UNIVERSITY OF ALBERTA

FACTORS DETERMINING ADOPTION OF *SESBANIA SESBAN* FALLOW IN FARMING SYSTEMS

BY

© CHRISTOPHER OPIO

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled FACTORS DETERMINING ADOPTION OF *SESBANIA SESBAN* FALLOW IN FARMING SYSTEMS submitted by CHRISTOPHER OPIO in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY.

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I dedicate this thesis to my mother and my late father, and peasant farmers in Africa.

Abstract

The effect of intensified agroforestry fallows on farming systems can be evaluated by understanding the social, economic and biophysical interactions that occur within rural systems. Much emphasis has been placed on *Sesbania sesban* fallow system in the subhumid, savanna ecozone of Africa. Yet the evaluation of its adaptation by farm households and potential impact on the farming systems of the *miombo* ecozone of Eastern Province, Zambia, has received little attention. Can the *Sesbania sesban* fallow system improve and sustain soil productivity? Could the fallow system make households less vulnerable economically? What are the costs and benefits of the *Sesbania sesban* fallow system? What household factors need to be considered to develop fallow options? Does the gender of head of household matter in considering the practice of *Sesbania sesban* fallow?

Using Katete District, located in the Eastern Province, Zambia, as a case study area, and hybrid maize (*Zea mays* L.) as a test crop, this study examined these issues during the 1991/1992 growing season. Two sub-populations were considered in the study: the male and female headed ox-hoe farm households. Based on systems theory, the study first examined the prevailing socioeconomic and biophysical aspects of the ox-hoe farming system to determine the households' production and consumption strategies, strengths and weaknesses. A questionnaire was used to collect the data on these household characteristics. Second, the short-term and long-term biological attributes of *Sesbania sesban* fallow system were simulated, based on the SCUAF model adapted from Young and Muraya (1990). Secondary soil-plant related data were used in the simulation. Third, based on the results from SCUAF simulation, and socioeconomic secondary data, net returns were estimated. The households' monthly labour demands and supplies, with or without *Sesbania sesban* fallow system, were also estimated based on the socioeconomic secondary data.

The results indicated that the practice of *Sesbania sesban* fallow by households can

improve and sustain soil organic carbon and nitrogen, erosion status and maize yield. Continuous maize cropping with or without fertilizer application can increase the rate of soil loss and reduce soil productivity in the long-term. The average male and female headed households would be worse-off economically under the fallow practice in the short-term, but better-off economically in the long-term. The practice of *Sesbania sesban* fallow would increase labour demands for the households during its establishment and management. While both the average male and female headed households would experience labour deficiencies during these periods, the female headed household would experience more labour shortages than the male.

The consequent reduced maize yields, loss in revenues, labour and costs associated with *Sesbania sesban* fallow system would be immediate impediments to adopting the system by the farm households. Ways to achieve a better fit between new fallow options and the social, economic and biophysical conditions in the region are identified and discussed.

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Chapter 1

Introduction

Interest in agroforestry[1] is increasing because of its potential to increase agricultural output, farm income, and fuelwood supply (e.g. Kwesiga et al. 1991, Onim et al. 1990, Adejuwon and Adesina 1990).

In Katete District, Eastern Zambia, there is increasing evidence that traditional shifting cultivation practices have been replaced by permanent cultivation systems because of demographic pressure on land use (Boehringer and Caldwell 1989). Long bush fallows (i.e. land, which consists of natural shrubs, trees and grasses, left uncultivated for a long period of time) have been shortened and often replaced completely by grass fallow (i.e. land, which consists of grasses, left uncultivated for at least 1, 2, or 3 years). Shortened fallow periods and continuous cropping have led to declines in soil fertility, crop yields and increased soil erosion (Kwesiga et al. 1991, Boehringer and Caldwell 1989). Agricultural households are increasingly dependent on chemical fertilizers.

Farmers have adopted several strategies in response to these problems. Strategies centre around application of inorganic fertilizers and crop rotation. However, due to the high cost of fertilizers, credit constraint, risk aversion and off-farm employment opportunities,

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[1]Agroforestry is a collective name for landuse systems where woody perennials (trees and shrubs) are deliberately used on the same land management unit with agricultural crops and/or animals, either in some form of spatial arrangement or temporal sequence. In agroforestry systems, there are both ecological and socioeconomic issues involved (Lundgren 1982). Agroforestry is a concept which is defined in many ways. Some people define it as trees plus crops; while to others, agroforestry means trees with food crops (Vergara 1985).

many farmers, especially female headed households, are not using fertilizers in their cropping systems. Crop rotations have not been effective in restoring soil physical and chemical properties. Crop outputs have remained low and continue to decline (Kwesiga et al. 1991).

Improved fallows, an agroforestry system which involves careful selection, establishment and management of certain plant species as an alternative crop in order to achieve one or more of the aims of natural fallow within a short time or on a smaller area, appears to offer a promising alternative for these farmers (Prinz 1986). Food security could improve for farm households, with higher soil productivity, reduced runoff and soil erosion (Nair 1987). A fallow-based agroforestry system could also reduce economic fragility for the households, restore and conserve ecospheric systems, and mitigate wildland deforestation. However, the real test of agroforestry improved fallow would have to be a clear demonstration that the economic, social well being and security of household members could be increased in the short-term and sustained in the long-term.

Much emphasis has been placed on *Sesbania sesban* (Merr.) var. *nubica* (Chiov.) improved fallow systems in subhumid, savanna ecozone of Africa. Yet the evaluation of its adoption by farm households and potential impact on the farming systems of the subhumid *miombo*[2] ecozone of Eastern Zambia has received little attention with the exception of pioneering work by Fred Kwesiga at Msekera Research Station.

Compared with continuous cropping based on fertilizer application, could the practice of *S. sesban* improved fallow by a farm household improve and sustain soil productivity? Would agroforestry fallow systems make households more or less vulnerable economically? What would be the costs and benefits from the practice of improved fallows? What household

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[2]*Miombo* woodland consists of an open mixture of shrubs, various trees species of moderate heights and tall grasses (Environmental Almanac 1993, New York: World Resources Institute).

factors need to be considered to develop fallow options? Does the gender of head of household matter in considering the practice of improved fallows?

This study was designed to seek answers to these questions. The main objectives of the study were (1) to identify the existing farming systems of the farm households; (2) to compare characteristics of the male and female headed farm households; (3) to determine if *S. sesban* improved fallow would enhance soil fertility, crop yield and control soil erosion in a farming system; (4) to determine if the practice of *S. sesban* improved fallow-cropping rotations would be socially and economically better than continuous fertilized cropping; and (5) to provide practical recommendations for enhancing the propensity to adopt improved fallow-cropping rotation options.

A systems theory approach was employed in the study. It considers a farming system as an open reciprocal learning relationship with other systems, including agroforestry research systems. An open system receives impulses from external social, economic and ecospheric systems and sends back other impulses to the same external systems (Forrester 1984). Performance of the system is an outcome of a two-way interaction among endogenous and exogenous behaviours. This interaction describes the efficiency, equilibrium, stability and sustainability of the farming system.

Based on the systems theory approach, two lines of investigation were followed. First, the researcher became familiar with social and economic behaviour and household institutions in the villages in the study area, Katete District. Distinctive behaviour of agricultural farm household systems, current farming conditions and production and consumption opportunities and constraints were observed and recorded. Second, an understanding of the biological and economic attributes of *S. sesban* (SS) improved fallow was gained from ongoing experimental plots and field trials at Msekera Research Station in the AFRENA[3] network associated with ICRAF[4].

This two-pronged approach is pluridisciplinary. A conceptual model of the farming system, including its relationships with social, economic, ecospheric and agroforestry systems is developed. Two sub-populations are included in the study, male and female headed farm households. Both groups are part of the ox-hoe[5] farming system typical of the region. A sample is selected randomly from each sub-population. A questionnaire is used to collect data. The data describe the existing farming practices and the households' perceptions about improved fallows and socioeconomic issues. The data are summarized in descriptive statistical forms and the sub-populations are compared. Some of these data are used to estimate the socioeconomic impact of the improved fallow on the households.

A soil model (SCUAF), adapted from Young and Muraya (1990), was used to predict both the short-term (1 to 6 years) and long-term (7 to 20 years) trends in soil organic carbon, nitrogen, maize yields and erosion status under continuous maize cropping based on: (a) no fertilizer use; (b) fertilizer application; and (c) *Sesbania sesban* improved fallow system. Different fallow-maize rotations were analyzed to determine options which should be considered by farm households. Based on the results from a SCUAF simulation and secondary data, both the short-term and long-term trends in net returns (net income) under maize cropping based on the fallow system (SS+M rotation) and fertilizer (CM+F) use were first estimated. Second, the socioeconomic behaviour of the households under the practice of CM+F and SS+M rotation were then estimated and compared to determine tradeoffs that

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[3]Agroforestry Research Networks for Africa

[4]International Centre for Research in Agroforestry

[5]Oxen are used for ploughing farmland and hand hoes are used for planting and weeding crops.

arise with these options.

Hybrid maize (*Zea mays* L.), referred to in the study as maize, was chosen as the crop for analysis for two reasons. First, it is the most important cash crop, not only for Katete, but the whole of Zambia (Mwape and Kraft 1990). Second, it was the only crop for which complete data were available for the simulation component of the study.

It is expected that the *S. sesban* fallow system would improve the existing fallow system in Katete District. Soil organic carbon and nitrogen and maize yields would improve. Ox-hoe farmers would also experience minimum soil loss under the fallow system. It is also expected that SS+M rotation would yield social and economic benefits for the farmers.

This thesis is organized such that each Chapter describes a separate but integrated part of the research. Chapter 2 provides a discussion of the theoretical foundations of the study, including framework for analysis and evaluation of agroforestry systems, and the review of the factors relating to the adoption of agroforestry systems. Chapter 3 presents a review of the role of improved fallows in maintaining land productivity. For the purpose of comparison with improved fallows, the dynamics of soil productivity and plant response under bush or natural fallows are also reviewed in this Chapter. This Chapter also presents the discussion of the soil model used in the study. Chapter 4 provides a discussion of the methods employed with respect to study design, data collection and processing and simulation. Chapter 5 presents results arising from the study. It also synthesizes these results and shows how the findings are related to the issues pertaining to the adoption of *S. sesban* improved fallow by the households under study. Chapter 6 provides a general summary and conclusions.

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Chapter 2

Theoretical Foundations of a Farming System and Agroforestry

2.1 Introduction

This chapter provides a discussion of the conceptual underpinnings of a farming system and agroforestry. The implicit assumption underlying the chapter is that the relationships between the farm household socioeconomic system and agroforestry improved fallow technology must be viewed as an evolving learning process between the households and agroforestry researchers or planners (technology generating systems). In this kind of relationship, information and impulses flow from the households to researchers or planners and vice versa. It is a two-way information and learning relationship which aims at achieving a better performance of both the households and the technology generating systems.

Several requirements must be met to understand these relationships. They include the discussion of (1) a theoretical framework for the farming system, including its complexity and linkages with other external systems; (2) a framework for analysis and evaluation of agroforestry systems and (3) the factors relating to the adoption of agroforestry systems.

2.2 Theoretical framework of a farming system

Most of the farming systems literature has been ignored because it is not within the scope of this study to provide a detailed account of a farming system.

2.2.1 A farm household as a learning enterprise or organization

Development workers and researchers typically live and work within human systems. Their work may be strongly influenced by the purposes and culture of their own systems. The goals, values and structure of farm households are not necessarily part of these systems. Consequently, the principles of *oikos* governing the behaviour of households are generally difficult to research.[1]

A farm household is an enterprise or organization which consists of the farmer (male or female) as the decision-maker and his (or her) family members (or dependents) as employees. Within the enterprise, there is a continuous and dynamic process of decision-making regarding expectations, priorities, allocation of resources, implementing activities, utilizing or distributing outputs and evaluating the overall performance of the household economy. Many of these decisions are routine day-to-day decisions made subconsciously. Conscious decisions of a more discrete nature, as defined by Koljonen (1984), like the purchase of a new plough or the adoption of improved fallow practices, are based on learning, memory of past events or experiences and on consideration of many pieces of information about the alternatives.

Learning, memory and knowledge about alternative innovations are influenced by farm households' goals, values, heritage, vision and objectives, and interactions among the attributes of the farm, and the households' relationships with external systems: ecospheric, economic, social and agroforestry research systems (Figure 2.1).

The farm household allocates labour, land and capital to produce for family consumption and may market surplus production. The production and consumption activities

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[1]Oikos is defined as the set of institutions and rules which govern learning, memory, definition of purpose, heritage, treatment of uncertainty and especially limits to predation. It is the Greek origin of the prefix "eco", and the concept of social milieu is part of it (Apedaile et al. 1992).

are determined in part by exogenous parameters in the ecospheric, social and economic systems that are nested in, and endogenous independent variables such as time dedicated to farm labour, off-farm labour, leisure, investment activities and many more (McKee 1986).

2.2.2 A farm household as a closed system or open system

Systems or thermodynamics theory is an excellent means by which the complexity and dynamic behaviour of a farm household can be understood. Thermodynamics, as used in this study, is concerned with the logical study of relating and predicting the various properties of a farming system, particularly as they are affected by external stimuli or impulses (adapted from Andrews 1971).

A system is an organized unitary whole, composed of two or more interdependent parts, components, or subsystems, and demarcated from its environment by easily evident or somewhat abstract boundaries (Kast and Rosenzweig 1974). Some systems (e.g. machines) have visible identifiable parts or components. In a farming system, however, boundaries separating the farming household from its external systems, and distinguishing subsystems from each other may be quite abstract, especially to the outside observer.

Although all systems seek equilibrium, they have a tendency toward entropy or disorganization (i.e. in case of interrupted learning). In seeking equilibrium, a system tends to resist change. A system in an equilibrium state, if disturbed by impulses from its external systems, usually adopts one or more strategies in an attempt to restore its equilibrium: (1) it ignores the disturbance; (2) it attempts to maintain the status quo by building a protective layer of behaviour against the intrusion or may even attack the intruder; or (3) if strategies 1 and 2 do not work, it changes sufficiently to restore its equilibrium (Johns and Morphet 1975). Systems can be classified as "closed" or "open" systems (Forrester 1984, Koljonen

1984).

2.2.2.1 Closed system

A closed system, sometimes called a "feedback" system, does not interact with external systems. For example, the air contained in a box is a closed system if the box is impervious to air (Andrews 1971). A closed system resists impulses from external systems. If a farming system continues to resist change, and at least one external system is open and dynamic, it is not likely to survive. It forms a tendency toward entropy, disorganization and self-destruction. A closed farming system is influenced greatly by its past behaviour, experience and heritage. It contains feedback loop structures that transmit results from past action of the system back to control future action or to achieve a future goal (Forrester 1984).

2.2.2.2 Open system

An open system receives impulses from external systems and sends back other impulses to the same external systems. For example, the cubic meter of air in a particular corner of the laboratory is an open system because it is constantly mixing with air from the rest of the laboratory (Andrews 1971). An open farming system is self-renewing and self-organizing. It has a dynamic equilibrium, because it attains a new equilibrium while changing to a new desired state or position. In this case, the system changes in some type of harmony with the dynamics and needs of its external systems and minimizes the tendency toward entropy (Johns and Morphet 1975).

Blegen and Nylehn, as reported in Koljonen (1984), provided a brief description of the decision-making by a farm household under an "open" system. First, the decision-maker looks for information relevant for the decision making. Second, the decision-maker examines several options, including their corresponding consequences which determine the range of choices. Third, the decision-maker chooses the alternative with the most promising benefits.

2.2.3 Oikos of a farm household system

A farm household institutionalizes (1) vision, goals and values, (2) heritage pattern and memory, (3) learning processes and (4) property rights regimes.

2.2.3.1 Vision, goals and values

A farm household has goals, objectives and values that are diverse and complex. These include security of basic needs such as food, clothing and shelter, generation and accumulation of income and favourable cash flow, conservation and increase of resource base, recreation and leisure and recognition and acceptance in the community. These goals, however, may vary among members of the household, or differ from that of the household itself. Several studies have shown that many members of the farm households have individual goals and needs that are independent of the goals of the farm household to which they belong (Rocheleau 1987). Therefore, a clear projection of the household behaviour should consider two major dimensions: the farm household-role-expectation and the goals of individual household members (Getzels et al. 1968).

2.2.3.2 Heritage pattern and memory of a farm household

The concept of "heritage pattern and memory" is introduced here to describe certain things (property, rules, norms, etc.) handed down from one's ancestors or the past as reflections of culture or tradition. A household belongs to a village, ethnic group or community. Attached to this hierarchy are societal rules or norms of behaviour and expectations that must be followed by every member of the society (Marks 1988).

These rules, traditions, or norms regulate behaviour or affect distribution and use of land, trees, livestock, gender or age rights and duties, community obligations and the concept of wealth. Milimo (1991), for example, provided an overview of matrilineal land inheritance among the *Cewa* people of Katete. Among these people, property, including land, is inherited through sisters' sons. This means that women neither inherit land, nor are they the first recipients of land donations from their parents and mothers' brothers. Land is inherited by, given to and belongs to males. If a woman is in need of it, a close male relative gives her part of what he uses. At the dissolution of a marriage, due to divorce or death of husband, the land which a couple had been using reverts to the absolute owners, the lineage of the husband.

2.2.3.3 Learning processes

Learning has been defined as:

> "The process by which an activity originates or is changed through reacting to an encountered situation, provided that the characteristics of the change in activity cannot be explained on the basis of native response tendencies, maturation, or temporary states of the organism such as fatigue or drugs" (Hilgard and Bower, referenced in Griffith 1984).

Learning is a process and not a product. It is a change in the behaviour of learners (Griffith 1984). However, measuring the process is so difficult that there is always a tendency to measure the product. For example, if an extension officer or an agency for change wants to find out whether a farmer (the learner) has learned how to practice SS fallow, the officer may not measure the farmer's capacity to perform. Instead, the evaluation of the learning process would require that the farmer performs or produces a product such as planting and managing SS which demonstrates comprehension of the desired ideas or processes. Therefore, to measure what is to be learned, the extension officer should emphasize learning objectives that state specifically what the farmer should produce or how the farmer should behave at the end of the learning experience. Production and learning, however, are not always equivalent.

Several learning theories are discussed in the literature of psychology and education. Such theories include conditional theory, connectionism, Gestalt theory, functionalism, information processing theory, experiential learning theory, personality and motivation theory. These theories are discussed in detail in Griffith (1984). In general, the theories emphasize that (1) until the learner comes to see a need for a skill or particular knowledge, his or her level of motivation of learning will be low, (2) the learner needs to be motivated, (3) learning process is facilitated by the practice the learner gains in making the first application of the new information or skill, and (4) the teacher (agency) for change must assess, formally or informally, the learner's level of knowledge, skills, and attitudes before beginning any instruction to minimize program failures.

One of the theories which appears to be relevant to understanding learning processes in farming practices is "personality and motivation theory". Hilgard and Bower, as referenced in Griffith (1984), identified several principles governing the theory. These include consideration of the learner's abilities, heredity, culture, anxiety and motivation levels, goals, and values. Culture, goals and values, for example, affect what is learned and how it is learned.

Consider a small scale *Cewa* farmer faced with a choice between two options: the practice of continuous cropping based on fertilizer application and that based on SS fallow-cropping rotations. The farmer may weigh each of these options based on several criteria, including cost/benefit considerations. The option which is simple, requires low inputs, beneficial economically in the short-term and conforms with the traditional farming practices may be chosen even if it is not sustainable in the long-term. Therefore, short-term goals can have an influence on long-term planning activities in that learning tasks that are perceived as directly relevant to the farmer's short-term aspirations are pursued with greater commitment than those which may be viewed as irrelevant but may have some long-term benefit (Griffith 1984).

2.2.3.4 Property rights regimes

Land tenure or property rights issues, including their effects on agricultural, forestry, or agroforestry development are extensively discussed in development literature (e.g. Mercer 1992). Property rights regime or land tenure system is one of the most important factors for determining whether or not agroforestry and other landuse measures will be utilized by small scaled farmers. Margrath (1989) reported that unless property rights are fully articulated and enforced, farm households' resource allocation will be inefficient and will produce social losses.

In Katete, a dual land tenure system exists. These are State and traditional land ownerships. The State land is under the control of the President who in turn makes grants and arranges leases through the Commissioner of Lands. Recipients of State land are individuals, groups and townships. Long-term leases are granted for township development and commercial farming. Some State land may also be used for resettlement schemes.

Traditional land may be occupied and used in accordance with customary law without lease or formal right of occupancy. Land tenure is traditionally under the control of a tribal Chief. Rights to ownership are mainly considered on the basis of birth or long-term residency. No land is held by one person or his/her family in perpetuity. Most importantly, no land may be enclosed without the consent of the village headman or Chief (ICRAF 1988).

The concept of "property" is a social convention, and may be defined as follows:

> "Property is a secure expectation over some benefit stream, with the security arising from collective sanctions and enforcement. Property represents the owner (s), and thing (s) owned, against all others with an interest in the thing (s). Property is the social convention that precludes all others from converting their interest in the asset (or income stream) into a claim. These others have duties to observe the rights of the owners" (Bromley 1986, p. 596).

This definition implies that in order to understand a farm household system, institutions, rules, or the individuals making the decisions affecting the relationships between the households and resources have to be known. As discussed above, these individuals or institutions could be a farm household, a tribal chief, a lineage or group of kin depending on the management decision to be made.

Under the traditional land tenure system, land ownership and management may be treated as an open access, common property, or private property (Marks 1988). In an open access scenario, no individual or group is excluded from access to extract resources (e.g. collecting water from a stream, or collecting firewood from a wildland). Anyone can make claims on resources because, according to the households, they are "free" or god's gifts. All households have access, but there is no assurance of a benefit stream.

In a common property ownership, more than one decision unit is involved (e.g. village headmen or Chiefs), the rules governing the use of the common property, and the natural system producing these units is not possessed or owned by individuals. In a private property ownership (e.g. livestock), the household retains ownership, determines resource use rates, and uses the resources as he or she wants.

Traditional landuse and the household's ownership and management of property such as livestock are perhaps one of the most important elements of the farming system in Katete. It is through these relationships that overgrazing, deforestation, and soil erosion occur when the carrying capacity of land is exceeded. Katete has the highest cattle population in Eastern Zambia. Small scale farmers rarely sell their cattle. They are mainly kept as a symbol of prestige, or as a form of saving "on the hoof" (ICRAF 1988). Thus, cattle are kept for personal satisfaction and identity in the villages, and they may be viewed as "mobile banks".

Cattle are herded in the woodland (bushland), *dambos* (seasonally waterlogged areas), and along stream edges during cropping periods. Herding and kraaling of cattle are done during the day and at night respectively. Immediately following the planting of crops, grazing and movement of cattle are restricted until July when crop residues are available. By September, crop residues are exhausted and cattle are herded in the *dambos*. Early in the rainy season, limited but unrestricted grazing is practised depending on the timeliness of the planting of crops. Cattle also get some supplementary fodder by browsing leaves and pods of local trees. After crop harvest, cattle graze freely in the cropland to feed on crop residues (ICRAF 1988).

Cattle are private property. Farmland is also viewed as private property, but with limited rights and traditional values. Chiefs have control over all traditional land tenure issues. Stream edges, *dambos*, and wildland are common property. The cropland (farmland) after harvest becomes an open access for communal grazing. This is an example of the dynamics of property rights which usually lead to undesirable behavioral response: free-rider or hold-out strategies. Free-ridership develops when households treat property as open access or common property (i.e. belongs to nobody) by refusing to contribute to an endeavour because they expect to benefit unequally from the contributions made by other households. If enough households seek to gain short-term advantage over others, for example, intensifying grazing on stream edges or wildland, destructive competition involving concealment, deceit, intimidation, threat, and various forms of violence occurs (Marks 1988). The effects of competition are overgrazing and soil erosion.

Increase in livestock leads to overgrazing, trampling in fields, soil compaction and erosion. As human populations increase, demand for farmland, building materials, firewood and fencing materials for *dimba* (gardens in *dambos*), also increases. In Kagoro, Katete District, the destruction of forest cover is most severe, and large areas of land are covered with secondary regrowth. Demand for grazing areas increases as the livestock population increases. Increases in livestock population has led to increasing effect of trampling in the fields and soil compaction and destruction, especially in Kagoro (Njovbu, per. comm.).

Overgrazing, soil erosion and deforestation degrade ecological systems which eventually affect food security. Production and consumption capability of farm households decline and the households become economically vulnerable.

2.3 A framework for analysis and evaluation of agroforestry systems

Designing agroforestry systems, such as improved fallows, is best done if potential outcomes indicate the likely benefits that can be enjoyed within a socioeconomic setting, acceptable time-frame by farmers and a physical domain. Based on the definition of agroforestry by several authors (e.g. Budowski 1980, Vergara 1982, Lundgren 1982), several principles of agroforestry systems can be identified: sustainability and stability, productivity and profitability, flexibility, social acceptability and ecological integrity (Tabora 1989).

2.3.1 Sustainability

The concept of sustainability has been defined in many ways by many authors. For example, it has been defined as the "ability of the system to survive through repeated shocks or major impulses from the environment such as detoriating soil quality, unfavourable output prices, etc." (Conway 1983). This is, however, usually difficult to determine because, in most cases, it is realized after the system has collapsed.

Sustainabilty is challenged in fragile archipelagic and insular environments by intensive agricultural activities and over-utilization of natural resources which have caused adverse climatic changes and massive nutrient removals in soils (Dahl 1984). In some cases, however, humans have also been able to develop sustainable ecosystems. For example, "some of the world's most diversified, attractive and productive ecosystems have been created by human activities which have profoundly transformed natural environments" (Dubos 1978). Agroforestry systems can also equal or exceed the productivity of the natural ecosystem and result in rehabilitative features (Budowki 1981).

The basis for sustainabilty and longevity in agroforestry systems is renewability. Tabora (1989) explained that ecosystem renewability presupposes that the system would continue to have the minimum resources and conditions necessary to return quickly to the original state. If such minimum conditions are not present, the system would have to take the long and expensive path to renewal in natural cycling. Therefore, production must increasingly depend on the conservation of ecosystem's resources such as nutrients, water and the basic environmental conditions.

2.3.2 Flexibility and resilience

Ecosystems exhibit responses to changes brought about by both endogenous and exogenous impulses (Conrad 1983). Agroecosystems display this particular response in flexibility and resilience, both are measures of versatility. Flexibility is an attribute that allows the agroecosystem to adjust to changes or to modify in order to preserve its wholeness or integrity. Resilience is the tendency of the agroecosystem to recover to its former state having been subjected to stresses. According to Roque (1977), flexibility calls for agroforestry to fit new circumstances and changes, and resilience calls for its capacity to recover from the stresses imposed on the agroecosystem.

The attribute of versatility is adaptability, an active and dynamic readiness of the system to adjust whenever necessary. In natural ecosystems, adaptability is a negative feedback, a switching mechanism that evokes a behaviour at proper time, rate and magnitude, and provides the ecosystem with the controls and reflexes to make it respond to composition and population adjustments, competition and complementation, community development and homeostatic responses.

2.3.3 Stability

In agroforestry systems, production can change or increase. Outputs vary with external disturbances. Thus, stability is never reached. Systems often encounter deficiencies in nutrients, light and water and excesses in the environment such as temperature, drought, and solar radiation. Humans and ecosystems are known to respond to these forms of disturbances with environmental homeostasis, anticipative indifference (as nutrient and water cycling), internalization of environmental uncertainties (as in nests and homes).

The basis for stability in agroforestry systems is equilibrium. Ecosystems, when disturbed, tend to direct forces of the system towards the state of equilibrium, referred to as "equi-efficiency" (Conrad 1983). It is the state of equilibrium where "an extremely efficient population would tend to expand its niche until its efficiency decreased to a point where it no longer provided competitive advantage". This response comes when populations divide the resources to produce comparable yield for comparable input, balancing various forces to a degree of constancy or regularity, achieving ecological and economic balance and social justice

(Tabora 1989).

2.3.4 Productivity and profitability

Productivity and profitability, as used in this study, are measured or evaluated in terms of crop output and net income, respectively. Productivity and profitability of the system may also be judged by the systems' efficiency, expressed in economic and ecosystem terms. Economic efficiency is concerned with the relationship of benefits (revenues) and may be expressed as the ratio of total revenue to the total cost (profitability), or the capability to attain the same outputs or products by minimizing the costs (cost-efficiency). Ecosystem efficiency is expressed in terms of the build-up of biomass, distribution of gains or minimization of losses. In humans, efficiency is expressed in ratios of ingestion to prey production, assimilation to ingestion, production to ingestion and consumer production to prey production (Dubos 1978).

2.3.5 Ecological integrity and social acceptability

To maintain the integrity of the ecosystem, an agroecosystem can be designed where there are less losses or where there are built-in traps and recycling modes. An agroforestry improved fallow is conceived to be one system, designed such that there is nutrient cycling, increase in the population of microbial degraders and cyclers, and distribution of outputs and inputs so as not to overload and overtax the farmer's limited resources.

A factor to be considered in ecological integrity and social acceptability is compatibility. It may be viewed as the confluence of many properties of humans and ecosystem in a greater ecosystem: their harmonious relationships as they assume role specialization, behavioral complementation, territoriality, mutualism, and resource partitioning as humans or populations recognize their interdependencies. It is compatibility or mutual reinforcement that provides integration and unity in an ecosystem (Tabora 1989).

... agroforestry terms, improved fallows can result in energy exchanges and conservation such as spatial and temporal distribution, buffering and storage of water and dissipation of the impacts of winds and high heats.

From the socioeconomic perspective, improved fallows can provide a flow of incomes and goods from the farm. Besides providing financial returns for farmers, the benefits from agroforestry improved fallow system can also include socioeconomic facets: fuelwood for cooking, materials for making granaries (storage areas for crops) and fencing *dimbas*, and employment in rural areas. However, for successful implementation of fallow programmes, beliefs, priorities, traditions, and taboos of farmers with respect to the fallow species should be considered. Most importantly, the design of improved fallow systems should fit the farmers' financial resources.

In summary, the framework for analysis of agroforestry systems should consider the principles and attributes of the systems: socially related objectives, the agroecosystem principles, conceptual properties and manifest elements. Socially related objectives include social relevance (appropriateness), profitability or maximum gain, balance or equilibrium, versatility and creativity, and longevity and reliability. Agroecosystem principles are ecological integrity, productivity, stability, flexibility and resilience, and sustainability and conservation. Conceptual properties are physical and social in characteristics. Complementation, practicability, distributivity, diversity and replenishment form the physical component of the conceptual properties. Socially-related characteristics are compatibility, efficiency, equitability or the pattern of distribution of benefits of the system among human populations interacting with the system, adaptability and renewability.

The objectives of agroforestry improved fallow system (ecosystem) are the conditions for the system to support the needs of the farmers and society, and the attributes that farmers and society require of itself. The principles are the attributes of the system that satisfy the objectives. The conceptual properties are attributes, whose outcomes fulfil the principles. The manifest elements measure or express the conceptual properties in terms of tangible features or criteria such as yield, income, losses, ecological feasibility and social acceptability. In designing agroforestry systems, each of the principles or indicators needs rigorous analyses and evaluation beforehand.

2.4 Review of the factors relating to the adoption of agroforestry systems

There are no known empirical studies that specifically address the adoption rates of agroforestry technologies (Mercer 1992). However, following an extensive review of empirical and theoretical studies on adoption behaviour in many developing countries, Feder et al. (1985) concluded that risk and uncertainty, farm size, human capital or vision, labour availability, credit, and land tenure are the key explanatory issues.

Farm households will be faced with two types of risks: subjective and objective risks (Mercer 1992). Subjective risks are associated with uncertainties due to lack of knowledge and experience with SS fallow practice. Objective risks are associated with uncertainties relating to possible environmental influences such as weather, insect pests, the timing and availability of inputs.

Theoretical studies indicate that there is an inverse correlation between the degrees of risk aversion and the amount of land allocated to new technologies (Feder et al. 1985). However, the probabilities of high adoption rates increase as information increases (e.g. through extension activities), reducing the subjective risks. The rate of adoption of new technologies is also related to the farm households' ability to capture and analyze the available information. This means that the less educated, the old and less ambitious, financially insecure, and the households with small landholdings would show less or no interest in SS fallow practice. Farm size, however, does not appear to be an important adoption factor. Ruttan suggested that farm size may act as a proxy for such factors as wealth, access to credit, capacity to bear risks, and access to scarce inputs and knowledge.

Farm households use a set of complex criteria in accepting or rejecting a new technology. These include the extent to which the new idea is considered to be superior to the existing one; the extent to which the new idea is perceived to be in line with existing values or structures within the society; ease of use; and the extent to which the new technology produces results that are visible to other farmers (Rogers and Shoemaker 1971, Kerkhoft 1990).

With respect to agroforestry improved fallow systems, farm households would be concerned with issues such as labour and costs of establishing the system, the probability of SS failing due to pest and disease attacks, additional labour and costs of replanting unsuccessful SS establishment, market failures for the fallow products, reliable water supply for the fallow establishment, knowledge about how to plant and manage SS system, and institutions and credit arrangements. Waste, humiliation and frustration can result if no market outlets exist for improved fallow products. If outputs grow rapidly without these outlets, prices fall and farmers may abandon the improved fallow programmes and be afraid of starting new ones (Reardon 1992).

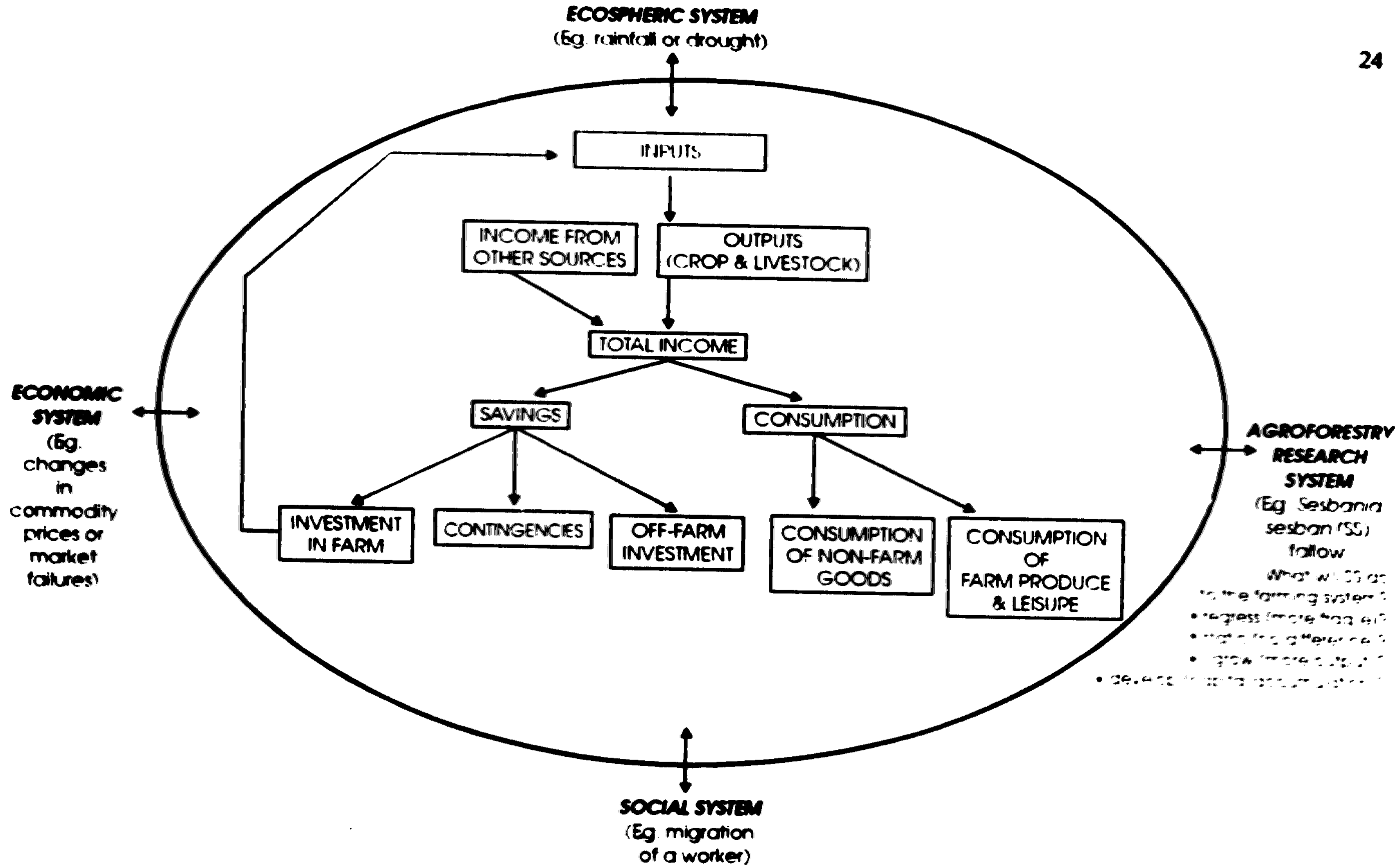

Fig. 2.1 Conceptual endogenous and exogenous flows and activities of a farming system

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Chapter 3

The Dynamics of Soil Fertility and Plant Response Under Natural and Improved Fallows

3.1 Introduction

The purpose of this chapter is to describe the importance of soil organic matter to crop production, and how changes in the organic matter and soil fertility are brought about and maintained by improved fallow systems as compared with soil changes under natural fallows. This information is critical to understanding the investment and production components of improved fallows in a farming system.

Organic matter is an ill-defined term used to cover organic materials in all stages of decomposition. In general, organic matter can be classified into two categories. The first is humus, a relatively stable material which is somewhat resistant to decomposition. The second category includes organic materials (e.g. crop residues) that are subject to fairly rapid decomposition (Tisdale et al. 1985). The sustainability of organic matter is affected by soil management practices, which in turn influence soil structure, root growth, water holding capacity and resistance to erosion. Organic matter acts as a reservoir of plant growth nutrients, cemented against leaching in organic molecules and gradually released into available forms to plants. Young (1985) reported that organic matter (represented as carbon) and nitrogen cycles are closely linked. Sanchez (1976) reported that, in unfertilized soils, the beneficial effects of organic matter consist of supplying most of the nitrogen and sulphur to plants, maintaining cation exchange capacity, blocking phosphorus fixation sites, improving structure in poorly aggregated soils and formation of complexes with micronutrients.

Nitrogen (N) is usually the most limiting factor not only in tropical landuse systems, but also in the temperate region (Sanchez 1976; Young and Muraya 1990). Therefore, an improvement in N supply, in most cases, increases crop yield. Nitrogen is a material for which agroforestry appears to offer a viable alternative to commercial fertilizers through the use of nitrogen-fixing species (Young and Muraya 1990).

The dynamics of soil productivity under shifting cultivation systems of varying periods in the tropics have been well studied and documented (e.g. Sanchez 1976; Bartholomew et al. 1953; Nye and Greenland 1960; Aweto 1985; Ekanade 1988). In general, these studies indicate that organic matter content and the concentration of nutrients in the soil decrease with continuing cultivation, but increase as the fallow period progresses. With respect to improved or planted fallows, however, relatively little is known about the dynamics of organic matter and nutrients (Adejuwon and Adesina 1990).

This chapter provides a review of (i) the forms and properties of nitrogen, including carbon (C); (ii) biological nitrogen fixation by leguminous plants; (iii) soil changes and plant response under shifting (natural) cultivation systems; and (iv) soil changes and plant response under improved fallow systems. A model for predicting changes in soil properties (N, C and erosion) and maize yield under the SS fallow (SCUAF) is also discussed. Understanding the importance of organic matter to crop production first requires knowing the basic forms and properties of soil organic C and N; and second, how changes to these elements are brought about by nitrogen-fixing plants such as SS. The development of the SCUAF model is based on this understanding. Background reviews of changes in soil productivity under natural fallows provide a framework upon which potential contributions of SS fallow can be evaluated.

3.2 Forms and properties of soil organic carbon and nitrogen

Soil organic C and N are present in several distinct forms: proteins, peptides, carbohydrates, lignin, organic acids, aromatics, lipids, some hydrocarbons, nucleic acids, and amino sugars (Kononova 1966; Bremner 1967; Paul 1970; Flaig 1971; Flaig et al. 1975). However, the character and stability of soil organic matter cannot be represented as a simple sum of these components (McGill et al. 1974; McGill and Paul 1976; Paul and McGill 1977). Furthermore, although the humified component of soil organic matter has a role in stabilizing these elements, its chemical characteristics do not exclusively explain stability (McGill and Cole 1981). Stability in soil, as shown by Ladd and Burtler (1975); Jenkinson and Rayner (1977); Anderson (1979); McGill et al. (1981), occurs because of several factors, including chemical recalcitrance, heterogeneity of components available for attack, physical protection, interaction with polyvalent cations, and adsorption to soil inorganic colloids. McGill et al. (1975, 1981) also showed that there is a close correspondence between C and N cycling through soil organic matter.

During the mineralization or mobilization of N, the C to which N is attached is converted to carbon dioxide (CO_2). This process is internal and is strictly catabolic. Thus, N mineralization occurs when soil organisms use N-rich materials as an energy substrate. Consequently, it is principally the need for C rather than the need for N that causes N mineralization (McGill and Christie 1983).

Nitrogen dynamics are similar to those of C (McGill et al. 1975). Energy and electrons to reduce N for fixation and denitrification, which respectively add N to and remove it from terrestrial systems, are provided largely by reduced C. Furthermore, internal N cycling interacts at the organism level with that of C most intimately through mineralization and mobilization relations. Thus, the balance between these two processes is sensitive to C utilization efficiency and to the C:N ratio of soil organisms. Immobilization is favoured by high efficiencies and low microbial C:N ratios, while the reverse conditions favour N mineralization (McGill et al. 1981). It has been suggested that microbial C:N ratios in soil are not constant. They fluctuate over time in response both to shifting substrate quality and a group of related organisms present. This fluctuation influences N availability (McGill et al. 1981).

The interactions of N cycles with C, sulphur and phosphorus are well documented. Cole and Heil (1981) summarized the effects of phosphorus on the N cycle. They emphasize that biologically active phosphorus controls the N cycle. They also conclude that microbial growth processes are the critical points at which N cycling is adjusted to phosphorus supply in terrestrial systems.

3.3 Biological nitrogen fixation by leguminous plants

Fixation of atmospheric N_2 is primarily undertaken by prokryotic organisms living freely or in association with certain plants. Almost 25% of the estimated global biological N_2 fixation is accomplished by the root nodule bacterium, *Rhizobium*, in association with agricultural legumes. The remainder of the global N_2 is fixed by various bacteria and actinomycetes, living either freely or in association with vegetation such as ferns, grasses, shrubs or trees (Haynes 1986). Rao et al. (1986) showed that SS forms root nodules by symbiotic association with *Rhizobium* sp. capable of fixing atmospheric nitrogen.

The various aspects of the physiology and biochemistry of biological N_2 fixation have been reviewed extensively (e.g. Rao 1988; Haynes 1986). Briefly outlined below are major features of the process of nitrogen fixation.

Nitrogenase enzyme complex is responsible for the reduction of dinitrogen to ammonia in all the major groups of N_2-fixing bacteria. It is made of two iron-sulphur proteins. During the process of fixation, electrons flow from the reducing agent, such as ferredoxin, to the MgATP-iron protein complex. The reduced MgATP-iron protein then affects the reduction of the Mo-iron protein, which is, in turn, implicated in the reduction of N_2 (Haynes 1986; Rao 1988).

3.4 Soil changes and plant response under shifting cultivation systems

Shifting cultivation is an agricultural system in which a site is selected, cleared, burned and cropped for fewer years than it is allowed to remain fallow (Sanchez 1976; Nye and Greenland 1960). It is the most predominant landuse system in the tropics. Shifting cultivation is commonly practised in sparsely human populated areas where lands are abundant, and fertilizers and power implements for ploughing are not available. Lands under shifting cultivation systems can support a human population of less than 32 persons km^{-2}, and in general it appears the system is fairly stable at that level. Increased pressure on lands due to increasing human population leads farm households to shorten the fallow period, and sometimes prolong the cropping period, hence reducing the fertility of the soil and the vigour of the plant growth or forest regrowth when the land is abandoned (Nye and Greenland 1960).

Two general types of shifting cultivation have been identified and discussed: those in forested regions and in the savannas (Sanchez 1976; Nye and Greenland 1960). In the forested areas, fields or parcels of land in varying sizes are selected, cleared by axe and machete during periods of minimal rainfall, and burned shortly before the first rains. Leaving much of the debris intact, crops such as maize, beans, rice and cotton are planted in holes dug with a planting stick. Intercropping and manual weeding then follow. Fields are normally abandoned for forest regrowth after the first or second harvest. The secondary fallow may be allowed to grow for 4 to 20 years before it is cut again for crop production (Sanchez 1976).

At the onset of the forested fallow system, forest plants re-establish rapidly either from new seeds or from well established roots inherited from a previous fallow. Roots feed the plants with nutrients. Some of these nutrients are stored, others are returned to the soil in the form of litter and rainwash from living leaves. Litter decays due to intensification of biotic activity mainly by termites, worms, bacteria and fungi in the soil surface, and this may all be added to the soil. Nutrient losses by sheet erosion are greatly reduced by the reduction of kinetic energy of the rain drops by the canopy cover and litter layer on the surface, and by the porous granular structure that develops in the mineral soil beneath it. Consequently, nutrients are transferred from the subsoil and stored partly in the topsoil by the process of vertical flux. Therefore, in the mature forest or bush, almost a closed cycle of nutrients between soil and vegetation is formed. Most of the carbon in the litter, however, is lost as CO_2. Nonetheless, some remains and becomes incorporated with the mineral soil as stable humus. Furthermore, oxidation of soil humus does not stop while the soil is under fallow, but during the early stages of the fallow, the rate of humus increase exceeds the rate of oxidation, and the humus will continue increasing until it reaches the equilibrium level achievable under a virgin forest. Forested fallow systems provide many beneficial physical changes in soils. The roots of trees bind the soil, improve structure, porosity and infiltration which lead to reduced erosion (Sanchez 1976; Nye and Greenland 1960).

Shifting cultivation in the savannas follows a different pattern than that of forested regions. In this system, vegetation is removed during the dry season by ploughing, usually by hand hoes, cutting or girdling the scattered trees, and burning. Nye and Greenland (1960) gave a typical account of the degradation of soil fertility under this system. They reported that when the savanna is burned and cleared for cropping, only few nutrients are deposited on the surface, in contrast to the forest. Grass and vegetation take time to recover, hence exposing the land to intense heat, and often to early and vigorous rains. Soil is more compact and less permeable due to the almost complete absence of soil cover and reduced litter. Nitrogen and C are lost in the burnt litter Furthermore, burning reduces the build up of humus in the top soil by reducing the amount of litter supplied to the soil organisms.

Sanchez (1976) reported that shifting cultivation in the savannas differs from that in forested regions in four main aspects: (i) the top soil is completely disturbed during the processes of removing grass roots, mounding and ridging; (ii) the cropping period is longer; (iii) the land lies bare during the dry season, hence creating substantial erosion hazards; and (iv) the plants that need to be weeded (i. e. competition for undesirable species) present a serious problem.

Closely related to shifting cultivation systems is the concept of bush fallow, a landuse system commonly practised by the Yanesha Indians of the central Amazonian Lowlands of Peru. The term bush fallow describes a system in which fallow vegetation consists of early pioneer trees and shrubs, the fallow period is short, and farmers consciously employ fallows to maintain land productivity (Staver 1989).

Many studies on bush fallow systems are available. Raintree and Warner (1986), and Ruthenberg (1976) reported that bush fallow cropping is the final stage in the intensification of shifting cultivation before the change to semi-permanent or permanent cropping. Staver (1988a) discussed the role of crop sequence, weeds and trees in bush fallow cropping. The discussion stressed that as the ratio of the length of the fallow (f) and cropping (c) stages decline (i. e. c greater than f), the bush fallow system is pushed closer and closer to becoming unsustainable. Furthermore, an extended cropping period, a shortened fallow period, or increased weeding can slow the rate of regeneration of trees and shrubs which are critical in humid tropical climates in restoring potential productivity (i. e. nutrients to the site).

Although many efforts were made to find ways to improve bush fallow cropping, such efforts were not successful (Ahn 1979; Nye and Greenland 1960). As indicated by Staver (1989), such unsuccessful efforts were due to many reasons, including insufficient attention to the structure and function of the bush fallow in restoring potential productivity and failure to take into account what farmers do and the criteria they might use.

The contributions of bush fallow systems to the soil productivity scheme are not precisely known. It appears that the contributions would vary with soil type, climate, and many other factors (Ahn 1979). It was observed that, during the fallow period, nutrients are accumulated in woody biomass (Nye and Greenland 1960), soil organic matter increases (Aweto 1981; Ramakrishnan and Toky 1981), soil chemical properties may improve (Sanchez 1979), weeds are eliminated and weed seed banks are reduced (Staver 1988a), and pest cycles are broken (Ofori 1974). Bush fallows vary from 3 to 10 years or more, depending on total available land and many factors in the family economy (Staver 1989).

To a farm household, the bush fallow may appear more attractive than any other landuse technology. The bush fallow establishes naturally. The land is cleared with simple tools and burned when opportunity costs for labour are low. Labour for planting and or management is not required. Furthermore, crop combinations, sequences, and cropping period, soils, and climate, dietary preferences, and labour availability, are usually compatible with the natural recovery of trees and shrubs as cropping intensity shrinks (Staver 1989).

In summary, shifting cultivation is extensively used in Africa for subsistence farming which requires long fallows for restoration of soil fertility and erosion control (FAO 1979). Until the last two or three decades, human population densities were low, and food needs and the basic necessities were met through cultivation of food staples grown in association with some perennial cash crops (Lal 1987). This kind of agricultural practice, however, was compatible with ecological systems because of several factors, including low human population, improvement in soil structure by plant roots, and erosion control through simultaneous growth of mixed crop species (Vietmeyer 1986). At the moment, this practice is not possible because of many factors, including ever increasing human population and changing patterns of agricultural activities.

In Eastern Zambia, for example, permanent cultivation systems have replaced the traditional system due to land pressure. Furthermore, fallow periods of 20 years or longer, which maintain modest yields with low financial inputs, are just no longer possible. Under the current practice, crops are often planted every year. Shortened fallows have also created many problems such as declines in soil fertility and crop yields, increased clearing of steep hillsides unsuitable for crop production, erosion, and additional labour requirements for fuelwood collection (Boehringer and Caldwell 1989).

Several strategies have been proposed to increase crop production in many parts of Africa. These include application of animal manure, mulching, and the use of green manures (a type of improved fallow). The application of animal manures in Africa can be effective. Most experimental evidence indicates that the effect of manure is related to its nutrient composition (Sanchez 1976). However, farm households' decisions to use either animal manures or chemical fertilizers are based on nutrient contents of these supplies, economics, transportation, and accessibility. Mulch farming has been shown to be beneficial for arid and semiarid conditions. For example, the practice reduces the magnitude of evaporation of water from soil (Sanchez 1976; Vietmeyer 1986). However, the difficulties in obtaining mulch material makes mulch farming a difficult innovation in Africa (Vietmeyer 1986). The application of N-fixing trees or shrubs in land use practice appears to offer a viable alternative to many farmers who experience problems of soil fertility, declining crop yields, and inability to buy inorganic fertilizers (Sanchez 1976).

3.5 Soil changes and plant response under improved fallow systems

Studies involving many different tree or shrub species on improved fallows have been reported (e.g. Kwesiga et al. 1991; Onim et al. 1990; Staver 1989; Boehringer and Caldwell 1989, Adejuwon and Adesina 1990). Leguminous species such as *Mucina*, *Pueraria*, and *Calopogonium*, as an alternative to bush fallow in rotation with grain monocrops were conducted at experimental stations beginning in the 1930's in Africa (Okigbo and Lal 1981) and continuing in the 1980's in Latin America (Sanchez and Benites 1987). In general, these studies demonstrate that these fallow species improve crop yield.

Adejuwon and Adesina (1990) showed that a *Gliricidium sepium* improved fallow system, under South Western Nigerian conditions, led to greater organic matter accumulation and increase in nitrate-nitrogen and potassium concentration in the soil. They also reported that the biomass retained greater amounts of nutrients during the fallow.

Among researchers, there is a considerable interest in SS because of its many characteristics (Table 3.1). Studies show that this species has several advantages over other perennial nitrogen-fixing counterparts. Dutt and Jamwal (1990) reported that, besides being a potentially suitable soil ameliorant, SS can tolerate adverse soil and climatic conditions, withstand seasonal flooding and waterlogged soils, tolerate saline and alkaline soils, and drought. Kwesiga et al. (1991) also reported that SS is suitable for improved fallow systems because of its fast growth, high biomass production and weed suppression, short time of three years to reach maturity, high litter production in growing seasons, prolific seed production, ease of propagation and destumping, and easily degradable biomass with no allelopathic effects to cereals after fallows.

3.6 Modelling and simulation of soil changes under *Sesbania sesban* improved fallow system

In agroforestry systems, the tree or shrub component can fulfil both productive and service roles. Although many products are obtained from trees or shrubs, the most important ones are usually timber, fuelwood, fodder, and fruit. The service roles include provision of shade for humans and livestock, shelter from wind, fencing and boundary marking, and moisture conservation (Young and Muraya 1990). For developing countries in general, however, the greatest benefit of agroforestry practices such as fallow systems appears to be soil conservation (Young 1985, 1986, 1987, 1988, 1989).

The term soil conservation, in its older and narrower meaning, meant protection against erosion. It is, however, now recognized that what is really important is the conservation of soil fertility, or the productive capacity of land. Although protection against erosion is one necessary condition for this, it is equally important to conserve organic matter and physical properties, especially in most developing countries where rapid rate of nutrient turnover or cyling prevail (Young 1989). Thus, soil conservation refers to maintenance of soil fertility. It is a major contributory factor to sustainable landuse.

It is important to understand and predict how soil fertility would change under SS fallow in Katete District, and to compare this with the effects of continuous cropping with or without fertilizer use. This approach can provide a useful mechanism for assessing the sustainability of SS fallow system, not only in biological terms, but also to determine whether it is beneficial both economically and socially for the agricultural households in Katete.

Models for predicting soil dynamics have been developed (e.g. McGill and Christie 1983; McGill and Cole 1981; Anderson 1987). However, none of these studies was specific to agroforestry systems. More recently, a model to describe soil changes under agroforestry (SCUAF), including its computer program, was developed and documented by Young and Muraya (1990). The prediction of soil changes under the SS fallow, in this study, is based on this model.

The SCUAF model was chosen for three reasons. First, the model is versatile in that it can predict soil changes under different agroforestry systems. These include shifting cultivation, improved fallow, hedgerow intercropping or alley cropping, taungya, trees on cropland, plantation crop combinations, multistorey tree gardens, boundary plantings, trees on erosion-control structures, windbreaks, and shelterbelts, live fences, biomass transfer, trees on rangelands or pastures, plantation crops with pastures, woodlots with multipurpose management, and fodder banks. SCUAF can also handle other non-agroforestry systems such as reclamation forestry leading to multiple use, agriculture, forestry, pastoralism and horticulture. Second, SCUAF is an interactive model: the user enters data in response to prompts on the screen, and selects the results required. It is primarily an input-output model representing soil-plant processes by means of relatively simple relations dependent on the data supplied. Third, where data are incomplete or missing, SCUAF contains a set of default data, specific to the chosen region or environment (Young and Muraya 1990).

3.6.1 The operation of the model

The SCUAF model works on the basis of whole years. It does not simulate fluctuations in soil processes and properties within a year. Its outputs can be obtained for any length of time, ranging from the short-term period of 3 to 5 years, to a long-term investigation of soil trends to about 50 years. However, it is most appropriate for the evaluation of soil trends over medium-term periods of 10 to 20 years, a length of time which is adequate for an indication of sustainability (Young and Muraya 1990).

Soil erosion, soil organic matter (represented as carbon) and nitrogen cycling are described by SCUAF. The control of erosion is an essential and fundamental step in the maintenance of soil fertility. Erosion leads not only to the reduction in profile depth and complete loss of soil, but also to losses of organic matter and plant nutrients in the eroded deposit (Young and Muraya 1990, Morgan 1986, Jacks 1986).

3.6.2 Origins of the model

The SCUAF model traces its origins to various sources. The erosion prediction model is based on the work by FAO (1979). This is a simplification of the universal soil loss equation (Wischmeir and Smith 1978). The basis for the carbon cycle rests on the work described by Nye and Greenland (1960), which is combined with evidence from research using the ^{14}carbon isotope labelling technique (Paul and van Veen 1978; Young 1989, p.110). Various carbon cycling models have also been considered which include work done by Jenkinson and Rayner (1977), Smith (1979), van Veen et al. (1981), Brunig and Sander (1983), Bosatta and Agren (1985) and Parton et al. (1987). The nitrogen cycle is derived from Frissel (1977), Roswall (1980), Wetselaar et al. (1981), Robertson et al. (1982), Stevenson (1986), Parton et al. (1987) and Young (1989, p.151).

3.6.3 Components of the model

There are three major components of agroforestry systems which are dealt with in the SCUAF model. These are trees or shrubs, crops, and soils. The trees or shrubs and crops form the plant compartment; while the soil compartment consists of an erosion element, the carbon and nitrogen cycles.

The tree or shrub component is partitioned into leaf (herbaceous matter), fruit (reproductive matter), wood and root. Organic additions such as compost or manure may be treated as an additional plant parts coming from outside the system. As a starting point, modelling is based on annual net primary production, or biomass growth of leaf, fruit, wood and root for the tree and crop, together with the biomass in organic additions. Plant biomass (dry matter) is then converted, by the model, into carbon and nitrogen.

The plant parts are subjected to various changes. Some parts are harvested annually, usually crop fruit and sometimes tree leaf (as fodder), tree fruit or crop leaf residues (as fodder or other uses). In some agroforestry research projects, the trees are allowed to grow for many years, hence increasing their woody biomass. These are later felled or coppiced. The time at which the trees are cut is referred to as "cut year", marking the year the trees (or perennial crop) are "cut" in some way (e.g. felling, coppicing), with an additional harvest. However, there may also be some non-harvest losses of plant parts due to factors such as burning and pest or disease destruction.

What is not harvested or lost "is removed" or subtracted from the plant compartment of the SCUAF model. Such material may be referred to as litter (natural leaf fall, tree prunings, crop and root residues). The litter or the plant material entering the "soil compartment" consists of about 50% carbon and a very variable percentage of nitrogen. This, however, depends on the plant parts and species (Young and Muraya 1990).

The soil compartment is that portion of the model which calculates the changes which occur yearly in soil properties. Outputs of litter, including its content of carbon and nitrogen from the plant components constitute an input to the soil compartment.

Erosion, one of the elements of the soil compartment, is estimated using a modified version of the universal soil loss equation (Wischmeier and Smith 1978):

$$\text{Erosion (kg/ha/yr)} = R \times K \times S \times C \times 1000 \tag{3.1}$$

where R = climate factor, K = soil erodibility factor, S = slope (LS in the universal soil loss equation (USLE)) and C = cover factor. The factor 1000 is used to convert from the unit of tonnes used in the USLE to that of kilogrammes used in SCUAF. The original version of the equation was based on non-metric units, giving erosion in tons per acre. The SCUAF model requires the metric version, which gives erosion in tonnes (converted to kilogrammes) per hectare. The climate and soil erodability factors differ between these versions. Therefore, SCUAF uses estimates of the factors for the metric version. The support practices factor (or the erosion-control practice factor), P, in the original version of the equation is also omitted because it is assumed that the agroforestry system itself may provide such support (Young and Muraya 1990).

The values of the factors are entered in the model. Cover is estimated separately for the tree and crop components, multiplied by the proportional areas under tree and crop in the agroforestry system, and adjusted for an element specific to the agroforestry system, the tree proportionality factor. This represents the extent to which the tree component has an effect in controlling erosion disproportionate to the area of land it occupies. Carbon and nitrogen losses in eroded soil are computed from the amount of soil loss, the carbon and nitrogen content of the top soil, and sediment enrichment factors which represent the empirical evidence that the eroded soil is richer in carbon and nitrogen than the soil from which it is derived.

The calculation of erosion values described here is necessary where erosion data or estimates are absent. However, where such information is available, the value of erosion can be entered directly as soil loss in kg/ha/yr.

With respect to the carbon cycle, litter is broken down and converted to soil organic matter or humus by soil meso-and micro organisms (Young 1989). Under tropical conditions, this process usually takes less than 6 months, during which more than half the carbon is lost as carbon dioxide, the first part of two losses (erosion and humus) through litter oxidation. Erosion initially removes the topsoil carbon contained in eroded sediment. The final loss is humus oxidation, in which a small proportion of soil humus carbon, commonly 3 to 4% annually, is oxidized by microorganisms. This is a "homeostatic process" in which the amount of oxidation loss varies with the amount of soil carbon present. Mathematically, the oxidation process was represented by Young and Muraya (1990) as:

$$C_{t+1} = C_t \times (1-k) \qquad (3.2)$$

where C_t is the carbon in year t, C_{t+1} the carbon one year later, and k is the decomposition constant. This is the equation which SCUAF adopts. In isotope studies, the same relationship is frequently expressed as:

$$C_{t+1} = C_t e^{-kt} \qquad (3.3)$$

where e is the exponential constant and r a constant. When there is a loss of less than 10% of soil carbon each year, r is nearly the same as the decomposition constant k. The SCUAF model adopts the former equation, using k.

The nitrogen cycle in the plant compartment is identical, and the nitrogen contained in the specified plant parts is regarded as the amount of nitrogen at the time at which each part leaves the compartment, either as harvest or litter (Young 1989).

Nitrogen is stored in the soil as organic (or humus) and mineral deposits, the mineral portion being relatively smaller than the organic part. It has been reported that mineral N in the soil represents a very small and usually transitory pool of N with respect to the total N stock of any ecosystem. Major forms of mineral N (NH_4^+ and NO_3^- -N) usually account for less than 2% of the total N content of soils, and this is the N directly available for direct plant uptake (Haynes 1986).

A proportion of nitrogen from the litter enters the soil humus, whereby the amount absorbed is checked by the litter carbon and the carbon:nitrogen (C:N) ratio of the soil humus. Furthermore, part of the humus nitrogen is converted annually to mineral form by a process of humus mineralization. Soil humus nitrogen undergoes changes similar to humus carbon: a gain from litter humification against which are set losses through erosion and mineralization (Young and Muraya 1990).

Soil mineral nitrogen forms the second phase of the nitrogen cycle to be modelled. The magnitude of the soil mineral nitrogen pool varies seasonally, sometimes containing only 1% of the nitrogen held in organic state. The SCUAF model assumes that the mineral nitrogen reservoir is built up and drawn down annually. Inputs to it come from the mineralization of litter and humus, non-symbiotic fixation, organic additions such as manure, and inorganic supplies such as fertilizers. Having determined the size of the mineral nitrogen pool, specificied fractions of this is lost through leaching, gaseous losses by denitrification and volatilization, and net fixation onto clay minerals (Young and Muraya 1990; Swift et al. 1979; Haynes 1986). SCUAF does not separate nor model the conversion between ammonia and nitrogen. Nevertheless, it allows for the observed evidence that the leaching loss of fertilizer nitrogen is proportionately more than that of organic sources (Young and Muraya 1990).

Plant uptake consists of soil mineral nitrogen absorbed by the plants. This is the portion which is not lost or leached. The soil mineral nitrogen is added to the nitrogen coming from the atmosphere into the plants through root nodules by a process of symbiotic fixation. No plausible way is found to divide plant nitrogen uptake between the tree and crop, but this is indicated by the nitrogen content of the biomass of each cycle which is specified at the start of the model (Young and Muraya 1990).

Plant growth slows as a result of low nitrogen and carbon supplies in degraded soil. SCUAF incorporates (or recognizes) three forms of soil degradation or improvement: changes in organic matter (carbon) relative to the initial conditions, nitrogen, and soil profile depth due to erosion. There is a feedback system adopted in the model which monitors carbon or nitrogen status in soil properties relative to their initial conditions. An improvement in soil carbon, nitrogen, and erosion status can correspondingly lead to the improvement in plant growth. Mathematically, Young and Muraya (1990) generally represented this improvement as:

$$NPP_t = NPP_1 \times [1+(((V_t - V_0)/V_0) \times VFF)] \qquad (3.4)$$

where NPP_t and NPP_1 are net primary production in years t and 1 respectively. V_t and V_0 are values of a variable in years t and 0 (initial conditions) respectively, and VFF is the feedback factor for the variable. Feedback variables used are carbon (soil organic carbon), nitrogen (plant nitrogen uptake), and depth (soil profile depth).

Considering changes in nitrogen in the plant-soil system as whole, gains are realized in symbiotic and non-symbiotic fixation, rain and dust, organic inputs and fertilizer. Losses are harvest (including fodder), erosion, leaching, gaseous losses and often burning. The plant-soil system appears to be an indicator of long-term sustainability. It also allows an assessment of whether annual system gains can compensate for losses when mature trees are removed as harvest or otherwise (Young 1989).

The SCUAF model simulates the effects of the predicted soil change upon plant growth. If the soil carbon, plant nitrogen uptake or soil profile depth decrease, plant growth is likely to become slower. If they increase, then plant growth become faster. The magnitude of the effects of soil properties upon the plant is specified by the user. The outputs of the SCUAF model include changes in erosion, soil carbon and nitrogen, C:N ratios, biomass production, and crop yields. The user can select and report the results required for the study (Young and Muraya 1990).

Table 3.1. Ecological characteristics of *Sesbania sesban*

Genus:	*Sesbania* Scopoli is a genus of about 40 species, comprising of 80 taxa
Family: Subfamily: Botanical tribe:	Leguminosae Papilionoidae Robinieae
Species:	Include *S. sesban* var. *sesban*, *S. sesban* var. *nubica*, *S. grandiflora* and *S. macrantha*
Distribution and range:	Tropical and subtropical regions (distribution throughout most of Africa and across Southern Asia to the Pacific) Altitude: 1000-2000 m above sea level (East Africa); and the foothills of the Himalayas in India Found in zones that are semiarid to subhumid with annual rainfall between 500 and 2000 mm
Edaphic conditions:	Sites that are seasonally very moist: along streams, lakes and swamps Well adapted to fluctuations in soil moisture; and tolerant of both drought and waterlogging
Reproduction:	From seeds
Taxonomy:	Pinnate leaves with opposite pinnules Leaflets range from 10 to 40 mm in length and 5 to 10 mm in width Leaflet pairs: 10-24 Flowers are usually borne in loose axillary racemes (about 4-20 flowers)
Growth characteristics:	Generally grow rapidly, producing high yields May be annual (herbs or shrubs) or perennial (shrubs or small trees) majority are annual herbs or shrubs from 1 to 4 m high with semiwoody stems The minority are perennial shrubs and trees from 2 to 10 m high (e.g. *S. grandiflora*, *S. sesban* var. *sesban*, *S. sesban* var. *nubica*)
Longevity:	Subgenus *Sesbania* may be short-lived (e.g. 2-3 years for *S. macrantha*, 5-10 years for *S. sesban*)
Pathogens:	Roots of *Sesbania sesban* are known to be attacked by parasitic nematodes, causing significant tree and crop losses (D'Hondt-Defrancq, 1993)

Source: Macklin, W. and Evans, D. O. (eds.). 1990. Perennial *Sesbania* species in agroforestry systems. Proceedings of a Workshop. March 27-31, 1989. ICRAF/NFTA. Nairobi, Kenya: ICRAF.

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Chapter 4

Methods

4.1 Introduction

An assessment of the effects of SS improved fallow on farm households in Katete requires an understanding of the socio-economic aspects of current farming conditions, including production, consumption and investment opportunities and constraints. Second, an understanding of the biological and economic aspects of the improved fallow system is also needed before examining its effects on the farm households. This chapter addresses these two requirements. It deals with the on-farm field work, data collection and analysis to fulfil the first requirement. With respect to the second requirement, the chapter presents a discussion of the on-station improved fallow data compilation, adjustment and analysis, and the application of the data to the current farming conditions to assess the potential effects of the improved fallow system on the households.

The methods used in this study included the following components:

(1) Field work (survey):

(a) Location, selection and description of the study area.

(b) Population of the households for the study

(c) Sampling design

(d) Formulation of the survey

(e) Developing, translating and pretesting of questionnaire

(f) Selection and training of field enumerators

(g) Method of interviewing the respondents

(h) Data analysis

(2) Secondary data sources

(3) The SCUAF simulation

4.2 Field work

4.2.1 Location, selection and description of the study area

Katete was selected as a study site for three reasons. First, it is under increasing stress from human and livestock populations, shortened fallows, and reliance on chemical fertilizers. Thus, Katete is a prime target area for soil related agroforestry practices. Second, on-farm agroforestry reference trials already exist in Kagoro, Katete. Three, the agroforestry project team at Msekera have well established working relationships with agricultural staff in Katete.

Katete is the most productive district in Eastern Zambia. It falls within the unimodal (one rainfall season) eastern plateau of Zambia which is marked by latitudes 10° and 15°S and longitudes 30° and 33°E (Figure 4.1). Maize and livestock production is common in Katete (ICRAF 1988). Cash crops include hybrid maize, sunflower, groundnuts, tobacco, and cotton. Food crops include local maize and beans. From *dambos*, assorted vegetables, sugarcane, bananas and other fruits are produced for both domestic consumption and sale. Fuelwood, honey, mushrooms and other wild fruits are gathered from the forest. Livestock includes cows, pigs, goats and chickens.

Katete District covers a total area of 3877 km^2. The population in 1990 was 139,679 people, of which 72,464 were female and 67, 215 were male. The population per km^2 was 35 persons (Central Statistics Office, 1990), exceeding the subsistence level of 32 persons per km^2 proposed by Nye and Greenland (1960). As explained in Chapter 2, Katete is mainly dominated by the *Cewa* tribe who practice a matrilineal type of kinship. The tribe favours large village settlements of up to 100 homesteads or families (Mpatishi per. comm.).

Katete is characterized by gentle to moderate slopes that are interspersed with hills, ridges, and minor escarpments in a rolling landscape. *Dambos* or seasonally waterlogged areas are also a common feature. The plateau, in some areas, rises to about 900 to 1200 metres above sea level. In low-lying areas, altitudes of 300 to 600 metres occur (ICRAF 1988).

The soils in Katete are variable. However, the most predominant soil group is the sandvelt. Commonly found soil types include the yellowish-red to light yellowish-brown, loamy sands or sands (acrisols by FAO/UNESCO classification), and the grey-brown, loamy sands (Kwesiga et al. 1991).

The climate is classified as subtropical (ICRAF 1988) or subhumid (Young and Muraya 1990) with three clearly defined seasons: (1) the warm, wet season (November to April), (2) the cool, dry season (May to August), and (3) the hot, dry season (September to October).

According to ICRAF (1988), annual rainfall averages at least 900 mm, ranging from 887 to 1014 mm, with approximately 85% of the rain falling in the months of December, January, February and March. Average air temperatures vary from 15° and 18° during the coldest months of June and July, to 21° and 26° during the hottest months of September and October. The growing season is 139 to 155 days long.

Marketing services are provided by several agencies. The major one is the Eastern Cooperative Union stationed in Chipata.

4.2.2 Population of the households for the study

Two sub-populations were considered for the study: the male and female headed agricultural households, all of whom were ox-hoe users and had been farming for at least 5 years. A female headed farm household was considered as someone who was single, divorced, or widowed, and had workers and dependents. A male headed household was considered a married man who had workers and dependents. The head of a farm household was regarded as a manager, with dependents or family members as his or her employees. According to Fred Kwesiga, this is the group of farmers for which an agroforestry improved fallow system has been intended.

Only the head of the household was considered for the interview because it was assumed that all household resources (land, labour and capital) were pooled, all expenditures were made out of pooled income, and that it was the head of the household making production and consumption decisions, and had the information regarding farm management. Interviewing each household member would have been a very costly activity given the financial constraints underlying this study.

The length of time of farming was important in selecting the male and female headed households for the study because it was necessary to concentrate only on those farmers who were relatively settled in villages and were committed to farming. The male and female headed households who had been farming for at least 5 years were selected and recorded on the sampling frame developed by the researcher.

4.2.3 Sampling design

In Katete district, there are 25 agricultural camps (Department of Agriculture Landuse Map, Chipata 1982). An agricultural camp is defined as a cluster of at least 500 farming households (Camp Officers, per. comm.). To control for homogeneity in the households, the selection of the camps for the study was based on the following criteria:

(1) Soil conditions: it was necessary to have a fairly uniform soil condition to minimize for variably in soil properties or productivity. Only those camps falling within the sandvelt soil group (1986 Agroclimatic and Farming Systems Map) were selected. It was not possible, however, to control for micro soil differences.

(2) Farming conditions: it was necessary to restrict the study to areas with similar farming conditions and farming practices (landuse and cropping patterns).

Out of 25 camps, 11 satisfied these conditions and were selected. The remaining 14 were rejected. The selected camps were Kafumbwe, Chilembwe, Kameta, Ngombaela, Kagoro, Gaveni, Chinkhombe, Mzime, Chanjoka, Kawalala, and Vulamkoko.

A sampling frame for recording all the names of both the ox-hoe male and female headed farm households who had been farming for at least 5 years in the selected camps was developed by the researcher. Names of the male and female headed households in each camp were collected by the camp officers and compiled by the researcher. Table 4.1 shows the total number of the male and female headed households in each camp.

Extraordinary circumstances such as households located near main roads, urban centres, and foreign project areas were avoided during the selection of households for interviews. The objective was to avoid bias from these influences which could affect the information collected from the respondents.

The selection of the sample size, each for the male and female headed households, was based on the variability of local farm conditions, degree of precision required, available time and money, accessibility in the villages, and the number of enumerators for the interview. Variability of local farm conditions was determined as follows: (1) data were collected on the constructed set of four questions regarding biographic aspects of household characteristics: age, education, and number of dependents and number of years of farming, and (2) based on the Dillion and Hardaker (1980) procedure, the data were subjected to a descriptive statistical analyses (i.e. means and standard deviations) to determine the variability among camps and households as the basis for determining the sample sizes from the male and female farmers.

Based on the criteria for the sample size selection outlined above, 60 male farmers and 60 female farmers were selected as sample sizes. As a guide, CIMMTY (1985) suggested that a minimum of 20 to 25 cases in each of the major sample categories would be adequate to make statistical comparisons between the groups. However, for practical purposes, a final sample size of 40 is usually sufficient for meaningful statistical analysis in a homogeneous group of farmers. Normally 50 farmers are selected to ensure that 40 is obtained as a final sample size.

As shown in Table 4.1, it was observed that there were variations in the number of male and female headed households among the camps. For each sub-population, the number of farmers to be selected from each camp for the interview (NSC) was calculated as follows:

$$NSC = (NFC/TNF) \times 60 \qquad (4.1)$$

where NFC is the number of farmers in each camp, and TNF is the total number of farmers in the camps. Second, the names of farmers to be interviewed were then randomly selected from the sampling frame. Table 4.2 shows the distribution of the farmers by gender and camp.

The sampling fraction was different for each camp because the number of farmers in each camp was also different. It was important to give each camp and farmer an equal chance of being picked.

4.2.4 Formulation of the survey

A conceptual model describing the farming system in Katete farming system was revised and a final version made (Figure 2.1, Chapter 2). The revision was based on the understanding gained from the interactions with the chiefs, camp officers, villagers, consultation of the existing literature, discussions with some officials of the Department of Agriculture in Chipata, and friends. It was important to obtain this understanding to ensure that the data collected reflected the socio-economic aspects of the current farming conditions in Katete District.

4.2.5 Developing, translating and pretesting the questionnaire

Based on the conceptual model developed in Chapter 2 (Figure 2.1), a questionnaire was developed (the final version included as Appendix 1). This formed an element of a structured survey. The questions were listed in a systematic manner which were to be presented to the respondent. The procedure adopted was similar to that of Casley and Kumar (1989).

The questionnaire contained questions which were both open-ended and closed. Open questions were to allow the respondent to give a response which was not pre-determined, but the response was recorded by the enumerator. Closed questions were to give the respondent a limited set of responses, and he or she had to identify one or more of those applicable to his or her situation.

The questions were worded such that they were simple for both the enumerators and the respondent to understand. Leading questions (i.e. a question phrased such that it looks if a certain answer seems to be expected) were avoided. Pleasant, interesting, and easy questions were put in the opening section of the questionnaire. Sensitive and difficult questions were put at the end of the questionnaire.

The enumerators were involved in the drafting and fine tuning of the questionnaire. The first draft of the questionnaire was made by the researcher. This was discussed with the enumerators and colleagues. The enumerators were then requested to work independently in translating the draft into the local language, *Nyanza*. Two drafts came out of the exercise which were later pooled and discrepancies dealt with. A third draft, still in the local language, was produced. This was converted to English and later translated into the local language making a fourth draft. This draft was checked by an independent third party before being translated again into English. The double reverse translation of the questionnaire from English to *Nyanza*, and then from *Nyanza* back to English was undertaken to ensure that each respondent was presented with clear and well defined identical questions. Most importantly, it was to make sure that the responses recorded were accurate. In order to achieve this task, the enumerators (who are English speakers) were involved in the translation because they were familiar with local idioms and terminologies. The revised copy was now ready for pretesting in a selected area within the study site.

The questionnaire was used to collect responses related to the household's land, labour and capital resources, its resource allocation processes, and priorities, especially:

a. Household characteristics: gender, dependents, relatives living away, age, education, diseases, witchcraft experiences.

b. Labour composition: gender, permanent, seasonal or causal labour, and mode of payment.

c. Livestock: types and number.

d. Landuse practices: years of farming, changes to landuse since farming begun, cropping patterns, area of land farmed, cultivated and under grass and wooded fallows,

e. Fertilizer use: type, quantity, cost and rate of application.

f. Household sources of income and expenditures.

g. Gathering of forest products: type, quantity, distance of gathering, and quantity consumed.

h. Household's perception of agroforestry improved fallows, tree planting, human population growth and agricultural development.

The questionnaire was pretested on three female and three male farmers. The enumerators and the researcher were involved in the exercise. The questionnaire was pretested to assess the wording of the question, construction of the sentence, question format, difficult questions, time requirement, interviewer's competence, and whether the questionnaire was generating the data as stipulated by the purpose and objectives of the study. The questionnaire was revised and the new version was made. The new version was tested with one male and one female headed farming household. The researcher and enumerators were satisfied with the final version of the questionnaire. The questionnaire was duplicated for the actual survey (Appendix 1).

4.2.6 Selection and training of field enumerators

Two field enumerators: a male and a female were selected and trained according to the procedure described by CIMMYT (1985). They were selected on the basis of five criteria: personality, local knowledge, qualifications and experience, competence, age and gender.

The personality factor was related to someone who was approachable and would be liked by farmers. Most importantly, he or she shoulu oe able to work hard, travel under difficult conditions, have patience, should be tactful and flexible, open-minded and sympathetic towards the farmers' problems. Knowledge of local language, farming practices and units of measurements, and customary laws and traditions of the farmers was one of the important factors considered in the selection of the enumerators. The enumerators were selected from the study area because the researcher could not understand the *Cewa* language.

The enumerators were selected based on qualifications and experience related to field surveys. References were obtained from previous employees as a basis for selection. The competence criterion was related to the enumerators' ability to observe, measure and record responses. The enumerators selected were 25 to 35 years old. It was assumed that someone within this age range would be flexible and able to conform to the cultural setting and perceptions of the farmers.

A male enumerator was chosen because male headed farming households would probably respect a male interviewer, considering that this is a male dominated society. Similarly, a female enumerator was considered as an appropriate person to interview female headed farming households. This is because women generally appear to feel more comfortable in discussing their farming activities with their female counterparts (Mpatishi per. comm.).

Training of the enumerators dealt with the following issues: orientation of the enumerators, techniques of interviewing, and familiarization with questionnaire. The orientation of the enumerators emphasized the purpose and objectives of the research, the concepts and terminologies used in the study, touring and meeting the local authorities, agricultural households in the study area, and field work organization, sampling procedure, sample size selection, logistic support, time-table for interviews, persons to be interviewed, and mode of payment.

Techniques of interviewing were mainly concerned with the issues relating to the relationships between the enumerators and the farmers during the interview process. The enumerators were made aware that they should consider the farmers as an important component of the survey process. Thus, they should introduce themselves in the most appropriate manner (e.g. greeting the farmer in the local language, introducing himself or herself where he or she was from, their names, the purpose and objectives of the study). They were to explain that each farmer had been picked on random basis. The enumerators were to know the place and the timing of the interview, the most convenient time for the interview such as holding interviews on the farmers' farms so as to check on the size of their farms, where possible. The enumerators were also taught how to ask questions. They were instructed to:

1. Not rush with questioning, the farmer was to be given plenty of time.
2. Avoid asking questions with obvious answers which could annoy the farmers and jeopardize the data collection process.
3. Keep the farmer on track during interviewing. This would require a tactful approach.
4. Take extreme care not to suggest answers for the farmers.
5. Have absolute patience with the farmer by re-phrasing the question if the farmer did not understand, and recording only relevant answers.
6. Maintain a high degree of alertness for inconsistent answers and to follow-up on them.
7. Work within the maximum time allowed for the interview. The limit was 1.5 hours.
8. Check and make sure that all questions had been properly answered and recorded in accordance with the purpose and objectives of the study before terminating the

interview.

9. Replace missing or unfriendly respondents, by selecting replacements randomly from a back up of households recorded in the sampling frame.

The enumerators were also made familiar with the questionnaire by involving them in its formulation and pretesting. They were also encouraged to offer suggestions or to ask additional questions on any aspect of the questionnaire. During the interviews, the enumerators were visited at regular intervals to ensure that they were following the above survey principles; and the questionnaire was being filled in correctly and fully, with all the blank spaces filled in and no question left unanswered. The researcher's role was then to collect and check immediately the completed questionnaire. Problems and errors observed (e.g. forgetting to record the respondent's years of schooling) were immediately explained to the enumerators. They were instructed to correct such mistakes immediately before leaving the field and to avoid repeating such mistakes.

The researcher kept a diary and a copy of the questionnaire to record comments and general observations about the local farming area while the enumerators were recording responses. The researcher also ensured that the enumerators had transport, adequate supply of questionnaires and pencils for the interviews. To avoid being "burnt out", and to keep the enumerators motivated, they were paid and made to feel part of the team by involving them in various stages of field work.

4.2.7 Method of interviewing the respondents

The respondents were interviewed between March and June 1992. Camp officers and chiefs were notified in advance on when the interview process would begin, the period it would cover, and the schedules for interviews (i.e. dates the interview would take place in each camp). The objective was to seek cooperation and to avoid any inconveniences (e.g. farmers not available either at home or in their fields) that could have occurred if prior arrangements were not made.

Based on the interview techniques discussed in section 4.2.6, the questionnaire was administered with face-to-face interviews supervised by the researcher. The enumerators were reminded during each interview to first ask the respondent for his or her permission. This approach was undertaken to check the willingness of the respondent, and to establish confidence and trust between the enumerators and the respondent. They were also reminded to introduce themselves politely and explain the purpose of the interview to the respondents. The interviews were conducted mainly at home and in the farmers' fields (where the fields were less than 1 km or the road was accessible by the vehicle).

Throughout the interview process, the researcher kept a dairy of observations and comments about the camps, by talking to the enumerators, camp officers and chiefs (through camp officers). This approach was undertaken because the researcher wanted to increase his understanding of the farming conditions in Katete by collecting additional information to supplement the information collected through the questionnaire.

4.2.8 Data analysis

The responses were coded and converted to scientific units where appropriate. The responses were compared with the data from published sources describing the Katete farming systems. Among the male headed households, 5 gave responses which were unreasonably high (as compared to existing typical values for the region). They were eliminated from the study. Responses from the female headed households were generally within the range typical for the region. However, 4 gave incomplete responses and 1 female headed household gave responses which were contradictory and doubtful. These households were also eliminated from the study. It was assumed that if the 10 households eliminated were included in the analyses, they would create biases and affect the accuracy of the results. Thus, a total of 110 households (55 male and 55 female headed households) was accepted as the final sample size for the analyses.

The responses were summarized and subjected to descriptive statistical computations such as normality tests, means, standard deviations, minimum and maximum values, percentages, and correlation coefficients, based on the procedure set out by Zar (1974). To test the hypothesis that "the male and female headed households were similar in characteristics, t-tests were performed as outlined in Zar (1974). A computer software package, SPSS/PC + Advanced Statistics, V2.0 (SPSS Inc. 1988) was used to perform the descriptive analyses.

4.3 Secondary data sources

The data for simulating changes in soil productivity under continuous maize cropping and SS improved fallow were the application rate of fertilizer/ ha under maize production, SS and maize biomass productions, soil organic C and N, slope, drainage, soil-plant feedback factors, N-fixation under SS, SS proportional factor, N gains and losses from the SCUAF system. All of these data were averages: they were not raw data. They were obtained from Kwesiga et al. (1991), Mhango (1991), SCUAF User's Handbook (Young and Muraya 1990), ICRAF (1988), Katete Meterological Department, Zambian Ministry of Agriculture, Department of Agriculture, Eastern Zambia, Onim et al. (1990), Macklin and Evans (1990).

Initial carbon and nitrogen levels, and other parameters used in simulations with SCUAF model are typical for Katete farming conditions and are generally within the range reported for the subhumid, miombo ecozone of Southern Africa (Vermeulen et al. 1993, Mhango 1991, Young and Muraya 1990). However, the initial SS net primary productivity (kg DM/ha/yr) value used in the simulations with SCUAF was based on Msekera data. The net primary productivity data typical for Katete farming conditions were not available. While Msekera has richer soils and operates under different practices than those of the Katete farmers, it was assumed that other input parameter values used in simulations with SCUAF would serve as "correcting or discounting factors" to reconcile SS biomass differences. Thus, SS net primary productivity and SS contribution to the improvement in soil fertility in Katete would be less than the production and contribution observed at Msekera.

Estimates of labour demand and costs associated with the establishment, tending and harvesting of SS seedlings were obtained from the interviews with the Agroforestry Technicians at the Research Station.

4.4 The simulation of changes in soil productivity under *Sesbania sesban* improved fallow

Predictions of changes in erosion, soil organic carbon, soil organic nitrogen, and maize yield over a 20 year period under SS fallow system, and continuous cropping with and without fertilizer use (i. e. for comparison with the fallow system) for the ox-hoe farming system in Katete were based on SCUAF model described previously.

SCUAF was tested for its accuracy and reliability by Vermeulen et al. (1993). The model was used to simulate natural miombo woodland and maize monoculture ecosystems in Zimbabwe. SCUAF outputs were compared to field measurements. The model accurately predicted changes in soil organic carbon in miombo woodland and maize monocrop systems. Maize productivity and plant nitrogen uptake were also well represented by the model. However, some problematic relationships within SCUAF were identified. The model was unable to accurately simulate miombo woodland productivity (biomass changes), and to accurately predict maize biomass changes under complex fertilization regimes because SCUAF was designed for frequently harvested agricultural systems which are always in the phase of rapid growth (Young and Muraya 1990).

4.4.1 The procedure

Following the SCUAF's input menu system, carbon and nitrogen cycles, climatic class, soil texture, drainage and reaction, and slope were specified and entered in the input menu as described in Appendix 3. Additional variables for the simulation also included:

1. Agroforestry system under study was SS improved fallow. It was simulated under several different fallow-maize cropping rotations (options) to determine the potential impact of each option on the farming system in Katete. The fractions of land under SS and maize were specified according the method set out by Young and Muraya (1990).

   In a similar fashion, a "control" (continuous cropping without fertilizer application) and one other treatment continuous maize cropping based on fertilizer application" were simulated to serve as a basis for comparison with SS fallow treatments, and primarily for the calculation of the amount of soil saved under various treatments.

   It was assumed that at the end of each fallow period, SS would be harvested and maize planted on the land. This assumption was based on discussions with the farm households and Camp officers.

2. Initial Soil Conditions:

   (i) Soil Depth: Entries for topsoil depth total depth of soil were calculated (except bulk densities) from the data provided by Mhango (1991). An average of the data from several locations in Katete was used in estimating soil depth as it was assumed here that these would reflect the general farming conditions in Katete and micro differences in soil conditions would even out (Mhango per. comm).

(ii) Carbon: Initial values for top soil carbon and subsoil carbon, both expressed in percentages, were calculated from the data provided by Mhango (1991). The values for topsoil and subsoil bulk densities, each expressed as g/cc, were assumed based on typical values suggested for Eastern Province by Young and Muraya (1990). For reasons given in (2i), only average values were used. The SCUAF model, therefore, calculates initial soil carbon (Young and Muraya 1990), expressed as kg/ha, as follows:

Soil depth considered x topsoil carbon x bulk density topsoil x 1000 (4.2)

where the constant of 1000 represents 10^8 square centimetres per hectare, divided by 10^2 to convert percent carbon to a fraction and by 10^3 to convert grammes to kilogrammes.

(iii) Nitrogen: The initial value for nitrogen in the topsoil, expressed in %, was calculated from the data provided by Mhango (1991). For reasons given in (2i), only the average value was used. The initial soil nitrogen (kg/ha) is computed by the model in a similar way by following the equation (2ii).

3. Erosion: Potential soil erosion (kg/ha/yr) is calculated by the model using the equation given previously in Chapter 3. Specifically, the following inputs were required for the calculation:

(i) Climate factor (R): was calculated following a procedure set out by Young and Muraya (1990) as:

$$R = 0.5 \times \text{mean annual rainfall} \tag{4.3}$$

where 0.5 is the constant given by the model. The mean annual rainfall was averaged from monthly values from the meterological data (1982-1992) provided by Katete District Meterological Office.

(ii) Soil erodability factor was calculated following the nomograph procedure set out by Wischmeier et al. (1971). The calculation was based on Mhango (1991) data.

(iii) Slope factor was calculated from the data presented in Young and Muraya (1990, p.77).

(iv) The value for cover factor under SS was obtained from the data presented in Young and Muraya (1990, p. 79).

(v) The value for cover factor under maize was also obtained from the data presented in Young and Muraya (1990, p. 79).

All the values for factors, except climate factor, were recorded as fractions. The potential soil erosion rates under SS and maize are computed by the equation given previously.

(vi) Tree proportionality factor is a measure of the extent to which total soil erosion in the system is controlled by the tree component. This value was obtained from Young and Muraya (1990, p. 78). Using this factor, SCUAF calculates erosion in year 1 under a given fallow system.

(vii) Carbon and nitrogen enrichment factors: values for these were also obtained from Young and Muraya (1990).

4. Initial Plant Growth:

(i) Net above-ground SS primary production, NPP (kg DM/ha/yr). The value for this was estimated from data presented in Kwesiga et al. (1991) using the procedure set out by Young and Muraya (1990).

(ii) Net above-ground maize primary (kg DM/ha/yr). The value for this was obtained from (Young and Muraya 1990).

(iii) All other entries such as SS roots as a fraction of above-ground NPP, maize roots as a fraction of above-ground NPP; and NPP in parts of SS and maize (kg/ha/yr) were calculated using the procedure set out by Young and Muraya (1990). Fractions of SS and maize retained as growth were also obtained from Young and Muraya (1990).

(iv) Carbon and Nitrogen: Data for C fractions in dry mass of SS and maize, and nitrogen percentages in the leaf, fruit, wood, and root of SS and maize were also based on data contained in Young and Muraya (1990).

5. Additions:

(i) It was assumed that because most farmers in Katete leave very little maize residues on their land after harvest (most are eaten by cattle), and because most farmers burn debris from their fields for a variety of reasons (Mpatishi per. comm.), no organic matter is added annually to the soil. However, data were not available to verify this assumption.

(ii) For continuous cropping with fertilizer (kg/ha/yr) application, most farmers use the recommended rate of application. Survey results from this study support this assumption. The recommended rate of application was obtained from data provided by the Zambian Ministry of Agriculture (1990). It is the rate recommended for the maize/ox-hoe farming system. The nitrogen fraction in fertilizer was calculated from the data provided by the Department of Agriculture, Eastern Province (1991, p. 38).

6. Removals:

(i) Harvest: Fruits are removed from SS at the end of each fallow period when they are matured before SS is removed from the land at the end of the fallow period. Similarly, maize is removed from the land at the end of each year.

(ii) Other losses from SS: It was assumed that there would be no other annual or periodic losses of plant material from the fallow system other than harvest.

7. Soil processes: These include conversion losses (litter to humus), humus decomposition constants (labile humus), nitrogen gains and losses. Estimates of these gains and losses were provided by Young and Muraya (1990). Nitrogen gains include symbiotic fixation per unit area of N-fixing in the tree (kg/ha/yr), non-symbiotic fixation (kg/ha/yr), and throughfall and stemflow (kg/ha/yr). A range of values of symbiotic fixation per unit area of N-fixing SS (kg/ha/yr) was used in the simulation to obtain an average. The values came from Onim et al. (1990) and Macklin and Evans (1990).

Nitrogen losses occur in two cases: mineral N of organic origin and fertilizer N. In the former case, fractions of mineral N leached under the tree or shrub and maize, and fractions of mineral N lost by gaseous losses (denitrification + volatilization) and by fixation onto clay minerals (net) are specified (Young and Muraya 1990).

8. Soil-plant feedback factors: These are values describing rise or fall in soil organic

carbon, plant nitrogen uptake, and soil profile depth (in percentages) for SS and maize in the SCUAF system. Estimates of the feedback factors were obtained from Young and Muraya (1990, p. 66).

For the purpose of comparing simulated maize yields at Katete to Msekera yield data, fallow lengths of 1, 2, and 3 years were used in simulations with SCUAF. Furthermore, it was also of interest to know when it is best to harvest SS, or to plant and harvest maize in a SS + maize rotation system in order to obtain sustainable maize yields. Figure 4.2 addresses this concerns by presenting simulation results over a 20 year period. It shows the highest levels (peaks) of maize yields which can be attained under SS fallow system. As time progresses, maize yields would decline under all fallow systems: SS planted for 1 year, cut at the end of the year, and then maize cropped continuously for the remaining simulation period (CM) or 1SS+CM; a 2 year of SS, followed by CM (2SS+CM); and a 3 year of SS, followed by CM (3SS+CM). In a 1SS+CM system, maize yield can be sustained until year 2; under 2SS+CM, it can be sustained until year 3 and 4; and in 3SS+CM, maize yield can be sustained until year 4.

Based on the results presented in Figure 4.2, different fallow-maize combinations, in a SS+M rotational system were simulated to determine the appropriate combinations.

4.4.2 The outputs

The outputs from the SCUAF simulation were: (1) changes in soil organic C and N, (2) soil erosion and (2) maize yield. These were obtained for each SS+M rotation considered and for continuous maize cropping with and without fertilizer application.

The potential soil saved (kg/ha/yr) among treatments was calculated from the soil erosion output as follows:

$$S = E_c - E_t, \qquad \text{Soil saved due to treatment effects,} \qquad (4.4)$$

where S is the potential soils saved or protected (kg/ha/yr) from erosion due to treatment effect, E is the potential soil loss (kg/ha/yr), c is control (continuous maize cropping without fertilizer application), t is the fertilizer + maize and the SS treatments outlined under the agroforestry system in Appendix 3.

To determine the socioeconomic effects of SS fallow system on ox-hoe farm households, estimates of labour demand and costs associated with SS fallow practice discussed in Section 4.3, together with the farm margin budgets (May 1990 input and output prices) produced by the Zambian Ministry of Agriculture, 1990, were used to estimate net returns and labour needed under SS+M rotation and CM+F for both the male and female headed households.

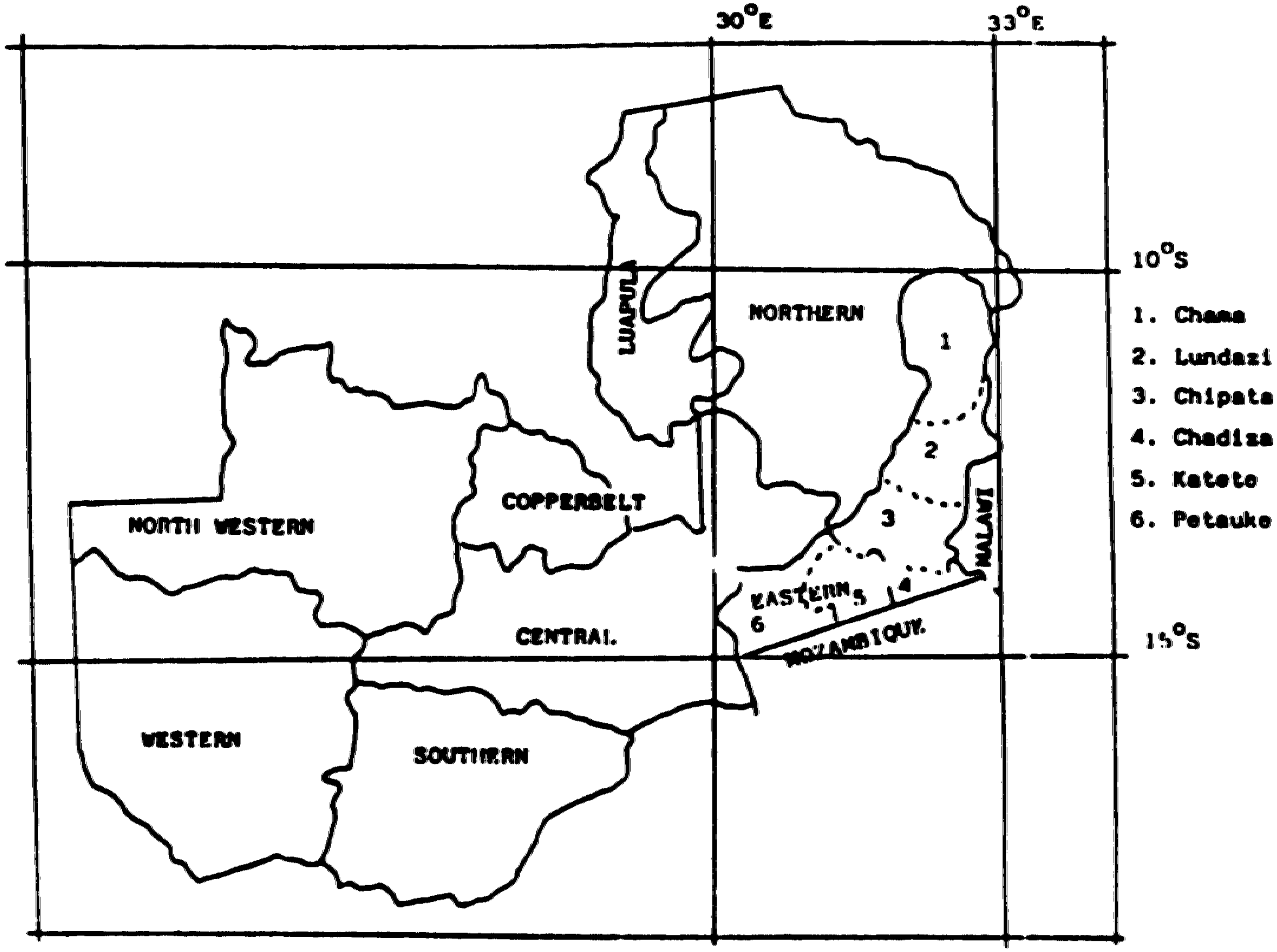

Fig. 4.1. The provinces of Zambia and the six districts of Eastern Province (ICRAF 1988).

Table 4.1. Distribution of male and female headed (HH) ox-hoe farm households in selected camps in Katete District, Eastern Province, Zambia, 1992

Agricultural Camp	Male HH	Female HH	Total
Kafumbe	347	30	377
Chilembwe	301	91	392
Kameta	161	15	176
Ngombaela	107	23	130
Kagoro	109	15	124
Gaveni	104	16	120
Chinkhombe	94	2	96
Mzime	142	37	179
Chanjoka	276	48	324
Kawalala			
Unit 1	44	7	51
Unit 2	85	11	96
Vulamkoko			
Unit 1	176	26	202
Unit 2	129	18	147
Unit 3	262	58	320
TOTAL	2337	397	2734
%	85.5	14.5	100

Note: A significantly high population (14.5%) of ox-hoe farmers in Katete District are female-headed.

Table 4.2. Number of male and female headed (HH) ox-hoe farm households randomly chosen from selected camps for the interview, Katete District, Eastern Province, Zambia, 1992

Agricultural Camp	Male HH	Female HH
Kafumbe	9	5
Chilembwe	8	13
Kameta	4	2
Ngombaela	3	4
Kagoro	3	2
Gaveni	2	2
Chinkombe	2	1
Mzime	4	5
Chanjoka	7	7
Kawalala		
Unit 1	1	1
Unit 2	2	2
Vulamkoko		
Unit 1	5	4
Unit 2	3	3
Unit 3	7	9
TOTAL	60	60

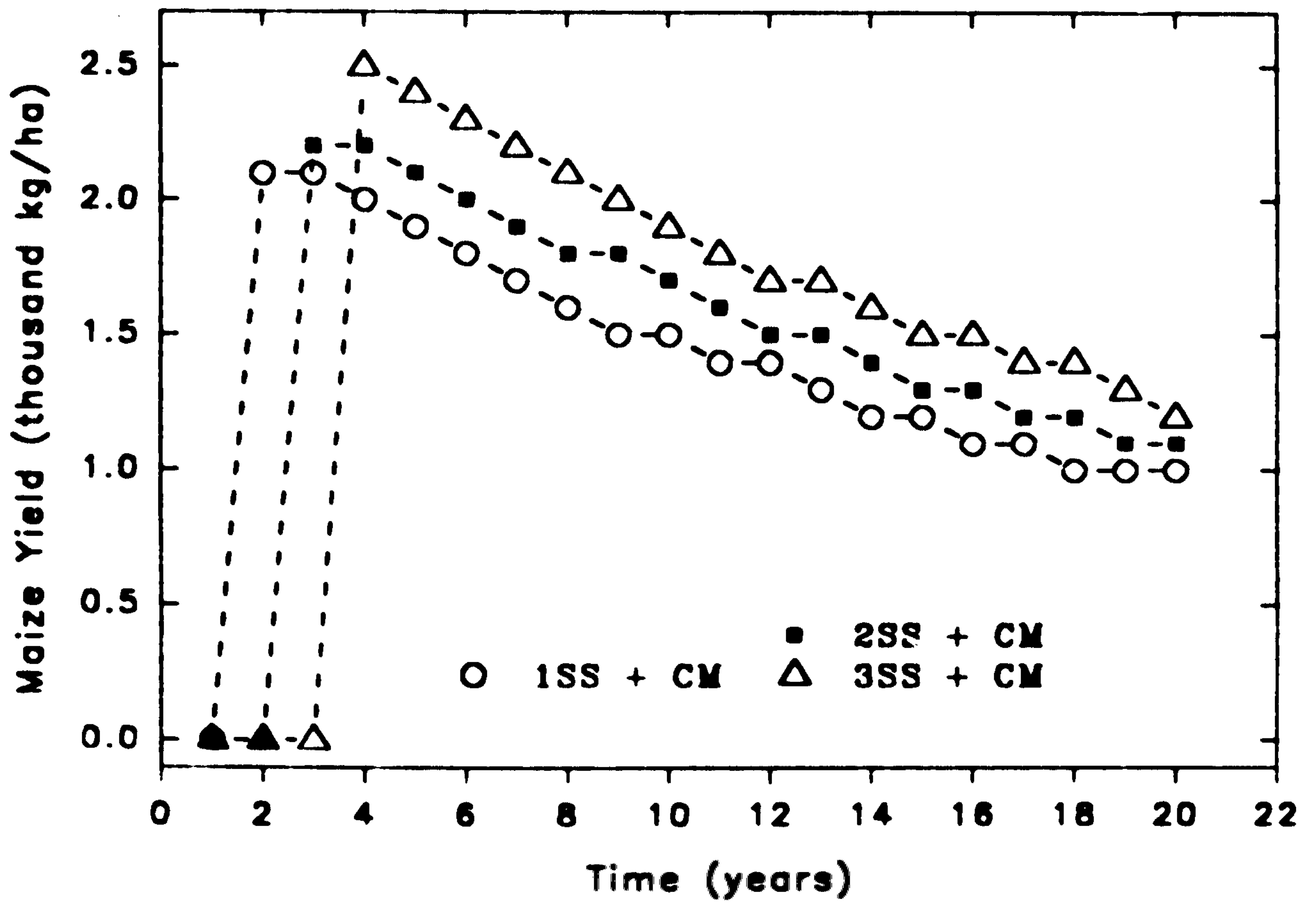

Figure 4.2. Simulated maize yields showing the points at which the yields begin to decline in *Sesbania sesban* fallow (SS) of 1, 2, and 3 years, each followed by continuous cropping of maize (CM). Based on the points, different combinations of fallow-maize rotations can be simulated to determine an optimum system.

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Chapter 5

Results and Discussion

5.1 Introduction

The results and discussion are grouped into three main sections. The first one provides a brief and general description of the local community, landuse practices and production systems in the study area, based on the [illegible] informal interviews with the enumerators, the Katete District Agricultural Officer (DAO), agricultural camp officers (ACOs), local chiefs and some farmers from the camps chosen for the study. Section two deals with the results and specific descriptions of the strengths and weaknesses of the sampled ox-hoe farm households, based on the formal interviews (questionnaire) by the enumerators, supervised by the researcher. The third section provides the results and discussion of the biological and socioeconomic effects of SS improved fallow on the farming system, based on SCUAF simulation, informal and formal surveys, and secondary data.

5.2 General description of the local community, landuse and production systems

The description of the local community covers a general overview of the community profile, farming systems and cropping calender, landuse practices and problems experienced by ox-hoe farmers in Katete District. The purpose of the overview is to provide a general framework for determining the effects of SS improved fallow on the existing rural systems which includes the farmers and their landuse practices.

5.2.1 Local community profile

In Katete District, farm households live and function within a social structure which largely determines their learning process or innovative behaviour. According to the DAO, enumerators and ACOs, Katete is dominated mainly by the *Cewa* people who practice the matrilineal (from mother side) land inheritance system discussed in chapter 2. In some southern parts of Katete, however, the *Nsenga* people are found, but their number is relatively very small and insignificant. All the tribes favour large village settlements of up to a hundred homesteads or families (ICRAF 1988).

In each village there is a *headman* (local chief). The headmen are answerable to a *paramount chief*, who maintains communication with the headmen through *Ndunas* (messengers) in matters relating to agricultural or rural development. The chiefs have to be informed of agricultural or rural development projects planned for the villages. This is because the jurisdiction of the customary landuse practices and other village issues is under the traditional chiefs (ACOs, per comm.). While they do not have direct control over agricultural or rural development projects, the chiefs exercise so much power that they can frustrate the projects themselves (Burdette 1988). It is, therefore, absolutely essential to solicit and obtain the support of the traditional chiefs in areas where agricultural or rural development projects such as agroforestry are launched.

Traditional power is strong enough that the villagers can not openly oppose or undermine the view of the chief. There are also societal rules, institutionalized patterns of behaviour and expectations that must be adhered to by every member of the community. For example, *Nywo* (traditional dancing) is a very important practice in Katete. Children between the ages of 10-15 have to go through this cultural ritual. They are generally not interested in schooling (Banda, per. comm.).

5.2.2 Farming systems and cropping calender

According to the ACOs, enumerators and DAO, there are three farming systems in Katete District: the hoe, ox-hoe and tractor-ploughing farming systems. The hoe farming system is primarily a maize based farming system with an average cultivated area of about 1.7 ha (ARPT 1984). It is a maize-livestock system. Local maize is the dominant crop grown and other important crops include groundnuts, sunflower, cotton, sweet potatoes, cowpeas, beans and pumpkins. The farming community are mostly subsistence or traditional farmers. Farm management practices are still traditional. The livestock kept are mainly goats, pigs and chickens.

The ox-hoe farming system, which is the focus of this study, has similar features of the hoe-cultivation system. However, in the ox-hoe farming system, draft or animal power is the major distinguishing element from the hoe cultivation as a means of land preparation. The average land cultivated under the hoe-ox farming system is about 3.2 ha (Njobvu and Sutherland 1991). Farmers depend on their own oxen and plough or rent them locally in the villages. The major crops grown include both the hybrid and local maize, groundnuts, sunflower, cotton, soyabeans, sweet potatoes and beans. Farmers use improved maize seed and fertilizer. Crop production is for home consumption and sale. Cattle, goats, pigs and chickens are the livestock kept.

The tractor-plough farming system is the practice of commercial farmers. Under this system, the average cultivated areas are more than 10 ha. Crops grown are mostly for sale, although a sufficient amount of food is grown for home consumption. Cultivation method is mainly by tractor plough. Increased dependency on improved seed is common. The majority of farmers grow hybrid maize and tobacco as cash crops with local maize as a means of food security (Njobvu and Sutherland 1991).

In all the farming systems described above, the family is the main source of labour. Hired labour is used to supplement family labour especially during weeding and planting of crops. Communal labour is usually organized for weeding and harvesting activities. From October to January, a period for land preparation, planting and weeding, labour availability appears to be an obstacle to crop production. The critical labour demand period is between November to January (DAO and ACOs, per. comm., ICRAF 1988).

According to the DAO and Phiri, the officer in charge of Katete Farmers Training Centre, a typical calender of cropping activities in Katete is as follows:

October: Land preparation (ploughing and ridging) for early planted crops just before the first rains. The crops are local maize, hybrid maize, cotton, beans, groundnuts and pumpkin.

November: Early planting of local maize, hybrid maize, cotton, groundnuts, beans and pumpkins. This is also a period where labour demands are the highest during the cropping season.

December: Fertilizing early planted crops, thinning cotton, weeding, planting soyabeans and sunflower and raising tobacco seedlings.

January: Planting tobacco, cotton spraying, weeding, and fertilizing.

February: Spraying and weeding cotton, and weeding tobacco.

March: Planting vegetables and weeding tobacco.

April: Clearing of surrounding fields and early burning around grazing areas.

May: Harvesting of maize, cotton and groundnuts.

June: Harvesting of other crops and marketing of maize.

July: Post-harvest activities which include shelling and storage of crops.

August: Marketing of other crop

September: Resting

5.2.3 Landuse practices and problems experienced by ox-hoe farm households

According to the ACOs, six distinct landuse practices characterize the ox-hoe farming system. The farmers divide their total landbase into blocks as follows:

(a) Block 1: Area of land for hybrid maize production. Hybrid maize is a cash crop.

(b) Block 2: Area of land allocated for local maize production. Local maize is grown for home consumption.

(c) Block 3: Area of land allocated for crops other than those described above.

(d) Block 4: Area of land left to fallow under grass cover.

(e) Block 5: Area of land left under wooded fallow as an investment for future cultivation. This is also an area where the farmers can collect firewood and other forest products. Wooded area may also be used for cattle grazing.

(f) Block 6: *Dambos* or seasonally waterlogged lowlands on which *dimbas* or gardens are established by farmers to raise fruits, sugarcane and vegetables during the dry season (DAO and ACOs, per. comm., ICRAF 1988). This is also a potential nursery area for SS seedling production.

The common landuse problems, according to ACOs, were deforestation, soil erosion on arable and grazing land, declining soil fertility, fertilizer dependency, limited access to fertilizer and draft power, and food insecurity. These problems have also been reported in previous studies undertaken in Katete (e.g. Njovbu and Sutherland 1991, ICRAF 1988).

Deforestation is an outcome of increased human activities on land due to demographic pressure. Trees or shrubs are cut for firewood, building and fencing materials, and charcoal production. Deforestation was most severe in Kagoro and Vulamkoko, Katete. Soil erosion was also prevalent in Kagoro. It is caused by increasing stress from livestock and human populations, continuous cultivation and excessive runoff (DAO, per. comm.). Soil erosion leads to loss of soil fertility, low crop yields and food insecurity. Fertilizer prices are so expensive that many farmers are unable to buy, and this has led to limited use of fertilizer in the cropping system. Many farmers also lack draft power. Thus, increased dependency on fertilizer and lack of draft power have also contributed low crop production and food insecurity.

In response to the problems of low soil fertility and declining crop yields, farmers have adopted several strategies. These are (1) crop rotation, (2) continuous cropping without fertilizer use, (3) continuous cropping based on fertilizer, for those farmers who are able to buy fertilizers, and (4) leaving the land to fallow under grass cover to restore soil fertility.

Leguminous crops such as groundnuts and soyabeans are used in crop rotation practice. It is estimated that these species can substitute up to 25 - 30% of the nitrogen requirement in subsequent maize production needs (Njovbu and Sutherland 1991). However, most farmers, according to the ACOs, have only small areas of farmland under groundnut, soyabeans or any other legume compared to the areas of farmland under local maize. Some farmers also have very limited land on which to practice crop rotation. The ACOs also told the researcher that some farmers claim that continuous cropping with or without fertilizer has resulted in declining maize yields.

Land is cultivated until soil fertility is exhausted before it is left to fallow for 2 or 3 years to allow it regain its natural fertility (Njobvu and Sutherland 1991 and ACOs, per. comm.). But this depends on the area of land the family needs. If a farmer has a small farmland and there is a critical need for food to feed his or her family, land may not be left to fallow. It is cultivated with food crops (Mpatishi, per. comm.). Leaving land to fallow may also be related to several factors. For example, it may be left to fallow by default due to labour constraints in the households during the cropping season. The land may then be cleared and planted with crops in the next season if labour is available (Mpatishi, per. comm.). Thus, it appears that leaving land to fallow under grass is often a random or planned activity, depending on many factors.

Farmers use certain weeds and grasses as indicators of soil fertility. For example, when *Hyparrhenia* spp. appears on the fallow land after 3 or 4 years, it means that the land is ready for maize cultivation for a further 5 years. The presence of *Striga* spp. on the fallow land indicates infertile soil; while *Tridax procuminens* indicates exhausted soils requiring fertilization (Njobvu and Sutherland 1991).

5.3 Characteristics of the ox-hoe farm households

This section provides the results, descriptions and discussion of the characteristics of the ox-hoe, male and female headed farm households, used interchangeably in the study as male and female farmers. The descriptions and discussions are based on the samples of 55 male and 55 female farmers. For the purpose of hypothesis testing, the characteristics of the farmers were classified into two groups: quantitative and qualitative characteristics.

5.3.1 Quantitative characteristics

The summary statistics including the mean (Min.), maximum (Max.), and standard deviation (Std.) of the selected characteristics of the male and female farmers, respectively, are shown in Tables 5.1 and 5.2. The comparison of the male and female farmers' characteristics are shown in Table 5.3. A t-test was performed to determine, at a 95% confidence interval, the differences between the male and female farmers with respect to their characteristics. The study hypothesis was that "the male and female farmers had the same characteristics".

5.3.1.1 Area of land under hybrid maize

The areas of land allocated for hybrid maize production (AHMZE) were normally distributed among the male and female farmers. The male farmers had a mean AHMZE of 3.30 ha; while the female had 1.00 ha. There was a significant mean AHMZE difference of 2.30 ha between the male and female farmers. Of the 55 male respondents, only 26 (47%) of the farmers cultivated hybrid maize. The minimum and maximum AHMZE were 0.25 ha and 9.00 ha, respectively. Among the 55 female respondents, 17 (31%) farmers cultivated hybrid maize. The AHMZE ranged from 0.25 ha to 3.00 ha. These results suggest that male farmers tend to have more AHMZE than the females. Because the production of hybrid maize in Katete is associated with fertilizer use and only a few female farmers are able to purchase the fertilizer, the number of female farmers involved in maize production is also expected to be lower than the male's (ACOs, per. comm.). In general, the results suggest that more than 50% of the male and female farmers in Katete are not growing hybrid maize because of their inaccessibility to fertilizer or some other factors.

5.3.1.2 Area of land under local maize

The male farmers had an average area of land under local maize (ALMZE) of 3.00

ha, about 2.3 times higher than the average for the female (1.30 ha). But the areas of land allocated for the local maize production were not normally distributed among the farmers. When the ALMZE values were transformed or normalized by log base 10 function (Zar 1974), a significant mean ALMZE difference was observed between the male and female farmers. All the 55 (100%) male farmers grew local maize. The ALMZE ranged from 0.50 ha to 10.00 ha. Similarly, all the 55 (100%) female farmers grew local maize. The minimum and maximum ALMZE were 0.40 ha to 4.00 ha. These results suggest that male farmers tend to have more ALMZE than the female. The results also suggest that local maize is the most important staple food crop and it is grown by all farmers in Katete. Unlike the hybrid maize production, farmers can grow it without applying fertilizer in their farmland (ACOs, per. comm.).

5.3.1.3 Area of land under other crops

The male farmers had an average area of land under other crops (XC) of 5.30 ha, about 2.7 times higher than the female's (2.00 ha). However, the areas of land allocated for the production of crops (soyabeans, sunflower, beans, etc,) were not normally distributed among the farmers. When the XC values were normalized, a significant mean XC difference was observed between the male and female farmers. All the 55 (100%) male farmers had XC. The minimum and maximum XC values for the male farmers were 1.40 ha and 20.00 ha, respectively. Similarly, all the 55 (100%) female farmers had XC, ranging from 0.4 ha to 8.00 ha.

It was also observed that XC was significantly and positively correlated with the AHMZE and ALMZE. For the male farmers, $r = 0.50$ for ALMZE and $r = 0.50$ for AHMZE, suggesting that as the XC increases, male farmers tend to increase AHMZE and

ALMZE. Similarly, for the female farmers, r = 0.79 for AHMZE and r = 0.81 for ALMZE, suggesting that as the XC increases, female farmers tend to increase AHMZE and ALMZE. These results again demonstrate the importance of maize in Katete. Because maize is used both as staple food and cash crop, a high priority is assigned to its production. As the production of other crops increase, maize production is also increased by farmers. Female farmers seem to exercise this strategy more strongly than the males.

5.3.1.4 Area of land under grass fallow

The areas of land left to fallow under grass (XG) were normally distributed among the farmers. The male farmers had a mean XG of 2.30 ha, about 2 times higher than the females' (1.00 ha). This difference was significant. Of the 55 male respondents, 29 (53%) had their land under grass fallow, ranging from 0.40 ha to 5.00 ha. Among the female farmers, 41 (75%) of the 55 respondents had land under grass, ranging from 0.20 ha to 3.50 ha. As shown in Figure 5.1, there was an observed relationship between the area under hybrid maize and that under grass fallow with respect to gender. More male farmers than the females tend to associate with an increase in the areas of land under grass and maize.

There were variations in responses regarding fallow periods, the number of years the land had been under grass fallows. About 40% of the farmers reported that they had left their land to fallow only for the 1990/91 season primarily because of labour constraints. The majority of the farmers (about 60%) had left their fields to fallow for periods ranging from 2 to 3 years, which is consistent with the normal practice in the region.

In general, these results suggest that the majority of farmers leave their fields to fallow under grass cover for 1, 2, or 3 years for many reasons, including labour deficiencies and soil fertility restoration.

5.3.1.5 Area of land under wooded fallow

The average area of land under wooded fallow (XW) for the male farmers was 3.60 ha, about 3 times higher than the females' (1.10 ha). However, XWs were not normally distributed among the male farmers, but they were for the females. When the XW values were normalized and compared, a significant mean XW difference was observed between the male and female farmers. Of the 55 male farmers, 38 (69%) respondents had land under wooded fallow, ranging from 0.50 ha to 10 ha. Similarly, of the 55 female farmers, 33 (60%) respondents had land under wooded fallow ranging from 0.08 ha to 3.00 ha. Wooded land is used as an investment or asset deferred for future cultivation. It is also used as a place where farmers can collect firewood (from drying, dead or fallen trees) and other forest products. There is, however, a general tendency to collect these items from communal lands (open access property). These results also suggest that about 40% of the farmers do not have land under wooded fallow. This means that either they have to intensify cultivation on their existing landbase or the chiefs have to allocate additional land to them. The intensification of crop cultivation, combined with increasing pressure from human and livestock population on the land can lead to soil degradation, food security problems and economic fragility.

In summary, the total landbase averages for the male and female farmers were 17.50 and 6.40 ha, respectively. With respect to the total average cultivated land (AHMZE + ALHMZE + XC), the male farmers had 11.60 ha and the female had 4.30 ha. The cultivated area differential between the male and female farmers could be that most female headed households do not own oxen for ploughing and are therefore labour constrained. In this study, it was found that 27 (49%) of the 55 female farmers owned oxen and plough; while 40 (73%) of the 55 male farmers had these resources. Female headed households have limited access to credit facilities from landing institutions due to cultural and traditional systems which place women in subordinate roles to that of men (Mpatishi, per. comm.)

In general, however, the total average landbase differential between the male and female farmers could be related to the matrilineal land inheritance system which tends to favour male farmers rather than the females (Milimo 1989). It is, therefore, typical to find the male farmers with more landbase than the females.

The farmers were not asked whether or not they had *dimbas*. The focus of the study was on arable lands. However, previous studies in the region indicate that a significant proportion of ox-hoe farmers have *dimbas* in Katete (Kwesiga and Chisumpa 1990).

5.3.1.6 Labour, number of workers and dependents

It was observed that the family was the main source of labour for agricultural production for the male and female headed households. Labour was supplied by the full time adult (more than 15 years old) family members or workers and children who worked, in many cases, mainly on weekends. Weekly labour inputs during the cropping season were normally distributed among the farmers. The average weekly labour input by adult workers (ADLAB) during the cropping season was 36 and 14 hr for the male and female farmers, respectively. The mean ADLAB difference between the male and female farmers was 22 hr. This was found to be significant. All the 55 (100%) male farmers used ADLAB, ranging from 6 to 80 hr. Similarly, all the 55 (100%) female farmers used ADLAB, ranging from 3 hr to 42 hr.

With respect to the children's weekly labour inputs (CHLAB), the male headed households had an average of 31 hr, about 5 times higher than the females' (6 hr). This difference was significant. For the male farmers, 44 (80%) of the 55 respondents used CHLAB, ranging from 3 to 40 hr. Among the female farmers, 21 (38%) of the respondents also used CHLAB, ranging from 2 to 14 hr. These results suggest that because male farmers have more land than the female to cultivate, a great deal of labour is demanded from the family. Children have to supplement the labour shortage. The maximum and mean CHLAB values for the male headed households seem to be quite high. They either suggest recall problems because none of the farmers surveyed kept records of daily labour inputs, or some households have children who do not go to school and each works work full time on the farm or off-farm.

In general, however, the ADLAB values observed here are within the range reported in previous studies (e.g. Central Statistics Office 1991). Female farmers spend less hours in the fields than the male because they have to allocate some of their household labour for off-farm activities such as brewing, trading, firewood collection and other domestic activities.

The male farmers had, on average, about 9 adult workers (WRKS), while the female had about 4 workers. But the number of workers "employed" by the female farmers were not normally distributed. When WRKS values were normalized, a significant mean WRKS difference was observed between the male and female farmers. Among the male farmers, all the 55 (100%) respondents had workers, ranging from 2 to 44 people. Similarly, all the 55 (100%) female farmers had workers, ranging from 1 to 12 people.

Dependents (DEP) include family members of the households.They were normally distributed among the farmers. The mean DEP for male farmers was about 11 people, and for the female was about 7 people. The mean difference of 4 people was significant. Among the male farmers, all the 55 (100%) respondents had dependents, the number ranging from 2 to 30 people. Similarly, for the female farmers, 54 (98%) of the 55 respondents had dependents, the number ranging from 1 to 14 people. The high number of dependents in the male headed households is due to the polygamous structure of the household. Most of the male farmers surveyed had more than one wife.

It was also observed that DEP was significantly and positively correlated with WRKS in both the male and female headed households, suggesting that as the number of dependents increases, farmers tend to have more workers. The r values for the male and female headed households were 0.58 and 0.59, respectively.

5.3.1.7 Use of inorganic fertilizer

Several types of inorganic fertilizers are stocked by the cooperatives and marketing boards in Katete. Those mostly sold to farmers are "D" compound for basal dressing and Urea or Calcium Ammonia Nitrate (CAN) for top dressing. Of the 55 male farmers, 31 (56%) of the respondents used FERT, the rate ranging from 200 to 220 kg/ha. Among the female farmers, 25 (45%) of the respondents used FERT, the rate ranging from 100 to 400 kg/ha. Fertilizer use, however, was not normally distributed among the farmers. The average rate of FERT application for the male farmers was 201.60 kg/ha and for the female farmers was 196.80 kg/ha. When the FERT values were normalized, a significant mean difference in FERT application rate was observed between the male and female farmers. The FERT averages applied by the farmers correspond to 200 kg/ha (100 kg/ha for "D" compound and 100 kg/ha of CAN), the rates recommended by the Zambian government for emergent small scale farmers who use their own or hired oxen or plough (Zambian Ministry of Agriculture 1990). Fertilizer was mainly used for hybrid maize production.

The results suggest that nearly 50% of the male or female headed households are unable to buy fertilizer. Because of high cost of fertilizer, some female farmers seem to be using less than the recommended application rate. But for those who can afford it, they tend to use FERT more than the recommended rate of application per unit area.

5.3.1.8 Crop yield and income

The male and female farmers were able report the yields of hybrid maize (including income), and local maize. They were also able to provide income estimates, but not yields for cotton, soyabeans, tobacco, groundnuts, soyabeans, sunflower and beans.

The production of maize (except local maize), was not normally distributed among the farmers. The male farmers produced, on average, 1119.10 kg/ ha of hybrid maize (PHMZE) while the females had even a higher average production of 1846.30 kg/ha, suggesting that female farmers appear to be efficient maize producers than the males. The differences in maize yield could also be due to recall (memory) problems by the farmers which probably resulted in some households to under-or overestimate maize production. The production differential was significant, based on normalized PHMZE values. Among the male farmers, 26 (47%) of the 55 respondents produced hybrid maize, ranging from 198 to 2250 kg/ha. Similarly, 17 (31%) of the 55 female farmers produced hybrid maize, ranging from 720 to 2250 kg/ha.

The average yield of local maize (PLMZE) for the male farmers was 932.60 kg/ha; while for the female farmers was 1545.70 kg/ha. The female farmers produced, on average, about 1.6 times more maize than the male. This production differential was significant. Among the male farmers, maize production ranged from 31.50 to 2250 kg/ha. Similarly, among the female farmers, maize production also ranged from 270 to 2250 kg/ha. Again the gender differences in local maize production suggest that female farmers appear to be more efficient maize producers than the males. The differences could also be due to recall or memory problems by the farmers which probably resulted in some households to under-or overestimate maize production.

The average annual income from hybrid maize for the male farmers was about ZK

10227 and for the female farmers was ZK 5751. However, maize income (IHMZE) was not normally distributed among the male farmers. Their income ranged from ZK 1422 to ZK 42660. Similarly, among the female farmers, the income ranged from ZK 1422 to ZK 21330. When the IHMZE values were transformed, a significant mean IHMZE differential was observed between the male and female farmers.

As expected, the IHMZE was significantly and positively correlated with AHMZE. The r values were 0.54, and 0.95 for the male and female farmers, respectively. These values suggest that as AHMZE increases, IHMZE also tends to increase, especially for female farmers. The basis for incremental production is more lands or more efficiency. This is consistent with the production of hybrid maize discussed above.

The average annual income from other crops (IOTHCR) for the male farmers was also significantly different from that of the females. For the male farmers it was about ZK 10248, and for the females was about ZK 1986. The IOTHCR was distributed among the farmers. Among the male farmers, it ranged from ZK 110.00 to ZK 61110.00. Only 28 (51%) of the 55 male respondents earned income from other crops. Among the female farmers, only 6 (11%) of the 55 respondents earned income from other crops, ranging from ZK 510 to ZK 6208. This suggests that either the majority of female farmers could not remember their earnings or they produced crops which were mainly for home consumption.

The sources of non-farm annual income (INOFF) were beer brewing, trading, making baskets, employment, remittances from relatives, hiring out-oxen and bee keeping. Trading and labouring (selling labour) were mainly the activities for the male headed households. Beer brewing was the main activity for the female headed households. About 29 % of the female farmers and about 13% of the male farmers received money from their relatives, suggesting that a relatively large proportion of female farmers in Katete depend on their relatives as sources of income.

The INOFF of the male and female headed households were not normally distributed among the female farmers. In the male headed households, 21 (38%) of the 55 respondents earned INOFF, ranging from 300 to ZK 40000. Similarly, among the female headed households, 44 (80%) of the 55 respondents earned INOFF, ranging from 100 to ZK 18800. The average values of INOFF were about ZK 7889 and ZK 2803 for the male and female headed households, respectively. When the INOFF values were transformed, it was observed that there was a significant difference in the average INOFF between the male and female headed households.

5.3.1.9 Age, years of farming and schooling

The ages (AGE) of the male and female headed households were normally distributed. In the male headed households, the minimum and maximum ages were 21 to 84 years. Similarly, among the female headed households, the ages ranged from 22 to 65 years. In general, the majority of the male and female farmers were in their 40s. There were very few farmers (less than 5%) in their 20s, suggesting that young people have probably migrated to urban areas for work or other reasons. There was no significant mean AGE difference between the male and female headed households. The AGE averages were 46 and 45 years for the male and female farmers, respectively. Life expectancy for Zambia is 53.4 years (World Resources Institute 1993). When the AGE averages are compared with the life expectancy, they suggest that the majority of male and female farmers in Katete are quite old.

The number of years of farming (YRFARM) by the male and female headed households were normally distributed. The average YRFARM for the male headed households was 18 years. It ranged from 5 to 53 years. For the female headed households, the average YRFARM was 16 years. It was not significantly different from the males'. Their minimum and maximum YRFARM were 5 and 30 years, respectively.

Compared with the AGE averages discussed earlier, the results pertaining to the YRFARM suggest that farmers in the region start active farming when they are, on average, about 28 years. However, the typical age of farming is usually between 15 to 20 years (ACOs, per. comm.).

The number of years of schooling (EDUC) by the female headed households was not normally distributed, but for the male it was. Male headed households had minimum and maximum values of EDUC of 1 and 12 years, respectively. Of the 55 respondents, 33 (60%) had EDUC. Similarly, for the female headed households, 23 (42%) of the 55 respondents had EDUC, ranging from 1 to 10 years. The EDUC averages were 6 and 5 years for the male and female headed households, respectively. When the transformed male and female EDUC values were compared, a significant mean EDUC difference was observed between the male and female headed households. The EDUC results suggest that the majority of the male and female headed households in Katete have at least attained primary education.

5.3.1.10 Migration from households

The number of people who left the male and female headed households (MIGR) were not normally distributed. In the male headed households, 33 (60%) of the 55 respondents experienced MIGR. The number of people who left the households ranged from 1 to 7. The average MIGR was 2 people. Similarly, in the female headed households, 43 (78%) of the 55 respondents experienced MIGR, with the minimum and maximum numbers of 1 and 6 people, respectively. The average MIGR was also about 2 people. When the transformed MIGR values in male and female headed households were compared, no mean

MIGR difference was observed between the two populations.

The MIGR results suggest that the majority of the male and female headed households in Katete could experience a great deal of labour constraints if the migratory trends continued. It was observed that MIGR and number of family workers were weakly, but negatively and significantly, correlated (r = -0.40) in the female headed households. Similarly, it was also observed that MIGR was significantly and negatively correlated (r= -0.57) with the production of hybrid maize in the female headed households. These relationships suggest that when MIGR increases, the number of workers decreases, and the production of hybrid maize also decreases in the female headed households. There was, however, no MIGR effect on the number of workers or the production of hybrid maize in the male headed households.

5.3.1.11 Livestock types and production

The livestock kept by the male and female headed households were cattle (CA), goats (GO) and pigs (PG). All the livestock, except the number of pigs, owned by the farmers, were not normally distributed among the male headed households, but they were for the females.

In the male headed households, 48 (87%) of the 55 respondents owned CA, ranging from 1 to 41 cattle. In the female headed households, 25 (45%) of the 55 respondents owned CA, ranging from 1 to 30 cattle. The averages were 9 and 5 cattle for the male and female farmers. When the CA values were transformed and compared, a significant difference was observed between the male and female farmers with respect to cattle ownership.

The CA was weakly, but significantly and positively correlated (r = 0.44) with fertilizer use in the male headed households. This relationship suggests that as the number of CA increases, male farmers tend to use more fertilizer for maize production. Cattle are sold to provide income for the households. Part of the income may be used to purchase fertilizer and

(Mpatishi, per. comm.).

No relationship between CA ownership and the rate of fertilizer application was observed in the female headed households. However, there was a significant and positive relationship between CA and child labour (r = 0.76). This relationship suggests that as the number of CA increases, female headed households tend to use more children, rather than the herdsmen, to herd the cattle. Male headed households commonly employ herdsmen, although children are sometimes employed to herd the cattle. Grazing of cattle is done along streams, in wooded areas or on farm lands after harvest, and in dambos in the dry season (ICRAF 1988, ACOs, per. comm.).

In general, the results pertaining to CA ownership suggest that cattle production appears to be the most favoured activity in Katete. This is expected because cattle are used mainly for oxen and ploughing, and for transportation activities associated with agricultural production. Cattle are also used as a symbol of wealth or "savings on the hoof" (Kwesiga and Chisumpa 1990).

Among the male headed households, 26 (47%) of the 55 respondents owned GO, ranging from 1 to 27. Similarly, among the female headed households, 24 (44%) of the 55 respondents owned GO. The minimum and maximum numbers of GO owned were 1 to 20, respectively. The averages for the male and female headed households were 4 goats in each case. When the GO values were transformed and compared, no difference was observed between the male and female headed households with respect to GO ownership.

There were significant relationships between hybrid maize income and GO (r = 0.83); and between GO and child labour (r = 0.65) in the male headed households. These relationships suggest that as the income increases, male farmers tend to buy or own more goats. Similarly, as the number of goats increases, male farmers tend to employ more children to herd the goats. In the female headed households, GO was significantly associated with the area of land cultivated with other crops (r = 0.65). This relationship suggests that as the number of GO increases, female headed households tend to cultivate more land with other crops. Thus, GO is probably used as a source of income to finance crop production.

Among the male headed households, 48 (87%) of the 55 respondents owned PG, ranging from 1 to 15. Similarly, among the female headed households, 37 (67%) of the 55 respondents owned PG, with the minimum and maximum numbers of 1 to 20, respectively. The averages for the male and female headed households were the same (i.e. 5 pigs each). There was no difference between the male and female headed households with respect to the ownership of PG.

There was a significant relationship (r = 0.67) between the expenditure on animal labour (ANLAB) and the number of PG in the male headed households. This relationship suggests that as ANLAB increases, male headed households tend to keep more pigs to finance crop production. Pigs are a source of cash in the villages. They are also important assets for the payment of labour (Kwesiga and Chisumpa 1990).

5.3.1.12 Expenditure patterns

Expenditures on food (EXPF), leisure (EXPL), manufactured goods (EXPMG) and animal labour (ANLAB) by the male and female headed households were normally distributed. Only 6 (11%) of the 55 male respondents incurred EXPF, ranging from ZK 55 to ZK 360 per week. The low response rate to the question relating to EXPF suggests that the majority of the male farmers probably did not remember their expenditure records. Their wives probably were responsible for buying the food, a typical situation in Katete (ACOs, per. comm.). The low response rate to the EXPF question also suggests that male farmers rely on food produced by the family labour. Among the female headed households, 35 (64%) of the 55 respondents incurred EXPF, suggesting that the majority of female farmers in Katete buy food. The minimum and maximum weekly expenditures were 10 to ZK 175. The average monthly EXPF for the male was about ZK 177, and for the female was about ZK 60. The difference between the averages was not significant.

The average monthly EXPL for the male farmers was ZK 820, and for the female was about ZK 89. The difference between the averages was significant. In the male headed households, only 5 (9%) of the 55 respondents spent money on leisure activities such as drinking and travelling. The monthly EXPL ranged from about ZK 12 to ZK 2000. The low rate of response to the question on EXPL could be due to recall problems, or the majority of farmers did not want to answer the question, especially on the issue relating to drinking. They probably considered the question to be very sensitive and personal. Furthermore, the majority of farmers either walk, use bicycles or rely on "free" transport when travelling from the villages to Katete District Headquarters to trade or purchase goods. Thus, they do not incur expenses on travelling (Mpatishi, per. comm.). It was also observed that GO was significantly and positively correlated with EXPL ($r = 0.99$). This relationship suggests that as the number of goats increases, male farmers tend to spend more money on leisure activities. It suggests that goats are sold to provide income for the consumption of leisure.

Among the female headed households, 7 (13%) of the 55 respondents incurred EXPL. The minimum and maximum monthly expenditures were ZK 35 and ZK 200, respectively. The low response to the question on EXPL could also be related to the same reasons suggested above.

It was also observed that EDUC was positively and significantly related to EXPL ($r = 0.99$). This relationship suggests that as the female farmers become more educated, they tend to spend more money on leisure activities, probably on travelling. No such relationship was observed for the male headed households.

The monthly average EXPMG (salt, soap, sugar, and kerosine or paraffin) for the male farmers was about ZK 209, and for the female was about ZK 177. There was no significant difference between the averages. In case of the male headed households, 54 (98%) of the 55 respondents incurred EXPMG. The monthly expenditures ranged from about ZK 10 to ZK 1300.

There was a very weak, but significant and positive relationship between DEP and EXPMG ($r = 0.40$). This relationship suggests that as the number of dependents increase, male farmers tend to incur more EXPMG.

For the female headed households, all the 55 (100%) respondents incurred EXPMG, the monthly expenditures ranging from ZK 3 to about ZK 449. There was also a very weak, but significant relationship between DEP and EXPMG ($r = 0.30$), suggesting that as the number of dependents increase, female farmers tend to increase their EXPMG.

The average annual ANLAB for the male farmers was about ZK 1561, and for the female was ZK 590. The difference between the averages was significant. Of the 55 male respondents, only 15 (27%) farmers incurred expenditure on ANLAB, ranging from ZK 100 to ZK 5200. The remaining 40 (73%) used their own oxen and plough. This is expected because male farmers had, on average, more cattle than the female (Table 5.3).

Among the female headed households, 20 (36%) of the 55 respondents incurred expenditure on ANLAB, ranging from ZK 50 to ZK 1500. Of the 55 respondents, 27 (49%) farmers used their own oxen and plough, and 8 (15%) borrowed these items from their neighbours or relatives.

The results pertaining to ANLAB suggest that the majority of the male and female farmers in Katete use their own oxen and plough. However, a few female farmers seem to borrow these items from their neighbours or relatives. Because male farmers have more farmland to cultivate than the female, their expenditures on ANLAB are expected to be higher than that of the female farmers. As discussed before, the expenditure on animal labour was significantly related to the number of pigs owned by the households, suggesting that pigs are a source of income for the payment of labour.

The male and female headed households' expenditures on other items such as funeral, church contributions, and school fees and medical treatment (OEXP) were not normally distributed. The expenditures on casual human labour (HLAB) and fertilizer (FERP) were not normally distributed among the male, but they were among the female farmers. The average annual OEXP for the male farmers was about ZK 1683, and for the female was about ZK 702. All the 55 (100%) male headed households incurred OEXP ranging from ZK 24 to ZK 7600. Similarly, all the 55 (100%) female farmers incurred OEXP ranging from ZK 7 to ZK 51[illegible] When the OEXP values were transformed and compared, a significant mean OEXP difference was observed between the male and female headed households.

There were variations in the annual HLAB among the households. Of the 55 male respondents, 30 (55%) of the farmers incurred HLAB, ranging from ZK 20 to ZK 7000. In the female headed households, 15 (27%) of the 55 farmers incurred HLAB. The minimum and maximum annual HLAB expenditures were ZK 50 to ZK 1500, respectively. When the HLAB values were transformed and compared, a significant mean HLAB was observed between the male and female headed households. These results suggest that the majority of female farmers do not hire labour probably because it is so costly for them. Male farmers have more income and many of them are able to hire more labour than the female.

The average annual expenditure on fertilizer per ha, or FERP, for the male farmers was about ZK 3094, and for the females was about ZK 2989. When the FERP values were transformed and compared, no significant difference was observed between the male and female farmers. The FERP expenditures were consistent with the fertilizer use. For the male headed households, the FERP ranged from ZK 112 to ZK 3520. Among the female headed households, it ranged from ZK 1600 to ZK 3840. Different fertilizer prices per kg were reported by the households, ranging from about ZK 8 to 16 ZK during the 1990/91 season.

Based on the income and expenditure patterns outlined in Table 5.3, the average total annual income and expenditure for the male and female headed households were estimated. The average male farmer had an annual income of about ZK 28364. His total expenditure was about ZK 36780. Thus, the farmer's cash balance was about ZK -8415. Similarly, the average female farmer had an annual income of about ZK 10539, and an expenditure of about ZK 10809, a cash balance of about ZK -270. The negative cash balances suggest that the average male and female headed households in Katete are fragile or vulnerable economically. In order to survive, the farmers probably get extra cash from their savings (i.e. livestock sales).

It should be noted, however, that the actual income and expenditure values may be lower or higher than those reported in Table 5.3. For example, expenditures on leisure and food may not be incurred every week or month, hence resulting to probably lower and break-even cash balances. None of the farmers sampled had documented his or her income and expenditure records. Thus, the income and expenditure values reported in this study were based on their memory. Nevertheless, the income and expenditure patterns suggest that the male and female farmers spend income under their control in different ways.

Consumption of food, leisure and manufactured goods are measures of poverty. Male headed households consume more of these goods than the female because they have higher income. Female headed households are more subject to poverty than the male (Mpatishi, per. comm.). The number of cattle owned by the male or female headed household reflects "wealth" status of the household. Because male headed households have more income than the females, they are able to buy more cattle and keep as savings or investments.

This study has examined various quantitative characteristics of the male and female farmers. The hypothesis that there was no difference, in terms of the characteristics, between the male and female farmers is, therefore, rejected. Instead, we generally conclude that the male and female headed households have different characteristics. However, with respect to MIGR, CA and GO characteristics, there are no differences between the male and female farmers.

5.3.2 Qualitative characteristics

Table 5.4 shows the results of qualitative characteristics of the male and female headed households with respect to their exposure to witchcraft, vision or perception of their future, knowledge of agroforestry including improved fallow systems, willingness to plant trees, perception about increase in human population, crop rotation practices, exposure to diseases, and dependence on firewood and other forest products. Because the responses were single numbers, no t-tests were performed to compare the two populations.

5.3.2.1 Exposure to witchcraft

About 33% of the male and 69% of the female headed households acknowledged exposure to or experienced witchcraft practices, suggesting that witchcraft is part of the cultural setting in Katete. A large proportion of the population of female farmers seems to be more exposed to or believe in witchcraft than the male. Because female farmers are more vulnerable economically than the male, they probably consider witchcraft to be a source of security. Witchcraft is a common practice in Katete, but many farmers are shy to talk about it openly (ACOs, per. comm.). This probably explains why there were low response rates to the witchcraft issue from the male farmers. Witchcraft represents an extreme state of jealousy which takes many forms such as death threat and intimidation by means of cultural rituals. These threats or intimidations are "sent" to the households in form of powerful psychological signals commonly by a relative of the household such as cousin, brother or nephew. In response to witchcraft, the farmer may be compelled to either migrate from the village (Marks 1988), simply ignore it, or the farmer may also engage into witchcraft practices to protect his or her interests (Mpatishi, per. comm.). In some cases, the farmer may undertake activities which do not make him or her appear "rich", a form of protective mechanism against witchcraft subjection from other people in the village (ACOs, per. comm.).

5.3.2.2 Vision or perception of the future

About 82 % of the male and 76 % of the female farmers reported that they would want to increase their agricultural production and improve the standard of living of members of their households. Improvements in the standard of living, as reported by farmers, included: (1) buying more cows, (2) increasing the size of farmland, (3) increasing food and cash crop productions, (4) having better residential homes, (5) having more scotch carts, (6) buying more ox-drawn equipment, (7) buying radios and bicycles, (8) sending children to schools, (9) buying better clothes, and (10) buying grinding mills. This suggests that the majority of the male and female farmers in Katete are development oriented people who, if given economically beneficial development projects and proper guidance and training, could develop by making informed decisions about their lives.

5.3.2.3 Knowledge of agroforestry improved fallow systems

Nearly 98% of the male and 89% of the female farmers were ignorant of the concept of agroforestry improved fallow systems, suggesting that the majority of farmers in Katete have no knowledge of agroforestry improved fallow systems. However, despite the lack of knowledge, female farmers seem to have more interest in the fallow systems than the males. About 64% of the 55 respondents reported that agroforestry fallow systems could provide income and food for their households. With respect to the male headed households, nearly 73% of the 55 respondents considered improved fallows a bad practice. One male headed household responded "You want my children to die; you cannot eat trees". He added "traditionally, he has not been mixing trees with crops or planting trees on his farms." Because the focus of this study was on agroforestry improved fallows, questions relating to the farmers' knowledge of other forms of agroforestry systems were not asked. It was, therefore, not possible to determine whether farmers had knowledge of other forms of agroforestry systems; whether they never had contact with AFRENA researchers before this study; what role, if any, do trees or shrubs have in their farming systems; and whether the farmers were aware of trees or shrubs around them, apart from woodland species.

5.3.2.4 Willingness to plant trees

About 89% of the male and 82% of the female farmers reported that they were interested in planting trees which were economically beneficial, primarily fruit-bearing trees. The fruits which were of interest to them include mangoes, guavas and oranges. But some farmers (less than 20%) reported that they were not interested in planting trees even if they were economically useful. The farmers gave several reasons for lack of interest in tree planting. To some households, tree planting requires a lot of labour for establishment, tending and harvesting. Others revealed that they are discouraged by the long time span between establishment and harvesting of tree products. These results suggest that the majority of the male and female farmers in Katete are interested in economically beneficial projects or fruits that are used both for cash and food. For example, mango trees are important sources of food during the dry season. Surplus produce is sold locally in the villages or in the Katete market. About 91% of the male and 27% of the female farmers had mango trees on their fields. Branches of mango trees are also lopped for fuelwood. This suggests that farmers tend to plant or keep trees that have multiple purposes.

5.3.2.5 Perception about increase in human population

Many farmers, especially male headed households (about 71%) revealed that having more children is good for household labour. The more children the farmer has, the more respect he or she gets from reference groups in the village. Children are regarded as future investments. They are expected to care for their parents or older members of the household as required by traditional norms. The more children the household has, the better because while some may die from diseases, others can survive. The farmers also reported that there is still plenty of land in Zambia so they need more people to occupy it.

There were, however, some farmers, especially female headed households (about 42%) who reported that "having too many people (children) could lead to intense competition for land, and that no land would be left for their future generations if there are too many people." Furthermore, because it is the females who have to clean, carry and feed the children during infancy stages, they tend to support limits to population growth.

5.3.2.6 The practice of crop rotation

Crop rotation was practised by all male and female headed households. Leguminous and non-leguminous crops were grown on rotational basis on farmlands. The objective was to improve soil fertility and increase crop output. According to the farmers, this practice has not generally produced successful results. Many of them believed that because their farms have been intensively cultivated for many years, much of the physical and chemical properties of the soil have been destroyed to the extent that crop rotation is less effective in restoring these properties.

5.3.2.7 Exposure to diseases

All the male and female farmers, including their family members suffered from malaria, backpain and diahorrea. According to farmers, these are some of the diseases affecting their productivity. Unsanitary conditions, presence of breeding grounds for mosquitoes (e.g. stagnant water, rotten mangoes on the compounds or near homes) and lack of health education were some of factors related to the outbreaks of diahorrea. Backpain was probably due to old age or stress from farm work.

5.3.2.8 Dependence on firewood and other forest products

As expected, all the male and female farmers depended on firewood, charcoal, mushrooms, honey, wild fruits, caterpillars, and medicinal needs, building and fencing materials, including poles and grass from the forests or wildland ("open" access property). Occasionally, caterpillars, wild fruits and honey are sold in local markets. It was not possible, however, to determine quantities of the materials sold in local markets. The farmers could not remember the quantities sold. Male and female farmers walked for at least 0.5 km from their homes to collect these forest products. It was mainly women and sometimes children who collected firewood. According to farmers, firewood from the forest is so dense that one headload (about 20 to 30 kg) is adequate for cooking for a week, for a family of about 4 people. This means that the monthly consumption of fuelwood for the family is between 80 and 120 kg. This is just a conservative estimate based on farmers' memory. The total monthly firewood consumption may be higher than that if the energy requirements for beer brewing are included in the estimate. Furthermore, during ceremonial activities such as *Nyao*, funeral rites and female *initiations* into adulthood, energy requirements are quite high (ACOs, per. comm.).

The farmers' preference for dense wood suggests that a tree or shrub species intended to be introduced in the villages as an alternative firewood species should be of similar or better qualities than those obtained from the forests. Otherwise, farmers may not consider using the species as firewood.

5.3.3 Summary of the household characteristics

In summary, this study has shown that significant differences exist between the male and female farmers in terms of land, labour, cattle production, crop production, income, consumption of food, manufactured goods and leisure, expenditure patterns, number of dependents and workers, age, and years of schooling and farming. The most important conclusions that can be drawn from this section are that the male and female headed households:

1. Have differential access to land, labour, capital and other productive inputs. Not all the male or female farmers are alike. There are variations in access to land, labour and capital among the male or female headed households.

2. Are fragile economically, especially the female farmers. Productivity and earnings of female farmers are lower than the males, suggesting that female farmers live under conditions of extreme poverty.

3. Are poorly educated.

4. Are economically rational as they show willingness to engage in economically beneficial projects such as the production of fruit trees.

5. Are mostly elderly farmers living in rural Katete.

6. Have differential weekly labour inputs into agricultural production during the calender of agricultural activities. Because females are overburdened by other off-farm activities, their weekly household labour input for agricultural production is much lower than the males'. The family is the main source of labour.

7. Are traditional and loyal to the local chiefs.

8. Are characterized by witchcraft practices, large family size (dependents), and matrilineal inheritance system which favours male farmers.

9. Consider maize and livestock productions as important activities.

10. Are dependent on inorganic fertilizer for maize (especially hybrid variety) production.

11. Are experiencing soil erosion problems and declining crop yields.

12. Are experiencing high rates of migration of family members from the households which will lead to household labour deficiencies.

13. Depend on forests or wildland for the collection of firewood, charcoal, building and fencing materials, and food.

14. Differ in perceptions about agroforestry improved fallow systems.

15. Have different perceptions about human population growth.

The above summary, including the details of the household characteristics discussed in section 5.3.3, show the strengths and weaknesses of the male and female farmers. Within this framework, the ensuing sections illustrate how an agroforestry SS improved fallow system would affect the farmers, if they were to practice the system.

5.4 Biological impact of *Sesbania sesban* improved fallow on the ox-hoe farming system

5.4.1 Influence of *Sesbania sesban* improved fallow on the rate of soil loss

Table 5.5 shows estimates of soil that could be saved (protected from erosion) under CM+F and the SS+M treatments. Figure 5.2 summarizes, graphically, trends in soil saved under these treatments over time. These results are based on SCUAF simulations and equation 4.4, Chapter 4.

Continuous maize cropping based on fertilizer application would result in the least amount of soil saved of all treatments (Table 5.5 and Figure 5.2). For the purpose of comparison to SS+maize rotation treatments, the amount of soil saved under CM+F were averaged under five rotations (Table 5.5 and Figure 5.2). The amount of soil saved under CM+F would be 0.73 thousand soil kg/ha in the fifth rotation.

As expected, more soil would be saved under SS+M rotation treatments than CM+F. For example, a 3SS+1M rotation would protect the most soil against erosion (31.64 thousand soil saved kg/ha in the fifth rotation). A 1SS+3M rotation would save the least amount of soils among the SS+M rotation treatments (8.87 thousand soil kg/ha in the fifth rotation).

In a 1SS+3M rotation, the mean (rotation average) amount of soil saved would be low (-2.80 thousand soil kg/ha); increase, but still low (-0.12 thousand soil kg/ha) in the second rotation; and then increase in the third, fourth and fifth rotations (3.21, 6.91 and 8.87 thousand soil kg/ha, respectively). Negative values (Table 5.5) indicate that soil saved under a fallow system is less than that under continuous cropping without fertilizer use, or that soil erosion under a fallow system (i.e. when maize is occupying the land) is greater than that under continuous maize cropping without fertilizer application, CM (Appendix 4). This suggests that 1SS+3M is not effective in controlling erosion. In all other SS+M rotation treatments, the mean amounts of soil saved would increase over time (Figure 5.2).

In each SS+M rotation treatment, the amount of soil saved under the periods of maize cropping would be much lower in the short-term (less than 6 years) than in the long-term period (7 to 20 years). This could be related to several factors. One probable explanation is that because most topsoils in Katete are already degraded by intensive cultivation, it would take time for the fallow to physically and chemically improve the topsoils to effectively reduce soil losses by runoff and erosion. There were no Katete soil erosion data with which to compare results of this study. However, based on previous studies (Nair 1987, Young 1986, Lal 1989), SS could improve soil physical conditions (i.e. by providing better surface protection through denser cover and a more extensive root system), hence reducing soil loss and runoff in Katete. The longer the SS fallow and the less the intensity of maize cropping, the more the soil would be saved and the higher the yield.

These findings are consistent with previous reports. Tisdale et al. (1985) reported that erosion is a symptom, not a primary cause of soil destruction. The main causes are impoverishment of nutrients, especially nitrogen and inadequate plant population. The characteristics of cropping systems and/or fertility management related to soil losses include the following:

1. The denseness of plant cover or canopy. This affects the amount of protection from impact of rain and evaporation. The amount of transpiration of water, thus allowing room for more water, is another factor. Residues and stems of crops (e.g. maize) and

trees (e.g. SS) reduce velocity of water and evaporation. Residues when turned back to the soil, make it more permeable to water.

2. The length of time the soil is in cultivated crop versus the amount of time the soil in a close-growing tree.

3. The time that crop or tree grows in relation to the distribution and intensity of rainfall.

4. The type and amount of root system.

5. The amount of residues returned to soil. Points 4 and 5 affect soil structure.

These authors also reported that when fertilizer was applied to small grains (crops), erosion was reduced. Erosion was reduced primarily due to the result of a denser cover and a more extensive root system of the growing crop (when fertilizer was applied). Improved practices (e.g. maize-forage rotation) were even more effective in controlling runoff and erosion than continuous cropping based on fertilizer application. Improved practices drastically reduced runoff and erosion. They provided better surface protection through denser cover, and a more extensive root system of forage species.

5.4.2 Effect of *Sesbania sesban* improved fallow on soil organic carbon and nitrogen

Crop yield depends, among other factors, on the status of soil nutrients such as organic C and N. Figures 5.3 and 5.4 show, respectively, the predicted changes in soil organic C and N under SS+M rotation systems. Changes in C and N based on CM+F are also shown for comparison with the dynamics of these elements under SS+M rotation.

Increases in concentrations of soil organic C would be observed in all SS fallow-maize rotation systems, except in 1SS+3M (i.e. due to low litter accumulation, erosion and oxidation). Soil organic C would increase in other SS+M rotation options although it would tend to fluctuate over time. A 3 year fallow, followed by 1 year of maize cropping (3SS+1M) rotation would give the greatest C accumulation in the soil (about 6385 kg C/ha would be added to the soil). The least C accumulation in the soil would be observed in a 1 year fallow, followed by 3 years of maize cropping (1SS+3M) rotation. In this case, about 2117 kg C/ha would be added to the soil at the end of first year. In a 2 year fallow, followed by 2 years of maize cropping (2SS+2M) rotation, about 4242 kg C/ha would be added to the soil at the end of second year. Under CM+F, C would decline steadily over time. For example, in the first year, it would decrease by 70 kg C/ha (about 3% from the initial value). Over 20 years, soil organic carbon would decrease by about 35% in the CM+F. This finding is consistent with that reported by Vermeulen et al. (1993). The decline in soil organic carbon is brought about by relatively (as compared to SS) low litter accumulation from maize plant, rapid decomposition of organic matter and by erosion.

There would be similar changes in N concentrations. Under CM+F, N accumulation would follow a considerably decreasing pattern over a 20 year period. For example, in the first year, it would decrease by 212 kg N/ha (about 5% from the initial value). This would probably be due to the effects of leaching or erosion.

Soil organic N would also increase in all the SS+M rotation treatments although it would tend to fluctuate over time. A 3SS+1M rotation, would provide the greatest N accumulation in the soil (about 952 kg N /ha would be added to the soil at the end of the third year). Under 1SS+3M rotation, about 313 kg N/ha would be added to the soil at the end of first year. In a 2SS+2M rotation, about 637 kg N/ha would be added to the soil at the end of the second year. Fluctuations in N accumulations in the soil would be observed in all the SS+M rotation options. With respect to both C and N accumulations in the soil, the results of 2SS+2M and 3SS+3M would be quite similar.

Based on the SCUAF simulation, the C and N results suggest that SS fallow could improve the organic C and N contents of the soil in the Katete ox-hoe farming system. The C values of this study are within the range reported in previous studies. For example, it has been reported that 12 month old *S. sesban* var. *nubica* added 448 kg N/ha/yr to the soil (Onim et al. 1990).

Soil organic C and N would increase in their concentrations with the progress of the fallow and time for many reasons. One probable reason is that the SS litter, especially the leaves, flowers, fruits and twigs, which would be produced as component of the fallow vegetation dynamics, would provide the raw material for the generation of soil organic C and N. Provided the foliage cover is maintained by farmers such that surface wash would be minimized, the soil organic C and N would continue to accumulate even though some of this may be lost through erosion and oxidation in the ecosystem (Jordan 1985).

The buildup of soil organic C and N would be generated by the activities of heterotrophic soil microorganisms (Tisdale et al. 1985). Nitrogen in some form and other nutrients would be needed by the microorganisms that decompose organic matter. In the case of continuous maize cropping without fertilizer use, for example, the N content would be relatively small in relation to the carbon present (Table 5.6). The microorganisms would utilize any NH_4^+ or NO_3^- present in the soil to facilitate the decomposition. This N would be needed to allow rapid growth of the microbial population which would accompany the addition to the soil of a large supply of carbonaceous material, *Sesbania sesban*. Because N also increases in proportion with C over time (Figures 5.3 and 5.4), there would normally be enough mineral N in the soil to support maize growth on a sustainable basis under a SS fallow system (except in 1SS+3M rotation system).

The ratio of the percentage of carbon to that of nitrogen, the C/N ratio, defines the relative quantities of these two elements in fresh organic materials, humus or the soil as a whole. The C/N ratios of undisturbed *miombo* forest and bush fallow at Msekera are 7.5 and 14.3, respectively[1].

At Msekera Station, Kwesiga et al. (1991) reported that the site on which they conducted their SS+M rotation experiment had an initial C/N ratio of 7.14, based on the soil depth of 0 -15 cm. After 3 years of SS fallow on the site, the C/N ratio was 8.43. The third year SS was removed from the site and maize was planted for one year. The carbon and nitrogen contents of the soil were then remeasured. The C/N ratio was 9.42, which is within the range reported for undisturbed soil organic matter at Msekera.

In this study, the C/N ratios, based on SCUAF simulation, also show an increasing trend over time. Initially, the C/N ratio would be 4.88. If a farmer were to plant SS on his or her field for 1, 2 or 3 years and remove it, the C/N ratios would be 5.00, 5.11 and 5.22, respectively. With 3 years of SS, followed by 1 year of maize cropping, the C/N ratio would be 5.43. These values are quite low as compared to the C/N values for stable soil organic matter or those reported by Kwesiga and his colleagues. Low C/N ratios would be expected for Katete ox-hoe farming system because farm lands have been intensively cultivated and soil organic matter is not stable. Due to increasing stress from cultivation and erosion, the organic matter has been degraded, hence reducing the depth or thickness of topsoil (Mhango, per. comm.).

5.4.3 Effect of *Sesbania sesban* improved fallow on maize yield

Based on SCUAF simulation, Table 5.7 and Figure 5.5 show maize yield trends under selected SS fallow systems. There would be differences in maize yield among the SS fallow

[1]Source: V.R.N Chinene and O.I. Lungu, Department of Soil Science, University of Zambia

systems. Under all the SS+M rotation systems, except 1SS+3M, mean (rotation average) maize yields would follow an increasing pattern over a 20 year period. The most stable and sustainable systems would appear to be 2SS+2M, 2SS+3M, 3SS+1M, 3SS+2M and 3SS+3M rotations. As expected, following each successive fallow period in all SS fallow-maize rotation options, maize yields in the second and third years of cropping would be lower than those in the first year of cropping (Table 5.7).

If the farmers were not to consider SS fallow practice and instead continue with the current practice of continuous cropping with or without fertilizer use, maize production would not be sustained in the long run. Maize yield would decline from 1.90 to 0.90 thousand kg/ha (about 53% decline over a 20 year period) under continuous cropping without fertilizer (Figure 5.6). Similarly, maize yield would decline from 2.00 to 1.30 thousand kg/ha (a 35% decline over a 20 year period) under continuous cropping based on fertilizer application (Table 5.7 and Figure 5.6). These findings are within the range of values reported by Vermeulen et al. (1993).

Compared with the Msekera Research Station mean (rotation averages) values for maize yields, based on 1SS+3M, 2SS+2M and 3SS+1M rotations, the yield data from this SCUAF study suggest that maize yields under SS+M rotations in Katete would be much lower than the station data, at least by 50%, depending on the SS+M rotation (Table 5.8).

The above results show that if the male or female farmers were to practice SS+M rotation, they would improve their maize output (yield) per unit area of land. Maize yield would increase with the intensification of the fallow. Continuous maize cropping with or without fertilizer by the farmers would not sustain yield in the long run.

Increased maize yield after one to three years of planted and managed SS fallows has been reported in previous studies (e.g. Prinz 1987, Saleen and Otsyina 1986, Hamid et al.

1984, Agboola 1980, Palm et al. 1988). In general, they demonstrated that lower yields were associated with continuously cropped plots due to damage in soil structure, rapid decomposition of organic matter and erosion. Erosion would cause loss of rooting depth for maize. It would reduce the amount of soil available for water supply, nutrients and physical support for maize. The effect would be gradual and progressive (Kidd and Pimental 1992). Conversely, increases in maize yields under fallow treatments were also shown to be related to accumulation of organic matter in the soil and improvement of soil physical structure. Sanchez et al. (1985) explained that it is possible to attain improvement in soil physical structure through the action of the opening of pores by root pressure and root decomposition. In a 1SS+3M rotation system (Figure 5.5), however, there would be a declining maize yield trend due to the low amount of soil saved (Figure 5.2) and low accumulations of soil organic carbon and organic nitrogen (Figures 5.3 and 5.4).

This study has also shown that, under farmers' conditions, maize output could be lower than those observed at Msekera Research Station. At Msekera, the SS+M rotation experiment was conducted under soil conditions different from those of the farmers. Kwesiga et al. (1991) reported that the site was a newly cleared *miombo* woodland which was already rich in soil organic carbon (C) and nitrogen (N). Thus, when SS was planted on the site, it enhanced the C and N pools which resulted into significant yield response per unit of land area. The site was also prepared with a tractor.

In Katete, the arable lands have been cultivated intensively. Soil physical and chemical properties have been degraded, and low N and C contents dominate the soil (Mhango 1991). Under these conditions, SS would be expected to grow poorly especially during the establishment stage. Consequently, yield response would also be low during the establishment stage, but increasing as time progresses. Based on a 6 month SS performance assessment, after establishment in Kagoro, Katete, Kwesiga et al. (1991) reported that the growth of SS in Katete was very poor as compared to the performance at Msekera. They explained that this was probably due to several factors, including differences in methods of land preparation, and lack of weeding, supervision, and a suitable *Rhizobium* strain. In future trials, (1) land preparation methods for field trials, both on-station and farmers' fields, must be standardized, (2) researchers must visit farmers frequently, and farmers and camp officers should be enabled to visit Msekera to learn about fallow establishment, management and benefits, and (3) SS seedlings should be inoculated with suitable *Rhizobium* strain (Kwesiga et al. 1991).

As shown in Table 5.7, mean (rotation average) maize yields under SS fallow systems in the short-term (less than 6 years) would be lower than mean maize yields based on fertilizer or no fertilizer application (Figure 5.6). Several factors may be contributing to this situation. One of the factors could be that the biological contributions (e.g. nutrient release) of the fallow treatments would still not be enough to create a pool of soil nutrients and improve soil conditions which could increase maize yields to compensate for yield losses during fallow periods. These results suggest that farmers would have to use fertilizer with SS or with maize after phasing out over a certain number of years. Adding fertilizer to SS during fallow establishment would not be socially acceptable by farmers because they could argue that if SS was to improve soil fertility, then what would be the point to fertilize it during its establishment. Adding a small amount of fertilizer, such as for "top dressing" purposes, during maize cropping, could probably be considered by farmers as it conforms with their cultural practices.

It is difficult to predict how the male and female farmers would incorporate SS fallow system into their farming practices if they were to adopt the system, or how they would behave in the short-term and long run with respect to landuse practices. With regards to SS fallow system, it is certain, however, that none of the farmers would put all land in SS at one time. It is also expected that the farmers would have several options, some of which could be:

1. Planting SS on (a) grassland, the area of farm land where soil is exhausted and had been left to fallow under grass cover for 1, 2 or 3 years to restore soil fertility, or (b) on the area allocated for maize or other crop production. Strategy (b) may not be considered by the farmer because SS would compete with maize or other crops for land. It would be unreasonable for the farmer to forego maize or crop production for the sake of SS. The farmer could consider strategy (a). A small portion (1 ha or 0.25 ha) of the grassland or any area of farmland, depending on the farmer's choice, may be planted with SS and the remaining portion of land planted with maize or other crops. This, however, depends on land and labour availability, and family needs. If this strategy were to be undertaken, it would result in additional labour and other SS establishment costs for the farmers. Establishing SS would involve planting, weeding and harvesting, and SS seedling costs. If it were a 2SS+3M or 3SS+3M, this would mean that maize output on the SS area would be foregone for 2 or 3 years, even though the system would sustain yield in the long run. Most importantly, if the farmer is experiencing land and food shortages, he or she would likely continue cultivating land, on a crop rotation basis, even if the system would not sustain yield in the long-term.

2. To continue with their current practice by leaving a portion of the exhausted farm land to fallow under grass cover for 1 to 3 years. In this case, the farmer knows that it would be difficult for him or her to plant SS on the land because it would result in additional labour and costs. This strategy would also depend on the availability of land and family needs. If there are land and food shortages, the farmer would not leave the

land under grass fallow. The land would be cleared and planted with crops appropriate to the farmer's objectives.

3. To continue using the inorganic fertilizer on the land under grass fallow or cultivated land. In this case the farmer would be harvesting crops annually. But crop yields are not expected to be sustained under this system in the long run. Many farmers would also not be able to buy fertilizer in the long-term because of its increasing cost.

4. To crop continuously without fertilizer use even if they would get low yields and the system would not sustain the yield in the long-term.

5. To continue with crop rotation even though this has not produced significant yield improvements (ACOs, per. comm).

If the male and female farmers were to plant SS on their farm land, utilizing all fallow and cultivated lands, they would be expected to establish the species on "scheduled" (phasing) arrangements, based on temporal and spatial considerations. Tables 5.9 to 5.14 show maize yields based on the temporal and spatial arrangements of 1SS+3M, 2SS+2M, 2SS+3M, 3SS+1M, 3SS+2M and 3SS+3M rotations in a farming system. Table 5.15 shows the summary of maize yields per hectare while phasing in SS fallows utilizing all fallow and cultivated lands. The yield data in Table 5.7 were used in the calculations. All the SS+M rotation systems, except 1SS+3M rotation would sustain maize yield in the long run. For the purpose of simplicity and convenience, each plot size was assumed to be 1 ha, but this could be of any size depending on the area of farm land the farmer has and his or her objectives. Similarly, the total area of land for phasing was also selected to correspond to the length of each SS+M rotation. What is important are the values indicated in the parentheses, average maize yields per hectare (Tables 5.9 to 5.14). Of all the SS+M rotation alternatives, 2SS+2M, 2SS+3M and 3SS+3M systems appear to be most desirable. Maize yields appear to be stable and sustainable under these SS+M rotation systems. A 3SS+1M rotation would be a financial disaster for the farmer because he or she would get yield for just one year from each rotation.

The cross over period or break-even point, the year SS+M rotation would produce higher yield than that which could be achieved under CM+F, would be after year 15, 18 or 19, depending on the SS+M combination (Table 5.15).

The farmers could increase their level of maize output in 2SS+2M, 2SS+3M and 3SS+3M rotation systems by adding 100 kg/ha of inorganic fertilizer at the time of planting maize. Tables 5.16 to 5.18 and Figure 5.7 show maize yields which could be achieved under each of these SS+M rotation systems, with and without the addition of 100 kg /ha of fertilizer. The addition of fertilizer would slightly increase the levels of maize output in 2SS+2M and 2SS+3M rotation systems. The greatest increase in the level of maize output could be achieved under 3SS+3M rotation system. This suggests that a longer SS fallow would require less input of fertilizer. But a shorter fallow would require more fertilizer to cause the same effect: yield response. Similar observations have been reported in previous studies (e.g. Prinz 1987, Kwesiga et al. 1991). The addition of fertilizer would advance the break-even points. In a 2SS+2M rotation system, the break-even point would be after year 14 (Table 5.16). In a 2SS+3M, it would be after year 12 (Table 5.17). But in a 3SS+3M rotation system, the break-even point would be after year 9 (Table 5.18). It was not possible to predict what would happen when fertilizer is not used after the break-even points. Maize yields would probably drop slightly but they may still be sustainable under SS fallow system especially in a 3SS+3M rotation because of the build up of organic C and N (Figures 5.3 and 5.4).

From a farmer's perspective, however, it would be unreasonable to consider applying

100 kg/ha forever during maize cropping after each fallow period. The farmer would probably abandon fertilizer use after the break-even points.

5.5 Socioeconomic effects of *Sesbania sesban* improved fallow on the ox-hoe farming system

To determine whether or not SS would improve the conditions of the households and sustain the ox-hoe farming system in Katete District, social and economic factors have to be evaluated in conjunction with the fallow system. This study showed that the SS fallow system would be biologically feasible. But if the improvement in maize yield, soil organic C and N or erosion control result in additional social and economic burdens for the farmers, they would not be expected to consider adopting it. In this section, the profitability, labour demands, fuelwood and other by-products of SS fallow system, knowledge to practice SS fallow system, effects of external stimuli on SS fallow system, other agroforestry options, and gender issues associated with the improved fallow practice are examined.

5.5.1 Profitability of *Sesbania sesban* improved fallow system to farmers

Tables 5.19 to 5.24 show the estimates of net returns (net income), expressed in Zambian Kwacha, per unit area (shown in parentheses) which could be achieved under selected SS+M rotations and CM+F. These estimates are based on maize yields shown in Tables 5.9 to 5.14, May 1990 input and output prices provided by the Zambian Ministry of Agriculture, 1990, and the interviews with the agroforestry technicians at Msekera. Table 5.25 shows the summary of the estimated net returns per hectare while phasing in selected fallows, utilizing the fallow and cultivated land. In order to estimate the trends in net income, with or without SS fallow, it was assumed that costs and prices would be constant over the 20 year simulation period. Only yield would change, and this would be affected by soil quality and quantity.

If the male or female farmers in Katete were to practice SS+M rotation system, they would be worse off economically in the short-term (1 to 6 years) because of the costs incurred in managing SS fallow system: establishment, maintenance and harvest costs. Furthermore, maize yields would be much lower in the short-term than in the long-term (7 to 20 years) to generate significant amount of income to compensate for the costs associated with SS fallow system (Table 5.15). Break-even (cross-over) points would occur after 3, 6, 4, 11, 6, 5 years in 1SS+3M, 2SS+2M, 2SS+3M, 3SS+1M, 3SS+2M, and 3SS+3M rotation systems, respectively (Table 5.25). This means that it would not be profitable to practice SS fallow system in the short-term. Net returns from the fallow system could be realized in the long-term, a period in which most of the present male and female farmers would have died, considering the life expectancy in Zambia and the average ages of the sampled farmers.

With the exception of 1SS+3M rotation, net income (net return) over all SS+M rotations would show an increasing trend in the long run. For example, Figure 5.8 shows increasing trends in net returns in 2SS+2M, 2SS+3M and 3SS+3M because of the increases in the concentrations of soil organic carbon and organic nitrogen, reduced soil loss and increases in maize yields. In a 3SS+3M rotation, for example, net return at year 20 would be ZK 2840. Continuous maize cropping based on fertilizer use (CM+F) would produce higher net income than SS+M rotations in the short-term. But CM+F practice would result in a decrease in net return, from ZK 2059 (year 1) to ZK -153 (year 20), about 100% decrease, because of the declines in soil organic carbon and organic nitrogen, increases in the rate of soil loss, and the decline in maize yield.

As discussed previously, farmers could apply fertilizer as usual during maize cropping. For example, if 100 kg of inorganic fertilizer/ha were applied during maize cropping in a

2SS+2M, 2SS+3M, or 3SS+3M rotation, break-even points would occur after year 6 in 2SS+2M or 2SS+3M rotation and after year 4 in 3SS+3M rotation as illustrated in Tables 5.26 to 5.28. Because of the costs incurred in buying fertilizer, net returns would drop. For example, at year 20 it would drop by ZK 146 and ZK 206 in 2SS+2M and 2SS+3M rotations, respectively. But in a 3SS+3M rotation, net return would increase by ZK 1777 at year 20 even if fertilizer costs were incurred. This is because in a 3SS+3M rotation system, there are more accumulations of C and N than in either 2SS+2M or 2SS+3M rotation to cause significant yield response.

The addition of inorganic fertilizer to 2SS+2M or 2SS+3M would be wasteful and uneconomical. Most importantly, it would be unwise for the farmer to continue using fertilizer forever. The farmer could either use SS only or use SS+M (plus fertilizer) during the early years of the fallow establishment on the farmland.

Based on the interviews with the agroforestry technicians at Msekera, it was estimated that it would cost a farmer ZK 3552 for establishing (land preparation, cost of seedling, transportation and planting in the field and weeding) SS; ZK 400 for maintenance (weeding) and ZK 286 for harvesting (cutting). The establishment estimates are based on 10000 seedlings/ha, spaced at 1.0 x 1.0 m, 10 Zambian *ngwee*/seedling plus an assumed 50% allowance for losses during planting, for replanting due to mortality caused by termites, nematodes (D'Hondt-Defrancq 1993) or other diseases, and for other establishment costs. It was assumed that no weeding would be required in the third year of the fallow: SS would have developed full canopy, and weeds suppressed by the third year (Kwesiga et al. 1991).

The occupation of SS on a piece of farm land for 1, 2, or 3 years would mean that no food or revenue would be obtained from the piece of land for these periods. A male or female farmer would put his or her piece of land out of production for 1, 2 or 3 years. Most importantly, the farmer would be incurring costs associated with the SS fallow system.

5.5.2 Labour demand for the practice of *Sesbania sesban* improved fallow system

Table 5.29 shows the estimated monthly labour demands, and male and female headed households' labour supplies during the cropping season. The demand estimates are based on the calender of cropping activities outlined previously in this chapter and the 1990 Zambian farm management model or guidelines developed by the Ministry of Agriculture. The estimates for the male and female headed households' labour supplies are based on the averages of cultivated land, number of full-time workers (adults) and the weekly labour input by a full-time worker (Table 5.3). Labour supplied by children is ignored because they are not full-time workers. Children are needed, in many cases, to supplement household labour when needed. Labour supplies by the male and female headed households are assumed to be constant each month. Farmers were not asked how much time they spend on doing off-farm activities per week, or how many family members do not work per week due to illness. Thus, it was not possible to discount time lost due to illness, or spent on doing off-farm activities from the monthly household labour supply. If these time elements were factored in, the actual monthly labour supply by the male or female headed household would probably be lower than the values reported in Table 5.29.

Under the current practice (Table 5.29), labour demand is highest in November, the planting period. The average male headed household experiences labour shortages of 19 and 69 hours per hectare in October and November, respectively. The situation for the female headed household is even worse. The average female headed household experiences labour deficiencies throughout the year. The greatest labour shortage is experienced in November (-134 hr/ha).

Based on the interviews with the agroforestry technicians at Msekera, it was estimated that the labour needed, per hectare, for the practice of SS fallow system would be as follows: (1) for land preparation labour demand would be 100 hr; (2) for transporting, digging planting holes and planting, it would be 600 hr; (3) for 1st and 2nd weeding, it would be 140 hr; and (4) for harvesting SS, labour demand would be 100 hr.

If the average male or female headed households were to consider practising the SS fallow system, they would have to provide additional labour for these activities. This means that in October, the farmer has to provide additional 100 hr for land preparation, 600 hr for transporting, digging planting holes and planting SS, 70 hr in January for 1st weeding, another 70 hr in March for 2nd weeding, and 100 hr during harvesting of SS in August, if it were a 1SS fallow (Table 5.30). For a 2SS fallow, the farmer would need labour for weeding and harvesting, and if were a 3SS fallow, he or she would need labour for harvesting only, assuming no weeding were required in the third year of the fallow. This suggests that the longer the fallow, the less labour would be required to maintain it.

These activities would create labour shortages for the average male and female headed households. The average male headed household would experience labour deficiencies in October, November, January, March and August. The greatest labour shortage would be experienceu in November (-699 hr). For the average female headed household, she would experience severe labour shortages throughout the cropping season, especially in November (-734 hr), October (-184 hr) and August (-114 hr). This means that the male or female headed households would have to hire labour, use children, or engage in communal (sharing) labour to make up for labour deficiencies.

The consequent reduced maize yields, loss in revenues, labour and costs associated with the SS fallow system would be impediments to adopting the agroforestry SS fallow practice. The real issues are how to (1) offset the need to defer production of maize in the first years of the fallow system, and (2) compensate for the loss in revenue or food production from the land during the SS fallow. There are no simple answers to these issues. Farmers could adopt several strategies. For example, they could store surplus food on which they would depend on during the SS fallow periods, or "hunger months", from January to March, a period when food is scarce in Katete (Boehringer and Caldwell 1989). However, this would depend on the amount of food produced and the number of dependents to be fed. Given the current food production levels and number of dependents in the male and female headed households, it is unlikely that the farmers would ever be able to store much, if any, surplus food. Most farmers in Katete have persistent food scarcity problems which are linked to production and the number of household dependents (ACOs, per. comm.).

5.5.3 Fuelwood and other uses of *Sesbania sesban* improved fallow system

It has been advocated that SS, besides adding N to the soil, could be used as fuelwood or poles (ICRAF 1988) to compensate for the opportunity costs associated with the fallow system. Farmers could get these fallow products from their farm lands, hence reducing deforestation and the amount of time spent in collecting the products from the forest. However, from a farmer's perspective, SS may not seem to be a desirable species and real solution to energy demand. For a 2SS or 3SS fallow, it means that the farmer would have to wait for 2 or 3 years before obtaining the fuelwood. When SS are cut after the fallow period, they have to dry for a few weeks before they can be used for daily cooking or periodic activities such as beer brewing.

It is also unlikely that the SS fuelwood, produced from a unit area, would sustain the households' energy needs for 2 or 3 years. According to Kwesiga (ICRAF 1991), farmers with

2 to 3 year old SS trees in their fields could harvest about 10 to 15 tons/ha (or 10000 to 15000 kg/ha) of firewood. The current total monthly consumption of hardwood, air-dry fuelwood for the Southern Africa region is estimated to be about 300 kg for a family of 6 people, 50 kg of fuelwood/person/month (Mangono 1992). This means that for the average male farmer, with about 11 dependents, the monthly consumption of fuelwood would be about 550 kg (50 kg x 11). For the average female farmer, with about 8 dependents, the monthly consumption of fuelwood would be about 350 kg (50 kg x7). Thus, the annual fuelwood consumption by the average male and female farmers would be 6600 and 4200 kg, respectively. Theoretically, this means that the SS fuelwood would sustain the average male farmer for about 1.5 to 2 years (10000 or 15000 kg divided by 6600 kg). Similarly, it would sustain the average female farmer for about 2 to 3.5 years (10000 or 15000 kg divided by 4200 kg). These estimates, however, are based on SS fuelwood production at Msekera. At Msekera, a 3 year SS produced an average diameter of about 3 cm, measured at breast height, or dbh (ICRAF 1991).

Based on the field trials, established and supervised by the agroforestry team, in Kagoro, Katete, the average dbh of a 6 month old SS was about 0.68 cm, suggesting that in Kagoro, the dbh of a 3 year SS would likely be much less than the performance at Msekera and so would the SS fuelwood production. About 5000 to 10000 kg of fuelwood/ha would be expected under the farmers' conditions. This means that for the average male and female headed households, the SS fuelwood from a 3SS fallow would sustain them for about 1.5 and 2 years, respectively.

In practice, however, the consumption rates of SS fuelwood would likely be higher than the estimates indicated above for the following reasons. First, SS is less dense (0.55 gm/cc, oven dry) than the forest fuelwood species (average of about 0.80 gm/cc) currently in use by the farmers. Second, SS burns much faster than the forest species (Dutt and Jamwall 1990). According to these researchers, for a wood to be an efficient supplier of energy, it should have high calorific value, high density, high volatile matter, but low ash content. These requirements are only partially met by SS. Because of small SS which would likely be produced, with relatively less dense wood and rapid burning, the monthly consumption rate of the SS fuelwood would be expected to increase. Thus, the unit area production of SS fuelwood stock (i. e. based on SS grown for three years) would probably sustain the farmers for only 6 to 12 months.

Another issue related to SS fuelwood is the question of social acceptability. It is not known whether farmers would, in the short run, accept SS as an alternative energy source. According to the agroforestry technicians at Msekera, some farmers living near the station were invited to come to collect "free" firewood from a stock of 3 year old SS after it had been cut from the experimental plot. The farmers refused to collect the wood, arguing that the SS firewood was so small in diameter that it wood burn like "grass". So long as farmers are still getting dense wood from the forest or lopping their mango trees for firewood, it is unlikely that SS can be considered as an alternative fuelwood. The SS fuelwood could be considered if there were no perfect substitutes: if farmers were using grass, crop residues or cowdung for cooking, a situation likely to be experienced in the long run. At the moment, fuelwood supply is not a problem in rural Katete. There is, however, a very high potential for energy crisis in the near future. This suggests that research on alternative energy sources should be considered in order to design the long-term solution to the expected energy problem in the region.

Several energy options have been suggested for the region. They include biogas, solar energy, electricity and improved cookstoves such as metal pans and pots (Mangono 1992).

Some of these options such as electricity involve high capital investments to establish. In Zambia, this may be an impossible project to pursue, at least for now, because of its weak economy. Much emphasis is now on improved cookstoves because of their fuel-saving capability. While it is argued that this strategy may reduce the consumption rate of fuelwood, energy demand for various domestic activities will continue to increase. Furthermore, the planting of SS would not eliminate the deforestation problem.

Fuel-saving technology and tree planting will provide planners with only a "breathing space" (Mangono 1992). Nevertheless, it is this breathing space that is needed while the most direct way to improve energy supply and long-term solution to energy demand are being examined.

Sesbania sesban could also be used for stacking, building and fencing purposes, and as fodder for livestock to compensate for loss revenue or food during fallow periods. But it is unlikely that farmers would consider SS for these activities. They would still prefer trees which are straight, durable, and resistant to termite attack. For example, some farmers in Katete use *Euphorbia turicalli* for fencing their *dimbas* because this species is known to produce chemical exudates which are toxic to termites (Kwesiga and Chisumpa 1990). Harvesting part of SS (when it is growing) as fodder could reduce SS biomass and amount of litter accumulation, resulting to formation of small amount of organic matter. Consequently, these factors could reduce the effectiveness of the fallow system in improving soil productivity. Labour for the harvesting activity would also compete with labour demand for off-farm and other farm activities.

5.5.4 Knowledge to practice *Sesbania sesban* improved fallow system

In estimating net income trends under SS fallow system, it was assumed that farm households would buy seedlings from private enterprises. Some households could specialize in SS nursery production. However, this would depend on the demand for SS in the villages. Given the potential high opportunity costs associated with SS fallow system, there may be no market for SS in the villages. Nevertheless, even if some households were to establish SS nurseries, they would have to be trained in basic forestry nursery techniques, as discussed in the literature (e.g. Kwesiga 1989, Briscoe 1990, Carter 1987). These would include (1) seed collection, handling, storage and pre-treatment; (2) seedbed preparation, soil mixtures including fertilizers and the inoculant, *Rhizobia*; (3) dates for seed sowing and transplanting; (4) nursery management including weeding, root pruning, spraying and watering; (5) hardening off and grading of planting stock; (6) lifting and transporting seedlings to farm lands for planting; (7) nursery protection which includes fencing against livestock, rodents and fire; and (8) avoidance of an outbreak of seedling diseases by maintaining general tidiness in the nursery.

These techniques are critical in the successful production of SS planting stock. As reported by Linyunga and Phiri (1983), a successful SS fallow establishment appears to depend on nursery SS planting stock. When SS is sown broadcast, it does not grow as fast as the potted specimens (Kwesiga, as reported by Linyunga and Phiri 1993). Thus, if farmers were to adopt SS fallow system, they would have to use nursery stock to obtain good results.

Farmers would also have to be trained in the management of SS fallow system (e.g. how seedlings are established, at what age or size, at what distance apart, straight line plantings, and weeding).

5.5.5 Gender issues and *Sesbania sesban* improved fallow system

There is increasing evidence that women have traditionally played important roles in agricultural production and in the use and management of trees. Despite this awareness, however, the importance of these roles is often obscured by prevailing assumptions that (1) women are housewives and are not heavily involved in agricultural production, (2) women are not significantly involved in tree production and use, (3) every woman has a husband or is part of a male headed household, and (4) women are not influential or active in public affairs (Fortmann and Rocheleau 1985).

This study has shown that female headed households, by choice or as a result of personal events such as death of a spouse, divorce, desertion, abandonment or of social trends such as a male outmigration, have assumed new roles which used to be traditionally important "male activities" in agricultural production (Table 5.3).

Besides agricultural production, female farmers have to participate in household activities such as caring for children and the house, collecting forest products such as fuelwood, grass and wild foods, water and cowdung for decorating the houses, milking cows, trading and beer brewing. However, if they were to practice an agroforestry fallow system, it would compete directly, in terms of labour demand, with these activities. At present female farmers suffer from labour shortages as a result of increased outmigration of household members. This suggests either discouraging outmigration (a very complex issue with which to deal), or introducing a fallow system which requires minimum labour, and less opportunity costs.

Male and female farmers have been shown, in this study, to have differential access to land. According to Milimo (1987), women continue to be discriminated against in the allocation of land despite the passage of the 1975 Land Act guaranteeing women equal access. Women's access remains limited by the control men have over distributing land. The act vests all land in the president, who in turn delegates his powers of allocation to district councils and traditional chiefs. The councils or chiefs are made up primarily of men and they often require a husband's consent for a married woman to receive land. Milimo adds that "in most cases, the husbands are reluctant because they prefer wives to work on their cash crops." If a woman is in need of land, a close relative gives part of what he uses.

Land is passed from one generation to the next. Land cannot be rented, sold or mortgaged (ACOs, per. comm.). With respect to male headed households, if a male dies, outmigrates or divorce occurs, the land which the couple has been using reverts to the absolute owners, the linage of the husband. This suggests that spouses of male headed households have insecure ownership of land: there is uncertainty as to whether they are able to claim future benefits arising from their investments in the land. In this study, it has been shown that SS+M rotation practice requires some sacrifices in the short-term in order to obtain significant economic and soil productivity gains in the long-term. However, if farm households hold temporary or insecure claims, as the case with married women in Katete, then they will be unwilling to accept costs for benefits to which they may have no right in the future.

Changes to tenure systems should be considered, involving chiefs and policy makers. Otherwise, it will remain one of the major obstacles to the development of improved agroforestry systems in the region. The female farmers' access to more land, or secured tenancy may be beyond the researchers' ability to change. It is a complicated policy issue. But lack of access to land constitutes serious obstacles to implementation of agroforestry fallow projects by female farmers.

In this study, a female enumerator was employed to conduct the interviews on the basis that it would be easier for female farmers to express their concerns and questions freely with the enumerator. This suggests that women extension workers and technical personnel would also be necessary to promote agroforestry improved fallow systems. Lessons from agricultural activities in many developing countries suggest that the mechanism for diffusion of improved agricultural technologies are gender based (Fortmann and Rocheleau 1985). Female extension workers tend to work with female farmers, while male extension workers also tend to work with male farmers. A recent national survey of agricultural extension workers in Zambia revealed that only about 5% were women compared to 95% male. The report also revealed that male extension workers tend to serve only male farmers (Central Statistics Office 1990).

If the farmers were to practice an agroforestry SS fallow system, the economic benefits would be gender biased. Male farmers would have more yield and income than the females because they have more access to land and credit facilities than female farmers. Furthermore, the priorities for the fallow system would also be influenced by gender. In this study, female farmers (64%) showed more interest in SS fallow system, while the males (73%) rejected the improved fallow idea. Because female farmers are the principal collectors of firewood and other forest products, getting firewood from the fallow system would reduce the collection time, decrease the distance travelled, change who collects (probably children), and change in transportation means, probably using animal carts. All these are potential benefits and reduction of workload for women.

5.5.6 Effects of external stimuli on the practice of *Sesbania sesban* improved fallow system

It was not possible, due to data limitations, to predict the effects of changes in random or stochastic shocks (external stimuli) on production and consumption capability of the male and female farmers, with or without SS improved fallow system. Such shocks or impulses could include migration of a worker from a household, pests or diseases, changes in the prices of maize, animal labour, hired human labour, non-farm goods, leisure, fertilizer and SS, number of dependents, and quantity of land and non-land capital on the farming system, with or without agroforestry SS fallow system. Because farming systems are complex and dynamic, the prediction of the short-term and long-term effects of these impulses on the household behaviour would require a sophisticated non-static household model to determine the dynamic behaviour of the households. The development of such a model would require a large and accurate data set observed over a long period of time (at least 5 years), based on the behaviour of the households with and without agroforestry SS improved fallow systems.

According to the survey results and Tables 5.29 and 5.30 of this study, the migration of a family member (worker) from a female headed household, for example, would cause severe labour deficiencies in the household. Because the practice of SS fallow system would result in additional labour demand for the household, the female farmer would experience even more serious labour constraints. In some parts of India, social forestry (community forestry and agroforestry) programmes have been shown to cause increased workload for women (Fisher 1992).

Many researchers (e.g. Mwape and Kraft 1990) have shown that these impulses significantly affect the behaviour of agricultural households operating under continuous cropping based on fertilizer use. For example, they reported that an increase in the prices of fertilizer, animal labour and leisure reduces the production and consumption capability of farm households. If farmers were to practice an SS fallow system, it is also expected that their production and consumption capability would be affected by the impulses.

In summary, several lessons can be learnt from the preceding sections. While researchers may aim at improving soil conditions, maximizing yields, and reducing deforestation, farmers seek to maximize their welfare, in addition to yield and profit. They seek to minimize risk, labour inputs or improve the seasonal distribution of the food supply. Farmers in Katete seek to provide a reliable supply of food for their families and to provide cash for what they regard as essential purchases. They take into account both ecological circumstances such as soils (e.g. by crop rotation practice to improve soil fertility) and socioeconomic ones such as profitability, riskiness and social acceptability in deciding what enterprises and management practices to adopt. About 73% of the male and 36% of the female headed households indicated that they were not interested in an agroforestry SS fallow system because the system would involve additional labour which would directly compete with other farm and off-farm activities (e.g. brewing and trading). Off-farm activities are important sources of household income. They contribute, respectively about 27 and 28% to the male and female headed households' total income (Table 5.3). Instead of incurring costs of ZK 3552, 400 and 286 for establishment, weeding and harvesting SS, respectively, the farmer would rather sell his or her labour for ZK 20/day (May 1990 rate, Zambian Ministry of Agriculture 1990), continue to trade or brew beer.

5.5.7 Other agroforestry options

It will be important to provide farmers with trees, shrubs, or fallow systems which farmers will want to adopt for economic reasons. If a particular crop or farming system is "good for the environment" but brings no economic or social benefits to farmers, or the opportunity costs associated with the crop or the system are higher than the prevailing practices, no farmer will change his or her habits (Rutter 1991). The ox-hoe farmers in Katete are very fragile economically. Thus, they would not be willing to make a sacrifice or forego income in the short-term for expected future gains.

While farmers have been assumed to be conservative, backward, irrational or not willing to change (e.g. Beltran 1976), farmers in Katete are development oriented people and respond to market forces. They are interested in adopting economically beneficial projects such as fruit tree farming (survey results, this study). Farmers adopt new practices that are perceived to be in their interests and reject those that are not (Schultz 1964). For example, the adoption of improved varieties of beans and groundnuts in the region were significantly and positively correlated with the attractive sale price for the produce, and the availability of local inputs such as land and extension guidance (Mulila et al. 1989).

According to Rocheleau and Raintree (1987), and Raintree and Warner (1986), improv... or planted fallows represent an intermediate step between intensive systems like alley cropping and extensive traditional systems of shifting cultivation. Two main types of improved fallows have been discussed in the literature: (1) "economically-enriched fallows", designed to increase the economic value of the fallow vegetation by enrichment with trees or shrubs valued for their cash or subsistence uses, (2) "biologically-accelerated fallows", designed to enhance and accelerate the vegetative regeneration of soil fertility (Rocheleau and Raintree 1987). These authors argue that interest in the adoption of biologically-enriched fallows (e.g. planting of fast growing N-fixing SS) is not likely to arise until the farmers themselves have accumulated sufficient experience with the struggle to maintain soil fertility, and adoption of economically-enriched fallows is likely to precede biologically-accelerated ones. This suggests that any plant species to be introduced in the farming system in Katete must, at any given time, be able to serve dual purposes: biological and socioeconomic functions.

Farmers traditionally grow annual crops such as beans, cowpea and pigeonpea, in rotation or intercropped with cereals. Recently, research on improved fallows involving pigeonpea was proposed for 1992/93 season at Msekera (Kwesiga et al. 1992). These legumes produce edible grain and improve soil fertility by fixing nitrogen through their root nodules (ICRAF 1991). Based on the on-farm observations in Chipata and the experiment at Msekera Research Station, Boehringer and Caldwell (1989) showed that *Cajanus cajan* (pigeonpea) has a high potential to alleviate some of the constraints farmers have in the Eastern Province of Zambia. They found that pigeonpea was easy to plant, exhibited vigorous growth, and required little attention in the fields. The labour demand for pigeonpea was relatively low as compared with other SS species experimented with in an alley cropping system. Pigeonpea, an indigenous species in the region, had the least mortality rate in comparison with other agroforestry species. In the alley cropping system, pigeonpea supplied 40 to 50 kg N/ha/yr. At the current recommended fertilizer levels for maize in the province, farm households could save their whole fertilizer "top-dressing" by using pigeonpea as a source of organic matter. Most importantly, pigeonpea could supply substantial amounts of food (pods and grain), recognised as such by farmers, from January or February through the dry season. Simultaneously, animals could browse the pigeonpea.

In designing new fallow options for farmers in Katete, researchers should consider plant species with biologically, socially and economically acceptable properties. Research on biological aspects of such species, including pigeonpea, over a wide range of environmental conditions in the region should be considered. Most importantly, socioeconomic analyses of the fallow species, including the effects of impulses, should be undertaken to estimate net returns to land and labour and social benefits of the species.

Without appropriate fallow systems, farmers cannot be expected to survive from agricultural production on marginally productive soil regimes. They will continue to cut trees as they expand their agricultural production in forested areas. They will continue to do so, not that they are unmindful of long-term consequences of their action, but because they have no real alternative at their disposal. While thermodynamics, ecology, common sense and economics show that conservation and environmental protection are worthwhile long-term goals, it is unlikely that the economically vulnerable farmers in Katete are willing to accept trade-offs in the area of environmental quality and conservation for deferred crop production or lost revenues (as is the case with SS fallow system) to which they assign a higher priority.

Farmers have a very complex decision-making process which researchers do not understand well. For example, nonquantifiable factors such as relationship to the natural environment and concern for future generations, are weighed against short-term monetary and social gains (Thompson 1985).

Researchers should take serious consideration of the rural systems, knowledge and views of farm households. According to Fisher (1992), externally funded projects have failed to work effectively through local institutions for many reasons. First, the projects have often ignored or overridden existing local knowledge and practices and imposed assumptions about aims and objectives of local resource management. Second, in most cases these aims and objectives usually "assert what is good for the local people" without taking serious consideration of local views and circumstances. Third, the projects have tended to be designed under the assumption that technical knowledge is more relevant and valid than a farmer's knowledge, and that "local people have no capacity to organize activities and need to be organized by outsiders".

Once the appropriate fallow system is introduced into the farming system and the path of intensification begins to involve permanent investments in the productivity of a fixed piece of land, adequate fencing with socially, economically and biologically acceptable plant species can become a precondition of further production increases: for example, by providing protection for intensive gardens or in creating paddocks for rotational grazing of livestock

(Rocheleau and Raintree 1987).

As part of the agroforestry systems approach, trees that can be used for fruit and nut production, fuelwood, building and fencing should be considered in the planning for an agroforestry system as they may facilitate the adoption of the system in the region. However, gender, ownership or tenure issues, and livestock and grazing management will have to be addressed if the agroforestry system is to be successful in the region.

Table 5.1. Summary statistics of selected characteristics of male headed ox-hoe farm households, Katete, Eastern Province, Zambia, 1992

Variable	Mean	Std. Dev.	Min.	Max.
Area of land (ha) for hybrid maize production (AHMZE)	3.30	2.30	0.25	9.00
Area of land (ha) for local maize production (ALMZE)*	3.00	2.25	0.50	10.00
Area of land (ha) for production of other crops (XC)*	5.30	3.85	1.40	20.00
Area of land (ha) under grass (XG)	2.30	1.36	0.40	5.00
Area of land (ha) under wooded fallow (XW)*	3.60	2.78	0.50	10.00
Weekly adult labour input (hr) during the cropping season (ADLAB)	36.00	24.75	6.00	80.00
Weekly child labour input (hr) during the cropping season (CHLAB)	31.00	18.20	3.00	40.00
Number of adult workers (WRKS)	9	6.78	2	44
Number of dependents (DEP)	11	5.10	2	30
Amount of fertilizer (FERT) used in kg/ha*	201.60	5.23	200.00	220.00
Hybrid maize yield (PHMZE) in kg/ha	1119.10	828.68	198.00	2250.00
Local maize yield (PLMZE) in kg/ha	932.60	694.27	31.50	2250.00
Income from hybrid maize (IHMZE) in ZK/yr*	10227.00	12017.57	1422.00	42660.00
Income from other crops (IOTHCR) in ZK/ha	10248.00	13051.41	110.00	61110.00
Income from off-farm activities (INOFF) in ZK/yr	7889.00	11372.70	300.00	40000.00
Age in years (AGE)	46	16.43	21	84
Years of farming (YRFARM)	18	12.01	5	53
Years of schooling (EDUC)	6	2.93	1	12
Number of people leaving the household (MIGR)*	2	1.61	1	7
Number of cattle (CA)*	9	9.57	1	41
Number of goats (GO)*	4	5.31	1	27
Number of pigs (PG)	5	3.51	1	15
Expenditure on food (EXPF) in ZK/week	177.00	138.59	55.00	360.00
Expenditure on leisure (EXPL) in ZK/month	820.00	1077.28	11.50	2000.00
Expenditure on manufactured goods (EXPMG) in ZK/month	209.00	210.17	9.60	1300.00
Expenditure on hired animal labour (ANLAB) in ZK/yr	1561.00	1511.64	100.00	5200.00
Other expenditures (OEXP) in ZK/yr*	1683.00	1947.58	24.00	7600.00
Expenditure on hired human labour (HLAB) in ZK/yr*	1804.00	2210.52	20.00	7000.00
Expenditure on fertilizer (FERP) in ZK/ha/yr*	3094.00	580.16	112.00	3520.00

* Not normally distributed among male headed ox-hoe farm households, based on Kolmogorov-Smirnov Goodness of Fit Test (Zar 1974); Std. Dev.= standard deviation; Min.= minimum value; and Max.= maximum value.
ADLAB = a full-time adult worker's weekly labour input; CHLAB = not a full-time labour input

Table 5.2. Summary statistics of selected characteristics of female headed ox-hoe farm households, Katete, Eastern Province, Zambia, 1992

Variable	Mean	Std. Dev.	Min.	Max.
Area of land (ha) for hybrid maize production (AHMZE)	1.00	0.71	0.25	3.00
Area of land (ha) for local maize production (ALMZE)*	1.30	0.88	0.40	4.00
Area of land (ha) for production of other crops (XC)*	2.00	1.39	0.40	8.00
Area of land (ha) under grass (XG)	1.00	0.66	0.20	3.50
Area of land (ha) under wooded fallow (XW)	1.10	0.66	0.08	3.00
Weekly adult labour input (hr) during the cropping season (ADLAB)	14.00	9.08	3.00	42.00
Weekly child labour input (hr) during the cropping season (CHLAB)	6.00	3.98	2.00	14.00
Number of adult workers (WRKS)*	4	2.21	1	12
Number of dependents (DEP)	7	2.85	1	14
Amount of fertilizer (FERT) used in kg/ha*	196.80	59.35	100.00	400.00
Hybrid maize yield (PHMZE) in kg/ha*	1846.30	547.71	720.00	2250.00
Local maize yield (PLMZE) in kg/ha	1545.70	631.67	270.00	2250.00
Income from hybrid maize (IHMZE) in ZK/yr	5751.00	5241.42	1422.00	21330.00
Income from other crops (IOTHCR) in ZK/yr	1986.00	2163.11	510.00	6208.00
Income from off-farm activities (INOFF) in ZK/yr*	2803.00	4230.06	100.00	18800.00
Age in years (AGE)	45	10.22	22	65
Years of farming (YRFARM)	16	8.13	5	30
Years of schooling (EDUC)*	5	2.27	1	10
Number of people leaving the household (MIGR)*	2	1.37	1	6
Number of cattle (CA)	5	5.98	1	30
Number of goats (GO)	4	3.95	1	20
Number of pigs (PG)	5	4.41	1	20
Expenditure on food (EXPF) in ZK/week	60.00	41.62	10.00	175.00
Expenditure on leisure (EXPL) in ZK/month	89.00	63.93	35.00	200.00
Expenditure on manufactured goods (EXPMG) in ZK/month	177.00	90.74	3.00	448.00
Expenditure on hired animal labour (ANLAB) in ZK/yr	590.00	424.45	50.00	1500.00
Other expenditures (OEXP) in ZK/yr*	702.00	1044.43	7.00	5100.00
Expenditure on hired human labour (HLAB) in ZK/yr	341.00	417.63	50.00	1500.00
Expenditure on fertiliser (FERP) in ZK/ha/yr	2989.00	676.81	1600.00	3840.00

* Not normally distributed among female headed ox-hoe farm households, based on Kolmogorov-Smirnov Goodness of Fit Test (Zar 1974); Std. Dev.= standard deviation; Min.= minimum value; Max.= maximum value
ADLAB = a full-time adult worker's weekly labour input; CHLAB = not a full-time labour input

Table 5.3. Comparison of selected characteristics of male and female headed on hoe farm households, Katete, Eastern Province, Zambia, 1992

Variable	Mean		t-value
	Male	Female	
Area of land (ha) for hybrid maize production (AHMZE)	3.30	1.00	4.82*
Area of land (ha) for local maize production (ALMZE)	3.00 (0.38)	1.30 (0.04)	6.43*
Area of arable land (ha) for production of other crops (XC)	5.30 (0.62)	2.00 (0.21)	7.69*
Area of arable land (ha) under grass (XG)	2.30	1.00	5.10*
Area of land (ha) under wooded fallow (XW)	3.60 (0.44)	1.10 (-0.05)	6.42*
Weekly adult labour input (hr) during cropping season (ADLAB)	36.90	14.00	6.06*
Weekly child labour input (hr) during cropping season (CHLAB)	31.00	6.00	8.90*
Number of full time adult workers (WRKS)	9 (0.88)	4 (0.48)	7.91*
Number of dependents (DEP)	11	7	4.51*
Amount of fertilizer (FERT) used in kg/ha	201.60 (2.30)	196.80 (2.27)	1.09 ns
Hybrid maize yield (PHMZE) in kg/ha	1119.10 (2.90)	1846.30 (3.24)	-4.00*
Local maize yield (PLMZE) in kg/ha	932.60	1545.70	-4.80*
Income from hybrid maize (IHMZE) in ZK/yr	10227.00 (3.77)	5751.00 (3.63)	1.19*
Income from other crops (IOTHCR) in ZK/yr	10248.00	1986.00	3.15*
Income from off-farm activities (INOFF) in ZK/yr	7889.00 (3.47)	2803.00 (3.14)	1.98*
Age in years (AGE)	46	45	0.49 ns
Years of farming (YRFARM)	18	16	0.93 ns
Years of schooling (EDUC)	6 (0.73)	5 (0.61)	1.78 ns
Number of people leaving the household (MIGR)	2 (0.20)	2 (0.20)	nd
Number of cattle (CA)	9 (0.77)	5 (0.50)	2.64*
Number of goats (GO)	4 (0.50)	4 (0.50)	nd
Number of pigs (PG)	5	5	nd
Expenditure on food (EXPF) in ZK/week	177.00	60.00	2.06 ns
Expenditure on leisure (EXPL) in ZK/month	820.00	89.00	1.51*
Expenditure on manufactured goods (EXPMG) in ZK/month	209.00	177.00	1.03 ns
Expenditure on hired animal labour (ANLAB) in ZK/yr	1561.00	590.00	2.42*
Other expenditures (OEXP) in ZK/yr	1683.00 (2.85)	702.00 (2.49)	3.05*
Expenditure on hired human labour (HLAB) in ZK/yr	1804.00 (2.79)	341.00 (2.29)	2.79*
Expenditure on fertilizer (FERP) in ZK/ha/yr	3094.00 (3.45)	2969.00 (3.46)	-0.09 ns

Significant at $P \leq 0.05$; ns= not significant; nd= no difference; ADLAB= full-time input per worker; CHLAB= full-time input. Transformed or normalized values are shown in parentheses, based on log base 10 function (Zar 1974). The t-tests were calculated on the original mean values if the values were normal. Otherwise, the normalized (parenthesized) values were used.

Table 5.4. Summary of statistics of selected qualitative characteristics of male and female headed ox-hoe farm households, Katete, Eastern Province, Zambia, 1992*

Variable	Male HH (n= 55) Frequency	%	Female HH (n= 55) Frequency	%
Experience witchcraft	18	33	38	69
Future plan: improvement in agricultural production/standard of living	45	82	42	76
Future plan: no plans	10	18	13	24
No knowledge of agroforestry improved fallow system	54	98	49	89
Have knowledge of agroforestry improved fallow system	1	2	6	11
Willing to practice agroforestry improved fallow system	15	27	35	64
Not willing to practice agroforestry improved fallow system	40	73	20	36
Willing to plant trees which bring money to the farm households	49	89	45	82
Not willing to plant trees	6	11	10	18
Have trees on farms: (mango trees)				
- yes	50	91	15	27
- no	5	9	40	73
Perception about human population growth: - good	39	71	22	40
- bad	14	25	23	42
- no idea	2	4	10	18
Practice crop rotation:	55	100	55	100
Suffer from diseases (occasionally or frequently)	55	100	55	100
Dependence on firewood and other forest products	55	100	55	100

*Statistical analysis to determine the observed differences between the male and female headed farm households cannot be performed because the data contain single numbers (Zar 1974). HH=headed household.

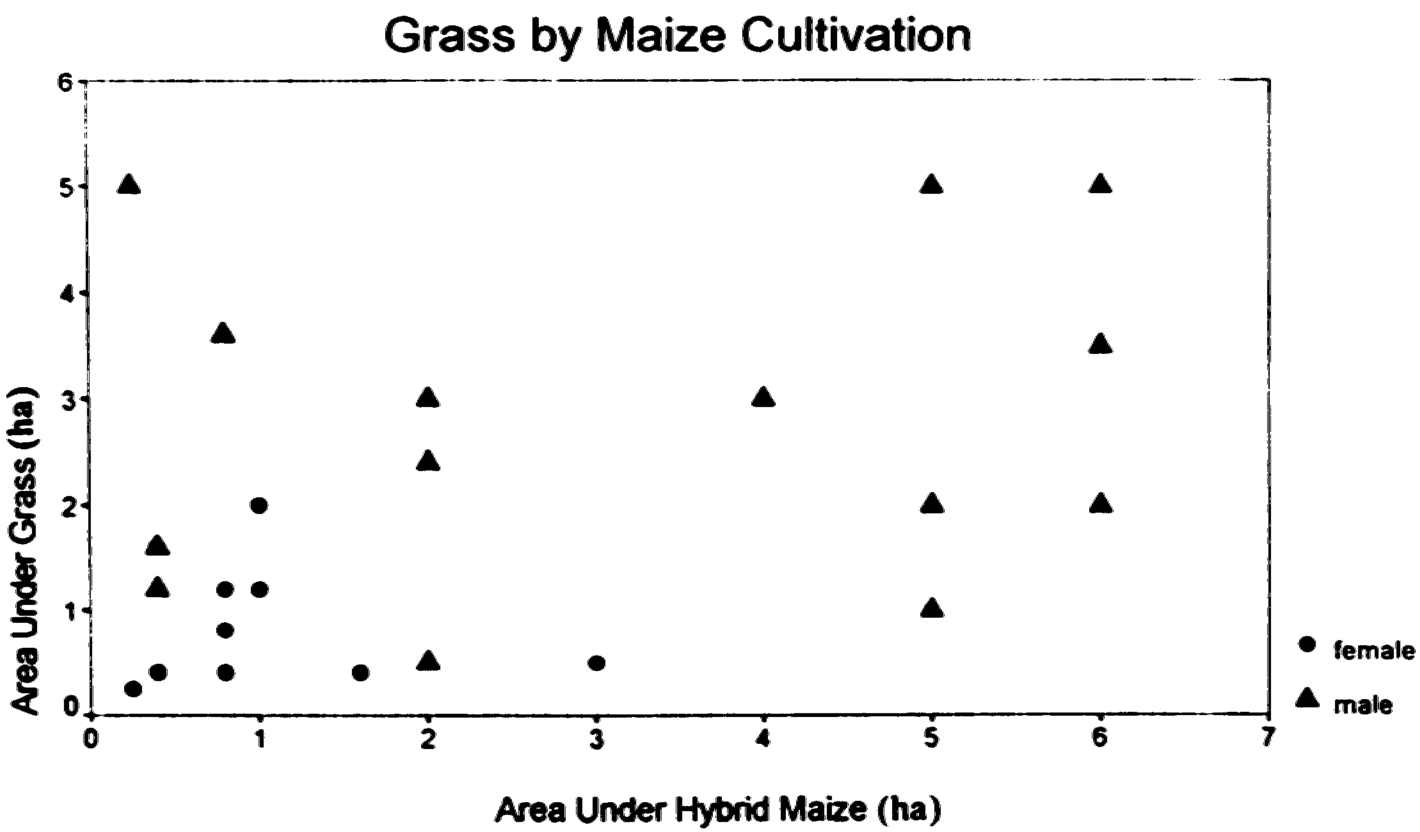

Figure 5.1. Male and female headed ox-hoe farm households: grass fallow vs maize cultivation, Katete, Eastern Province, Zambia, 1992

Table 5.5. Estimated soil saved (expressed in thousand kg/ha) under selected treatments, Katete, Eastern Province, Zambia[1]

Year	Fert. (1)	1SS+3M (2)	2SS+2M (3)	2SS+3M (4)	3SS+1M (5)	3SS+2M (6)	3SS+3M (7)
1	nd	16.24	16.24	16.24	16.24	16.24	16.24
2	nd	-8.93	16.44	16.44	16.44	16.44	16.44
3	0.09	-8.66	-5.20	-5.20	17.35	17.35	17.35
4	0.16	-9.86	-4.43	-4.43	-0.95	-0.95	-0.95
	0.06	**-2.80**	**5.76**		**12.27**		
5	0.25	19.00	19.03	-5.41	19.07	-0.75	-0.75
				3.53		**9.67**	
6	0.35	-4.64	19.95	19.91	19.98	19.95	-1.25
							7.85
7	0.46	-7.23	3.69	20.87	20.93	20.90	20.86
8	0.58	-7.61	2.01	4.03	10.20	21.87	21.84
	0.41	**-0.12**	**11.17**		**17.55**		
9	0.71	22.72	22.80	1.57	22.86	10.76	22.84
10	0.86	0.16	23.84	1.86	23.89	9.26	11.30
				9.65		**16.55**	
11	1.00	-5.14	11.80	24.82	24.95	24.88	9.26
12	1.18	-4.91	9.20	25.92	19.58	25.98	10.01
	0.94	**3.21**	**16.91**		**22.82**		**16.02**
13	1.36	26.91	27.03	12.76	27.11	27.10	27.03
14	1.55	4.86	28.19	8.99	28.26	21.15	28.19
15	1.75	-2.34	19.56	9.92	29.44	19.79	29.37
				16.48		**23.78**	
16	1.96	-1.79	16.94	30.47	27.95	30.57	22.70
	1.66	**6.91**	**22.93**		**28.19**		
17	1.50	30.90	31.05	31.04	31.16	31.12	19.96
18	0.79	8.03	31.40	19.87	31.49	31.45	20.31
							24.59
19	0.30	-1.57	24.61	14.87	31.80	28.36	31.68
20	0.31	-1.88	21.48	15.13	32.11	27.03	32.01
	0.73	**8.87**	**27.14**	**22.27**	**31.64**	**29.71**	

[1]Calculated from the SCUAF potential annual soil erosion outputs (Appendix 4).

The values in bold and underlined indicate rotation averages.

Soils saved= soil erosion under the control (continuous maize cropping with no fertilizer treatment) minus soil erosion under a treatment (numbered from 1 to 7 in the parentheses).

nd= no difference.

Fert. = continuous maize cropping with fertilizer application.

SS = *Sesbania sesban* (fallow).

M= Maize cropping.

1, 2, 3= years of fallow or maize cropping.

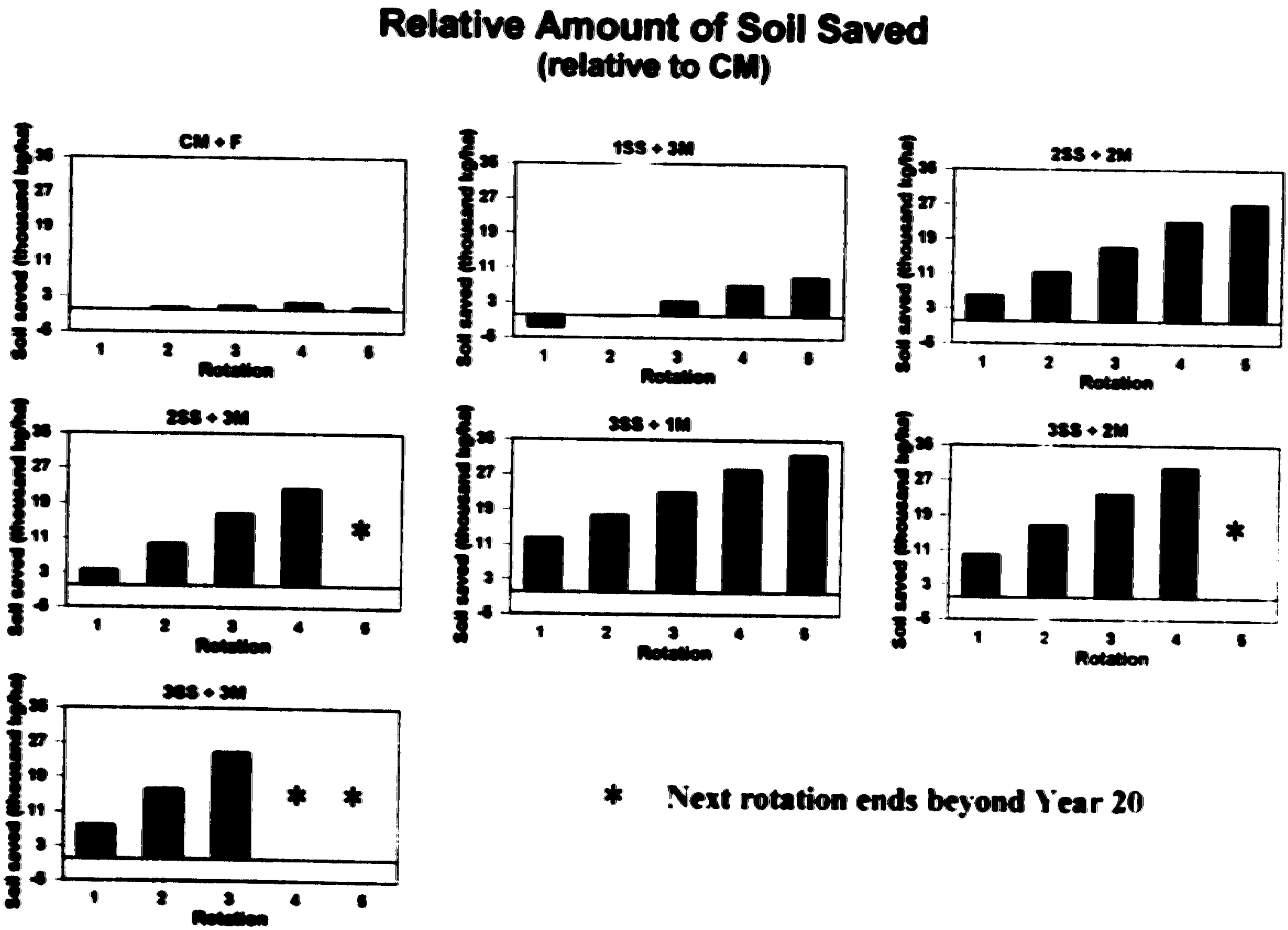

Figure 5.2. Estimated soil saved trends in CM+F and SS+M systems over five rotations, relative to continuous maize cropping without fertilizer use (CM). For the purpose of comparison to SS+M systems, the estimates of soil saved in continuous maize cropping based on fertilizer application (CM+F) are averaged over five rotations, Katete, Eastern Province, Zambia.

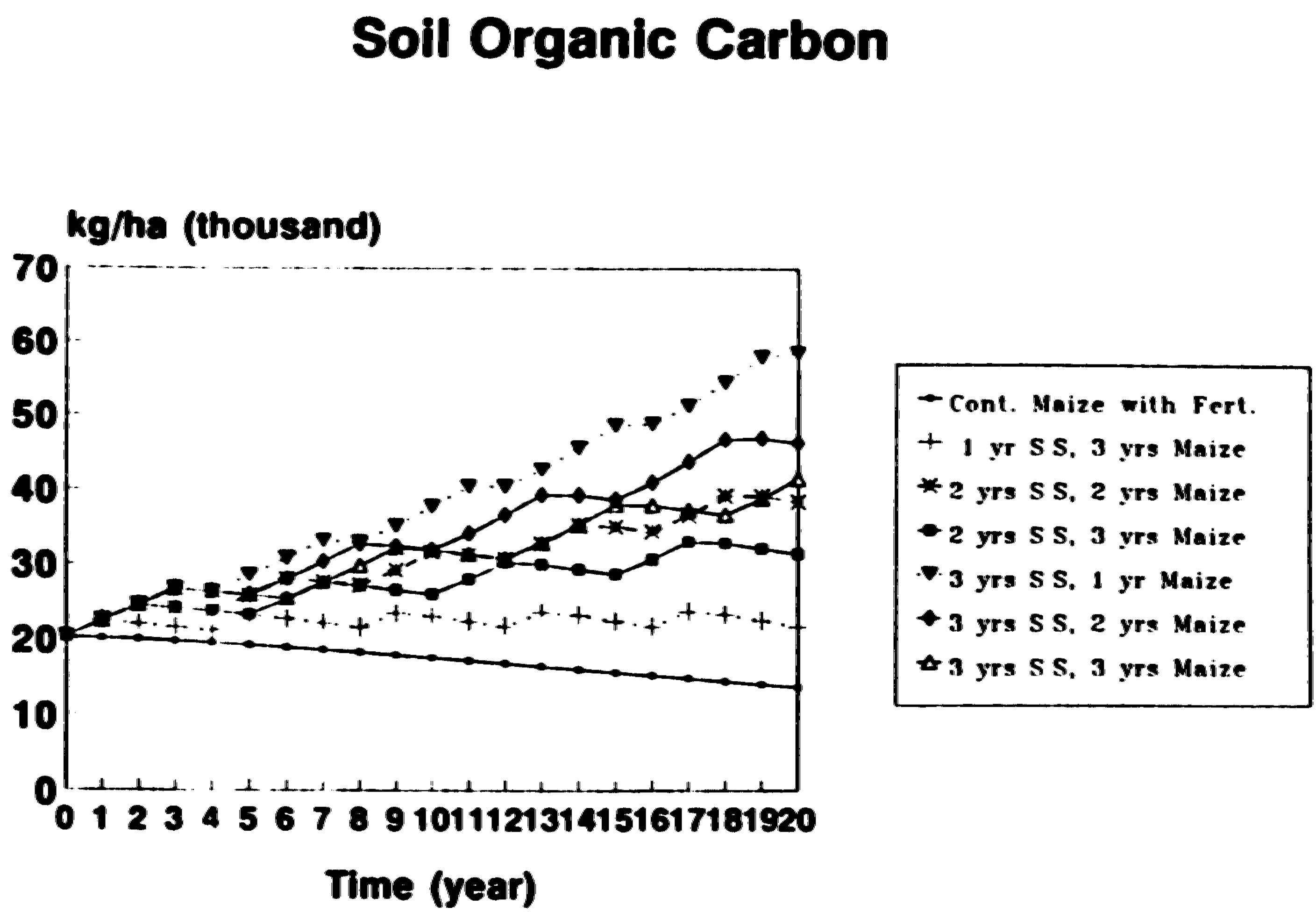

Figure 5.3. Simulated changes in total soil organic carbon (thousand kg/ha) under selected *Sesbania sesban* (SS) fallow+maize cropping rotation systems and continuous maize cropping with fertilizer application, Katete, Eastern Province, Zambia.

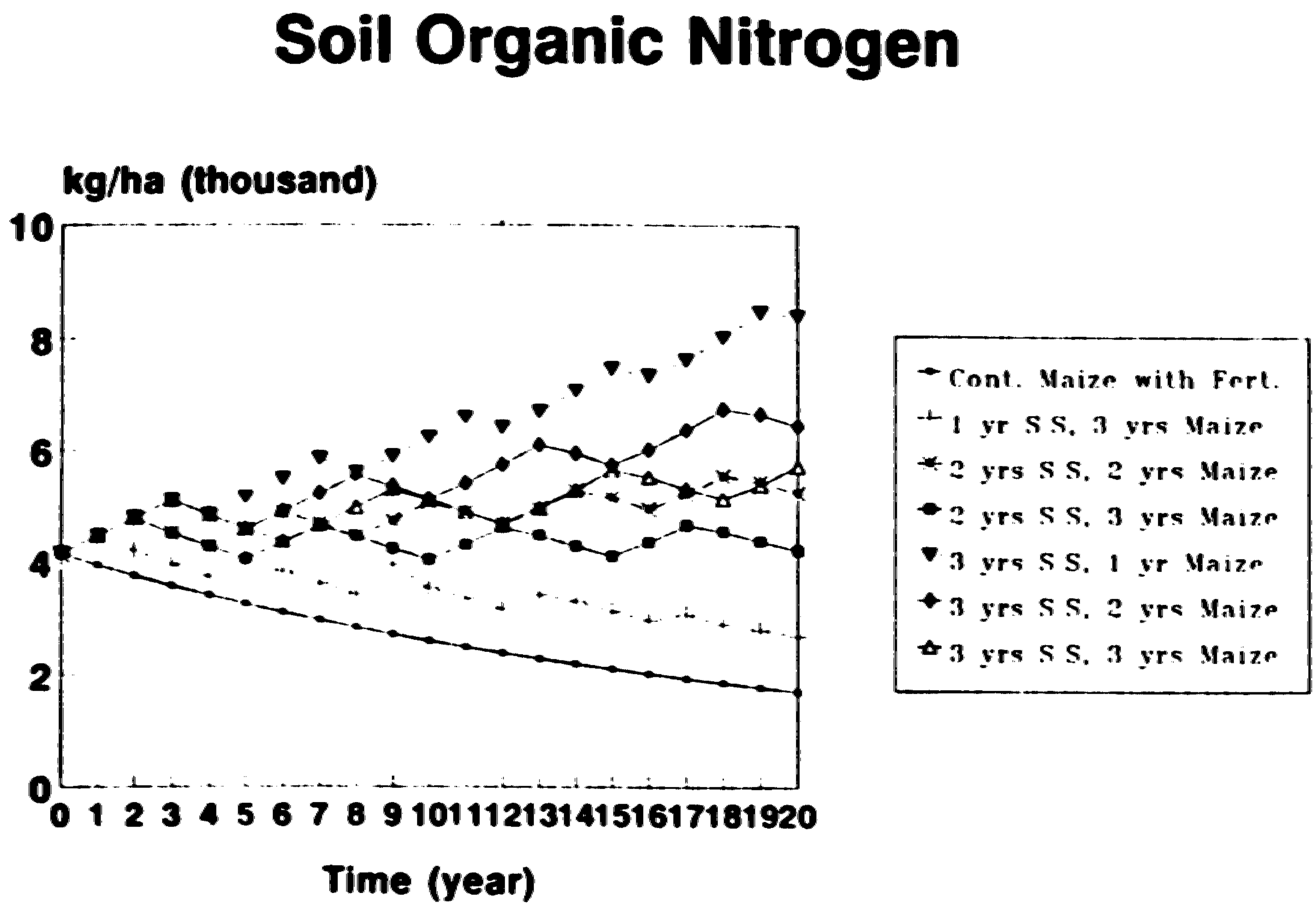

Figure 5.4. Simulated changes in soil organic nitrogen (thousand kg/ha) under selected *Sesbania sesban* (SS) fallow + maize cropping rotation systems and continuous maize cropping with fertilizer application, Katete, Eastern Province, Zambia.

Table 5.6. Simulated soil organic C and N under continuous maize cropping without fertilizer application, Katete, Eastern Province, Zambia

Year	Total C (thousand kg/ha)	Total N (thousand kg/ha)
Initial value	20280	4160
1	20095	3947
2	19912	3756
3	19685	3576
4	19425	3408
5	19134	3249
6	18818	3100
7	18480	2960
8	18122	2826
9	17747	2700
10	17358	2580
11	16958	2465
12	16547	2356
13	16129	2252
14	15705	2152
15	15276	2057
16	14843	1965
17	14417	1879
18	14001	1798
19	13593	1721
20	13197	1648

Table 5.7. Simulated maize yields (expressed in thousand kg/ha) based on fertilizer use and selected *Sesbania sesban* fallow systems, Katete, Eastern Province, Zambia

Year	Fert. (1)	1SS+3M (2)	2SS+2M (3)	2SS+3M (4)	3SS+1M (5)	3SS+2M (6)	3SS+3M (7)
1	2.00	0	0	0	0	0	0
2	2.00	2.10	0	0	0	0	0
3	1.90	2.10	2.20	2.20	0	0	0
4	1.90	2.00	2.20	2.20	2.50	2.50	2.50
	1.95	**1.55**	**1.10**		**0.63**		
5	1.80	0	0	2.10	0	2.40	2.40
				1.30		**0.98**	
6	1.80	2.10	0	0	0	0	2.30
							1.20
7	1.70	1.90	2.60	0	0	0	0
8	1.70	1.80	2.30	2.60	3.20	0	0
	1.75	**1.45**	**1.22**		**0.80**		
9	1.70	0	0	2.20	0	3.10	0
10	1.60	2.10	0	2.10	0	2.60	3.10
				1.38		**1.14**	
11	1.60	1.80	3.00	0	0	0	2.50
12	1.50	1.70	2.40	0	4.10	0	2.50
	1.60	**1.40**	**1.35**		**1.03**		**1.35**
13	1.50	0	0	2.90	0	0	0
14	1.50	2.10	0	2.20	0	3.90	0
15	1.50	1.70	3.50	2.20	0	2.90	0
				1.46		**1.36**	
16	1.40	1.70	2.50	0	5.20	0	3.80
	1.48	**1.38**	**1.50**		**1.30**		
17	1.40	0	0	0	0	0	2.70
18	1.40	2.10	0	3.20	0	0	2.80
							1.55
19	1.40	1.60	4.00	2.20	0	4.90	
20	1.30	1.60	2.70	2.30	6.60	3.30	
	1.40	**1.33**	**1.68**	**1.54**	**1.65**	**1.64**	

Treatments are numbered, in parentheses, from (1) to (7).
The values in bold and underlined are rotation averages.
Fert. = Fertilizer.
0 = Fallow.
SS = *Sesbania sesban*.
M = Maize cropping.
1, 2, 3 = years of fallow or maize cropping.
Values for maize yields have been rounded up to two decimal points.

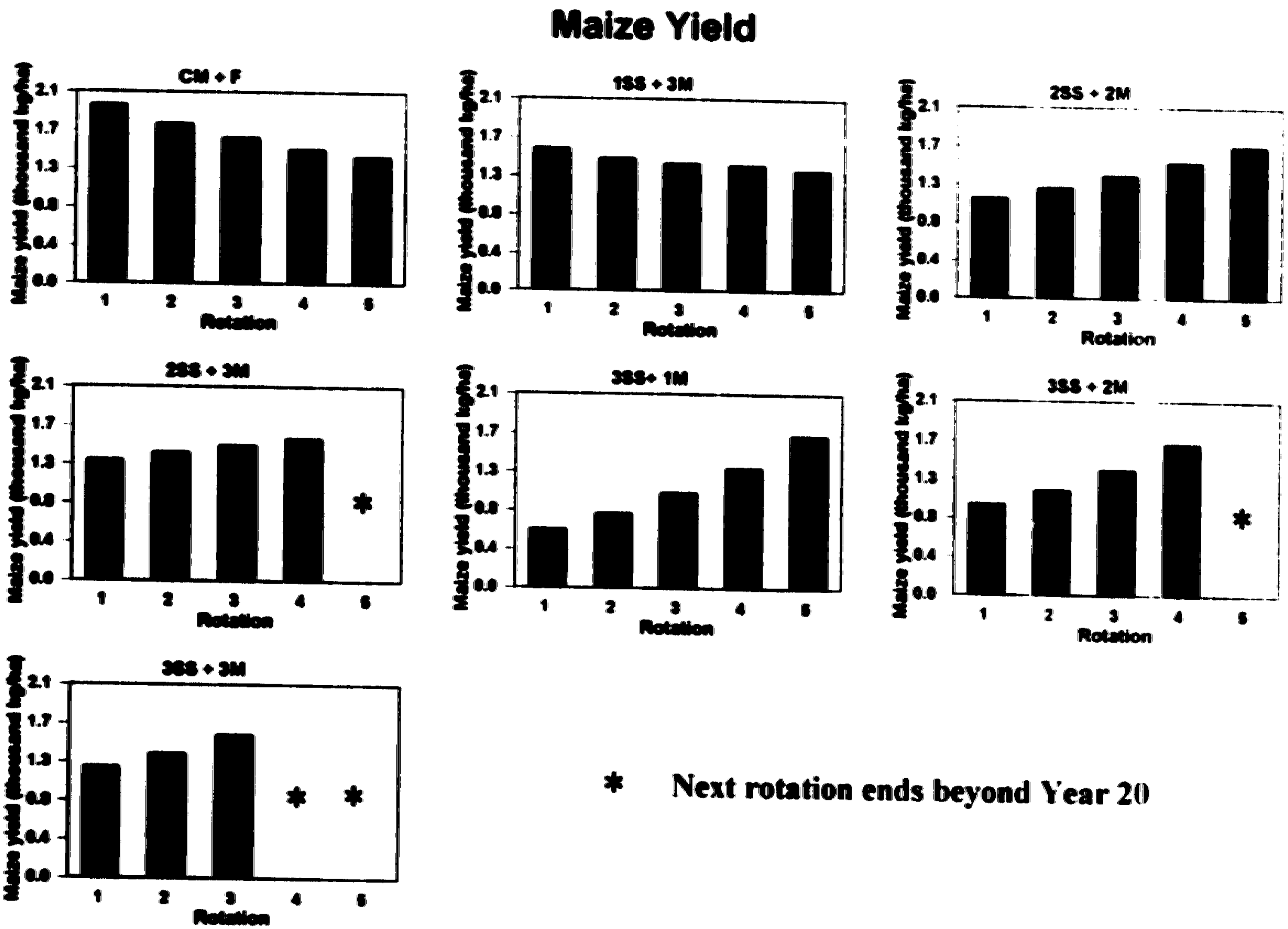

Figure 5.5. Estimated maize yield trends in CM+F and SS+M systems over five rotations. For the purpose of comparison to SS+M systems, the estimates of maize yields in continuous maize cropping based on fertilizer application (CM+F) are averaged over five rotations. Katete, Eastern Province, Zambia.

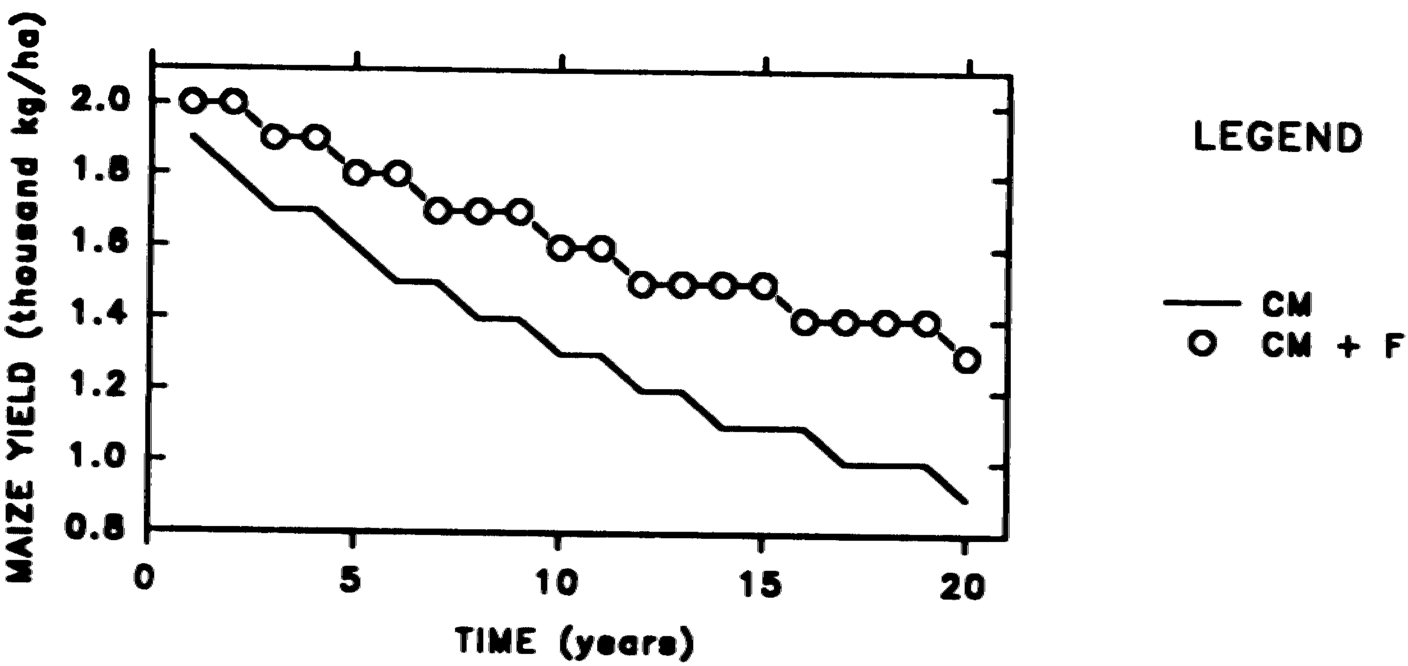

Figure 5.6. Simulated maize yield trends in continuous cropping based on: (1) no fertilizer use (CM), and (2) fertilizer application. Katete, Eastern Province, Zambia. Maize yields have been rounded up to two decimal points.

Table 5.8. Comparison of the trends in maize yields obtained from *Sesbania sesban* fallow systems at experimental plots at Msekera Research Station and that simulated for Katete, Eastern Province, Zambia

	YEAR			
TREATMENT	1	2	3	4
1SS+3M	SS	2.30* (2.10)	3.80 (2.10)	4.40 (2.00)
2SS+2M	SS	SS	5.00 (2.20)	5.60 (2.20)
3SS+1M	SS	SS	SS	6.00 (2.50)

Simulated maize yields for Katete are shown in parentheses. Otherwise Msekera Research Station average yield values (Kwesiga et al. 1991). Maize yields are expressed in thousand kg/ha.
*Affected by unreliable (droughty condition) rainfall (Kwesiga et al. 1991)
SS = *Sesbania sesban* (fallow).
M = Maize cropping.

Table 5.9. Maize yields (expressed in thousand kg/ha) based on the phasing of *Sesbania sesban* fallow in the 1SS + 3M rotation system, utilizing a 4 ha farm. Katete, Eastern Province, Zambia

Year	Maize yields/ha				Total maize yields	Total maize yields based on fertilizer application*
	1	2	3	4		
1	0	2.00	2.00	2.00	6.00 (1.50)	8.00 (2.00)
2	2.10	0	2.00	2.00	6.10 (1.53)	8.00 (2.00)
3	2.10	2.10	0	1.90	6.10 (1.53)	7.60 (1.90)
4	2.00	2.10	2.10	0	6.20 (1.55)	7.60 (1.90)
5	0	2.00	2.10	2.10	6.20 (1.55)	7.20 (1.80)
6	2.10	0	2.00	2.10	6.20 (1.55)	7.20 (1.80)
7	1.90	2.10	0	2.00	6.00 (1.50)	6.80 (1.70)
8	1.80	1.90	2.10	0	5.80 (1.45)	6.80 (1.70)
9	0	1.80	1.90	2.10	5.80 (1.45)	6.80 (1.70)
10	2.10	0	1.80	1.90	5.80 (1.45)	6.40 (1.60)
11	1.80	2.10	0	1.80	5.70 (1.43)	6.40 (1.60)
12	1.70	1.80	2.10	0	5.60 (1.40)	6.00 (1.50)
13	0	1.70	1.80	2.10	5.60 (1.40)	6.00 (1.50)
14	2.10	0	1.70	1.80	5.60 (1.40)	6.00 (1.50)
15	1.70	2.10	0	1.70	5.50 (1.38)	6.00 (1.50)
16	1.70	1.70	2.10	0	5.50 (1.38)	5.60 (1.40)
17	0	1.70	1.70	2.10	5.50 (1.38)	5.60 (1.40)
18	2.10	0	1.70	1.70	5.50 (1.38)	5.60 (1.40)
19	1.60	2.10	0	1.70	5.40 (1.35)	5.60 (1.40)
20	1.60	1.60	2.10	0	5.30 (1.33)	5.20 (1.30)

Values for maize yields have been rounded to two decimal points.
0 = fallow.
Numbers in parentheses indicate average maize yields/ha.
* CM+F for comparison with 1SS + 3M rotation.

Table 5.10. Maize yields (expressed in thousand kg/ha) based on the phasing of *Sesbania sesban* fallow in the 2SS + 2M rotation system, utilizing a 4 ha farm, Katete, Eastern Province, Zambia

Year	Maize yields/ha				Total maize yields	Total maize yields based on fertilizer application*
	1	2	3	4		
1	0	2.00	2.00	2.00	6.00 (1.50)	8.00 (2.00)
2	0	0	2.00	2.00	4.00 (1.00)	8.00 (2.00)
3	2.20	0	0	1.90	4.10 (1.03)	7.60 (1.90)
4	2.20	2.20	0	0	4.40 (1.10)	7.60 (1.90)
5	0	2.20	2.20	0	4.40 (1.10)	7.20 (1.80)
6	0	0	2.20	2.20	4.40 (1.10)	7.20 (1.80)
7	2.60	0	0	2.20	4.80 (1.20)	6.80 (1.70)
8	2.30	2.60	0	0	4.90 (1.23)	6.80 (1.70)
9	0	2.30	2.60	0	4.90 (1.23)	6.80 (1.70)
10	0	0	2.30	2.60	4.90 (1.23)	6.40 (1.60)
11	3.00	0	0	2.30	5.30 (1.33)	6.40 (1.60)
12	2.40	3.00	0	0	5.40 (1.35)	6.00 (1.50)
13	0	2.40	3.00	0	5.40 (1.35)	6.00 (1.50)
14	0	0	2.40	3.00	5.40 (1.35)	6.00 (1.50)
15	3.50	0	0	2.40	5.90 (1.48)	6.00 (1.50)
16	2.50	3.50	0	0	6.00 (1.50)	5.60 (1.40)
17	0	2.50	3.50	0	6.00 (1.50)	5.60 (1.40)
18	0	0	2.50	3.50	6.00 (1.50)	5.60 (1.40)
19	4.00	0	0	2.50	6.50 (1.63)	5.60 (1.40)
20	2.70	4.00	0	0	6.70 (1.68)	5.20 (1.30)

Values for maize yields have been rounded to two decimal points.
0 = fallow.
Numbers in parentheses indicate average maize yields/ha.
* CM+F for comparison with 2SS + 2M rotation.

Table 5.11. Maize yields (expressed in thousand kg/ha) based on the phasing of *Sesbania sesban* fallow in the 2SS+3M rotation system, utilizing a 5 ha farm, Katete, Eastern Province, Zambia

Year	Maize yields/ha					Total maize yields	Total maize yields based on fertilizer application*
	1	2	3	4	5		
1	0	2.00	2.00	2.00	2.00	8.00 (1.60)	10.00 (2.00)
2	0	0	2.00	2.00	2.00	6.00 (1.20)	10.00 (2.00)
3	2.20	0	0	1.90	1.90	6.00 (1.20)	9.50 (1.90)
4	2.20	2.20	0	0	1.90	6.30 (1.26)	9.50 (1.90)
5	2.10	2.20	2.20	0	0	6.50 (1.30)	9.00 (1.80)
6	0	2.10	2.20	2.20	0	6.50 (1.30)	9.00 (1.80)
7	0	0	2.10	2.20	2.20	6.50 (1.30)	8.50 (1.70)
8	2.60	0	0	2.10	2.20	6.90 (1.38)	8.50 (1.70)
9	2.20	2.60	0	0	2.10	6.90 (1.38)	8.50 (1.70)
10	2.10	2.20	2.60	0	0	6.90 (1.38)	8.00 (1.60)
11	0	2.10	2.20	2.60	0	6.90 (1.38)	8.00 (1.60)
12	0	0	2.10	2.20	2.60	6.90 (1.38)	7.50 (1.50)
13	2.90	0	0	2.10	2.20	7.20 (1.44)	7.50 (1.50)
14	2.20	2.90	0	0	2.10	7.20 (1.44)	7.50 (1.50)
15	2.20	2.20	2.90	0	0	7.30 (1.46)	7.50 (1.50)
16	0	2.20	2.20	2.90	0	7.30 (1.46)	7.00 (1.40)
17	0	0	2.20	2.20	2.90	7.30 (1.46)	7.00 (1.40)
18	3.20	0	0	2.20	2.20	7.60 (1.52)	7.00 (1.40)
19	2.20	3.20	0	0	2.20	7.60 (1.52)	7.00 (1.40)
20	2.30	2.20	3.20	0	0	7.70 (1.54)	6.50 (1.30)

Values for maize yields have been rounded to two decimal points.
0 = fallow.
Numbers in parentheses indicate average maize yields/ha.
* CM+F for comparison with 2SS + 3M rotation.

Table 5.12. Maize yields (expressed in thousand kg/ha) based on the phasing of *Sesbania sesban* fallow in the 3SS+1M rotation system, utilizing a 4 ha farm, Katete, Eastern Province, Zambia

Year	Maize yields/ha				Total maize yields	Total maize yields based on fertilizer application*
	1	2	3	4		
1	0	2.00	2.00	2.00	6.00 (1.50)	8.00 (2.00)
2	0	0	2.00	2.00	4.00 (1.00)	8.00 (2.00)
3	0	0	0	1.90	1.90 (0.48)	7.60 (1.90)
4	2.50	0	0	0	2.50 (0.63)	7.60 (1.90)
5	0	2.50	0	0	2.50 (0.63)	7.20 (1.80)
6	0	0	2.50	0	2.50 (0.63)	7.20 (1.80)
7	0	0	0	2.50	2.50 (0.63)	6.80 (1.70)
8	3.20	0	0	0	3.20 (0.80)	6.80 (1.70)
9	0	3.20	0	0	3.20 (0.80)	6.80 (1.70)
10	0	0	3.20	0	3.20 (0.80)	6.40 (1.60)
11	0	0	0	3.20	3.20 (0.80)	6.40 (1.60)
12	4.10	0	0	0	4.10 (1.03)	6.00 (1.50)
13	0	4.10	0	0	4.10 (1.03)	6.00 (1.50)
14	0	0	4.10	0	4.10 (1.03)	6.00 (1.50)
15	0	0	0	4.10	4.10 (1.03)	6.00 (1.50)
16	5.20	0	0	0	5.20 (1.30)	5.60 (1.40)
17	0	5.20	0	0	5.20 (1.30)	5.60 (1.40)
18	0	0	5.20	0	5.20 (1.30)	5.60 (1.40)
19	0	0	0	5.20	5.20 (1.30)	5.60 (1.40)
20	6.60	0	0	0	6.60 (1.65)	5.20 (1.30)

Values for maize yields have been rounded to two decimal points.
0 = fallow.
Numbers in parentheses indicate average maize yields/ha.
* CM+F for comparison with 3SS + 1M rotation.

Table 5.13. Maize yields (expressed in thousand kg/ha) based on the phasing of *Sesbania sesban* fallow in the 3SS + 2M rotation system, utilizing a 5 ha farm, Katete, Eastern Province, Zambia

Year	Maize yields/ha					Total maize yields	Total maize yields based on fertilizer application*
	1	2	3	4	5		
1	0	2.00	2.00	2.00	2.00	8.00 (1.60)	10.00 (2.00)
2	0	0	2.00	2.00	2.00	6.00 (1.20)	10.00 (2.00)
3	0	0	0	1.90	1.90	3.80 (0.76)	9.50 (1.90)
4	2.50	0	0	0	1.90	4.40 (0.88)	9.50 (1.90)
5	2.40	2.50	0	0	0	4.90 (0.98)	9.00 (1.80)
6	0	2.40	2.50	0	0	4.90 (0.98)	9.00 (1.80)
7	0	0	2.40	2.50	0	4.90 (0.98)	8.50 (1.70)
8	0	0	0	2.40	2.50	4.90 (0.98)	8.50 (1.70)
9	3.10	0	0	0	2.40	5.50 (1.10)	8.50 (1.70)
10	2.60	3.10	0	0	0	5.70 (1.14)	8.00 (1.60)
11	0	2.60	3.10	0	0	5.70 (1.14)	8.00 (1.60)
12	0	0	2.60	3.10	0	5.70 (1.14)	7.50 (1.50)
13	0	0	0	2.60	3.10	5.70 (1.14)	7.50 (1.50)
14	3.90	0	0	0	2.60	6.50 (1.30)	7.50 (1.50)
15	2.90	3.90	0	0	0	6.80 (1.36)	7.50 (1.50)
16	0	2.90	3.90	0	0	6.80 (1.36)	7.00 (1.40)
17	0	0	2.90	3.90	0	6.80 (1.36)	7.00 (1.40)
18	0	0	0	2.90	3.90	6.80 (1.36)	7.00 (1.40)
19	4.90	0	0	0	2.90	7.80 (1.56)	7.00 (1.40)
20	3.30	4.90	0	0	0	8.20 (1.64)	6.50 (1.30)

Values for maize yields have been rounded to two decimal points.
0 = fallow.
Numbers in parentheses indicate average maize yields/ha
* CM+F for comparison with 3SS + 2M rotation.

Table 5.14. Maize yields (expressed in thousand kg/ha) based on the phasing of *Sesbania sesban* fallow in the 3SS+3M rotation system, utilizing a 6 ha farm, Katete, Eastern Province, Zambia

Year	Maize yields/ha						Total maize yields	Total maize yields based on fertilizer application*
	1	2	3	4	5	6		
1	0	2.00	2.00	2.00	2.00	2.00	10.00 (1.67)	12.00 (2.00)
2	0	0	2.00	2.00	2.00	2.00	8.00 (1.33)	12.00 (2.00)
3	0	0	0	1.90	1.90	1.90	5.70 (0.95)	11.40 (1.90)
4	2.50	0	0	0	1.90	1.90	6.30 (1.05)	11.40 (1.90)
5	2.40	2.50	0	0	0	1.80	6.70 (1.12)	10.80 (1.80)
6	2.30	2.40	2.50	0	0	0	7.20 (1.20)	10.80 (1.80)
7	0	2.30	2.40	2.50	0	0	7.20 (1.20)	10.20 (1.70)
8	0	0	2.30	2.40	2.50	0	7.20 (1.20)	10.20 (1.70)
9	0	0	0	2.30	2.40	2.50	7.20 (1.20)	10.20 (1.70)
10	3.10	0	0	0	2.30	2.40	7.80 (1.30)	9.60 (1.60)
11	2.50	3.10	0	0	0	2.30	7.90 (1.32)	9.60 (1.60)
12	2.50	2.50	3.10	0	0	0	8.10 (1.35)	9.00 (1.50)
13	0	2.50	2.50	3.10	0	0	8.10 (1.35)	9.00 (1.50)
14	0	0	2.50	2.50	3.10	0	8.10 (1.35)	9.00 (1.50)
15	0	0	0	2.50	2.50	3.10	8.10 (1.35)	9.00 (1.50)
16	3.80	0	0	0	2.50	2.50	8.80 (1.47)	8.40 (1.40)
17	2.70	3.80	0	0	0	2.50	9.30 (1.55)	8.40 (1.40)
18	2.80	2.70	3.80	0	0	0	9.30 (1.55)	8.40 (1.40)
19	0	2.80	2.70	3.80	0	0	9.30 (1.55)	8.40 (1.40)
20	0	0	2.80	2.70	3.80	0	9.30 (1.55)	7.80 (1.30)

Values for maize yields have been rounded to two decimal points.
0 = fallow.
Numbers in parentheses indicate average maize yields/ha.
* CM+F for comparison with 3S + 3M rotation.

Table 5.15. Summary of maize yields (thousand kg) per hectare while phasing in *Sesbania sesban* fallows, utilizing all fallow and cultivated lands, Katete, Eastern Province, Zambia

Year	Treatment						CM+F
	1SS+3M	2SS+2M	2SS+3M	3SS+1M	3SS+2M	3SS+3M	
1	1.50	1.50	1.60	1.50	1.60	1.67	2.00
2	1.53	1.00	1.20	1.00	1.20	1.33	2.00
3	1.53	1.03	1.20	0.48	0.76	0.95	1.90
4	1.55	1.10	1.26	0.63	0.88	1.05	1.90
5	1.55	1.10	1.30	0.63	0.98	1.12	1.80
6	1.55	1.10	1.30	0.63	0.98	1.20	1.80
7	1.50	1.20	1.30	0.63	0.98	1.20	1.70
8	1.45	1.23	1.38	0.80	0.98	1.20	1.70
9	1.45	1.23	1.38	0.80	1.10	1.20	1.70
10	1.45	1.23	1.38	0.80	1.14	1.30	1.60
11	1.43	1.33	1.38	0.80	1.14	1.32	1.60
12	1.40	1.35	1.38	1.03	1.14	1.35	1.50
13	1.40	1.35	1.4[illegible]	1.03	1.14	1.35	1.50
14	1.40	1.35	1.44	1.03	1.30	1.35	1.50
15	1.38	1.48	1.46	1.03	1.36	1.35	1.50
16	1.38	*1.50	*1.46	1.30	1.36	*1.47	1.40
17	1.38	1.50	1.46	1.30	1.36	1.55	1.40
18	1.38	1.50	1.52	1.30	1.36	1.55	1.40
19	1.35	1.63	1.52	1.30	*1.56	1.55	1.40
20	*1.33	1.68	1.54	*1.65	1.64	1.55	1.30

Values for maize yields have been rounded to two decimal points.

*Break-even (cross over) point compared to continuous maize cropping based on fertilizer application (CM+F).

Table 5.16. Maize yields, expressed in thousand kg/ha, based on the phasing of *Sesbania sesban* fallow in the 2SS+2M rotation system, utilizing a 4 ha farm (100 kg/ha of inorganic fertilizer added during maize cropping), Katete, Eastern Province, Zambia

Year	Maize yields/ha				Total maize yields	Total maize yields based on fertilizer application*
	1	2	3	4		
1	0	2.00	2.00	2.00	6.00 (1.50)	8.00 (2.00)
2	0	0	2.00	2.00	4.00 (1.00)	8.00 (2.00)
3	2.20	0	0	1.90	4.10 (1.03)	7.60 (1.90)
4	2.40	2.20	0	0	4.60 (1.15)	7.60 (1.90)
5	0	2.40	2.20	0	4.60 (1.15)	7.20 (1.80)
6	0	0	2.40	2.20	4.60 (1.15)	7.20 (1.80)
7	2.60	0	0	2.40	5.00 (1.25)	6.80 (1.70)
8	2.50	2.60	0	0	5.10 (1.28)	6.80 (1.70)
9	0	2.50	2.60	0	5.10 (1.28)	6.80 (1.70)
10	0	0	2.50	2.60	5.10 (1.28)	6.40 (1.60)
11	3.10	0	0	2.50	5.60 (1.40)	6.40 (1.60)
12	2.60	3.10	0	0	5.70 (1.43)	6.00 (1.50)
13	0	2.60	3.10	0	5.70 (1.43)	6.00 (1.50)
14	0	0	2.60	3.10	5.70 (1.43)	6.00 (1.50)
15	3.50	0	0	2.60	6.10 (1.53)	6.00 (1.50)
16	2.70	3.50	0	0	6.20 (1.55)	5.60 (1.40)
17	0	2.70	3.50	0	6.20 (1.55)	5.60 (1.40)
18	0	0	2.70	3.50	6.20 (1.55)	5.60 (1.40)
19	4.10	0	0	2.70	6.80 (1.70)	5.60 (1.40)
20	2.90	4.10	0	0	7.00 (1.75)	5.20 (1.30)

Values for maize yields have been rounded to two decimal points.
0 = fallow.
Numbers in parentheses indicate average maize yields/ha.
* CM+F for comparison with 2SS + 2M rotation.

Table 5.17. Maize yields, expressed in thousand kg/ha, based on the phasing of *Sesbania sesban* fallow in the 2SS+3M rotation system, utilizing a 5 ha farm (100 kg/ha of inorganic fertilizer added during maize cropping), Katete, Eastern Province, Zambia

Year	Maize yields/ha					Total maize yields	Total maize yields based on fertilizer application*
	1	2	3	4	5		
1	0	2.00	2.00	2.00	2.00	8.00 (1.60)	10.00 (2.00)
2	0	0	2.00	2.00	2.00	6.00 (1.20)	10.00 (2.00)
3	2.20	0	0	1.90	1.90	6.00 (1.20)	9.50 (1.90)
4	2.40	2.20	0	0	1.90	6.50 (1.30)	9.50 (1.90)
5	2.20	2.40	2.20	0	0	6.80 (1.36)	9.00 (1.80)
6	0	2.20	2.40	2.20	0	6.80 (1.36)	9.00 (1.80)
7	0	0	2.20	2.40	2.20	6.80 (1.36)	8.50 (1.70)
8	2.60	0	0	2.20	2.40	7.20 (1.44)	8.50 (1.70)
9	2.30	2.60	0	0	2.20	7.10 (1.42)	8.50 (1.70)
10	2.30	2.30	2.60	0	0	7.20 (1.44)	8.00 (1.60)
11	0	2.30	2.30	2.60	0	7.20 (1.44)	8.00 (1.60)
12	0	0	2.30	2.30	2.60	7.20 (1.44)	7.50 (1.50)
13	3.00	0	0	2.30	2.30	7.60 (1.52)	7.50 (1.50)
14	2.40	3.00	0	0	2.30	7.70 (1.54)	7.50 (1.50)
15	2.40	2.40	3.00	0	0	7.80 (1.56)	7.50 (1.50)
16	0	2.40	2.40	3.00	0	7.80 (1.56)	7.00 (1.40)
17	0	0	2.40	2.40	3.00	7.80 (1.56)	7.00 (1.40)
18	3.30	0	0	2.40	2.40	8.10 (1.62)	7.00 (1.40)
19	2.50	3.30	0	0	2.40	8.20 (1.64)	7.00 (1.40)
20	2.50	2.50	3.30	0	0	8.30 (1.66)	6.50 (1.30)

Values for maize yields have been rounded to two decimal points.
0 = fallow.
Numbers in parentheses indicate average maize yields/ha.
* CM+F for comparison with 2SS + 3M rotation.

Table 5.18. Maize yields, expressed in thousand kg/ha, based on the phasing of *Sesbania sesban* fallow in the 3SS+3M rotation system, utilizing a 6 ha farm (100) kg/ha of inorganic fertilizer added during maize cropping), Katete, Eastern Province, Zambia

Year	Maize yields/ha						Total maize yields	Total maize yields based on fertilizer application*
	1	2	3	4	5	6		
1	0	2.00	2.00	2.00	2.00	2.00	10.00 (1.67)	12.00 (2.00)
2	0	0	2.00	2.00	2.00	2.00	8.00 (1.33)	12.00 (2.00)
3	0	0	0	1.90	1.90	1.90	5.70 (0.95)	11.40 (1.90)
4	2.50	0	0	0	1.90	1.90	6.30 (1.05)	11.40 (1.90)
5	3.50	2.50	0	0	0	1.80	7.80 (1.30)	10.80 (1.80)
6	3.20	3.50	2.50	0	0	0	9.20 (1.53)	10.80 (1.80)
7	0	3.20	3.50	2.50	0	0	9.20 (1.53)	10.20 (1.70)
8	0	0	3.20	3.50	2.50	0	9.20 (1.53)	10.20 (1.70)
9	0	0	0	3.20	3.50	2.50	9.20 (1.53)	10.20 (1.70)
10	3.30	0	0	0	3.20	3.50	10.00 (1.67)	9.60 (1.60)
11	4.00	3.30	0	0	0	3.20	10.50 (1.75)	9.60 (1.60)
12	3.80	4.00	3.30	0	0	0	11.10 (1.85)	9.00 (1.50)
13	0	3.80	4.00	3.30	0	0	11.10 (1.85)	9.00 (1.50)
14	0	0	3.80	4.00	3.30	0	11.10 (1.85)	9.00 (1.50)
15	0	0	0	3.80	4.00	3.30	11.10 (1.85)	9.00 (1.50)
16	4.30	0	0	0	3.80	4.00	12.10 (2.02)	8.40 (1.40)
17	4.60	4.30	0	0	0	3.80	12.70 (2.12)	8.40 (1.40)
18	4.50	4.60	4.30	0	0	0	13.40 (2.23)	8.40 (1.40)
19	0	4.50	4.60	4.30	0	0	13.40 (2.23)	8.40 (1.40)
20	0	0	4.50	4.60	4.30	0	13.40 (2.23)	7.80 (1.30)

Values for maize yields have been rounded to two decimal points.
0 = fallow
Numbers in parentheses indicate average maize yields/ha.
* CM+F for comparison with 3S + 3M rotation.

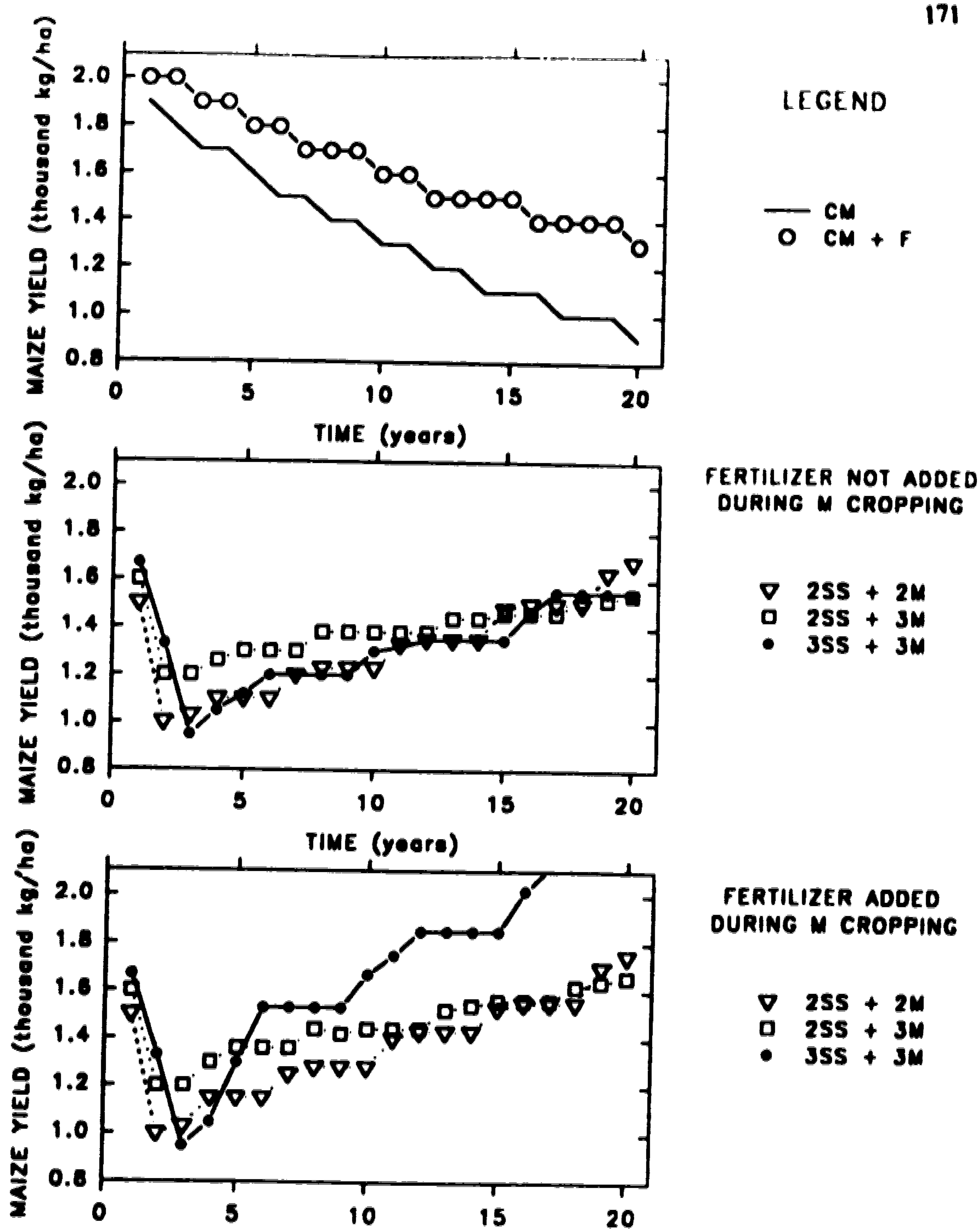

Figure 5.7. Estimated maize yields under selected *Sesbania sesban* (SS) fallow + maize (M) rotations and continuous cropping with and without fertilizer application. Katete, Eastern Province, Zambia.

Table 5.19. Estimated net returns based on the phasing of *Sesbania sesban* fallow in the 1SS+ 3M rotation system, utilizing a 4 ha farm, Katete, Eastern Province, Zambia

Year	Net returns/ha				Total net returns	Total net returns based on fertilizer application*
	1	2	3	4		
1	-3838	2059	2059	2059	2339 (584.75)	8236 (2059)
2	3933	-3838	2059	2059	4213 (1053.25)	8236 (2059)
3	3933	3933	-3838	1743	5771 (1442.75)	6972 (1743)
4	3617	3933	3933	-3838	7645 (1911.25)	6972 (1743)
5	-3838	3617	3933	3933	7645 (1911.25)	5708 (1427)
6	3933	-3838	3617	3933	7645 (1911.25)	5708 (1427)
7	3301	3933	-3838	3617	7013 (1753.25)	4444 (1111)
8	2985	3301	3933	-3838	6381 (1595.25)	4444 (1111)
9	-3838	2985	3301	3933	6381 (1595.25)	4444 (1111)
10	3933	-3838	2985	3301	6381 (1595.25)	3180 (795)
11	2985	3933	-3838	2985	6065 (1516.25)	3180 (795)
12	2669	2985	3933	-3838	5749 (1437.25)	1916 (479)
13	-3838	2669	2985	3933	5749 (1437.25)	1916 (479)
14	3933	-3838	2669	2985	5749 (1437.25)	1916 (479)
15	2669	3933	-3838	2669	5433 (1358.25)	1916 (479)
16	2669	2669	3933	-3838	5433 (1358.25)	652 (163)
17	-3838	2669	2669	3933	5433 (1358.25)	652 (163)
18	3933	-3838	2669	2669	5433 (1358.25)	652 (163)
19	2353	3933	-3838	2669	5117 (1279.25)	652 (163)
20	2353	2353	3933	-3838	4801 (1200.25)	-612 (-153)

Net returns are expressed in Zambian Kwacha.
Negative net returns are evidence of significant costs of fallow associated with labour, oxen hire, price of seedlings and net revenue forgone during the fallow period. Constant prices and costs are assumed based on the Zambian Ministry of Agriculture Guidelines (Model), 1990, and interviews with agroforestry technicians at Msekera Research Station.
* CM+F for comparison with 1SS + 3M rotation.

Table 5.20. Estimated net returns based on the phasing of *Sesbania sesban* fallow in the 2SS+2M rotation system, utilizing a 4 ha farm, Katete, Eastern Province, Zambia

Year	Net returns/ha				Total net returns	Total net returns based on fertilizer application*
	1	2	3	4		
1	-3552	2059	2059	2059	2625 (656.25)	8236 (2059)
2	-686	-3552	2059	2059	-120 (-30.00)	8236 (2059)
3	4249	-686	-3552	1743	1754 (438.50)	6972 (1743)
4	4249	4249	-686	-3552	4260 (1065.00)	6972 (1743)
5	-3552	4249	4249	-686	4260 (1065.00)	5708 (1427)
6	-686	-3552	4249	4249	4260 (1065.00)	5708 (1427)
7	5513	-686	-3552	4249	5524 (1381.00)	4444 (1111)
8	4565	5513	-686	-3552	5840 (1460.00)	4444 (1111)
9	-3552	4565	5513	-686	5840 (1460.00)	4444 (1111)
10	-686	-3552	4565	5513	5840 (1460.00)	3180 (795)
11	6777	-686	-3552	4565	7104 (1776.00)	3180 (795)
12	4881	6777	-686	-3552	7420 (1855.00)	1916 (479)
13	-3552	4881	6777	-686	7420 (1855.00)	1916 (479)
14	-686	-3552	4881	6777	7420 (1855.00)	1916 (479)
15	8357	-686	-3552	4881	9000 (2250.00)	1916 (479)
16	5197	8357	-686	-3552	9316 (2329.00)	652 (163)
17	-3552	5197	8357	-686	9316 (2329.00)	652 (163)
18	-686	-3552	5197	8357	9316 (2329.00)	652 (163)
19	9937	-686	-3552	5197	10896 (2724.00)	652 (163)
20	5829	9937	-686	-3552	11528 (2882.00)	-612 (-153)

Net returns are expressed in Zambian Kwacha.
Negative net returns are evidence of significant costs of fallow associated with labour, oxen hire, price of seedlings and net revenue forgone during the fallow period. Constant prices and costs are assumed based on the Zambian Ministry of Agriculture Guidelines (Model), 1990, and interviews with the agroforestry technicians at Msekera Research Station.
* CM+F for comparison with 2SS + 2M rotation.

Table 5.21. Estimated net returns based on the phasing of *Sesbania sesban* fallow in the 2SS+3M rotation system, utilizing a 5 ha farm, Katete, Eastern Province, Zambia

Year	Net returns/ha					Total net returns	Total net returns based on fertilizer application*
	1	2	3	4	5		
1	-3552	2059	2059	2059	2059	4684 (936.80)	10295 (2059)
2	-686	-3552	2059	2059	2059	1939 (387.80)	10295 (2059)
3	4249	-686	-3552	1743	1743	3497 (699.40)	8715 (1743)
4	4249	4249	-686	-3552	1743	6003 (1200.60)	8715 (1743)
5	3033	4249	4249	-686	-3552	8193 (1638.60)	7135 (1427)
6	-3552	3933	4249	4249	-686	8193 (1638.60)	7135 (1427)
7	-686	-3552	3933	4249	4249	8193 (1638.60)	5555 (1111)
8	5513	-686	-3552	3933	4249	9457 (1891.40)	5555 (1111)
9	4249	5513	-686	-3552	3933	9457 (1891.40)	5555 (1111)
10	3933	4249	5513	-686	-3552	9457 (1891.40)	3975 (795)
11	-3552	3933	4249	5513	-686	9457 (1891.40)	3975 (795)
12	-686	-3552	3933	4249	5513	9457 (1891.40)	2395 (479)
13	6461	-686	-3552	3933	4249	10405 (2081.00)	2395 (479)
14	4249	6461	-686	-3552	3933	10405 (2081.00)	2395 (479)
15	4249	4249	6461	-686	-3552	10721 (2144.20)	2395 (479)
16	-3552	4249	4249	6461	-686	10721 (2144.20)	815 (163)
17	-686	-3552	4249	4249	6461	10721 (2144.20)	815 (163)
18	8039	-686	-3552	4249	4249	12299 (2459.80)	815 (163)
19	4249	8039	-686	-3552	4249	12299 (2459.80)	815 (163)
20	4565	4249	8039	-686	-3552	12615 (2523.00)	-765 (-153)

Net returns are expressed in Zambian Kwacha.

Negative net returns are evidence of significant costs of fallow associated with labour, oxen hire, price of seedlings and net revenue forgone during the fallow period. Constant prices and costs are assumed based on the Zambian Ministry of Agriculture Guidelines (Model), 1990, and interviews with the agroforestry technicians at Msekera Research Station.

* CM+F for comparison with 2SS + 3M rotation.

Table 5.22. Estimated net returns based on the phasing of *Sesbania sesban* fallow in the 3SS+ 1M rotation system, utilizing a 4 farm, Katete, Eastern Province, Zambia

Year	Net returns/ha				Total net returns	Total net returns based on fertilizer application*
	1	2	3	4		
1	-3552	2059	2059	2059	2625 (656.25)	8236 (2059)
2	-400	-3552	2059	2059	166 (41.50)	8236 (2059)
3	-286	-400	-3552	1743	-2495 (-623.75)	6972 (1743)
4	5197	-286	-400	-3552	959 (239.75)	6972 (1743)
5	-3552	5197	-286	-400	959 (239.75)	5708 (1427)
6	-400	-3552	5197	-286	959 (239.75)	5708 (1427)
7	-286	-400	-3552	5197	959 (239.75)	4444 (1111)
8	7409	-286	-400	-3552	3171 (792.75)	4444 (1111)
9	-3552	7409	-286	-400	3171 (792.75)	4444 (1111)
10	-400	-3552	7409	-286	3171 (792.75)	3180 (795)
11	-286	-400	-3552	7409	3171 (792.75)	3180 (795)
12	10253	-286	-400	-3552	6015 (1503.75)	1916 (479)
13	-3552	10253	286	-400	6015 (1503.75)	1916 (479)
14	-400	-3552	10253	-286	6105 (1503.75)	1916 (479)
15	-286	-400	-3552	10253	6015 (1503.75)	1916 (479)
16	13729	-286	-400	-3552	9491 (2372.75)	652 (163)
17	-3552	13729	-286	-400	9491 (2372.75)	652 (163)
18	-400	-3552	13729	-286	9491 (2372.75)	652 (163)
19	-286	-400	-3552	13729	9491 (2372.75)	652 (163)
20	18153	-286	-400	-3552	13915(3478.75)	-612 (-153)

Net returns are expressed in Zambian Kwacha.
Negative net returns are evidence of significant costs of fallow associated with labour, oxen hire, price of seedlings and net revenue forgone during the fallow period. Constant prices and costs are assumed based on the Zambian Ministry of Agriculture Guidelines (Model), 1990, and interviews with agroforestry technicians at Msekera Research Station.

* CM+F for comparison with 3SS + 1M rotation.

Table 5.23. Estimated net returns based on the phasing of *Sesbania sesban* fallow in the 3SS+2M rotation system, utilizing a 5 ha farm, Katete, Eastern Province, Zambia

Year	Net returns/ha					Total net returns	Total net returns based on fertilizer application*
	1	2	3	4	5		
1	-3552	2059	2059	2059	2059	4684 (936.80)	10295 (2059)
2	-400	-3552	2059	2059	2059	2225 (445.00)	10295 (2059)
3	-286	-400	-3552	1743	1743	-752 (-150.40)	8715 (1743)
4	5197	-286	-400	-3552	1743	2702 (540.40)	8715 (1743)
5	4881	5197	-286	-400	-3552	5840 (1168.00)	7135 (1427)
6	-3552	4881	5197	-286	-400	5840 (1168.00)	7135 (1427)
7	-400	-3552	4881	5197	-286	5840 (1168.00)	5555 (1111)
8	-286	-400	-3552	4881	5197	5840 (1168.00)	5555 (1111)
9	7093	-286	-400	-3552	4881	7736 (1547.20)	5555 (1111)
10	5513	7093	-286	-400	-3552	8368 (1673.60)	3975 (795)
11	-3552	5513	7093	-286	-400	8368 (1673.60)	3975 (795)
12	-400	-3552	5513	7093	286	8368 (1673.60)	2395 (479)
13	-286	-400	-3552	5513	7093	8368 (1673.60)	2395 (479)
14	9621	-286	-400	-3552	5513	10896 (2179.20)	2395 (479)
15	6461	9621	-286	-400	-3552	11844 (2368.80)	2395 (479)
16	-3552	6461	9621	-286	-400	11844 (2368.80)	815 (163)
17	-400	-3552	6461	9621	-286	11844 (2368.80)	815 (163)
18	-286	-400	-3552	6461	9621	11844 (2368.80)	815 (163)
19	12781	-286	-400	-3552	6461	15004 (3000.80)	815 (163)
20	7725	12781	-286	-400	-3552	16268 (3253.60)	-765 (-153)

Net returns are expressed in Zambian Kwacha.
Negative net returns are evidence of significant costs of fallow associated with labour, oxen hire, price of seedlings and net revenue forgone during the fallow period. Constant prices and costs are assumed based on the Zambian Ministry of Agriculture Guidelines (Model), 1990, and interviews with the agroforestry technicians at Msekera Research Station.
* CM+F for comparison with 3SS + 2M rotation.

Table 5.24. Estimated net returns based on the phasing of *Sesbania sesban* fallow in the 3SS+3M rotation system, utilizing a 6 ha farm, Katete, Eastern Province, Zambia

Year	Net returns/ha						Total net returns	Total net returns based on fertilizer application*
	1	2	3	4	5	6		
1	-3552	2059	2059	2059	2059	2059	6743 (1123.83)	12354 (2059)
2	-400	-3552	2059	2059	2059	2059	4284 (714.00)	12354 (2059)
3	-286	-400	-3552	1743	1743	1743	991 (165.17)	10454 (1743)
4	5197	-286	-400	-3552	1743	1743	4445 (740.83)	10454 (1743)
5	4881	5197	-286	-400	-3552	1427	7267 (1211.17)	8562 (1427)
6	4565	4881	5197	-286	-400	-3552	10405 (1734.17)	8562 (1427)
7	-3552	4565	4881	5197	-286	-400	10405 (1734.17)	6666 (1111)
8	-400	-3552	4565	4881	5197	-286	10405 (1734.17)	6666 (1111)
9	-286	-400	-3552	4565	4881	5197	10405 (1734.17)	6666 (1111)
10	7093	-286	-400	-3552	4565	4881	12301 (2050.17)	4770 (795)
11	5197	7093	-286	-400	-3552	4565	12617 (2102.83)	4770 (795)
12	5197	5197	7093	-286	-400	-3552	13249 (2208.17)	2874 (479)
13	-3552	5197	5197	7093	-286	-400	13249 (2208.17)	2874 (479)
14	-400	-3552	5197	5197	7093	-286	13249 (2208.17)	2874 (479)
15	-286	-400	-3552	5197	51972	7093	13249 (2208.17)	2874 (479)
16	9305	-286	-400	-3552	5197	5197	15461 (2576.83)	978 (163)
17	5829	9305	-286	-400	-3552	5197	16093 (2682.17)	978 (163)
18	6145	5829	9305	-286	-400	-3552	17041 (2840.17)	978 (163)
19	-3552	6145	5829	9305	-286	-400	17041 (2840.17)	978 (163)
20	-400	-3552	6145	5829	9305	-286	17041 (2840.17)	-918 (-153)

Net returns are expressed in Zambian Kwacha.
Negative net returns are evidence of significant costs of fallow associated with labour, oxen hire, price of seedlings and net revenue forgone during the fallow period. Constant prices and costs are assumed based on the Zambian Ministry of Agriculture Guidelines (Model), 1990, and interviews with agroforestry technicians at Msekera Research Station.
* CM+F for comparison with 3SS + 3M rotation.

Table 5.25. Summary of estimated net returns, expressed in Zambian Kwacha per hectare, while phasing in *Sesbania sesban* fallows, utilizing all fallow and cultivated lands, Katete, Eastern Province, Zambia

Year	Treatment						CM+F
	1SS+3M	2SS+2M	2SS+3M	3SS+1M	3SS+2M	3SS+3M	
1	585	656	937	656	937	1124	2059
2	1053	-30	388	42	445	714	2059
3	1443	439	699	-624	-150	165	1743
4	*1911	1065	1201	240	540	741	1743
5	1911	1065	*1639	240	1168	1211	1427
6	1911	1065	1639	240	1168	*1734	1427
7	1753	*1381	1639	240	*1168	1734	1111
8	1595	1460	1891	793	1168	1734	1111
9	1595	1460	1891	793	1547	1734	1111
10	1595	1460	1891	793	1674	2050	795
11	1516	1776	1891	793	1674	2103	795
12	1437	1855	1891	*1504	1674	2208	479
13	1437	1855	2081	1504	1674	2208	479
14	1437	1855	2081	1504	2179	2208	479
15	1358	2250	2144	1504	2369	2208	479
16	1358	2329	2144	2373	2369	2577	163
17	1358	2329	2144	2373	2369	2682	163
18	1358	2329	2460	2373	2369	2840	163
19	1279	2724	2460	2373	3001	2840	163
20	1200	2882	2523	3479	3254	2840	153

*Break-even (cross-over) point compared to continuous maize cropping based on fertilizer application (CM+F).
Values for net returns have been rounded to completed Zambian Kwacha

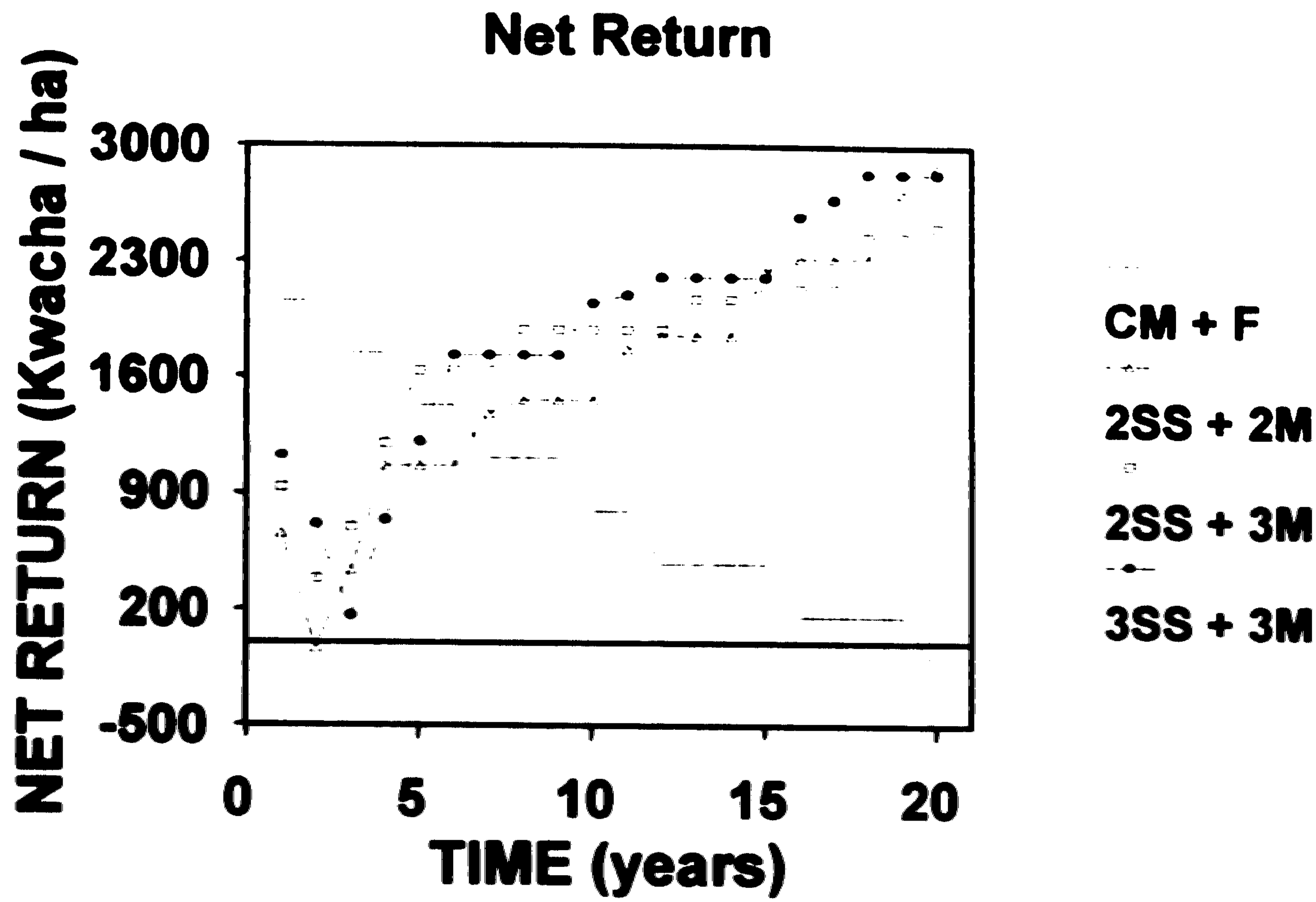

Figure 5.8. Estimated net return trends in CM+F, 2SS+2M, 2SS+3M and 3SS+3M systems over a 20 year period, Katete, Eastern Province, Zambia.

Table 5.26. Estimated net returns based on the phasing of *Sesbania sesban* fallow in the 2SS+ 2M rotation system, utilizing a 4 ha farm (100 kg/ha of inorganic fertilizer added during maize cropping), Katete, Eastern Province, Zambia

Year	Net returns/ha				Total net returns	Total net returns based on fertilizer application*
	1	2	3	4		
1	-3552	2059	2059	2059	2625 (656.25)	8236 (2059)
2	-686	-3552	2059	2059	-120 (-30.00)	8236 (2059)
3	3483	-686	-3552	1743	988 (247.00)	6972 (1743)
4	4115	3483	-686	-3552	3360 (840.00)	6972 (1743)
5	-3552	4115	3483	-686	3360 (840.00)	5708 (1427)
6	-686	-3552	4115	3483	3360 (840.00)	5708 (1427)
7	4747	-686	-3552	4115	4624 (1156.00)	4444 (1111)
8	4431	4747	-686	-3552	4940 (1235.00)	4444 (1111)
9	-3552	4431	4747	-686	4940 (1235.00)	4444 (1111)
10	-686	-3552	4431	4747	4940 (1235.00)	3180 (795)
11	6327	-686	-3552	4431	6520 (1630.00)	3180 (795)
12	4747	6327	-686	-3552	6836 (1709.00)	1916 (479)
13	-3552	4747	6327	-686	6836 (1709.00)	1916 (479)
14	-686	-3552	4747	6327	6836 (1709.00)	1916 (479)
15	7591	-686	-3552	4747	8100 (2025.00)	1916 (479)
16	5063	7591	-686	-3552	8416 (2104.00)	652 (163)
17	-3552	5063	7591	-686	8416 (2104.00)	652 (163)
18	-686	-3552	5063	7591	8416 (2104.00)	652 (163)
19	9487	-686	-3552	5063	10312 (2578.00)	652 (163)
20	5695	9487	-686	-3552	10944 (2736.00)	-612 (-153)

Net returns are expressed in Zambian Kwacha.
Negative net returns are evidence of significant costs of fallow associated with labour, oxen hire, price of seedlings and net revenue forgone during the fallow period. Constant prices and costs are assumed based on the Zambian Ministry of Agriculture Guidelines (Model), 1990, and interviews with agroforestry technicians at Msekera Research Station.
* CM+F for comparison with 2SS + 2M rotation.

Table 5.27. Estimated net returns based on the phasing [illegible] in [illegible] 2SS+3M rotation system, utilizing a 5 ha farm (100 kg/ha of in[illegible] [illegible]ied during maize cropping), Katete, Eastern Province, Zambia

Year	Net returns/ha					Total net returns	Total net returns based on fertilizer application*
	1	2	3	4	5		
1	-3552	2059	2059	2059	[illegible]	[illegible] ([illegible].80)	10295 (2059)
2	-686	-3552	2059	2059	205[illegible]	[illegible]39 ([illegible]7.80)	10295 (2059)
3	3483	-686	-3552	1743	1743	2731 (546.20)	8715 (1743)
4	4115	3483	-686	-3552	1743	5[illegible] (1020.60)	8715 (1743)
5	3483	4115	3483	-686	-3552	6843 (1368.60)	7135 (1427)
6	-3552	3483	4115	3483	-686	6843 (1368.60)	7135 (1427)
7	-686	-3552	3483	4115	3483	6843 (1368.60)	5555 (1111)
8	4747	-686	-3552	3483	4115	8107 (1621.40)	5555 (1111)
9	3799	4747	-686	-3552	3483	7791 (1558.20)	5555 (1111)
10	3799	3799	4747	-686	-3552	8107 (1621.40)	3975 (795)
11	-3552	3799	3799	4747	-686	8107 (1621.40)	3975 (795)
12	-686	-3552	3799	3799	4747	8107 (1621.40)	2395 (479)
13	6011	-686	-3552	3799	3799	9371 (1874.20)	2395 (479)
14	4115	6011	-686	-3552	3799	9687 (1937.40)	2395 (479)
15	4115	4115	6011	-686	-3552	10003 (2000.60)	2395 (479)
16	-3552	4115	4115	6011	-686	10003 (2000.60)	815 (163)
17	-686	-3552	4115	4115	6011	10003 (2000.60)	815 (163)
18	6959	-686	-3552	4115	4115	10951 (2190.20)	815 (163)
19	4431	6959	-686	-3552	4115	11267 (2253.40)	815 (163)
20	4431	4431	6959	-686	-3552	11583 (2316.60)	-765 (-153)

Net returns are expressed in Zambian Kwacha.
Negative net returns are evidence of significant costs of fallow associated with labour, oxen hire, price of seedlings and net revenue forgone during the fallow period. Constant prices and costs are assumed based on the Zambian Ministry of Agriculture Guidelines (Model), and interviews with agroforestry technicians at Msekera Research Station.
* CM+F for comparison with 2SS + 3M rotation.

Table 5.28. Estimated net returns based on the phasing of *Sesbania sesban* fallow in the 3SS + 3M rotation system, utilizing a 6 ha farm (100 kg/ha of in organic fertilizer added during maize cropping), Katete, Eastern Province, Zambia

Year	Net returns/ha						Total net returns	Total net returns based on fertilizer application*
	1	2	3	4	5	6		
1	-3552	2059	2059	2059	2059	2059	6743 (1123.83)	12354 (2059)
2	-400	-3552	2059	2059	2059	2059	4284 (714.00)	12354 (2059)
3	-286	-400	-3552	1743	1743	1743	991 (165.17)	10454 (1743)
4	4431	-286	-400	-3552	1743	1743	3679 (613.17)	10454 (1743)
5	7591	4431	-286	-400	-3552	1427	9211 (1535.17)	8562 (1427)
6	6643	7591	4431	-286	-400	-3552	14427 (2404.50)	8562 (1427)
7	-3552	6643	7591	4431	-286	-400	14427 (2404.50)	6666 (1111)
8	-400	-3552	6643	7591	4431	-286	14427 (2404.50)	6666 (1111)
9	-286	-400	-3552	6643	7591	4431	14427 (2404.50)	6666 (1111)
10	6959	-286	-400	-3552	6643	7591	16955 (2825.83)	4770 (795)
11	9171	6959	-286	-400	-3552	6643	18535 (3089.17)	4770 (795)
12	8539	9171	6959	-286	-400	-3552	20431 (3405.17)	2874 (479)
13	-3552	8539	9171	6959	-286	-400	20431 (3405.17)	2874 (479)
14	-400	-3552	8539	9171	6959	-286	20431 (3405.17)	2874 (479)
15	-286	-400	-3552	8539	9171	6959	20431 (3405.17)	2874 (479)
16	10119	-286	-400	-3552	8539	9171	23591 (3931.83)	978 (163)
17	11067	10119	-286	-400	-3552	8539	25487 (4247.83)	978 (163)
18	10751	11067	10119	-286	-400	-3552	27699 (4616.50)	978 (163)
19	-3552	10751	11067	10119	-286	-400	27699 (4616.50)	978 (163)
20	-400	-3552	10751	11067	10119	-286	27699 (4616.50)	-918 (-153)

Net returns are expressed in Zambian Kwacha.
Negative net returns are evidence of significant costs of fallow associated with labour, oxen hire, price of seedlings and net revenue forgone during the fallow period. Constant prices and costs are assumed based on the Zambian Ministry of Agriculture Guidelines (Model), 1990, and interviews with the agroforestry technicians at Msekera Research Station.
* CM+F for comparison with 3SS + 3M rotation.

Table 5.29. Monthly estimates of labour demands, supplies and surpluses (or deficiencies) for the average male and female headed ox-hoe farm households, expressed in hr/ha, based on routine cropping activities, Katete, Eastern Province, Zambia, 1992

Month	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT
Labour Demand:	140	190	103	74	66	69	61	100	103	96	70	Resting
Labour Supply: (Male HH)	121	121	121	121	121	121	121	121	121	121	121	Resting
Surplus or deficiency:	-19	-69	18	47	55	52	60	21	18	25	51	Resting
Labour Supply: (Female HH)	56	56	56	56	56	56	56	56	56	56	56	Resting
Surplus or deficiency:	-84	-134	-47	-18	-10	-13	-5	-44	-47	-40	-14	Resting

Labour supply indicates labour available from the household, and is assumed to be constant every month. Effects of sickness and time allocated for off-farm activities could not be discounted from the supply due to data limitations.
Supply estimates are based on average cultivated land, average number of full-time workers, and average number of hours worked during the week by each full-time worker.
Demand estimates are based on Farm Management Guidelines, model (Zambian Ministry of Agriculture 1990).
Labour surplus or deficiency= difference between the demand and supply.
HH = Average male or female headed ox-hoe farm household.

Table 5.30. Monthly estimates of labour demands, supplies and surpluses (or deficiencies) the average male and female ox-hoe farm households, expressed in hr/ha, based on routine cropping activities and *Sesbania sesban* (SS) fallow, Katete, Eastern Province, Zambia, 1992

Month	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT
Labour demand:	240[a]	790[b]	103	144[c]	66	139[d]	61	100	103	96	170[e]	Resting
Labour supply: male HH	121	121	121	121	121	121	121	121	121	121	121	Resting
Surplus or deficiency:	-119	-669	18	-23	55	-18	60	21	18	25	-49	Resting
Labour supply: female HH	56	56	56	56	56	56	56	56	56	56	56	Resting
Surplus or deficiency:	-184	-734	-47	-88	-10	-83	-5	-44	-47	-40	-114	Resting

[a] Includes labour for preparing (ploughing) land for SS establishment.
[b] Includes labour for transporting, digging holes and planting SS.
[c] Includes labour for the first weeding of SS.
[d] Includes labour for the second weeding of SS.
[e] Includes labour for harvesting SS.
Labour supply indicates labour available from the household, and is assumed to be constant every month. Effects of sickness and time allocated for off-farm activities could not be discounted from the supply due to data limitations.
Supply estimates are based on the average cultivated land, average number of full-time workers, and average number of hours worked during the week by each full-time worker.
Demand estimates are based on Farm Management Guidelines, model (Zambian Ministry of Agriculture 1990), and interviews with the agroforestry technicians at Msekera Research Station (in case of SS fallow).
Labour surplus or deficiency = difference between the demand and supply.
HH = Average male or female headed ox-hoe farm household.

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Chapter 6

Summary and Conclusions

In Katete District, farmers traditionally fallow land to restore soil fertility. However, increasing demographic pressure on land resources has resulted in shorter fallow periods, declining soil fertility and crop yields and increasing soil erosion. Farmers adopt several strategies in response to these problems. Strategies include clearing new land, often destroying forest, botanical diversity and soil properties; continuous cropping using expensive chemical fertilizers, continuous cropping without fertilizer application, leading to lower levels of crop production; and crop rotation with leguminous and non-leguminous crops.

Intensified agroforestry fallows with leguminous trees and shrubs provide a promising alternative for these farmers. Fallow species grow and make their contribution to soil fertility more quickly than natural vegetation. They may also provide by-products such as poles and fuelwood. Most importantly, the objectives of agroforestry intensified fallows are to stabilize fragile ecosystems and to reduce poverty. Agroforestry systems are aimed at addressing problems of marginal farmers: food and economic security.

Fallow-based agroforestry research in subhumid Africa focuses mainly on the indigenous nitrogen-fixing tree, *Sesbania sesban* (SS). Improvements in long-term maize, soil organic carbon and organic nitrogen and erosion control are achieved and sustained under SS fallow. The intensified fallow system involves social and economic burdens for farmers. Maize yield is reduced in the short-term. Significant costs are associated with establishment, weeding, and harvesting of SS. Farmers have to learn about SS nursery stock production techniques, management of SS stands and ways to integrate the fallow system into their household economic system.

No income is derived from the land when SS occupies it. It may be argued that SS can be used as fodder to offset maize losses during fallow periods. However, removal of SS in the form of fodder reduces the amount of biomass production and the potential for litter accumulation. Using SS as fodder reduces the effectiveness of the fallow system for improving soil productivity. Because of the relatively small dimension and low wood density of SS, farmers have reported that it burns too rapidly to be suitable for fuelwood.

The practice of SS fallow system demands additional labour from households. The additional labour demand directly competes for labour for other farm and off-farm activities. Female headed households experience more labour deficiencies than the males during land preparation, planting and weeding of SS. To make up for labour deficiencies, farmers have to hire more labour, use children or engage in communal labour (labour sharing).

The results suggest that a ley fallow practice, using N-fixing annual species would fit better in these subhumid permanent household farming systems in Katete area. Pigeonpea (*Cajanus cajan*) is an example of such an alternative to agroforestry SS fallow system. Pigeonpea supplies food and income annually to farm households. Relatively less labour is involved in establishing and managing pigeonpea. Thus, it is more likely to be accepted by farmers than SS.

Based on a systems theory approach, this study illustrated some typical flaws in the "top-down" approach to the problems of subsistence farming in fragile eco-regions. The first flaw is the assumption that a new fallow system is required and would be accepted by economically vulnerable households farming under degraded soil regimes. Understanding the impact of SS on a farming system requires the knowledge of social, ecological and biological interactions that occur in rural systems. The ranking of improvement in soil fertility as the most important constraint may not match farmers' rankings of the problems they encounter. Researchers' aims of improving soil conditions, maximizing yields and reducing deforestation can contradict farmers' welfare, objectives, needs to manage uncertainty, needs to improve the seasonal distribution of food and supply and the opportunity costs to farming from off-farm employment. For example, 73% of the male headed households in this study indicated that they were not interested in SS fallow system because it would involve additional labour which could compete for labour needed for other farm and off-farm activities.

Ox-hoe farmers in Katete are old and their households are economically fragile. They are unwilling to make a sacrifice, forego income in the short-term, or make trade-offs in the area of food security for future environmental quality and conservation. Non-quantifiable factors such as relationship to the natural environment and concern for future generations are weighed against short-term monetary and social gains. Most importantly, short-term goals often influence a farmer's long-term planning activities. Continuous cropping with or without fertilizer application, perceived as directly relevant to the farmer's short-term aspirations, are pursued with greater commitment than a forest fallow system which may have long-term benefits but intangible results to offset labour costs and foregone crop production.

The main problem in the ox-hoe farming system in Katete District is how to improve existing fallow systems. Under what conditions could SS contribute to the alleviation of food security problems and economic vulnerability of the male and female headed households? There is no simple answer to this question. Under the current matrilineal tenure system, almost all agroforestry practices can be affected by the insecurity of land tenure and the control chiefs have over land allocation and use. Male and female headed households have significant differential access to land due to tenure systems and allocation of credit facilities from chiefs, who are males, and lending institutions in the region. Male headed households are favoured in financial arrangements. An agroforestry SS system requires sacrifice in the short-term for long-term benefits. In the case of male headed households, wives have temporary or insecure ownership of land. There is uncertai:.ty (e.g. concern of being divorced in future) as to whether women are able to claim future benefits arising from their investments in land. Under these circumstances, married women may not be willing to accept costs for benefits to which they may have no right in the future. Benefits are more immediate from ley fallow systems than from SS fallow system.

The introduction of a new agroforestry technology should avoid the flaws in the "top-down" approach to problems of subsistence farming. Researchers and farmers should engage in a "joint learning relationship" or a two-way flow of knowledge and ideas. Without this relationship, neither researchers nor farmers are likely to be satisfied. Farmers will not receive relevant information on new fallow options that may help solve their food and economic problems. For example, information on how to establish, intensify and manage improved fallow systems, how to make adjustments or transitions to improved agroforestry systems, and how to retain benefits. Researchers will not receive the satisfaction of seeing their research activities and results which have absorbed limited budgets under difficult field conditions, contribute to farmers' food security and economic problems. In particular, researchers will not learn about farmers' indigenous knowledge about farming systems, how fallow systems can be grown within the prevailing landuse systems, and how farming systems relate to other social, economic, and biophysical systems.

To conclude, several issues are identified by this research, which materially affect the introduction of new agroforestry technologies in farming systems. These issues are: gender; property rights; the immediate cost of initial deferred production; feasibility of new technologies with respect to *miombo* soil conditions in contrast to degraded soils of Katete farming systems; the appropriateness of the technologies with respect to nursery requirements, livestock needs, labour demands and food security needs; and the need for social scientists to work with biophysical scientists in dealing with agroforestry research. Gender issues are critical in the adoption of an agroforestry system. In Katete, female headed households spend a lot of time managing uncertainty (witchcraft or jealousy). They are also more effective than males with respect to crop yields. Agroforestry systems could probably increase female farmers' uncertainty, especially if they were to be successful in generating wealth. Wealth or any signs of it is one of the factors promoting witchcraft and jealousy in Katete.

The social science component of the agroforestry research in Katete could be stronger than it has been. However, simply hiring a socioeconomist, while a necessary condition, may not be sufficient. The social science component should include development sociology and development economics. Qualified personnel require further training, through workshops, in human behaviour with respect to agroforestry and rural systems. Personnel in all disciplines should be trained in how to work with scientists of other disciplines before joining field research teams.

The research reported in this thesis could make two important contributions. First, it illustrates why and how agroforestry research should be done effectively within the complexity of both human and biophysical systems. Second, it shows how researchers can advance in their agroforestry work.

Appendices

Appendix 1

OX-HOE FARMERS IN KATETE DISTRICT, EASTERN PROVINCE, ZAMBIA: QUESTIONNAIRE REPORT FORM, MARCH 1992

FARMER INTERVIEW: TO BE ANSWERED BY FARMERS.

A. FARMER PFRSONAL CHARACTERISTICS

1. Name of the Household Head (HH) --

2. Male headed (MH) ------------------------ Female headed (FH) ------------------------

3. What is your ethnic group (tribe)?

   1) ------------------- Chewa

   2) ------------------- Ngoni

   3) ------------------- Tumbuka

   4) ------------------- Nsenga

   5) ------------------- Other

4. What is your inheritance pattern?

   1) ---------- Patrilineal (inheritance from father side)

   2) ---------- Matrilineal (inheritance from mother side)

5. How old are you? -------------- years (Ask for NRC)

6. How many people live with you at the moment who are more than 15 years old?

   ---------- Males

   ---------- Females

7. How many people live with you at the moment who are less than 15 years old?

   ---------- Males

   ---------- Females

8. How many people live away from you but depend on you? ---------------

9. How many years of schooling have you got? ---------------

B. FARMER BACKGROUND AND FARMING EXPERIENCE

10. Where did you grow up?

    1) ----------- Village

    2) ----------- Town

11. How long have you been farming? ------------

12. What changes in the farming have you made since:

    a) Last year? --

    ----

    b) Last 5 years? --

C. LAND (UPLAND OR ARABLE) RESOURCES

13. Please provide the following information:

    a) Total land in possession (ha, ac, or lima) ----------------------------------

    b) Total land under crops (ha, ac, or lima) ----------------------------------

    c) Total land under wooded fallow (ha, ac, or lima) ----------------------------

    d) Total land under grass fallow (ha, ac, or lima) ----------------------------

14. Please provide information for the following:

Crop	Area		Gross Yield (Income) (Virgin Land)	Gross Yield (Income) (Continuous Cropping)
	ha	ac		
a) Hybrid maize	---	---	----------------	--------------------------
b) Local maize	---	---	----------------	--------------------------

c) Groundnuts				
(Shelled)....	---	---	------------------	-----------------------------
(Unshelled)..	---	---	------------------	-----------------------------
d) Cotton	---	---	------------------	-----------------------------
e) Beans	---	---	------------------	-----------------------------
f) Sunflower	---	---	------------------	-----------------------------
g) Other	---	---	------------------	-----------------------------

15. Do you practice crop rotation?

--------- No (If no go to question 16)

--------- Yes (If yes, please explain how you do it?) --

----

16. When working on your fields, do you use borrowed, rented oxen, a plough or your own oxen and plough? How do you pay for these?

Sources	Amount spent in Kwacha	Payment in other forms e.g. goats, drinks	How often? (1)...every week (2)...every season (3)...every month
a) borrowed ox and plough	------------	--------------------	---------------------
b) Borrowed plough	------------	--------------------	---------------------
c) Own ox and plough	------------	--------------------	---------------------
d) Rented plough	------------	--------------------	---------------------
e) Rented ox and plough	------------	--------------------	---------------------
f) Rented oxen	------------	--------------------	---------------------

17. Do you use fertilizers in your fields?
 a) ---------- No (If no, please go to question 18)
 b) ---------- Yes (If yes, please provide the following information):

Type of Fertilizer	Is this a loan?	Is this bought?	Crops	Area ha	ac	lima	Quantity applied
-------------	---------	---------	Hybrid maize	---	---	-------	-------------
-------------	---------	---------	local maize	---	---	-------	-------------
-------------	---------	---------	G/nuts	---	---	-------	-------------
-------------	---------	---------	Cotton	---	---	-------	-------------
-------------	---------	---------	Sun/flower	---	---	-------	-------------
-------------	---------	---------	Beans	---	---	-------	-------------
-------------	---------	---------	Others	---	---	-------	-------------

D. LABOUR

18. How many family members, and people work full-time or part-time? Please complete the information below.

People	Full-time i.e. Permanent labour	Part time (Casual)	Form of payment and cost
Children:			
Males	----------------	--------------	----------------------
Females	----------------	--------------	----------------------
Adults (more than 15 years):			
Males	----------------	--------------	----------------------
Females	----------------	--------------	----------------------

19. How many days and hours per week do your family members work in your fields?

Family members	Number of days in a week	Number of hours in a day
Children:		
Males	------------------	----------------------
Females	------------------	----------------------
Adults:		
Males	------------------	----------------------
Females	------------------	----------------------

E. GATHERING OF MAIN FOREST PRODUCTS

20. Please provide the following information:

a) Type of products gathered
b) Who gathers it?
c) How far do you collect these?
d) Amount gathered
e) Amount consumed per given time
f) Amount sold per given time
g) Where it is sold

Forest products	Amount collected	Who gathers	How far are these products collected	Amount consumed per given time	Amount sold per per given time	Where it sold
Fruit (per season)	--- use the quantity	-------	---------	---------	----------	----------
Honey (per season)	--- buckets	-------	---------	---------	----------	----------
Charcoal (per week)	--- bags (25kg)	-------	---------	---------	----------	----------
	--- bags (50kg)	-------	---------	---------	----------	----------
	--- bags (80kg)	-------	---------	---------	----------	----------
	--- bags (90kg)	-------	---------	---------	----------	----------
Poles (per week)	--- numbers	-------	---------	---------	----------	----------
Firewood (per week)	--- stacks	-------	---------	---------	----------	----------
	--- head-loads	-------	---------	---------	----------	----------
Mushroom (per season)	--- baskets	-------	---------	---------	----------	----------
Grass (per season)	--- head-loads	-------	---------	---------	----------	----------
Other	--------	-------	---------	---------	----------	----------

F. OTHER ACTIVITIES

21. Please complete the table by indicating other important activities which you do besides farming which bring money.

Activity	Kwacha (per week, month, or year)
------------------------------------	--
------------------------------------	--
------------------------------------	--
------------------------------------	--

G. REMITTANCES FROM RELATIVES

22. Do you receive money from relatives working away from your home?

0) ---------- No (If so, please go to question 23)
1) ---------- Yes

If yes, please indicate:

a) The amount per year ------------ Kwacha

b) Source ------------ (e.g daughter or son)

H. FARMER SAVING (INVESTMENTS)

23. Please indicate:

a) Type of resources you own

b) How much of it/how many of it

Type of Resources	Number or Quantity	Amount (Kwacha) Spent in Obtaining
Livestock:		
Pigs	---- Number(s)	------------
Cows	---- Number(s)	------------
Goats	---- Number(s)	------------
Bicycle	---- Number(s)	------------

Iron Sheet	---- Number(s)	-------------
Grinding mill	---- Number(s)	-------------
Vehicle	---- Number(s)	-------------
Scotch cart	---- Number(s)	-------------
Radio	---- Number(s)	-------------

I. FARMER REVEALED PREFERENCES OR PERCEPTION OF THE FUTURE

FUTURE PLANS

24. Do you have plans for the future?
Yes ---------- No ----------

If yes, what are these plans?

----

25. Do you have resources to fulfill these plans?
Yes ---------- No ----------

If yes, what are these resources?

----

26. What is preventing you from achieving these plans?

AGROFORESTRY IMPROVED FALLOWS

27. Do you know anything about agroforestry improved fallows?
Yes ------------ No ______________

28. What do you think of agroforestry improved fallow?

----

29. If there was a tree which could improve the soil, would you plant it?
Yes ------------ No ------------

If no, why couldn't you plant it?

----

30. If yes, do you have the resources to raise the tree?
<u>Resources</u>:
Land ---------------------------
Labour -------------------------
Capital ------------------------
Water sources ------------------

31. Where would you get the following:

<u>Resources</u>	Where to obtain (Please tick one) <u>Provided by yourself?</u>	<u>Or should be provided by project</u>
Seeds	------------------	---------------------------
Seedlings	------------------	---------------------------
Management	------------------	---------------------------

TREES ON FARM

32. Do you have trees on your farms, if yes what are those trees and for what purpose?

<u>Trees</u>	<u>Purpose</u>	<u>Ranking of Importance</u> <u>1st priority</u>	<u>2nd priority</u>
--------------	----------------------	-----------	-----------
--------------	----------------------	-----------	-----------
--------------	----------------------	-----------	-----------
--------------	----------------------	-----------	-----------

33. What plans do you have for agroforestry (that is growing trees and crops together in the same field) in near future?

J. LAND TENURE

34. What are the rights (rules or regulations) you have regarding your fields?

----

35. Who has the right to use resources (crops, trees and other products in your field?

----

36. Do you have the right to prevent other persons from using the resources from your fields? Yes or No?
----

37. If somebody wanted to buy your fields, would you sell it to him or her?
Yes -------------- No --------------
If yes, please explain:

If no, why?

----

38. If you had money, could you buy more fields?
Yes -------------- No --------------
If yes, why? --

If no, why? ---
----

39. Are you renting (loaning) your fields to anybody now, and for what period and why?
Yes -------------- No --------------

Period: ------------------------------------

Reasons: --

K. OTHER ISSUES

40. What do you think of increase in human population? Does it bother you?

----

41. What do you think of:

a) Inflation: --

b) Market prices for agricultural inputs: --

c) Market prices for agricultural outputs: --

L. FARMER CONSUMPTION/EXPENDITURE

42. How much of the following things do you consume per week?

Manufactured goods e.g. Sugar, Salt, etc.	Kwacha spent per week
a) ------------------	------------------------
b) ------------------	------------------------
c) ------------------	------------------------

Food	
a) ------------------	------------------------
b) ------------------	------------------------
c) ------------------	------------------------

Leisure	
a) Travel	------------------------
b) Recreation	------------------------
c) Other	------------------------

43. Please indicate what payment, including the amount, you make to other people.

<u>Ceremonies and gifts</u>

Marriages (Specify) -- Kwacha per year
Naming ceremonies (specify) -------------------------------- Kwacha per year
Gifts (specify) -- Kwacha per year
Initiation ceremonies -------------------------------------- Kwacha per year
Funerals --- Kwacha per year
Church contributions --------------------------------------- Kwacha per year
School fees -- Kwacha per year
Medical expenses --- Kwacha per year

M. HOUSEHOLD OUTMIGRATION

44. Is there any member of your family who has left you and is now living elsewhere? (Urban centres)

---------------- No (If no, please go to question 45)
---------------- Yes
If yes, how many? ------------ Men (over 15 years old).
------------ Female (over 15 years old).

Could you indicate reasons why they left?

N. HOUSEHOLD EXPOSURE TO DISEASES

45. Do you or any member of your family experience any diseases?

0 ---------------- No (If no, please go to question 46)
1 ---------------- Yes
If yes, please indicate the type of diseases: --
-- --

O. EXPOSURE TO WITCHCRAFT

46. Do you experience witchcraft from other people?

0 ---------------- No
1 ---------------- Yes
If yes, how does it affect you? --

INTERVIEW SUMMARY: TO BE FILLED BY INTERVIEWER

NAME OF THE AGRICULTURAL CAMP --

DATE OF 1ST VISIT ------------ AM/PM DATE OF 2ND VISIT ------------------

DURING 1ST VISIT:

---------------------- SURVEY WAS COMPLETED

---------------------- FARMER ASKED THE INTERVIEWER TO RETURN LATER

---------------------- FARMER WAS NOT AVAILABLE

---------------------- FARMER WAS UNWILLING TO PARTICIPATE

DURING 2ND VISIT:

---------------------- SURVEY WAS COMPLETED

---------------------- FARMER ASKED THE INTERVIEWER TO RETURN LATER

---------------------- FARMER WAS NOT AVAILABLE, THEREFORE, LOOK FOR REPLACEMENT.

---------------------- FARMER WAS UNWILLING TO PARTICIPATE, THEREFORE, LOOK FOR REPLACEMENT

NAME OF INTERVIEWER --

TIME INTERVIEW STARTED --

TIME INTERVIEW ENDED --

TOTAL TIME TAKEN FOR INTERVIEW --

GENERAL COMMENTS ABOUT THE INTERVIEW

Appendix 2

Definition and measurement of selected variables collected from Katete District during the 1991/92 study (Household quantitative characteristics)

ADLAB = The farm household's adult weekly labour input in hours during the 1990/91 cropping season. An adult is defined as a person older than 15 years and working full-time for the household.

AGE = Age of the male or female headed farm household in years.

AHMZE = Area of the land in hectares which is cultivated with hybrid maize by the male or female headed farm household (1990/91 season).

ALMZE = Area of the land in hectares which is cultivated with local maize by the male or female headed farm household (1990/91).

ANLAB = The male or female headed household's annual expenditure, in Kwacha, on hired animal labour.

CA = The number of cows owned by the male or female headed farming household.

CHLAB = The farm household's child weekly labour input in hours during the cropping season. Persons less than 15 years of age are regarded as children.

DEP = The male or female headed farm household's total number of dependents.

EDUC = The number of years of schooling undertaken by the male or female headed farm household.

EXPF = The male or female headed farm household's weekly expenditure (in Kwacha) on food.

EXPL = The male or female headed farm household's monthly expenditure (in Kwacha) on leisure (travels, drinks, etc.). Weekly expenditures were calculated first and then expressed on a monthly basis.

EXPMG = The male or female headed farm household's monthly expenditure (in Kwacha) on manufactured goods (salt, sugar, soap, and paraffin). Weekly expenditures were calculated first and then expressed on a monthly basis.

FERT = Amount of fertilizer (in kilograms) applied per hectare by the male or female headed farm household for hybrid maize production (1990/91).

FERP = The male or female headed household's annual expenditure, in Kwacha per hectare, on fertilizer (1990/91 season).

HLAB = The male or female headed household's annual expenditure, in Kwacha, on hired human labour (1990/91 season) .

IHMZE = The male or female headed farm household's gross annual income in Kwacha (1990/91 season).

GO = The number of goats owned by the male or female headed farm household.

INOFF = The male or female headed farm household's annual income, in Kwacha, from off-farm activities (1990/91 season).

IOTHCR = The male or female headed farm household's gross annual income in Kwacha (1990/91 season).

MIGR = The number of people who have left the male or female headed household's compound and are now living elsewhere.

OEXP = The male or female headed farm household's annual expenditures (in Kwacha) on other items (school fees, funeral, church contributions, etc.).

PG = The number of pigs owned by the male or female headed farm household.

PHMZE = The male or female headed farm household's production of hybrid maize (kg/ha) during the 1990/91 season.

PLMZE = The male or female headed farm household's production of local maize (kg/ha) during the year 1990/91 season.

WRKS = The number of full-time adult workers (male and female) available to the male or female headed farm household.

XC = The area of the land land (in ha) owned by the male or female headed household (1990/91 season).

XG = The area of the land under grass fallow (in ha) owned by the male or female headed farm household (1990/91 season).

XW = The area of the land under wooded fallow (ha) owned by the male or female headed farm household (1990/91 season).

YRFARM = The number of years the male or female headed farm household has been farming.

Note: The household qualitative characteristics were measured in terms of "how many households were or were not participating in an issue asked (i.e. count data)

Appendix 3

Input data for *Sesbania sesban* improved fallow: SCUAF simulation

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1. Cycle:
Carbon and Nitrogen

2. Documentation:
SCUAF's manual
File names and titles
Dates and notes

3. Climate:
Class 2, subhumid (Based on Young and Muraya 1990, ICRAF 1988)

4. Soil Texture: for most cultivated ox-hoe farms in Katete
"Clayey" (a mixture of sandy loam, sandy clay and gravely clay, based on Mhango 1991)

5. Drainage: for most cultivated farms in Katete
Free or well-drained (Based on Mhango 1991)

6. Soil Reaction: for most cultivated farms in Katete
Acid (pH 5.1-6.4; Young and Muraya 1990, Mhango 1991)

7. Slope: for most cultivated ox-hoe farms in Katete
Less than 5^0 (or less than 8%), based on Mhango (1991)

8. Agroforestry System: *Sesbania sesban* fallow-maize
1 year of fallow, followed by continuous maize cropping
2 years of fallow, followed by continuous maize cropping
3 years of fallow, followed by continuous maize cropping

1 year of fallow + 3 years of maize cropping rotation (R= 0.25)
2 years of fallow + 2 years of maize cropping rotation (R= 0.50)
2 years of fallow + 3 years of maize cropping rotation (R= 0.40)
3 years of fallow + 1 year of maize cropping rotation (R= 0.75)
3 years of fallow + 2 years of maize cropping rotation (R= 0.60)
3 years of fallow + 3 years of maize cropping rotation (R= 0.50)

Continuous maize cropping + fertilizer use (R= 0.00)
Continuous maize cropping + no fertilizer use (R= 0.00)

R = fallow: maize ratio
or R= maize: maize, i.e no ratio (R= 0.00)

For fallow systems (depending on the period):
Fraction of land under the tree (*Sesbania*) = 1.00 or 0.00

Fraction of land under maize = 0.00 or 1.00
N-fixing fraction for the tree is 1.00
Maize does not fix N, so a fraction of 0.00 is entered.

Other assumptions: At the end of each fallow period, *S. sesban* would be harvested and maize planted on the land.

9. Initial Soil Conditions:
Top soil depth (cm) = 20.00
Soil depth considered for C and N (cm) = 20.00
Total depth of soil (cm) = 119.00
Initial C, Top soil (%) = 0.78
Initial C, Sub soil (%) = 0.78
Bulk density, Top soil (g/cc) = 1.30
Bulk density, Sub soil (g/cc) = 1.50
Initial N, Topsoil (%)= 0.16

These were based on data provided by Mhango (1991). Only average values of the data from several similar locations in Katete were used as it was assumed here that these would reflect the general farming conditions in Katete and micro differences in soil conditions in Katete would even out (Mhango, per. comm.). Based on Young and Muraya (1990), initial C and N are computed as:

Soil depth considered x topsoil carbon (or nitrogen) x bulk density topsoil x 1000,

where the constant of 1000 represents 10^8 square centimetres per hectare, divided by 10^2 to convert percent C or N to a fraction and by 10^3 and to convert grammes to kilogrammes.

10. Erosion:
Climate factor = 0.5 x mean annual rainfall in Katete (Young and Muraya 1990 procedure)
= 0.5 x 1090.88 mm
= 545.44
Soil erodability factor = 0.10
Slope factor = 0.50
Cover factor under the tree = 0.01
Cover factor under maize 0.60
Tree proportionality factor = 1.00
Carbon enrichment factor = 2.00
Nitrogen enrichment factor = 2.00

The mean annual rainfall was calculated from the meterological data (1982-1992) provided by Katete District Meterological Office. Soil erodability factor was calculated following the nomograph procedure set out by Wischmeier et al. (1971).

Estimates of slope factor, cover factor, enrichment factors and the tree proportionality factor were obtained from the data presented in Young and Muraya (1990). Tree proportionality factor is a measure of the extent to which total soil erosion in the system is controlled by the tree component. Using this factor, SCUAF calculates erosion in year 1 under a given fallow system.

11. Initial Plant Growth:

NPP (kg DM /ha/yr) in parts of the tree, based on data from Kwesiga et al. (1991):

Leaf = 8480.00
Fruit = 530.00
Wood = 17490.00
Root = 10600.00

NPP in parts of maize, based on data from Young and Muraya (1990):

Leaf = 4000.00
Fruit = 2000.00
Wood = 0.00
Root = 2400.00

Roots as fraction of above ground NPP, the tree = 0.40
Roots as fraction of the above ground NPP, maize = 0.40

Carbon fraction of the tree retained annually as growth, based on data from Young and Muraya (1990):

Leaf = 0.00
Fruit = 0.00
Wood = 0.90
Root = 0.67

Carbon fraction of maize retained as growth annually, based on data from Young and Muraya (1990):

Leaf = 0.00
Fruit = 0.00
Wood = 0.00
Root = 0.00

Also, based on data from Young and Muraya (1990):

Fraction of coarse root in soil depth considered, the tree = 0.40
Fraction of coarse root in soil depth considered, maize= 0.00
Fraction of coarse roots of the tree below soil depth considered = 0.40
Fraction of coarse roots of maize growing below soil depth considered = 0.20
Carbon fraction in dry mass, the tree = 0.50
Carbon fraction in dry mass, maize = 0.50

Nitrogen percent in:

	Tree	Maize
Leaf	2.50	1.00
Fruit	2.50	2.50
Wood (stem)	0.50	0.50
Root	1.515	1.515

12. Additions (in simulating continuous maize cropping option):
Fertilizer (kg/ha/yr) = 200.00 (recommended by the Zambian Ministry of Agriculture)
Nitrogen fraction in fertilizer = 0.24 (based on data provided by the Department of Agriculture, Eastern Province (1991, p. 38).

13. Removals:
None other than harvest.

14. Carbon Cycle (conversion losses: litter to humus), based on estimates from Young and Muraya (1990):
Through oxidation = 0.75
Through roots = 0.60
Through organic additions = 0.60
Through decay of coarse roots of the tree (at least 1 year later) = 1.00
Through decay of coarse maize roots (at least 1 year later) = 0.00
Through decay of remaining coarse roots of the tree (2 years later) = 0.25
Through decay of remaining coarse roots of maize (2 years later) = 0.00

Humus Decomposition Constants:
K for the tree = 0.03
K for maize = 0.04

Nitrogen Cycle:

Gains:

Symbiotic fixation (kg/ha/yr) of N-fixing of the tree: values used are 245 (Macklin and Evans 1990); 334, 420, 448, 600 (Onim et al. 1990), and 100 (Young and Muraya 1990) to get the average estimate. Fractions (0.334, 0.420, 0.448, 0.600, 0.100) of these entering the soil humus are also estimated and simulated to get the average estimate.

Non-symbiotic fixation (kg/ha/yr) = 4.00
Fraction of non-symbiotic fixed N entering soil humus = 0.00
Atmospheric inputs: rain, dust (kg/ha/yr) = 6.00
Throughfall and stemflow (kg/ha/yr) = 5.00

Losses:

Fraction of mineral N of organic origin leached:

Under the tree = 0.0125
Under maize = 0.05
By denitrification and volatilization = 0.050
By fixation into clay mineral (net) = 0.00

Fraction of fertilizer N leached under maize = 0.025

Fraction of fertilizer N leached by:

Gaseous losses = 0.05
By fixation onto clay minerals = 0.00

15. Soil-plant feedback factors, based on estimates from Young and Muraya (1990):

Carbon:

The tree = 0.25
Maize = 0.50

Nitrogen:

The tree = 0.25
Maize = 0.50

Soil depth:

The tree = 0.50
Maize = 1.00

Only one-fraction humus fraction (labile carbon) was assumed. Labile carbon decomposes according to the decomposition constant. It is assumed that it acts as a buffer, thus reducing C loss. Furthermore, it is exclusively the labile humus that is of interest as far sustainability is concerned. It is the fraction that can be changed by landuse and management. It is also widely known that the greatest changes in soil C take place within the top soil. Therefore, it is appropriate to assume that most topsoil C is in labile form, while most of the C in lower horizons is in stable state (i.e. decomposes much more slowly), management significantly affects topsoil C, and therefore, in runs of SCUAF, C changes in topsoil only should be modelled (Young and Muraya 1990).

Appendix 4

Potential annual soil erosion (expressed in kg/ha) under selected treatments

YR	NO FERT	FERT	1SS+3M	2SS+2M	2SS+3M	3SS+1M	3SS+2M	3SS+3M
1	16527	16527	286	286	286	286	286	286
2	16700	16697	25629	263	263	263	263	263
3	17591	17499	26255	22795	22795	240	240	240
4	18412	18249	28275	22843	22843	19358	19358	19358
5	19284	19030	289	253	24691	219	20034	20034
6	20175	19823	24810	223	262	193	228	21421
7	21095	20632	28328	17409	229	169	198	236
8	22041	21458	29651	20034	18008	11837	174	203
9	23016	22302	295	220	21443	160	12261	179
10	24021	23163	23857	185	22159	130	14762	12726
11	25054	24042	30198	13259	239	109	171	15798
12	26118	24940	31029	16920	197	6536	139	16110
13	27213	25856	300	187	14450	103	118	187
14	28339	26792	23484	150	19354	76	7190	150
15	29496	27746	31831	9934	19574	58	9707	127
16	30684	28720	32470	13744	214	2731	117	7985
17	31207	29712	307	155	170	49	88	11249
18	31515	30724	23486	119	11641	29	69	11209
19	31817	31515	33383	7207	16959	14	3462	137
20	32111	31799	33986	10631	16978	1	5077	103

YR= year; FERT = fertilizer; SS= *Sesbania sesban*; M= maize; and 1, 2, 3 are SS fallow or maize cropping periods (expressed in years).