relation to head of the house): [ ] Head of the house = 1; Spouse = 2; Son = 3; Daughter = 4; Relative = 5; Non-relative = 6.

Working on the farm: [ ] Yes = 1; No = 2.

Off-farm: [ ] Yes = 1; No = 2.

Non-working: [ ] Yes = 1; No = 2.

Absentee: [ ] Yes = 1; No = 2.

C. HOUSEHOLD LITERACY AND EDUCATION LEVEL.

Literacy.									Education level.			At school
Bemba.					English.							
No	Speak	Read	Write	Code	Speak	Read	Write	Code	Prim	Sec.	College	
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												

Codes:
Literacy level:
Bemba: [ ] Speak only = 1; Speak and read = 2; Speak, read and write = 3; None = 4.

English: [ ] Speak only = 1; Speak and read = 2; Speak read and write = 3; None = 4.

Education ;level: [ ] Grade 1-7 = 1; Grade 8-9 = 2; Grade 10-12 = 3; College = 4.

Currently at school: [ ] Yes = 1; No = 2.

D. FAMILY LABOUR.

(A) Has anybody in the household been employed in wage work, piece work, or work for others during the last 12 months?

By whom	Mandays involved per month.												Wage/ manday	Total/ year.
	S	O	N	D	J	F	M	A	M	J	J	A		

Codes:
By whom: [ ] Head of the house = 1; Spouse = 2; Son = 3; Daughter = 4; Relative = 5; Non-relative = 6.

Months: September, October, ..., August.

(b) Mark with X the activity for which family labour is employed.

Category.	Jun, July, Aug.	Sept, Oct, Nov.	Dec, Jan, Feb.	Marc, Apr, May.
A. Male				
1				
2				
3				
4				
5				
A. Female.				
1				
2				
3				
4				
5				
Child.				
1				
2				
3				
4				
5				

Codes:
Activities: [ ] Clearing/ploughing = 1; Sowing = 2; Weeding = 3; Harvesting = 4; Other = 5.

(c) Have you, or anybody in the household participated in the following activities this season?

Activity	Yes/No	Who	When	Hours	Own-use	Sales	Income
Beer brew.							
Fishing.							
Caterpillars col.							
Ichikanda roots.							
Mushroom col.							
Charcoal.							
Wood carving.							
Hand craft.							
Other.							

Codes:
Activities: [ ] Beer brew = 1; Fishing = 2; Caterpillar collection = 3; Ichikanda roots collection = 4; Mushroom collection = 5; Charcoal burning = 6; Wood carving = 7; Hand craft = 8; Other = 9.

Reply: [ ] Yes = 1; No = 2.

Who: [ ] Head of the house = 1; Spouse = 2; Son = 3; Daughter = 4; Relative = 5; Non-relative = 6.

When: [ ] All around the year = 1; Dry season = 2; Wet season 3.

Own-use: [ ] Yes = 1; No = 2.

Sales: [ ] Yes = 1; No = 2.

E. HIRED LABOUR BY HOUSEHOLD.

(a) Did the household employ wage labour, or piece work labour or any other during the last 12 months?

By whom	Mandays involved per month.												Wage/ manday	Total/ year
	S	O	N	D	J	F	M	A	M	J	J	A		

Codes:
By whom: [ ] Male adult = 1; Female adult = 2; Male child = 3; Female child = 4..

Months: September, October, ..., August.

(b) Mark with an X the activity in which labour is commonly hired.

Category	Jun, July, Aug.	Sept, Oct, Nov.	Dec, Jan, Feb.	Marc, Apr, May.
A. Male.				
1				
2				
3				
4				
5				
A. Female.				
1				
2				
3				
4				
5				
Child.				
1				
2				
3				
4				
5				

Codes:
Activities: [ ] Clearing/ploughing = 1; Sowing = 2; Weeding = 3; Harvesting = 4; Other = 5.

F. PHYSICAL DESCRIPTION OF THE FARM.

Plot.	Size (ha)	Farm type	Distance	Tenure	Security
Total.					

Codes:
Size: [ ] < 1 ha = 1; 1 ha-2 ha = 2; 2 ha-3 ha = 3; 3 ha -4 ha = 4; 4 ha-5 ha = 5; 5 ha-6 ha = 6; 6 ha-7 ha = 7; 7 ha-8 ha = 8; 8 ha-9 ha = 9; 9 ha- 10 ha = 10; > 10 ha = 11.

Distance from the house: [ ] < 0.5 km = 1; 0.5 km-1 km = 2; 1 km-1.5 km = 3; 1.5 km-2 km = 4; > 2 km = 5.

Farm type: [ ] Smallholder = 1; Emergent = 2; Small commercial = 3.

Tenure: [ ] Communal = 1; Private = 2; Leased = 3; Borrowed = 4; Other = 5.

Security (expected length of tenure): [ ] < 3 yrs = 1; 3-5 yrs = 2; 5-7 yrs = 3; 7-9 yrs = 4; 9-11 yrs = 5; 11-13 yrs = 6; 13-15 yrs = 7; > 15 yrs.

G. CROPPING SYSTEM.

Main crop	Surface area	Mandays/ha	Cost of prod./ha	Yield(kg)/ha	Product use
1					
2					
3					
4					
5					
6					
7					
8					
Inter crop	Surface area	Mandays/ha	Cost of prod/ha	Yield(kg)/ha	Product use
1					
2					
3					
4					
5					

Summary: Total area cultivated:[ ]; Total area intrercropped: [ ]; Total area not intercropped: [ ].
Crops: Millet = 1; Maize = 2; Cassava = 3; Sorghum = 4; G. nuts = 5; Beans = 6; Soya beans = 7; P. peas = 8; Other = 9.
Use of product: [ ] Food = 1; Sales = 2; Both = 3; Other = 4.

H. CULTIVATION METHODS.

Cultivation methods.	Plots.									
	1	2	3	4	5	6	7	8	9	10
Manual										
Hired manual labour.										
Animal drawn.										
Hired animal drawn.										
Owner operated tractor.										
Hired tractor.										
Other.										

Codes:
Cultivation methods: [ ] Manual = 1; Hired manual labour = 2; Animal drawn = 3; Hired animal drawn = 4; Owner operated tractor = 5; Hired tractor = 6; Other = 7.

I. FALLOW SYSTEM.

Plot.	Last crop cultivated.	Year cultivated	Years under fallow.	Area (ha).
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Summary:
Total area of fallow land (ha): [ ].

Total surface of fallow and cultivated land (ha): [ ].

J. SYSTEM OF CROP ROTATION.

Plot.	1	2	3	4	5	6	7	8	9	10
Seasons										
Yr 5										
Yr 4										
Yr 3										
Yr 2										
Yr 1										

Codes:
Main crop = 1; Intercrop = 2; Other = 3.

K. INPUT CONSTRAINTS.

Input type	Kg	Quality	On time	Late				Not available
				1	2	3	4	
Seed.								
Fertiliser								
Insecticides								
Other								

Codes:
Input types: [ ] Seed = 1; Fertiliser = 2; Insecticides = 3; Other = 4.

Quality: [ ] Good = 1; Bad = 0.

Late: In number of weeks.

On time: [ ] Yes = 1; No = 0.

Not available: [ ] Yes = 1; No = 0.

I. WHAT TYPE OF LIVESTOCK DO YOU OWN?

Type	No.	Who looks after them.	Hours used.	Uses	How dispersed.				Bred/
					Cons.	Sales	To who	Payment	bought
Oxen									
Bulls									
Cows									
Calves									
Goats									
Sheep									
Chickens									
Ducks									
Pigs									
Other									

Codes:
Who looks after them: [ ] Head of the house = 1; Spouse = 2; Son = 3; Daughter = 4; Relative = 5; No-relative = 6.

Uses: [ ] Draft power = 1; Meat = 2; Leather = 3; Wool = 4; Milk = 5; Manure = 6; Live animals = 7; Breeding stock = 8; Eggs = 9; Other = 10.

Type: [ ] Oxen = 1; Bulls = 2; Cows = 3; Calves = 4; Goats = 5; Sheep = 6; Chicken = 7; Ducks = 8; Pigs = 9; Other = 10.

To who: [ ] Private traders = 1; Cold Storage Board = 2; Other = 3.

Bred = 1; Bought = 2; Other = 3.

M. PASTURE.

Type of pasture.	Seasonal production.	Labour needs per month.			Cost of production.	Seasonal wastage.

Codes:
Types: [ ] Grasses = 1; Browses = 2; Crop by-products = 3; Other = 4.

Seasonal wastage: [ ] < 2 % = 1; 2-5 % = 2; 5-8 % = 3; 8-11 % = 4; 11-14 % = 5; 14-17 % = 6; 17-20 % =7; > 20 % = 8

N. FARM HOUSEHOLD FOOD PATTERN.

1. Which of the following best characterises the general strategy of the household with respect to food supply? [ ]

(a) The household aims to produce nearly all its staple foods and usually succeeds in doing so.
(b) The household would like to produce all its staple foods but often fails to do so.
(c) The household aims primarily to generate sufficient cash income to purchase a substantial amount of its staple foods and relies on farm produced food only to supplement purchases.

Codes:
(a) = 1; (b) = 2; (c) = 3.

2. When are food shortfalls experienced within the year? [ ]

Codes:
December = 1; January = 2; February = 3; January to February = 4; Other = 5.

3. Which foods are affected? [ ]

Codes:
Staple foods = 1; Minor foods = 2; Both = 3; Other = 4.

4. Does the household cope with food production shortfalls? [ ]

(a) Insurance crop/ farmine crops are used as alternatives.
(b) Purchases food.
(c) Food aid from government, NGO's and external agents.
(d) Sell their labour to obtain food known as " food form work ".

(e) Other.

Codes:
(a) = 1; (b) = 2; (c) = 3; (d) = 4; (e) = 5.

5. What are the causes of food production problems?

(a) Resource constraints.
(b) Farm management constraints..
(c) Inadequate moisture*.
(d) Low soil fertility*.
(e) Poor soil physical conditions*.
(f) Other climate related factors*.

* Constraints on plant growth.

Codes:
(a) = 1; (b) = 2; (c) = 3; (d) = 4; (e) = 5.

O. GENERAL FARM HOUSEHOLD EXPENDITURE.

Expenditures.	Estimated amounts. (Zk)
Staple foods.	
Minor foods	
Sundries.	
Fuelwood.	
Building materials.	
Crop inputs.	
Hired labour.	
Farm equipment.	
Livestock.	
Veterinary services.	
Raw material for home industry.	
School fees.	
Social expenses.	
Other.	

Codes:
Expenditures: Staple foods = 1; Minor foods = 2; Sundries = 3; Fuelwood = 4; Building materials = 5; Crop inputs = 6; Hired labour = 7; Farm equipment = 8; Livestock = 9; Veterinary services = 10; Raw material for home building = 11; School fees = 12; Social expenses = 13; Other = 14.

(b) Does the household always have enough cash to meet its needs? If not, which expenditures are most difficult to meet? [ ]

Codes:
Crop inputs = 1; School fees = 2; Both = 3; Other = 4.

P. GENERAL HOUSEHOLD INCOME.

Sources of cash.	Estimated amounts. (Zk).
Sale of cash crops.	
Surplus food crops.	
Livestock/livestock products.	
Cottage industry products.	
Gifts or remittances.	
Off-farm employment.	
Credit.	
Other.	

Codes:
Sale of crops = 1; Surplus food crops = 2; Livestock/livestock products = 3; Cottage industry products = 4; Gifts or remittances = 5; Off-farm employment = 6; Credit = 7; Other = 8.

(2) Which of the following best characterises the role and adequacy of cash income in the household in the household economy? [ ]

(a) Cash income is low and mainly used to meet subsistence needs.
(b) Cash income is more than adequate to meet subsistence needs and there is a moderate " surplus " left over for " luxury goods and/or savings/investment.

Codes:
(a) = 1; (b) = 2.

(3) If the answer to question (2) is (a), then what are the causal factors responsible for low cash income? [ ]

Codes:
Low yields due to poor soils = 1; Lack of support from the government = 2; Both = 3; Other = 4.

Q. HOUSEHOLD ENERGY NEEDS.

(a) What fuels are used by the household?

Type of fuel	Collected /purchased	Person	Purpose	Time/ trip.	Dist/ trip.	Quantity /trip.	Trips/ month	Quantity /year.	Annual/ costs.

Codes:
Types of Fuel: [ ] Firewood = 1; Charcoal = 2; Crop residues = 3; Manure = 4; Paraffin = 5; Other = 6.

Collected = 1; Purchased = 2; Other = 3.

Person: [ ] Head of the house = 1; Spouse = 2; Son = 3; Daughter = 4; Relative = 5; No-relative = 6.

Purpose: [ ] Cooking = 1; Lighting = 2; Heating = 3; Brewing beer = 4; Firing bricks = 5; Firing tobacco = 6; Sale = 7; Other = 8.

Time per trip: [ ] < 30 min = 1; 30 min-1 hr = 2; 1 hr-1 hr 30 min = 3; 1 hr 30 min-2 hrs = 4; 2 hrs-2 hrs 30 min = 5; 2 hrs 30 min-3 hrs = 6; > 3 hrs = 7.

Distance: [ ] < 0.5 km = 1; 0.5 km-1 km = 2; 1 km-1.5 kms = 3; 1.5 kms-2 kms = 4; 2 kms-2.5 kms = 5; 2.5 kms-3 kms = 6; > 3 kms = 7.

(b) Does the household anticipate future difficulties in meeting its fuel needs? [ ]

Codes:
Yes = 1; No = 0.

R. HOUSEHOLD SHELTER NEEDS.

(a) How does the household supply its needs for building poles?

Person	Source	Purpose	Time/ trip.	Dist/ trip.	Quantity /trip.	No of trips / year.	Quantity /year.	Annual costs.

Codes:
Person: [ ] Head of the house = 1; Spouse = 2; Son = 3; Daughter = 4; Relative = 5; No-relative = 6.

Source: [ ] Gathered = 1; Bought = 2; Payment/gift = 3; Other = 4.

Purpose: [ ] Building oh the house = 1; Fencing = 2; Storage bin = 3; Livestock pens = 4; Tobacco shed = 5; Sale = 6; Other = 7.

Time per trip: [ ] < 30 min = 1; 30 min-1 hr = 2; 1 hr-1 hr 30 min = 3; 1 hr 30 min-2 hrs = 4; 2 hrs-2 hrs 30 min = 5; 2 hrs 30 min-3 hrs = 6; > 3 hrs = 7.

Distance: [ ] < 0.5 km = 1; 0.5 km-1 km = 2; 1 km-1.5 kms = 3; 1.5 kms-2 kms = 4; 2 kms-2.5 kms = 5; 2.5 kms- 3 kms = 6; > 3 kms = 7.

S. HOUSEHOLD TIMBER NEEDS.

(a) How does the household supply its need for timber?

Person	Source	Purpose	Time/ trip.	Dist/ trip.	Quantity /trip.	No of trips /month.	Quantity /year.	Annual costs.

Codes:
Person: [ ] Head of the house = 1; Spouse = 2; Son = 3; Daughter = 4; Relative = 5; No-relative = 6.

Source: [ ] Cut and saw = 1; Bought = 2; Payment/gift = 3; Other = 4.

Purpose: [ ]House construction = 1; Furniture = 2; Livestock pens = 3; Fencing = 4; Storage bins = 5; Sale = 6; Other = 7.

Time per trip: [ ] < 30 min = 1; 30 min-1 hr = 2; 1 hr-1 hr 30 min = 3; 1 hr 30 min-2 hrs = 4; 2 hrs-2 hrs 30 min = 5; 2 hrs 30 min-3 hrs = 6; > 3 hrs = 7.

Distance: [ ] < 0.5 km = 1; 0.5 km-1 km = 2; 1 km-1.5 kms = 3; 1.5 kms-2 kms = 4; 2 kms-2.5 kms = 5; 2.5 kms- 3 kms = 6; > 3 kms = 7.

T. CREDIT/BORROWING.

(a) Have you ever used credit during the last 12 months?

Type of credit.	When secured.	Purpose.	How much	From who	Cost of credit	Repaid.

Codes:
Type of credit: [ ] Formal = 1; Informal = 2.

When secured? [ ] September = 1; October = 2; November = 3; December = 4; Other = 5.

Purpose: [ ] Seed = 1; Fertiliser = 2; School fees = 3; Other = 4.

From who: [ ] NCU = 1; Lima Bank = 2; ZCF = 3; CUSA = 4; Other = 5.

U. MARKETING SEASON.

Crop	Financial institutions.			Private traders.			Local consumers.		
	Quantity	Price	Dist.	Quantity	Price	Dist.	Quantity	Price	Dist..

Codes:
Crops: Millet = 1; Maize = 2; Cassava = 3; Sorghum = 4; G. nuts = 5; Beans = 6; Soya beans = 7; P. peas = 8; Other = 9.

Distance: [ ] < 0.5 km = 1; 0.5 km-1 km = 2; 1 km-1.5 kms = 3; 1.5 kms-2 kms = 4; 2 kms-2.5 kms = 5; 2.5 kms- 3 kms = 6; > 3 kms = 7.

V. STORAGE.

(a) Does the household experience any wastage from store in the course of the year and by how much?

Crop	When does the loss occur.				% Loss.
	Jan-March	Apr-June	July-September	Oct-December	

Codes:
Crops: Millet = 1; Maize = 2; Cassava = 3; Sorghum = 4; G. nuts = 5; Beans = 6; Soya beans = 7; P. peas = 8; Other = 9.

% Loss: < 2 % = 1; 2-5 % = 2; 5-8 % = 3; 8-11 % = 4; 11-14 % = 5; 14-17 % = 6; 17-20 % =7; > 20 % = 8

W. TREE PLANTING AND AGROFORESTRY.

I am going to ask you questions about tree planting and agroforestry.

1. In your opinion, how available are trees and tree products e.g. firewood, poles and timber in your area? [   ]

(a) Plenty.
(b) Enough.
(c) Scarce.

codes:
(a) = 1; (b) = 2; (c) = 3.

2. Do you know about planting of trees on farms for food, fodder, poles, fuelwood, medicine, soil fertility and for prevention of soil erosion? [   ]

(a) Yes.
(b) No.

Codes:
(a) = 1; (b) = 0.

3. If you do know kindly complete the Table under X.

X. TREE PLANTING.

Smallholding tree planting.

Species	Planting year.	Location.	Purpose.	Source of seedling.	Price/ seedling.	Tending cost/year.	Harvesting costs/year.

Codes:
Species: [ ] Eucalyptus = 1; Oranges = 2; Papaws = 3; Mangoes = 4; Guavas = 5; Pines = 6; F. congetsa = 7; C. cajan = 8; S. sesban = 9; T. vogelli = 10; C. spectabilis = 11; C. calothyrlus =12; L. luecocephala = 13; G,. sepium = 14; Other = 15.

Location: [ ] Home gardens = 1; Crop-land = 2; Boundary land = 3; Fallow land = 4; Woodlot = 5; Grazing land = 6; Other = 7.

Purpose: [ ] Poles = 1; Fuelwood = 2; Fodder = 3; Medicine = 4; Soil fertility = 5; Soil conservation = 6; Shade = 7; Other = 8.

Source of seedlings: [ ] SPRP = 1; ARPT = 2; Forestry Department = 3; Private nurseries = 4; NGO's = 5; Collected from the wild = 6; Other = 7.

4. Have you had any problems in obtaining tree seedlings or seeds for agroforestry purpose? [ ]

(a) Yes.
(b) No.

Codes:
(a) = 1; (b) = 0.

If yes, please explain ....
....
....

5. Of the following agroforestry systems being promoted by various extension services, which one do you prefer and why?

(a) Home gardens.
(b) Intercropping.
(c) Alley cropping.
(d) Boundary planting.
(e) Fodder banks in grazing land.
(f) Woodlots.

Selected system: [ ]
Codes:
Systems: (a) = 1; (b) =2; (c) = 3; (d) = 4; (e) = 5; (f) = 6.

Reasons:...[ ]
(a) To safe guard my land.
(b) More food production from one unit of land.
(c) Harvesting various food and cash crops close to my home.
(d) More food production and check soil erosion.
(e) Production of food crops and demarcate my land.
(f) Demarcate land property.
(g) Other.

Codes:
Reasons: (a) = 1; (b) = 2; (c) = 3; (d) = 4; (e) = 5; (f) = 6; (g) = 7.

6. What are the problems associated with tree planting?

(a) High labour requirements.
(b) No exclusive rights.
(c) High land demand.
(d) Poor markets.
(e) High input costs.
(f) Other.

Codes:
Problems: [ ] (a) = 1; (b) = 2; (c) = 3; (d) = 4; (e) = 5; (f) = 6.

7. And how important are they as constraints?

Constraint.	Relative importance.
(a) Land availability.	
(b) Labour availability.	
(c) Land tenure.	
(d) Seeds/seedlings availability.	
(e) Availability of markets.	
(f) Costs in general	
(g) Other	

Codes:
Constraints: [ ] (a) =1; (b) = 2; (c) 3; (d) = 4; (e) = 5; (f) = 6; (g) = 7.
Relative importance: Very important = 1,.............., Not important = 7.

Y. GENERAL FAMILY TIME-USE.

Activity	Hours per week.			Monthly time use.			Yearly time use.		
	A	B	C	A	B	C	A	B	C
Cooking.									
Water collection.									
Maintenance of construction.									
Cleaning of household.									
Other.									

Codes:
Activity: Cooking = 1; Water collection = 2; Maintenance of construction = 3; Cleaning of household = 4; Other = 5.

Adult Male = 1; Adult female = 2; Child = 3.

Appendix 4.0
Farmer Categories.

Criteria used to categorise farm household types follows the frame developed by Adaptive Research Planning Team (ARPT) (1987), adjusted to suit the present economic conditions. To qualify for a particular category the household satisfied two of the criteria with each resource.

Criteria:

Labour	LP	LR	CP	CR
1.a Household members working on farm <= 4	X			
1.b Household members working on farm >= 4		X		
Cash				
1.a Rarely used cash or commodities to pay for labour <= 50			X	
1.b Regularly used cash or commodities to pay for labour >= 50				X
2.a Purchased 2 or less bags of fertiliser			X	
2.b Used more than 2 bags of fertiliser				X
3.a Income from 1985/86 season			X	
3.b Income from 1985/86 season				X

LP = labour poor; LR = labour rich; CP = cash poor; CR = cash rich.

Appendix 5.0
Crop input prices.

	Price (Zk)
Seed (Zk/kg)	
Maize	116.66
Millet	266.60
Cassava	Nil
Groundnuts	444
Beans	350
Soya beans	350
Fertiliser (Zk/Kg)[1]	
Compound D	190
Ammonium Nitrate	190
Lime	90
Hire rates	
Labour (Zk/Woman equivalent day)[2]	1500

[1] Calculated at the import parity price.

[2] Market rate.

Appendix 6.0
An illustration of how LINDO can solve a PGP problem.

The procedure starts by asking LINDO to minimise the deviation from their highest priority goal by solving the LP problem as described in Chapter 7, sub-Sections 7.4.1 and 7.5.1.

A goal is represented by a constraint and a corresponding objective statement regarding the direction in which deviations are to be minimised.

Goal 1 (*Highest Priority*):

$$Min\ d_1^-$$

$$st.\quad p_{11}x_1 + p_{12}x_2 + d_1^- \geq A_1 \quad \text{(Income Target).}$$

Note! The constraint is not written as an equality - only the negative deviation is present.

$$d_1^-, x_1, x_2, \geq 0 \qquad x_1, x_2 \in F$$

Where: F is the feasible set.

The preferred solution has $d_1^- = 0$ i.e. the income target level is attained - but could also be exceeded. Hence the importance of the *Simonian concept of satisficing behaviour.*

If goal 1 (Income target can be met) there is an objective function value of *zero* - and one of multiple sets of x_1, x_2 values will be returned. There are multiple solutions satisfying goal 1.

Introducing goal 2. We drop d_1^- from both the objective function and the first constraint row. Goal 2 is represented by a constraint and the corresponding objective entry.

$$Min\ d_2^-$$

$$st.\quad p_{11}x_1 + p_{12}x_2 \geq A_1 \quad \text{(Income Target).}$$

$$p_{21}x_1 + p_{22}x_2 + d_2^- \geq A_2 \quad \text{(Energy Target).}$$

$$d_2^-, x_1, x_2 \geq 0 \qquad x_1, x_2 \in F$$

By dropping d_1 from the model we insist that $d_1^- = 0$. If the objective returned is *zero* it implies that there are multiple solutions which satisfy goals 1 and 2.

Introducing goal 3 we drop d_2^- from both the objective row and the energy constraint row.

Min d_3^-

st. $p_{11}x_1 + p_{12}x_2 \geq A_1$ (Income Target).

$p_{21}x_1 + p_{22}x_2 \geq A_2$ (Energy Target).

$p_{31}x_1 + p_{32}x_2 + d_3^- \geq A_3$ (Farmer Preference Target).

If all 3 goals are met simultaneously, the objective value will remain zero.

Introducing goal 4, we drop d_3^- from the objective function and goal constraint 3.

Note that goal 4 is an equality constraint.

Min $d_4^- + d_4^+$

st. $p_{11}x_1 + p_{12}x_1 \geq A_1$ (Income Target).

$p_{21}x_1 + p_{22}x_2 \geq A_2$ (Energy Target).

$p_{31}x_1 + p_{32}x_2 \geq A_3$ (Farmer Preference Target).

$p_{41}x_1 + p_{42}x_2 + d_4^- - d_4^+ \geq A_4$ (Budget Target).

When both negative and positive deviations are present expressing as an equality goal it is likely that the objective function will be *non zero* - and the procedure can terminate.

In the event that the objective function is still *zero* indicating multiple solutions it may be necessary to maximise or minimise one or more of the positive deviations excluded according to preferences.

The integration of agroforestry systems into the farming systems of Northern Region of Zambia: A Multiple Objective Goal Programming Approach.

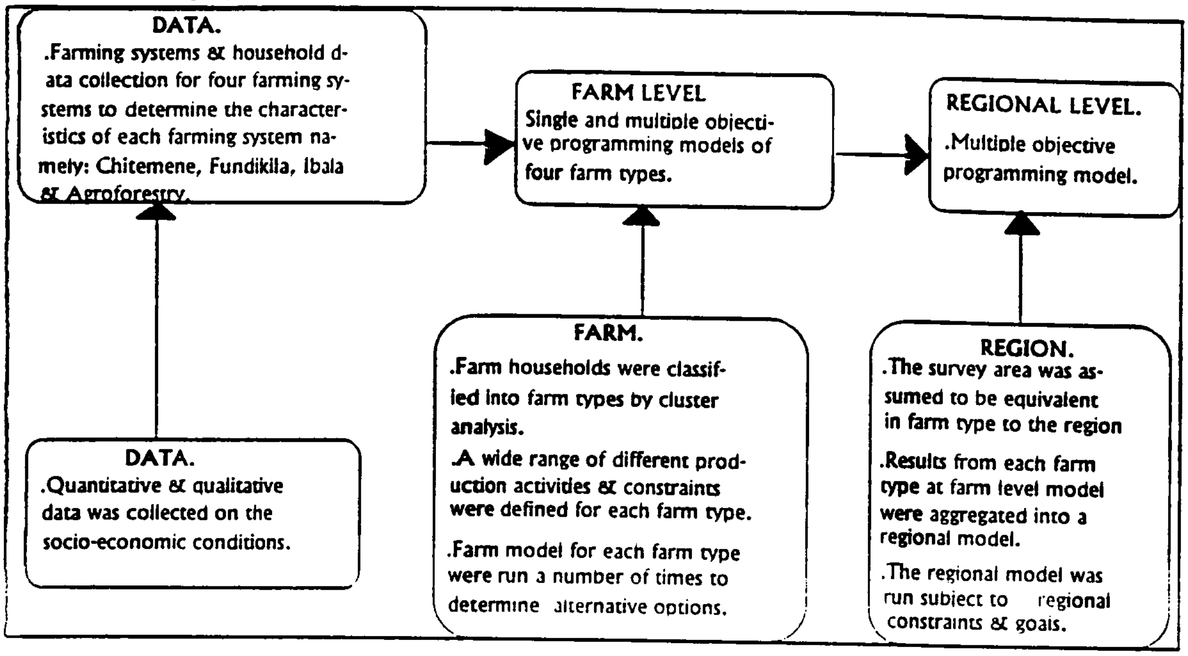
Kenneth Nkowani, Murray McGregor & Barry Dent.

DEFINITION OF THE PROBLEM:

.There is a decreasing capability for the natural resource base to sustain continued production under existing farming systems.

.The need to develop a land-use mix which will enhance food production while at the same time maintaining ecological stability, preserving natural resources and meeting social objectives.

MODEL FRAMEWORK:



APPLICATION OF OUTPUT:

.Decision-making tool to aid planners, researchers, extension officers, farmers and those involved in rural development activities by providing increased understanding of the interactions between alternative management scenarios.

.Where multiple conflicting goals are concerned, the output from the region will offer valuable information to resolve conflicts and deal effectively with the potential trade-offs between resource constraints, multiple objectives and the priorities and needs of a farm household as well as those at regional level.

Presented at the Agricultural Economics Society Conference, 7-9th April, 1995, Girton College, Cambridge, UK.

Appendix 8.0
Modelling Land/Resource-use options open to Smallholder Farmers in the Northern Region of Zambia: A Multiple Objective Programming Approach.

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Abstract of Proposed Paper.

The farming systems of the Northern Region of Zambia were analysed along with other options in the context of farm family resource structures by use of a Single and Multiple Objective Mathematical Programming Models. Paucity of specific data relating to the area made estimation of good technical coefficients difficult. Production activities were therefore described using data from a variety of sources, thereby allowing exploration beyond historically observed activities.

The Multilevel Systems Approach used in this research where individual farm-level decision models are aggregated into a regional resource planning model is presented and the resulting model structure is described. The models are used to investigate land/resource use options open to smallholder farmers in the Northern Region of Zambia. In addition, the models attempt to explore an approach which takes preferences from the farm level through to regional level planning and decision-making.

The overall implication of the findings of the study seem to suggest that land-use options with lower and more realistic quantities of resource material would surfice under current smallholder behavioural patterns. This is consistent with regional expectations where poverty significantly constrains behaviour and survival seems to be the overriding objective. Opportunities exist for raising living standards in the rural areas if the liquidity position of the smallholder farmer at the beginning of the growing season can be improved. In an average rainfall year, an increase in cash availability would enable the farmer to purchase fertiliser, hire labour and buy other inputs - all of which would serve to increase food security and rural welfare in the long run.

Key Words: Farming Systems, Resource Structures, Single and Multiple Objective Models, and Multilevel Systems Approach.

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Appendix 9.0
Modelling Human Food Systems: An Expository Integer Programming Approach.

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Abstract of Proposed Paper.

Any least cost-minimisation models solving energy and protein requirement in human diets may not satisfy the palatability and portion size criteria since eating certain kinds of foods is a social habit. In order to introduce a sense of balance in terms of palatability, it is necessary to control the portion size of some classes of ingredients in the diet.

In this paper, an expository integer programming analysis is used which minimises deviances from actual diet choice and food consumption levels to the satisfaction of both constraints.

Key Words: Expository, integer programming, cost-minimisation, palatability, portion size, and deviance.

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Appendix 10.0
Incorporating Biophysical and Multiple Objectives in Planning Models of Low Resource Farmers in Ghana: A Multilevel Systems Approach.

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Abstract of Proposed Paper.

The integration of sustainable uses of land sensitive to the wishes of immediate stakeholders and broader society whilst avoiding biophysical and environmental risks involves many inherent conflicts. These conflicts can be captured in model formats by imbedding the output from biophysical models into the socio-economic framework established at farm-level which sets out the farm family objectives coupled with resource constraints under which smallholders operate. The modelled farm-level output which defines the results of decisions taken by small farmers provide the major source of data for the regional-level model in exploring trade-offs between different aims and perceptions under all foreseeable policies with the aim of selecting management options which satisfy the set of regional objectives.

This paper contends that development of a region is heavily determined by decisions at micro (family) and regional-levels. In order to aid in conflict resolutions in the use of finite resources, micro and regional-levels may be integrated in a multilevel systems concept to understand and model decisions and linkages at and between all levels.

Key words: Sustainable, biophysical, environmental risks, conflicts, multiple objectives and multilevel.

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The Stagnation of Smallholder Agriculture in the Northern Region of Zambia: Problems, Conflicts and Production Systems

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Food security is seriously threatened by the low productivity of smallholder farmers, endemic poverty and widespread land degradation in the Northern Region of Zambia. The challenge is how to raise smallholder productivity at farm level in the face of developmental conflicts caused by demographic change, economic growth, strife and insecurity. The government is caught between the Structural Adjustment Programme (SAP) drawn up to enable it to pay off its huge foreign debt on the one hand, and the need to cushion the vulnerable sections of society (mostly smallholder farmers) from the worst aspects of the monetary squeeze on the other. Current evidence points to a dangerous imbalance, with the poor being hit hardest; but there are further steps which could be taken to support smallholders.

Kenneth Nkowani, a senior lecturer at the Zambia College of Forestry, Kitwe, is currently a Beit Trust Fellow at the Institute of Ecology and Resource Management, University of Edinburgh. His work involves the use of multiple objective mathematical models linked with risk programming routines in the analysis of farming systems in Northern Zambia.

Murray McGregor is Head of the Rural Systems and Management Section at SAC and Honorary Lecturer at the University of Edinburgh. He leads a number of research programmes relating the analysis of rural systems, in particular the application of quantitative methods, to farmer decision-making, farm management and land-use planning, and modelling the socioeconomic and environmental impact of rural policy.

Barry Dent is Head of the School of Resource Economics and Professor of Agricultural Resource Management at the Institute of Ecology and Resource Management, University of Edinburgh, since 1986. Before this he was professor of farm management and rural evaluation at the University of Lincoln, New Zealand.

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The ideal of sustainable agriculture is not being realized in the Northern Region of Zambia. Here, some of the obstacles to food security and rural development will be described, and possible solutions suggested.

Sustainable agriculture

Surveys of the burgeoning literature on sustainable agriculture suggest that the term is not capable of being defined by one objective function (Ehui and Spencer, 1993). Rather, at least three functions have to be achieved by a sustainable agriculture: environmental (to maintain or enhance the agricultural resource base), socioeconomic (to provide equitable economic rewards to individual farmers and rural communities in the production sector), and productionist (to produce a sufficient food supply). Two more can be added to this list: budgetary (to absorb a sustainable proportion of state expenditure), and political (to retain a sufficient level of support by society). To date no consensus of opinion exists over operational definitions of these functions, and so the phrase 'sustainable agriculture' is becoming more open to many interpretations by different interest groups, including environmentalists, foresters, agriculturalists, economists, sociologists, ecologists, engineers and soil scientists.

These definitions recognize the limited nature of resources and the need to evaluate trade-offs, making difficult choices between resource use now and conservation for the future. It is also clear that agriculture will only be truly sustainable if the social and cultural dimensions of those who put agricultural production into practice are totally integrated in the process and if the decisions over implementation belong to them. However, there are a number of problems affecting the agricultural development pattern in Zambia. Spatial and temporal variations in the character of farming systems appear to have evolved as a result of changing ecological and sociopolitical conditions, economic growth, strife and insecurity, and demographic change.

Problems

Farming systems

A striking feature of the Northern Province is the diversity of its agro-ecological and socioeconomic conditions, leading to complexity in land-use patterns. Traditionally, cultivation in the area has been based on a shifting system of *chitemene*, or 'bush and fallow'. However, the effects of expanding population pressure, consumption patterns and externally created market forces have exposed the inherent limitations of shifting cultivation (Ojungu, 1992). Premature cutting of the bush has led to low crop yields and soil erosion, plus persistence of weed and crop diseases. As a result, shifting cultivation has given way to semi-permanent and permanent systems such as *fundikila* (bush–grass–fallow) and *ibala* (continuous cropping) in areas of high population densities (Matthews *et al.*, 1992a). These farming systems have been well described by several authors (Bolt and Holdworth, 1987; Bolt and Silavwe, 1988; Holden, 1988; Matthews *et al.*, 1992a).

Not only are differences in land-use systems detected between households in the same village, but also among villages of the same region, and across the region. In the semi-permanent and permanent cropping systems, severe yield decline under long-term monocropping with commercial fertilizers has been reported (Matthews *et al.*, 1992c). A number of reasons for this decline have been postulated. Among the important ones are acidification effects due to the use of N fertilizers, soil degradation due to loss of soil organic matter, and infestation by weeds and pests. Where nitrogenous fertilizers are used, the initial growth of crops is significantly increased, but where subsequent rains are insufficient or late the plants create their own drought conditions because they have used too much of the retained soil moisture through rapid growth induced by the fertilizer application, seriously affecting the subsequent yield.

Land area and soils

Land *per se* is not a limiting factor in the region. However, the shortage of cleared land reflects the scarcity of labour, and of cash for land preparation and other inputs (Bolt and Silavwe, 1988). The average holding in the region during the early part of the century was 1 ha, and few were as large as 2 ha, but farm size has increased as a result of the introduction of more intensive farming systems. This is supported by a recent study carried out in Kasama District within the region (Nkowani *et al.*, 1995) which reported that the number of plots worked by each farmer ranged from one to eight, with most farmers having five. Slightly less than half of the households fell within the range of four to eight plots each. The largest farm was a 5.5 ha *ibala* field and the smallest a *chitemene* of 1.72 ha.

The soils in the area, although initially fertile, are becoming increasingly acid (pH 4.5–6.5) when brought into permanent cultivation. This is due mainly to leaching, crop removal and the acidifying effects of nitrogenous fertilizers. The occurrence of low fertility at low pH is caused by low availability of phosphates, deficiencies of calcium and magnesium and a build-up of aluminium and manganese toxicity. To maintain fertility and allow permanent cultivation of these soils, an application of lime has been recommended. However, this presents practical problems, because lime is both expensive and difficult to transfer from main centres to outlying areas in the quantities required. It is also frequently not available. Even it was available in quantities required, it would not provide a panacea because raising the pH has been reported by Matthews *et al.* (1992a) to induce deficiencies of zinc, manganese and iron, which are often already very scarce. Smallholder farmers have therefore evolved forms of shifting cultivation characterized by short cropping rotations, but because the soils are not given time to regenerate their fertility, there is a general decline in crop yields through time.

Insecurity of land tenure

The natural resources of the Northern Region are not privately owned and holders have no secure and enforceable property rights. Forests, water and grasslands are common property resources held by the state or local communities rather than by private individuals. Hence the Bemba people have no permanent system of land tenure; the chief holds the land in trust and an individual maintains rights to a field only as long as he or she has it under cultivation, before fertility declines and they move on (Holden and Joseph, 1991; Chinene and Lungu, 1992). Traditionally, therefore, there is no incentive to maintain fertility over prolonged periods of time. As a result land degradation continues unabated leading to the decline of crop yields (Matthews *et al.*, 1992a; Lungu and Chinene, 1993). Security of tenure and rights regarding land, water, livestock and trees are thus preconditions for a farmer to take the long-term view and invest in good husbandry (Chinene and Lungu, 1992).

Uncertainties of the market system

A number of factors have contributed to the dismal performance of production systems in the region, which has been costly to the taxpayer and infuriating to the farmer. The major factors reported as inhibiting farming progress relate to a poor distribution and storage network, failure to provide inputs as a result of poor infrastructure and long delays between crop delivery and payment. Elsewhere it has been reported that the government's elimination of subsidies on marketed crops, and the deregulation of the marketing of fertilizer and other inputs in fulfilment of the International Monetary Fund (IMF) and World Bank conditions have had adverse effects on the smallholder farmer. Producer prices have risen, but tight credit restrictions and high interest rates have prevented poor farmers from improving their lot. Market forces have exposed them to competition with farmers close to the points of consumption and input supply (Matthews *et al.*, 1992c). Many small farmers, unable to afford inputs, are returning to the traditional *chitemene* and *fundikila* systems, putting more pressure on these low production systems.

Institutional changes

Pressures on the central government deficit have led to stringent budget cuts and measures to institute structural changes, including the licensing of private traders to share the burden in the marketing of agricultural crops (Pottier, 1993). There are two reasons why these measures are unlikely to benefit the target group of smallholders. First, the target group has little to sell — either to the co-operative unions or to the licensed traders. Second, the licensed traders are highly sensitive to costs and are unlikely to penetrate into the remote areas to deal in bulky low-value produce. For many farmers the only opportunity to sell their crops comes from entering into client relations with one of the unlicensed traders who travel through rural areas buying up produce.

These traders make cash advances which allow the farmers to buy tools, seeds and other inputs, and to maintain their families. However, they tie farmers to particular traders and offer prices which are set low, thereby transferring all risk to the borrower while at the same time price fluctuations operate to the advantage of the lender. This means that securities such as standing crops are grossly undervalued in relation to what the lender expects to be their market value. This undervaluation results partly from the monopoly power of the lender and partly from the personalized nature of the relationship in which the loan is made (Pottier, 1993).

Exchange rate devaluations

The effect of a series of exchange rate devaluations on agriculture has been to reduce the negative impact of deteriorating external terms of trade, which are a problem for most African countries. These developments have however had adverse effects on the target groups. Devaluation and inflation have raised the prices of tools and consumer goods; terms of trade have become even more unfavourable for smallholders, particularly for those located at some distance from large markets. One result of this 'economic stabilization policy' is increased pressure on smallholder production systems. Smallholders are pressured to produce and sell more and to do so under unfavourable economic conditions (Pottier, 1993). They are also able to purchase less and thus have less health and energy.

Access to credit facilities

Credit facilities are directed towards the production of hybrid cash crops which are accessible to emergent and small commercial farmers instead of food crops grown by smallholders. Hence, poor access to credit inhibits small farmers (who are in the majority) from purchasing seed and fertilizer or, more importantly, from hiring labour. There is an urgent need to look at the criteria used for assessing credit applications. Given the success of the group responsibility approach to credit repayment, serious consideration should be given to its application among resource-poor farmers (ARPT, 1988). An approach of this kind may appear to present a risk to credit agencies, but with careful planning and administration, this could be minimized, with great potential financial and social benefits to the community and Zambia as a whole.

Other market reform effects

Although the aims of the structural adjustment programme (SAP) may be noble, privatization has magnified the problems of unemployment and poverty in Zambia, where 80% of the economy was previously controlled by the government. Infant mortality rose from 97 to 107 per 1000 live births between 1985 and 1990, while under-five mortality rose from 152 to 200 per 1000 live births and is rising faster with Aids. Over half of all deaths in Zambia during that period were among the under-10s, mostly from malnutrition, while over 70% of Zambians are now thought to live below the poverty line, and life expectancy is 46 years. The Chief Justice Matthew Ngulube warned recently that if this suffering went on unchecked, there would be a danger of "widespread instability" led by unemployed, marginalized smallholder farmers and despairing school leavers.

Availability of labour

Difficulty in recruiting labour for food crops, particularly during peak times such as land preparation, weeding and harvesting, is becoming more widespread (Pottier, 1993). One major reason is that men mostly control the labour of their wives and tend to deploy that labour power away from food into cash crop farming. This ideology and practice of male dominance has produced problems such as alcoholism and family violence, limiting the ability of men and women to focus on the underlying causes of their common, but different, exploitation. Other causes of the labour problem include the introduction of modern high yielding varieties, which impose rigorous timing constraints and labour peaks, and the increasing pursuit of off-farm, income-raising activities. For many people, off-farm activities have become more attractive than raising crops (Pottier, 1993). This change in circumstances, imposed from the outside, lowers the priority status of food for the home. An additional cause is reduced access to labour associated with the decline in community-based or other mutual support mechanisms, often related to broad organizational changes such as the transition from large community groupings to nuclear households.

Absentee heads of households

As a legacy of colonialism, agriculture at village level is increasingly monetized, and many males have migrated to urban areas for better-paying jobs. The absence of household heads weakens traditional village bonds and reduces the ratio of labour to land below the level required for traditional agricultural practices. This undermines the ability of households to produce sufficient grain and other food from the farm. Furthermore, large areas of land owned by the wealthy few based in urban centres may be assigned to relatives, who farm the land just enough to establish the continuing interest of the absent owner.

Sociological factors

Some urban dwellers view farmers in the rural setting as primitive and uneducated people with nothing to offer. People in the villages, therefore, tend to grow up with a feeling that they are inferior to people living in urban centres. This problem is augmented by the lack of good schools, health facilities, roads, shops and transport facilities. Hence, they have little motivation to raise themselves above subsistence level.

In the rural areas, children are regarded as a store of wealth, and so farmers' attitudes towards family size are very conservative. It is also acceptable for a man to have more than one wife. Wives and children provide the necessary labour for crop production, while at the same time their rights over the crop surplus which goes for sale are not well established.

Gender bias in development programmes

Gender-linked problems have been exacerbated because intra-household gender relations (and intra-gender relations) have been ignored and western dualism and expectations imposed (Pottier, 1993). Prominent among these interventions are agricultural extension projects that target men only, thus ignoring women's pivotal position between production and consumption; nutritional schemes that 'teach the mothers' while neglecting the constraints to which they are subjected at home; and programmes for macroeconomic structural adjustment. In the final analysis these interventions have increased rather than reduced food insecurity in households.

Training, research and extension

Agricultural training and research has remained conservative and elitist with premature emphasis on topics such as crop genetics and hybridization, and agricultural mechanization for large-scale production systems. It is not that these technologies are unimportant in themselves, but that they appear unimportant where such fundamental questions as the location, quality and availability of agricultural land, effects of land tenure and reforms on agricultural production, and spatial and temporal changes in crop demands have not been adequately addressed (Ojungu, 1992). Agricultural systems in the area require techniques that can handle the problems of water retention, soil acidity and soil loss (Matthews *et al.*, 1992b).

Furthermore, the traditional approach to research and extension in rainfed crops, which has relied on the so-called progressive farmers, has not fared well. 'Progressive' too often has simply meant 'well endowed'; people with abundant resources of land, labour, and physical and human capital are generally less averse to risk, and it is mostly they who have adopted new technologies (Ojungu, 1992). Research and extension strategies have further neglected the process of diffusion and of reaching a large mass of farmers over long distances with poor communications and infrastructure. Research and extension agents were instructed to introduce standard technical innovations only to the most progressive farmers with the hope that somehow these innovations would trickle down to the majority, but this assumption has proved false at least in the rainfed environments of Zambia.

It is better to recognize that farming systems are generally heterogeneous and dynamic, and that limiting the role of extension to transmitting standard technical recommendations limits the development of extension workers' own understanding of farmers' management problems. This inhibits two-way communication between farmers and extension workers, and restricts the contribution of extension workers to the development of innovations.

Conflicts

Traditional versus modern agriculture

In order to increase agricultural production, whole rural communities have been and are still advised to clear woodland areas at the expense of ecological stability, leaving behind a trail of exhausted land (Ojungu, 1992). Another pressure comes from the adoption of cash crops. Farmers in the Northern Province used to take the precaution of planting several varieties of crops such as sorghum and millet which had different moisture requirements, in order to safeguard against variable rainfall. But with the adoption of groundnuts, maize and so on for export, they now plant varieties which produce more, but which require good rainfall to do so, and therefore run the risk of producing nothing at all if drought occurs (Matthews *et al.*, 1992c).

Inappropriate technology is a further problem. Many new tools, or forms of crop husbandry, have been tried unsuccessfully in farming systems in Northern Region of Zambia, on the assumption that a particular task was limiting or unnecessary, or that traditional crop production methods were giving poor yields. The truth is that the farmers' knowledge of the environment in which they work is highly complex and organized and research will only be useful if it is consistent with well-tried traditional methods.

The status of education

A transient subculture is emerging among the 'educated' class in Zambia, and conflicts often arise between the resource decisions of the 'uneducated' and the ruling 'educated' classes. Because of the suspicion in which the educated are often held, new techniques and innovations generally take a long time to be adopted by the rural farmers, the majority of whom are uneducated.

Attitudes of politicians

Traditional and party official reactions to state intervention often differ. Local-level party politicians display two distinct attitudes, depending on the context. When sharing official platforms they back the national programmes and join in the exhortations to 'feed the nation'. On the other hand in their day-to-day contacts with the villages the same politicians sympathize with the peoples' need for better remuneration for their crops, more immediate rewards for their labour an[d] greater state intervention for the rural poor with respect to credit facilities an[d] incentives. Transparency in their dealings at grass-roots and national levels would command more respect and understanding.

Agriculture versus forestry

Zambia still conforms to the old doctrine, originating from the colonial past, of state ownership of all natural resources including land, water, minerals and forests. Thus the government follows the western type of conservation strategy of promoting a system of delineation of protected areas, with an aim of controlling human activities in the area and preventing the loss of natural characteristics. A licence is required before anyone can cut trees or remove other products from a forest estate, or commercially exploit woodlands outside the forest estate. This conservation approach has been criticized as being technocratic and hierarchical because there is no farmer participation in the design of conservation techniques, and there is little or no public participation in the planning of measures for a particular area.

Furthermore, forests are seen to harbour wild animals and stand in the way of agricultural expansion, and so people have looked at forests and forestry with mixed feelings. Relations between foresters on one hand and farmers, charcoal burners, pit sawyers, and craftsmen on the other hand have been hostile in many cases, because foresters have seen these people as destroyers of forests who should be kept out at all costs, while they see foresters as policemen who exclude them from land and the forest resource that is traditionally theirs. Under such conditions, the forests have not flourished, and some farmers have come to view tree planting and conservation as an alien activity. This conflict coupled with unsustainable land-use practices, poverty and an increasing human population has caused extensive degradation of the natural resource base in the area. In any case, these so-called 'protected areas' are often illegally encroached upon for cultivation, grazing, timber, poles, fuelwood, hunting and medicines. Forest policy needs to be revised in the context of an inevitably diminishing forest estate, with a clear guide as to economic, social and environmental priorities.

Crop production versus livestock production

The main cause of conflict between crop and livestock production is over the use of land, labour and capital resources. Crop land is encroaching into grazing areas as the area of cultivated land increases. As a result, the land available for grazing is decreasing over time leading to a deterioration in the condition of animals, and increased soil erosion brought about by overgrazing and rainfall run-off. As villages expand, agriculture also expands into marginal lands previously used for grazing by livestock.

Human strategies versus Nature

The goal of agriculture as it is now generally practised is to have a high rate of production with little standing crop left, or in other words a high ratio of production to biomass. Nature's strategy on the other hand is the reverse, namely a high ratio of biomass to production (Ojungu, 1992). For resources to be constantly available at reasonable costs the nature and rate of environmental modifications must resemble the natural successional pattern. Unfortunately this is not the case in the Northern Region. The physical environment (resource base) has been highly modified by the effects of rapid population growth, a sudden influx of high-impact technology, and changes from simple to complex and more demanding consumption patterns. As a result, shortages of supplies have occurred, especially with vegetation-based resources (wild fruits and vegetables, fodder, firewood, poles, timber, grass for roof-thatching), wild game, soil loss and water resources.

People's needs versus government needs and priorities

In many cases, the needs of individuals and government are in conflict. The source of conflict often lies in the approach towards achieving a set of goals. At government level, food is seen as a source of foreign exchange and government revenues, and as a strategic commodity which can be used as a means of control, a political weapon, and an instrument of social welfare. The government's other concerns include the provision of services and infrastructure, regional expenditure, employment and environmental degradation. Individuals however are mainly concerned with achieving stable or increasing food production, cash income, energy, forest products and leisure time, and in decreasing production costs, debt to be serviced, and uncertainty generally. The objectives of farm families are often in conflict with those of national policy-makers.

Off-farm income

Studies carried by Bolt and Silavwe (1988) found that off-farm income on average constituted 43% of the total income of all farmer categories in the Northern Region. A recent study by Nkowani *et al.* (1995) found that on average off-farm income constituted 21% of the total household income of overall farming systems. The significant difference between these studies could be attributed to sample size. The essential feature of off-farm income is its relative independence from seasonal climatic factors, and its potential to bring a regular stream of income throughout the year. A steady income is derived from sales of beer, piece-work, manufacturing of charcoal, loans, remittances, catching of fish, hunting, crafts and so on. In contrast, crop sales provide a large single payment at harvest. It is clear that off-farm activities are an essential component of livelihoods for all farming systems and are likely to continue to compete with agricultural activities for intra-household labour especially. The fact that off-farm income increases with commercialization also supports awareness of the need for a broad-based strategy among smallholders in the area (Bolt and Silavwe, 1988).

Top-down development or participation?

Agriculture in general has not performed well in the Northern Region of Zambia. Two schools of thought prevail on policy prescriptions for rainfed agriculture in the region. The first makes a case that farmers need to be moved rapidly from subsistence farming to growing high-yielding cash crops, but experience has shown that returns from adopting commodity-based recommendations (embodied in packages of high-yielding seed and fertilizer) have generally not met expectations (Ojungu, 1992). Adequate data on farmers' preferences and constraints are not available to allow the standardized recommendations made by research stations to be adapted to real situations. The second approach holds that learning arises as a consequence of interactions between farmers and a system of knowledge that is based on assembling solutions or providing opportunities. Farmers provide information on needs, constraints and resources available; the diagnostic system provides information on the possibilities available for solving problems. This approach is characterized by dialogue, participation, user control, and adoption of farming systems research.

Development versus conservation

It is difficult to carry out meaningful development without threatening the environment, even in a small way. For this reason, all serious government policy formulations ought to give due emphasis to appropriate conservation measures to go with various development activities. For instance, tree felling for *chitemene* and charcoal production in the Northern Province opens up vast pieces of land annually, leaving the land prone to degradation. Government policy strongly condemns these practices and has declared them illegal but has failed to recognize the lack of suitable alternatives. It is important that strategies for sustainable development are formulated through the active participation of local people and based on their needs, knowledge and skills.

Policy implications

Zambian smallholders have to contend with low income levels, high dependence on food crop production, high labour surplus, poor access to credit and extension services, and food deficit. Agricultural problems and conflicts can be seen from the viewpoints of the farmer, the community and the nation. We have seen that the present agricultural situation in the region emanates from conflicts between present and future needs, and between satisfying individual needs and those of society at large; hence, choices must continually be made in a never-ending search for balance between conflicting interests.

The government therefore faces hard choices in identifying policy measures that will be sympathetic to this sizeable group of deprived persons and at the same time be consistent with the general thrust of market liberalization, particularly reducing the size of the government sector. Three areas stand out for consideration, assuming that the chosen direction in the economic system is irreversible. These are land reform, the agricultural marketing structure and the economic support services.

In land reform, a start could be made by resettling those who are unemployed and have ventured away from their home districts in search of wage employment. A complementary measure would be to ensure stability of tenure to enable a farmer to take a long view and invest in good husbandry. Marketing could be improved if the government were to be more assertive not only in promoting private traders in the remote areas, but also by providing strong incentives and technical assistance. The base of international and inter-regional trade could usefully be decentralized to allow traders in remote areas near bordering countries to exercise greater discretion about where they market agricultural products, especially across borders.

Economic support services, which the government intends to strengthen, might usefully diversify from the current agricultural extension services which tend to concentrate on cash crops and those farmers with large land holdings. Livestock development, especially for small ruminants in densely populated areas, could receive more attention as cash-generating activators. Apart from this, business and crafts extension should be tried, with the better-off farmers as a target group of potential investors and entrepreneurs. Lastly, concerted effort should be directed towards diversification in smallholder crops through agroforestry techniques.

Conclusions

The present study has identified resource constraints and conflicts as being at the root of much of the deprivation that exists among the Northern Region smallholder farmers, but the problem is being compounded by the effects of market reform, especially price liberalization (including non-agricultural prices). Although the options for reform which are sympathetic to the vulnerable group seem to be limited, further worthwhile steps could still be taken. These include more serious consideration of changes in the land tenure system, support for private traders to operate in rural areas, and a more comprehensive approach to rural extension, to include non-traditional areas such as livestock development, business and craft development, and crop diversification through agroforestry techniques.

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