CASE STUDIES IN AGROFORESTRY DIAGNOSIS AND DESIGN NO.3

19

AGROFORESTRY SYSTEMS FOR THE SEMIARID AREAS OF MACHAKOS DISTRICT, KENYA

by

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with

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In Collaboration with

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MINISTRY OF AGRICULTURE

INTERNATIONAL COUNCIL FOR RESEARCH IN AGROFORESTRY

March 1983

Acknowledgements

In addition to those persons involved in the writing of this study, several others contributed to the effort behind the report. Participants in the diagnostic field survey included P. von Carlowitz of ICRAF, H. Scott, J. Kioko and J. Katiku of MIDP, and J. Asley, S. Odhiambo and G. Okwach of Katumani. Notable contributors to the design work following the diagnosis were P.A. Huxley and D. Rocheleau of ICRAF, J. Odera, C. Kirinya and D. Nyamai of KARI, and P. Kusewa of Katumani.

F O R E W O R D

As part of its programme of work ICRAF has established a Collaborative and Special Projects Programme (COSPRO) to strengthen the capability of national institutions to develop agroforestry systems. In order to cover a wide spectrum of agroecological and socioeconomic conditions, COSPRO is organized on the basis of geographical regions, on the assumption that regional land management systems share broadly similar cultural conditions. Within each of these regions, three or four major ecological zones are selected, to build a geographical/ecological framework in which potential research sites are to be located. Sub-Saharan Africa is one of such geographical regions.

This third case in the ICRAF Series on Case Studies in Agroforestry Diagnosis and Design is the result of such collaborative activities between scientists from ICRAF and the Kenya Agricultural Research Institute, the National Dryland Farming Station at Katumani, and the Machakos Integrated Development Programme. The joint exercise led to the formulation of a research project, which is now being implemented by the Kenyan Institutions with the technical back-stopping of ICRAF and the sponsorship of IDRC.

The aim of the research project is to develop improved systems of agroforestry land management which are appropriate to the mixed farming systems characteristic of Kenya's semiarid zone, with particular attention to the farming situation in Machakos district.

The case study is the result of an application of ICRAF's Diagnostic and Design methodology (D&D) by a multidisciplinary team of scientists from the participating institutions. The purpose of the initial 'rapid appraisal' D&D exercise was to diagnose existing and future land management constraints and agroforestry potentials, design appropriate agroforestry systems and formulate plans for research to develop the candidate agroforestry technologies through a combination of on-farm and field station research. As the project progresses, the iterative D&D process is repeated in modified form to take stock of project experience, refine the diagnosis and the design, and introduce appropriate modifications into the research plan in order to optimize the productivity, sustainability and adoptability of the experimental technologies.

In due course, prototype agroforestry technologies and land management systems arising from this process will be evaluated for extension and adaptive research throughout a wider recommendation domain in Kenya and in similar farming situations in other parts of the world.

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1. THE SEMIARID LANDS OF KENYA

Rapid population growth in Kenya (approx. 3.8-4.0 percent per annum), limited arable land and a shortage of employment opportunities in the industrial and service sectors have led to a substantial growth in the number of small-holders farming and ranching on Kenya's marginal lands. This trend is expected to continue into the twenty-first century. While increased settlement and exploitation of these lands provide a basis for the livelihood of small-scale farmers, the results are mixed. The soils, especially those on the steeper slopes, are subject to serious erosion. Much of the range land has been overgrazed and the ground cover in some areas is badly degraded. Also, rainfall in the semi-arid zone is low (600 to 800 mm on average) and subject to considerable variability. These factors, combined with traditional methods of farming and ranching, have led to a low standard of living for many of the rural populace in these areas. During times of rainfall deficiency the Government of Kenya has had to divert scarce Treasury funds to famine relief for those most seriously affected. Moreover, the resulting depletion of the natural resources (forestry included) does not augur well for future generations who are expected to live on these marginal lands.

A pre-investment inventory study of the marginal/semi-arid lands in Kenya was conducted during 1977 and 1978 by the Consortium of International Development, the U.S. Soil Conservation Service (U.S.D.A.) and staff of the Ministries of Agriculture, Water Development and Natural Resources. The principal theme running throughout this study is that major investments in soil conservation works, farm production technology and infrastructure are needed to reverse the rapid decline in the quality of life and the condition of the physical environment in the semiarid lands.

Several institutions are now geared to fulfil this goal. The Katumani Research Station in collaboration with a team of F.A.O. experts and KARI in collaboration with U.S.A.I.D. experts are presently engaged in researching appropriate agricultural systems for the semi-arid areas while the European Development Fund sponsors an integrated development programme in Machakos District (M.I.D.P.). So far, most research is focused on purely agricultural and/or livestock systems, although the potential role of trees, expecially in solving the imminent energy shortage, has been clearly recognised by each of these institutions.

It is in this context that the formulation of an agroforestry research project is an important and appropriate contribution to the overall development of the semi-arid lands. The research plan discussed in this case study report proposes the refinement of results of on station species and provenance studies so far accumulated at Kibwezi, Hola, Ramogi and elsewhere through application to the farming situation, at Kakuyuni, Machakos District, Kenya.

2. METHODOLOGY

The identification of appropriate agroforestry systems and research needs for the target area was based on an application of ICRAF's diagnosis and design methodology (D&D), which is described in greater detail in Lundgren and Raintree (1983) and ICRAF (1983a, 1983b). A summary of the methodological steps taken in the preparation of this case study is presented below.

The first step was to select a specific study area, followed by an analysis of existing baseline data and a 'windshield' reconnaissance survey of the area coupled with preliminary interviews with qualified informants (articulate farmers, local officials, researchers, etc.) in the area. The output of this step was a basic structural-functional understanding/description of the area and its predominant land use systems.

The next step was to conduct a brief farm classification survey to identify one or two farming system types on which subsequent research would focus and to choose a sample of representative farms.

Subsequent to the selection of the focal system(s), a diagnostic survey of representative farms was conducted, followed by a diagnostic analysis of problems, constraints and potentials for agroforestry interventions to improve the performance of the selected farming system(s).

This led to the formulation of design proposals for agroforestry systems and technologies and, subsequently, to the identification of research needed to generate and test the candidate technologies and systems.

3. BIOPHYSICAL AND SOCIOECONOMIC CHARACTERISTICS OF THE TARGET AREA

3.1 Location of the target area

The Kakuyuni catchment area is located in Machakos District on the Yatta Plateau. It falls within agroclimatic zone 5 (Sombroek *et al.*, 1982), which comprises about one million hectares (i.e. 69% of the district's land area), and supports 465,000 persons (1979 census), i.e. 43% of the district's population. Kakuyuni is considered to be representative of the more densely populated areas of zone 5, where farmers are more dependent on agriculture than grazing (see Figure 1).

3.2 Terrain and Soils

The catchment area is about 1,200 meters above sea level and the terrain is gently to moderately sloping.

Soils in the catchment area are described as well drained, shallow to deep dark red, friable clay in many places rocky (nito rhodic ferralsols and nito chromic cambisols, including lithic and bouldery phases). In some depressions a poorly drained, very dark greyish-brown to black, very firm, slightly calcereous, cracking clay can be found, in many places with a saline and sodic deeper subsoil (pellic vertisols, partly saline - sodic phase, with eutric or vertic gleysols) (Sombroek *et al.*, 1982).

The ferralsol-cambisol soil association, including lithic phases, suffers from low inherent fertility once the organic matter content is lowered, as it quickly is by arable cropping, and also has a low capacity to retain added nutrients (although this is still worth doing). Maintaining or raising the organic matter content is particularly important.

The dark vertisols found in poorly drained depressions are very difficult to cultivate because clays are heavy, sticky and stiff when wet and hard when dry. The poor drainage also causes problems for most crops other than rice.

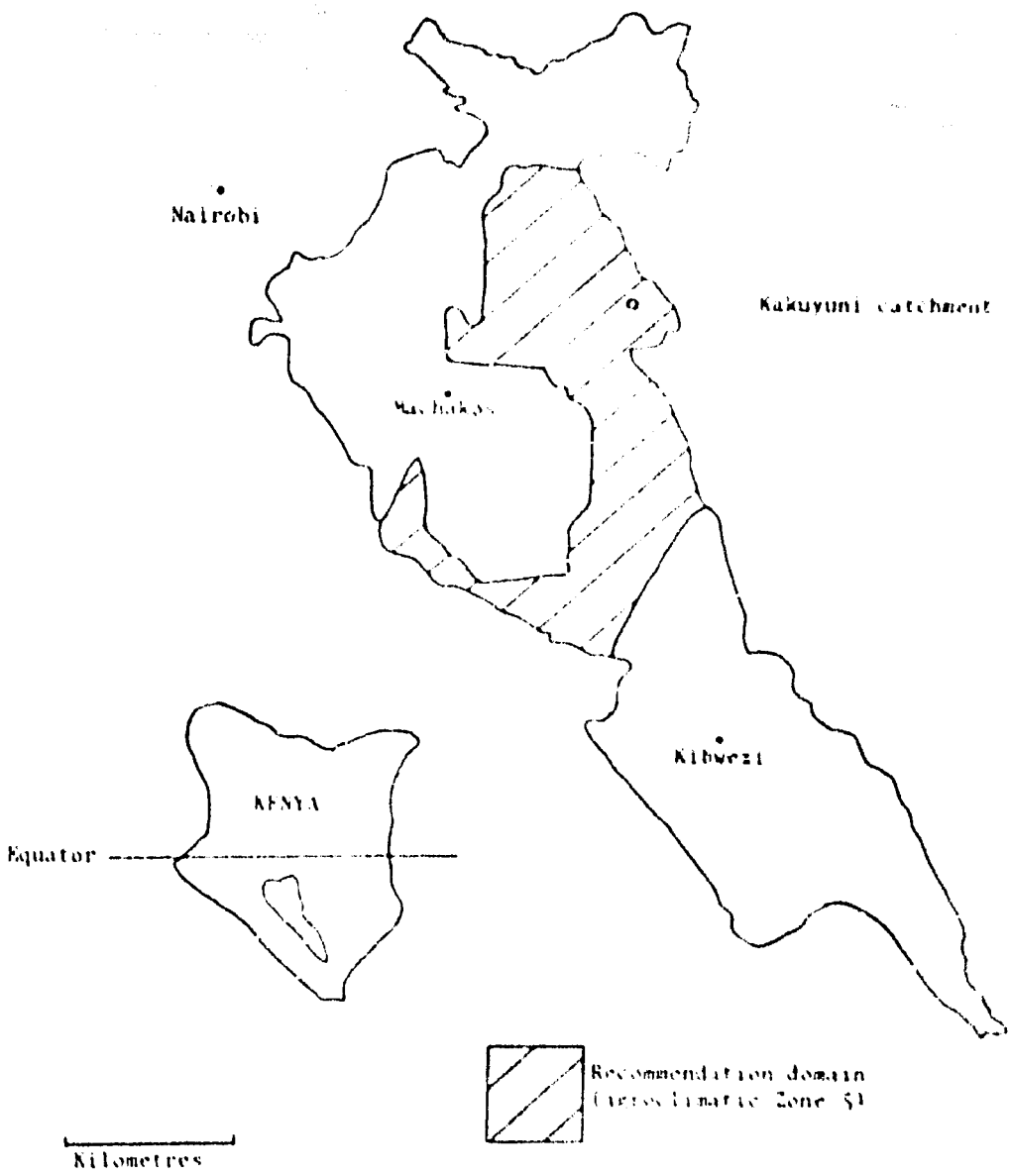

Figure 1. Location of the research site and recommendation domain in Machakos District, Kenya

3.3 Climate

The main climatic parameters for the target area, derived from climate maps and formulas published by Woodhead (1968) and the Kenya Meteorological Department, are presented in a climate diagram (Fig. 2).

It can be seen that optimal water requirements (E_T), on average, are only met in November, while the lower limit of normal plant water needs (0.4 Eo) is exceeded by precipitation in April, November and December only.

These already unfavourable climatic conditions are further aggravated by the variation in rainfall from one season and one year to the next (see Table 1).

Table 1. Seasonal rainfall probability for the project site (Jätzold, 1979).

	Percent probability of receiving more than:				
	100 mm	150 mm	200 mm	250 mm	300 mm
March-May (Mean 195 mm)	75%	54%	38%	23%	15%
October-November (Mean 305 mm)	96%	90%	74%	58%	39%

The projected onset and cessation of the rains in the project area are as follows:

	Onset	Cessation	Duration
"Long rains"	12-16 March	1-5 May	50 days
"Short rains"	18-22 October	22-26 December	60 days

This shows that the names "long rains" and "short rains" are somewhat misleading in the survey area, as the rainy period October-December is longer than the season March-May. Furthermore the rainfall quantity is higher and the probability of receiving a certain amount tends to be greater; therefore one can conclude that the rainy season October-December poses less risk to cropping activities.

3.4 Woody vegetation

The dominant tree/shrub vegetation in the area is comprised mainly of *Combretum molle*, *Acacia abyssinica*, *Balanites aegyptiaca* and *Terminalia brownii*. While these species are mainly found on the red clay soils, *Acacia drepanolobium* is common on the black clay soils.

3.5 Service infrastructure

Marketing of agricultural produce, mainly maize and beans, takes place through middlemen (shopkeepers), who in turn sell to the National Cereal and Produce Board as well to private traders from elsewhere. There is one market day each week in nearby Kitangi market. Although there is some form of price control, the farm gate price received by the farmer is often lower. The Kenya Farmers' Association sells agricultural inputs, such as seeds, chemicals, artificial fertilizers and livestock feed in its store in Machakos town (40 km). Very little is available locally, although the Machakos Integrated Development Programme is making an effort to improve this situation.

Figure 2. Climate diagram for the Kakuyuni area.

The government provides agriculture and livestock extension service, mostly at the location level, where a farmer may go to seek advice. Credit for small subsistence farmers is hardly available.

3.6 Population and land use

The majority of the population in Machakos District are Akamba people who have gradually shifted their emphasis from cattle grazing to arable cropping over the past fifty years.

Because of the rather unfavourable climatic conditions in zone 5, people moved into these areas only fairly recently mainly because of a population increase in the higher potential zones. The Kakuyuni catchment area is no exception to this pattern since farmers started settling in only as late as the 1950's. Until now no land has been officially adjudicated to invididual farmers in the area, although adjudication has been completed in some other parts of Machakos District.

Population density in Kinyatta Location, of which the Kakuyuni catchment area is a part, is 65 persons/km^2 (1979 census). This confirms the fact that the catchment is representative of the more densily populated areas of agroclimatic zone 5, where the overall population density is 47/km^2.

According to a recent aerial survey (Ecosystems Ltd., 1981), land use in Kinyatta location is as follows: 9,975 hectares are classified as cropland, 965 hectares as fallow, 5,065 hectares as infrastructural overhead, while the remaining 29,604 hectares can be used for grazing. Most of the area which is suitable for grazing is unimproved bushland in which the farmers invest very little labour. The fact that so much of the area is still in this condition does suggest that, given the present method of agriculture, labour is a constraining factor.

The livestock population, according to the same source, was estimated at 12,326 heads of cattle and 8,207 shoats. Based on herd composition data from the area, a stocking rate of about 0.4 A.U. $hectare^{-1}$ of grazing land was computed. This appears to be well above the stocking rates recommended by Rossiter and Ndegwa (1974), i.e. 0.16 A.U.

The main crops grown by the farmers are maize, cowpeas, beans and pigeon peas. The most common trees/shrubs and their uses are shown in Table 2.

Table 2. Most common indigenous trees and shrubs and their uses as observed in the Kakuyuni catchment area.

Name			Uses						
Botanical	Family	Location	Fuelwood	Building Material	Craft Wood	Fodder	Food	Fencing	Medicinal and other purposes
Acacia albida	Mimosaceae	G	X	X	X	X		X	
Acacia drepanolobium	Mimosaceae	A	X					X	
Acacia tortilis	Mimosaceae	G	X	X		X			
Balanites aegyptiaca	Balanitaceae	G,AB	X	X	X	X	Fruits	X	
Cassia singueana	Caesalpiniaceae	G & A	X						Stomach ache, horse also used for human rigening
Combretum molle	Combretaceae	B	X	X	X	X			
Commiphora africana	Burseraceae	G & A						X	Prevention of infection on open wounds
Croton megalocarpus	Euphorbiaceae	G & A	X	X					
Grewia tenax	Tiliaceae	G	X	X		X	X		
Harrisonia abyssinica	Simaroubaceae	G	X			X			Stomach ache and diarrhoea
Hymenodictyon parvifolium	Rubiaceae	G	X						
Ipomoea spathulata	Convolulaceae	G							
Kigelia aethiopica	Bignoniaceae	G & A					Brew		
Lannea schweinfurthii	Anacardiaceae	G	X	X					
Maytenus putterlickioides	Celastraceae	B	X			X		X	Rheumatism
Oncocarpus birkii	Papilionaceae	G & A	X			X			Drunks
Pappea capensis	Sapindaceae	B	X	X		X			Treatment of bruises
Rhus ivariensis	Anacardiaceae	G & A	X	X		X	X	X	Stomach ache & black measles
Securinega virosa	Euphorbiaceae	G	X			X			Tuberculosis
Terminalia brownii	Combretaceae	G & A	X	X	X	X			
Thespesia danis	Malvaceae	B	X	X			X		

G Grazing area
A Arable land
B Black Cotton soil

3.7 Distribution of farm resources

The distribution of the farm size in the Kakuyuni catchment area varied from 3 to 17 hectares, as shown in the following histogram.

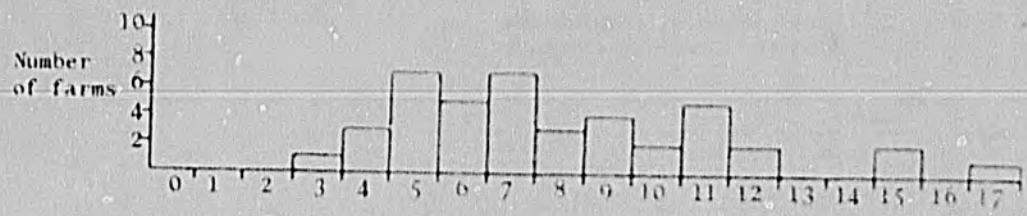

Figure 3. Farm size distribution in Kakuyuni catchment (hectares)

All farms were of a mixed enterprise composition, i.e. crops as well as livestock (cattle and shoats). The distribution of the livestock population over the farms is presented in the following histogram.

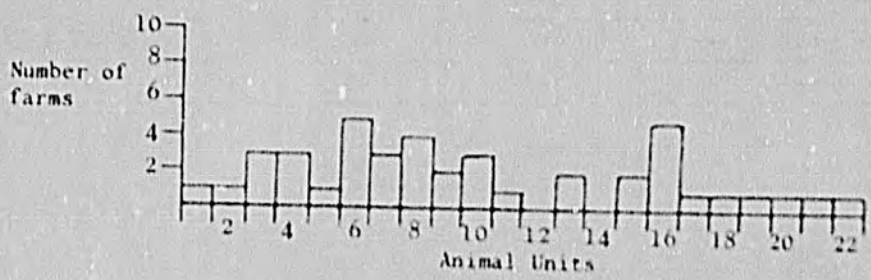

Figure 4. Livestock distribution on farms in Kakuyuni catchment.

A regression analysis of the farm size data indicate that the crop acreage increases with farm size. According to a survey in nearby Mwala Location, Machakos District, this is caused by the fact that most farmers want to reserve part of their land for grazing (Rukandema, 1981).

$Y = 0.15 + 53x$ ($r = 0.91$, $n = 43$) in which y = acreage of cropland (in hectares), x = farm size (in hectares), r = correlation coefficient, n = number of observations.

It is doubtful, however, that this straight line would continue once the crop acreage has reached a certain size, since it is exptected that labour and/or draught animal power would become constraining factors.

Although on average the larger farms were found to keep slightly more livestock units than the smaller farms, no clear relation could be found between farm grazing area and number of livestock units. This may be explained by the fact that most smaller farms rent additional grazing land during the latter part of the main dry season (August-October).

The grazing area of the farm is not only a source of food for the animals, but it is also the farmer's main source of fuelwood, poles and timber.

Most farmers rely entirely on family labour to produce their crops and to tend their livestock. The average farm family consists of two adults and a varying number of children who assist on a part-time basis.

The farm's capital resources are limited to land, livestock, buildings and ox-plough(s).

4. DIAGNOSIS OF FARMING SYSTEMS

4.1 Present resource utilization patterns and problems

4.1.1 Cropping activities

The cropland is cultivated on a permanent basis and is usually planted twice a year, following the bimodal rainfall pattern, with a mixture of maize, beans, cowpeas and pigeon peas.

Land preparation takes place at the onset of the rains and most farmers use oxen. Farmyard manure is applied to part of the cropland, usually prior to the start of the short rains (October-November). Due to lack of appropriate means of transport, most of the manure is applied on the cropland nearest the cattle coral (boma). The soil nutrient status and organic matter content of the remaining cropland is, therefore, rather low.

The most common planting practice involves a simultaneous ploughing/planting operation. One person follows behind the plough and puts the seeds in the furrow and each plough line covers the seeds of the previous furrow with soil. Intercropping, in-row as well as in alternating rows, is the rule.

Owing to the rather short duration of the rainy seasons, planting time is critical and ploughing has to be completed as early as possible. The larger farmers, who like to cultivate as much area as possible to raise cash, are usually faced with a labour and draught animal constraint. A few may be able to hire some additional labour, but most rely on family labour. Moreover, at field preparation/planting time, when fodder resources for the animals are at their lowest, work performance of the oxen is rather poor. The smaller farmers have similar problems with their oxen and some also seem to have labour problems because they hire themselves out to larger farmers to earn some extra cash for household expenses.

The labour constraint is further compounded by the fact that the first weeding has to take place one to two weeks after planting. In practice, planting and weeding often take place simulteneously.

Rukandema (1981), calculated monthly labour requirements for an average farm in Mwala, i.e. 7.47 hectares with 1.95 hectares cropped twice a year. The following labour profile is based on these data (Fig. 5).

Because of the labour constraints at planting time, weeding is often not done properly, resulting in moisture stress for the agricultural crops as well as an increase in the weed population. The latter is particularly evident on the larger farms, where couch grass (*Digitaria scalarium*) has infested parts of the cropland. Eventually farmers abandon such areas and open new cropland within the grazing land to compensate for the lost land. However, the couch grass is not suppresed during grazing and the land is therefore permanently lost for cropping if no measures are taken to remove it.

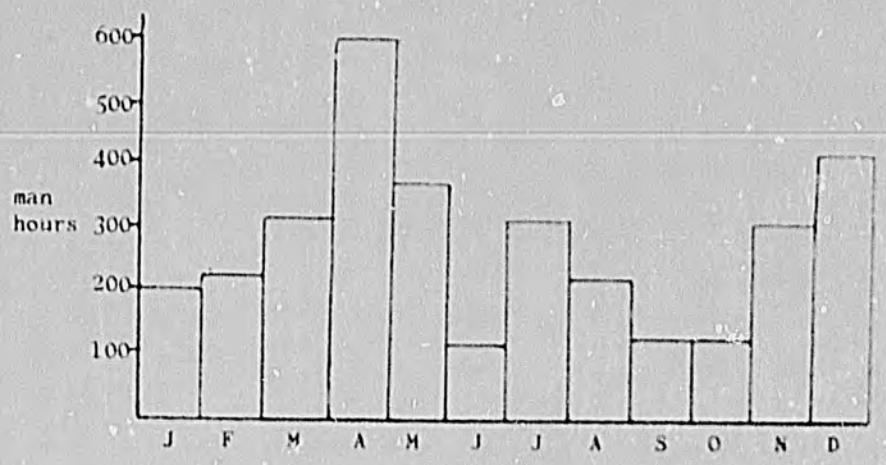

Figure 5. Labour profile of cropping activities on a typical farm in Mwala Location, Machakos District. Source: Rukandema (1981).

In spite of the widespread concern over insect and other pest problems, the overwhelming majority of farmers do not take any measures to protect their crops. Insect damage is therefore quite high for maize, pigeon peas and cowpeas. Some of the early sown maize is often eaten by squirrels.

Harvesting is a labour-intensive hand operation for all crops. Transport of produce from field to home is normally done by head/shoulder loads and sometimes with ox-cart or wheel-barrow. After harvest, most farmers allow their livestock to browse crop residues in the field, especially pigeon pea leaves. Some crop residues, mostly maize stover, are collected and used as supplementary feed in the boma, especially at the end of the dry season when the quality of the grazing is almost nil. The removal of such crop residues is considered beneficial from a field sanitation point of view; it also leads to a further reduction in the organic matter content of the soil. Wind erosion occurs during the months of August, September and October, when most fields are harvested and bare, at the same time strong winds are common.

Crop produce is stored in simple storage structures, ranging in quality from grass-thatched to more sophisticated tin roofed structures. After drying, maize is usually stored on the cob while the other crops are mostly threshed after drying and then put into gourds. Ashes are used frquently to combat insect problems during the storage period.

Due to limited land resources and some of the outlined production constraints, the smaller farmers are usually unable to provide sufficient food for the family.

All small farmers interviewed reported food shortages during the period September to February because of insufficient cropland acreages combined with usually poor harvests from the long rains crop (March, April). On average KShs. 400-500 month^{-1} was reportedly spent to purchase additional food for the family during that period (see food profile, Figure 6.).

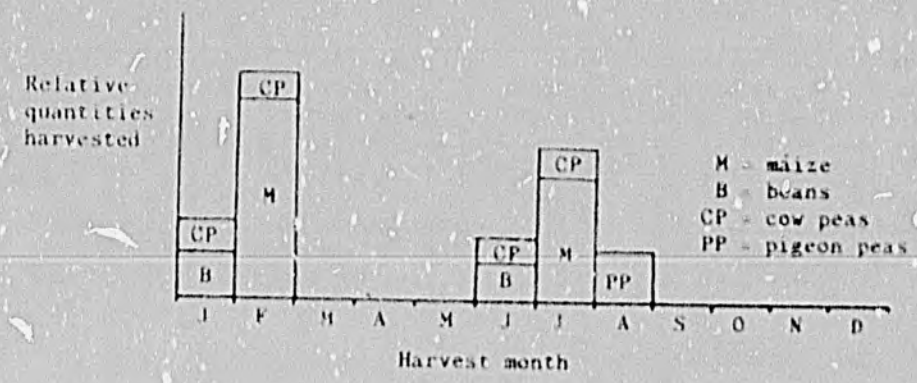

Figure 6. Food production profile, Kakuyuni

The larger farms are by and large self-sufficient in their food requirements and sell part of the surplus produce to raise cash. Food shortages do occur, however, in years with poor rainfall.

4.1.2. Grazing land/livestock activities

Cattle are of small East African Zebu type which are used to provide draught power (bullocks only) and milk and are sold to meet big cash expenses. Sheep and goats are mainly kept for sale and home consumption, some farmers also consume goat milk.

Due to the poor vegetation cover in the grazing land and over-stocking on most farms, there usually is a feed shortage towards the end of the dry season. Some farmers, usually the smaller ones, rent additional grazing land at KShs. 500-700 for a period of 2 to 3 months. These expenses are met by selling animals. Because of overstocking, significant portions of the grazing area are badly eroded.

Over the past years, smaller farmers have seen a decline in their grazing land area because it was given over to food production, most likely because of an increased demand for food by growing families and little scope for off-farm employment.

The labour requirements for herding the cattle are quite high since cattle have to be prevented from entering the crop areas (inadequate or no fencing). During the dry season, drinking water for livestock becomes very scarce in the area and farmers have to herd their animals to the Athi River (approximately 7 km) every other day.

Tick-borne diseases, like East Coast Fever, anaplasmosis, heart water and Nairobi sheep disease, as well as pneumonia coccidoisis and anthrax, were reported for the Yatta Plateau (Neunhäuser *et al.*, 1983).

While labour is used for crop and livestock activities, it is also used to collect fuelwood, to keep bees, to engage in wood carving, to make charcoal, or to engage in off-farm employment. Most firewood is obtained from the grazing land but the annual increment from the existing vegetation is very low i.e. 1-2 m^3 hectare $^{-1}$ (KRSMU 1981). Since part

of this annual increment is used for fencing purposes, the actual fuelwood off-take may even be lower.

Consumption of fuelwood is estimated at between 1 to 2 m^3 $capita^{-1}$ and although it is doubtful that consumption is a linear function of the family size, it is not difficult to see that most farms can only meet their requirements by consuming the standing volume and/or "borrowing" from friends and neighbours. The small farmers in particular, spend a considerable amount of time (labour) collecting fuelwood from neighbouring places. This shortage of fuelwood on the small farms may be further compounded because of the anticipated expansion of the crop areas. This may lead, in turn, to an increasing amount of labour being spent on this activity if no appropriate measures are taken.

4.1.3 Cash constraints

Because of the uneven inflow of cash, farmers usually experience serious cash shortages during the growing periods of the crops. At the same time the total amount of cash is usually insufficient to meet the farmer's basic needs, let alone improve his production resources (for example fencing).

While relatively little cash is spent on the purchase of agricultural inputs (aside from the rental of additional grazing land by the smaller farms), considerable amounts of cash are spent on additional food (especially on the smaller farms), clothing, children's school fees and maintenance and/or improvement of buildings. In this respect, it is worth mentioning that dwellings are often damaged by strong winds during August-September.

Owing to the rapidly dwindling tree resources on the farms in the area, farmers who engage in charcoal making or wood carving have to purchase trees, thus increasing the cash outflow.

4.1.4 Summary of present problems and constraints

The relationship between the identified problems in both the smaller and the larger farms are presented in causal diagrams (Figs. 7 and 8).

Both farming systems suffer from a very low level of productivity in crop as well as the livestock activities. The causes for these low production levels are basically the same for both farm types except, perhaps, that the shortage of labour contributes more to the low level of productivity on the larger farms than on the smaller farms, while the lack of land resources at the present moment is only affecting the production of the smaller farms.

4.2 Future farming systems and sustainability problems

The present conversion of grazing areas into cropland on the smaller farm is expected to erode even further the production base for livestock, firewood, timber and poles. Because of the apparent preference for crop activities, it is very likely that the grazing areas on the small farm will gradually disappear, forcing the farmers to abandon livestock altogether or reduce their number and adopt a new feeding strategy (cut and carry), since herding tends to become too labour-intensive per livestock unit when the herd size decreases.

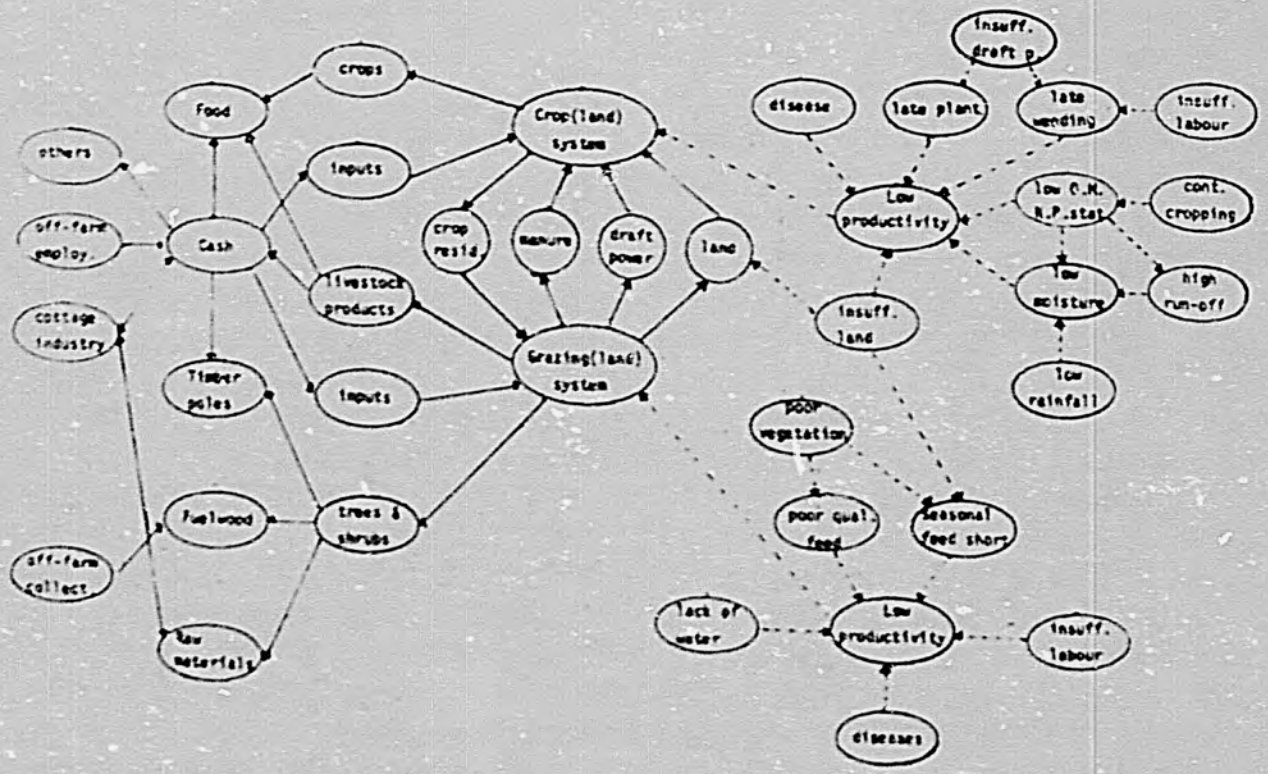

Figure 7. Combined input-output and causal factors diagram (small farms). Unbroken lines (———) indicate the flow of inputs and outputs within the farming system. Broken lines (- - -) indicate the chain of causal influences responsible for diagnosed problems.

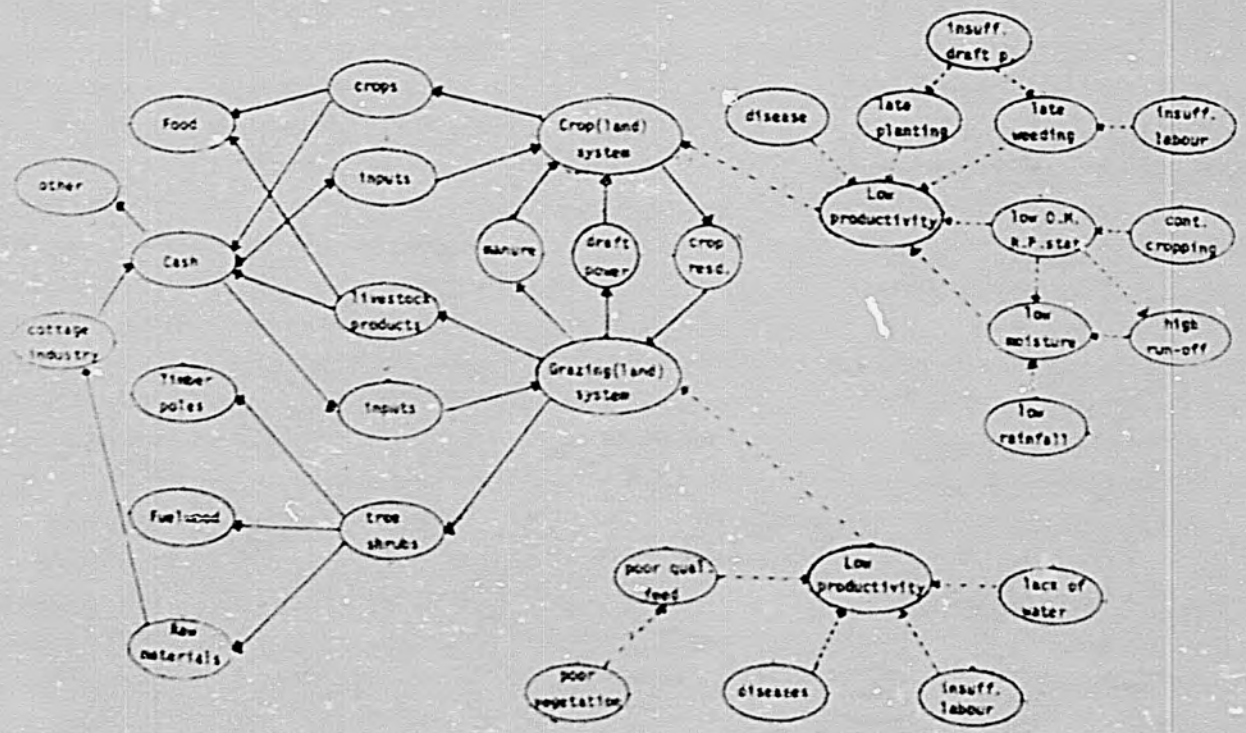

Figure 8. Combined input-output and causal factors diagram (large farms). Unbroken lines (———) indicate the flow of inputs and outputs within the farming system. Broken lines (- - -) indicate the chain of causal influences responsible for diagnosed problems.

Such a reduction in livestock numbers may have various effects on the farming systems as can be seen in the causal diagram.

Effects on the crop production system:

loss of manure
loss of draught power

Effects on the food system:

loss of part of the food supply (livestock products)

Effects on the cash system:

loss of part of the cash income and/or loss of saving function

The scope for conversion of grazing land into crop land seems to be limited on the large farms due to a lack of labour and draught animal power. It seems, therefore, realistic to assume that the large farms in the medium term will still have grazing areas as well as be engaged in livestock activities.

These trends as well as the other identified factors affecting the sustainability and productivity of the production systems will have to be addressed when designing appropriate agroforestry research.

5. APPROPRIATE TECHNOLOGIES

5.1 Design specifications

The following set of specifications for design of appropriate technological interventions are derived from the diagnosis of farming system problems and potentials. The specifications are expressed in terms of *functional specifications* (i.e. the general type of improvement and the specific constraints to be addressed by the intervention) and relevant *farm resource restrictions* (i.e. the limits within which the design must be conceived in order to fit the system).

5.1.1 Functional design specifications

Improve productivity of the crop production system

i) Maintain or improve soil organic matter
ii) Improve soil nutrient status
iii) Reduce erosion and water run off
iv) Remove labour bottlenecks at field preparation and weeding time
v) Improve pest and disease management

Improve productivity of the livestock production system

i) Improve quantity and quality of fodder
ii) Improve seasonal distribution of fodder
iii) Improve drinking water availability
iv) Reduce labour requirements of feeding
v) Improve veterinary service

Improve cash balance of the farm

i) Decrease (future) cash outflow
- reduce need to buy food
- reduce need to buy building materials
- reduce need to buy raw materials for on-farm cottage industries
- reduce need to buy agricultural inputs

ii) Increase cash inflow
- improve productivity of crop and livestock production
- improve raw materials supply for on-farm cottage industries

iii) Improve seasonal distribution of cash

5.1.2 Farm resource restrictions

Large farms

i) Ample land resources
ii) Insufficient labour resources
iii) Low level of capital

Small farms

i) Insufficient land resources
- no grazing areas on some farms

ii) Insufficient labour resources
- part time engaged in off-farm activities

iii) Low level of capital

- no draught animal power on some farms

5.2 Non-agroforestry alternatives

Improving the service infrastructure as well as creating off-farm employment opportunities were not explicitly mentioned in the design specifications but there should not be any doubt that these areas need attention in order to raise the general standard of living of the farmers.

Some of the previously mentioned design specifications are also difficult to achieve by means of agroforestry, e.g. improve crop pest and disease management, reduce storage losses, improve drinking water availability for livestock, improve veterinary services.

The Kenyan institutions responsible for project implementation are, in fact, already pursuing some of these objectives with non-agroforestry technologies, e.g. improve storage facility structures, construct dams to collect and store water, etc.

All the other design specifications may be accomplished with agroforestry as well as non-agroforestry technology. In some cases these may be mutually exclusive while others may complement each other.

It is difficult, however, to say at this stage whether the agroforestry alternatives are superior to the non-agroforestry alternatives. The results of the non-agroforestry experiments/developments at present being conducted by the implementing institutions should therefore be carefully compared with the results of the agroforestry experiments. Some of the non-agroforestry experiments/demonstrations are: use of artificial fertilizers and crop rotation to improve/restore soil fertility, soil conservation works, etc.

5.3 Agroforestry Technologies

5.3.1 Hedgerows with or without an upper storey of fuelwood or fruit trees in the cropland ('alley cropping')

The main purpose of the hedgerows would be to improve the productivity of the crop production system which, in turn, would reduce the cash outflow

from the smaller farms while the cash inflow of the larger farmers would be increased.

Lopping the hedges, 15 cm above ground, would take place twice a year, two to three weeks before land preparation and planting. The branches would be spread in the alleys in between the hedges and the woody components would be removed just before ploughing and to be used as fuelwood (in a similar way as the traditional pigeon pea stems). The remaining, already decomposing, leaves and small twigs would be ploughed into the soil.

Such a system aims at improving the soil nutrient status, maintaining soil organic matter, controlling erosion (by reduced runoff) and making better use of land, labour and draft animal resources.

An *ex ante* economic analysis of such a land use system was conducted (Hoekstra, 1983) on the following assumptions:

i) between-row spacing is 2 meters
ii) row width 1 meter
iii) production starts after about 18 months (after transplanting)
iv) total dry matter production m^{-1} $year^{-1}$ is 0.9 kg.
v) 60% of the dry matter is leafy mulch and 40% woody stems
vi) organic N in the leafy material in 3.75 percent
vii) a mixture of maize and beans is grown in the alleys (traditional cropping pattern)
viii) 1 kg of organic N results in 13.5 kg of additional maize, while the bean production remains the same (yield per unit area doubles)

The analysis indicated that the addition of nutrients to the maize and beans in the alley as well as the fuelwood output would result in a better use of the land, labour and draught animal resources as compared to the traditional maize bean mixture:

	Hedgerows	Traditional
N.P.V.* $hectare^{-1}$ $year^{-1}$	1,286	631
N.P.V.* $man\text{-}day^{-1}$	15.2	8.6
N.P.V.* draught power $unit^{-1}$	1,459	435

* at 12%

The potential addition of organic matter by the leafy mulch and the roots of both the maize/beans mixture and the hedgerow is estimated at 1,630 kg $hectare^{-1}$ $year^{-1}$, which is computed as follows:

above ground biomass production of 2 crops of maize and beans occupying 0.5 hectare is about 6,400 kg $year^{-1}$ (harvest index 0.4), while the above ground biomass of the remaining 0.5 hectare of hedgerows is 4,500 kg $year^{-1}$. The percentage of roots is estimated at 25% of the above ground biomass production while the conversion factor of root dry matter to organic matter is estimated at 0.4, i.e. added organic matter 1,090 kg $hectare^{-1}$ $year^{-1}$. The annual quantity of leafy mulch added to the soil is 2,700 kg and the conversion factor of leafy mulch to dry matter to organic matter is estimated at 0.2, i.e. added organic matter 540 kg $hectare^{-1}$ $year^{-1}$.

The loss in organic matter due to cropping depends on the organic matter content of the soil. Assuming a 1% soil organic matter content (common for soils in semi-arid regions under natural conditions) the loss is estimated at 1,500 kg hectare^{-1} year^{-1}, while, if the soil organic matter content has already when lowered, because of cultivation, to about 0.5%, the loss would be 750 kg hectare^{-1} year^{-1}.

The computation of the annual loss is based on the following assumptions: top soil depth 0.2 m, specify gravity soil 1,500 kg/m^3 and a coefficient of decomposition under cultivation (k_c) of 0.05.

It may, therefore, be concluded that the hedgerow system will prevent a future decline in the organic matter status of the soil; however, it is unlikely that it would be able to raise it significantly in the short run.

The following tree/shrub species were identified for the hedgerows:

Leucaena leucocephala, Combretum sp., Erythrina sp., Cassia siamea

The addition of a top storey of fuelwood trees is meant to decrease present and future labour requirements to collect fuelwood or to prevent a future cash outflow. The trees would be coppiced on a regular basis. The following tree species were identified for this purpose:

Azadirachta indica, Jacaranda mimosifolia, Cassia siamea

The addition of a top storey of fruit trees aims at increasing the farm's cash inflow as well as to improve the seasonal distribution of cash.

The following tree species were identified for this purpose:

Carica papaya (pawpaw), Zizyphus mauritiana (Bertree)

5.3.2 Rehabilitation of useful tree species in the grazing land

The purpose of managing existing woody vegetation in the grazing land is to improve the quantity and quality of fodder and woodfuel (firewood and charcoal) produced on this part of the farm. Useful trees are present in most grazing areas but their productivity is limited by browsing pressure on the smaller trees and poor infiltration of rain water.

Improved management practices would include:

i) construction of individual microcatchments for each tree to be treated

ii) protection of small trees against browsing by livestock by appropriate fencing practices (e.g. cut thorn bushes around trees)

iii) thinning and/or prunning of tree shoots and branches and propping up to encourage vertical growth beyond browsing height (for eventual management by lopping or, in the case of pod-producing trees, simply letting the pods drop to the ground)

The local tree species identified for this treatment are:

Acacia tortilis, Balanites aegyptiaca, Commiphora africana, and *Terminalia brownii*

5.3.3 Fodder/browse trees in the grazing land

The purpose of these trees would be to improve the quantity, quality and the seasonal distribution of fodder on the farm. This, in turn, will increase the farmer's cash income.

This system is more appropriate for the larger than for the smaller farms, since the latter may only have very small grazing areas left (see 5.3.4 for small farm design).

Establishment of the trees will be a major problem because of the existing free grazing system. Trees will therefore require protection in the initial years. Making use of the existing thorny bush vegetation may be considered, i.e. heaping dead thorn bushes around the seedlings, or planting the seedlings within the area covered by thornbush.

Fod-producing trees with a fairly light canopy to allow grass or shrub growth underneath should be given priority.

The following species were identified:

Prosopis pallida, Acacia albida, Zizyphus sp., Balanites aegyptiaca

5.3.4 Cut and carry fodder systems in the grazing land or farm boundaries with or without an upper storey of fuelwood, timber, poles and/or craftwood trees

The purpose of such system is also to improve quantity and quality as well as seasonal distribution of fodder, especially on the smaller farms. Such a system will also contribute to lowering the labour inputs required per A.U. as compared to the existing practice of herding a small number of animals.

Tree species identified for this purpose are:

Prosopis pallida, Leucaena leucocephala, Acacia saligna, Stylosanthes scabra

The addition of an upper storey of fuelwood trees serves a similar purpose as in the hedgerow system explained earlier (see 5.3.1).

The addition of an upper storey of timber/pole trees and/or craftwood trees aims at reducing (future) cash expenditures for building materials and on-farm cottage industries.

The following species were identified for these purposes:

Craftwood: *Brachylaena hutchinsii, Dalbergia melanoxylon*
Timber/poles: *Terminalea brownii, Casuarina equisetifolia, Agave(sisal)*

5.3.5 Living fences around the grazing land with or without an upper storey of fuelwood trees

The purpose of this fence is to reduce the labour input requirements of the free grazing system on the larger farms as well as to reduce the need for cash expenditures on fencing materials.

Two species were identified for this purpose:

Parkinsonia aculeata, Commiphora africana

The addition of an upper storey of fuelwood trees serves a similar purpose as in the hedgerow systems (see 5.3.1).

5.3.6 Windbreak around the home compound

The purpose of this system is, in the first instance, to protect the buildings inside the home compound from damage by wind and so reduce the need for cash expenditure. The use of fruit trees for this purpose would help to increase the farm's cash inflow as well as the seasonal distribution of the inflow.

Mangifera indica is proposed for this purpose.

A hedgerow with some of the previously identified species may be added as an understorey.

5.3.7 Fruit trees in the home compound

These trees would provide the necessary shade and improve the cash inflow as well as its seasonal distribution.

Mangifera indica is proposed for this purpose.

6. RESEARCH PROGRAMME

6.1 On-farm versus on-station research

Five factors were considered to determine whether research on these candidate technologies should be carried out on farm and/or on station.

Readiness of proposed technology:

The principles of living fences and boundary planting are more or less known in the area, however tree planting in the grazing land to provide animal fodder, the hedgerow system in the cropland and the windbreak around the homestead are relatively unknown to the farmers, although some are known in other parts of Kenya. The proposed tree species and management practices are not well known nor tested in the area, perhaps with the exception of the mango trees proposed for the windbreak and the home compound.

Farmers/extension officers attitude towards on farm trials:

M.I.D.P. in its program in the Kakuyuni catchment started introducing some trees. Farmers appear to be very keen to plant trees, often even without knowing their useful purposes, with the possible exception of tree planting in the cropland itself.

Riskiness of the proposed technology:

The positive effects as well as the feasibility of establishing a hedgerow system in the cropland are still relatively uncertain, while at the same time the introduction of these hedgerows may result in a reduction of the arable land and therefore in the production of basic food crops. The risks imposed by the other candidate technologies are considerably lower since the opportunity cost of the land used (production forgone) is low. Care should be taken, however, with regard to the introduction of trees in the grazing areas which may have the potential of becoming a weed (*Prosopis*, *Leucaena?*).

Need for the candidate agroforestry technology to be exposed to different environmental conditions:

Because the recommendation domain for the proposed candidate agroforestry technologies is limited to part of agroclimatic zone 5, some of the differences in rainfall conditions have been eliminated, reducing the need to test the technologies at many different sites. However soil conditions in this zone differ considerably, requiring the testing of the technologies

on different sites. The soil types found in the project area offer this opportunity.

Need for the candidate technology to be exposed to real farming systems conditions:

Due to the absence of free grazing conditions on the Research Station, establishment trials (especially protective measures) in the grazing area and living fence trials have to be conducted on farm. Similarly, windbreak trials have to suit the specific farm conditions and are therefore best conducted on farm. Furthermore, farmer evaluation of all the technologies is essential.

A summary of the weighing of these 5 factors for the candidate agroforestry technologies in the study area is presented below.

Table 3. Weighting of on farm/on station research factors

Technology	Readiness	Attitude	Riskiness	Need for env. Exposure	Need for farm sys exp.
3.1	L	L	H	M	H
3.2	L-M	H	M	M	H
3.3	L-M	H	L	M	H
3.4	M	H	L	M	H
3.5	M	H	L	L-M	H
3.6	M	H	L	L-M	M

L = Low M = Medium H = High

Based on a simultaneous weighing of these factors it is recommended to conduct simultaneous on farm/on station research for the following technologies 5.3.3. - 5.3.5 sequential on station/on farm research for 5.3.1 and on farm research only for 5.3.2, 5.3.6 and 5.3.7 (see also section 6.2)

6.2 Research required on candidate agroforestry technologies

6.2.1 Hedgerows in the cropland

Purpose: see 5.3.1

Variable factors

a) species
b) establishment methods
c) spacing in and between rows
d) cutting height and frequency
e) rate of application of mulch
f) time of application

Parameters to be monitored

a) labour inputs for establishment, maintenance and harvesting
b) survival rates and growth
c) yield of mulch
d) resistance to termites
e) rate of decomposition
f) nutrient content of mulch
g) soil nutrient status and moisture balance
h) erosion
i) weed development (including labour requirements)
k) crop yields

The addition of an upper storey will add the following variable factors:

a) species
b) in-row spacing
c) harvesting frequency and method

As a result, the following additional parameters have to be measured:

a) labour inputs, establishment, maintenance and harvesting
b) yield (including fruiting season for fruit trees)
c) yield adjacent crops

Type of research

On-station

Species selection (elimination, survival/vigor, phenology) establishment methods and management practices required in the first years of this land use system. Suitability of species will not only depend on growth performance in general but also on the suitability of the leafy components to improve soil nutrient status, water holding capacity and O.M. status of the soil. To analyse these aspects a series of independent mulching trials will be carried out, using different tree leaves. Such experiments will have to be complemented by soil and leaf analyfis. This on-station research will continue over the entire life of the project.

On-farm

Testing of some of the best species and establishment methods developed on station in the previous year of the project (researcher managed, inputs and evaluation jointly by farmers and researchers).

6.2.2 Rehabilitation of useful trees in the grazing land

Purpose: see 5.3.2

Variable factors

a) species
b) protection methods (block vs. individual trees)

Parameters to be monitored

a) existing vegetation (for block approach)
b) labour input for fencing, treatment of trees, construction of micro-catchments
c) growth (tree height and ground cover; latter only for block approach)
d) farmers' reaction

Type of research

On farm

Effects of microcatchments, growth form management and on woodfuel and fodder production (researcher managed, inputs and evaluation jointly by farmers and researchers).

6.2.3 Fodder/browse trees in the grazing land

Purpose: see 5.3.3

Variable factors

a) species
b) spacing
c) establishment methods

Parameters to be monitored

a) labour inputs for establishment, maintenance (harvested by animals)
b) survival rates and growth (termite resistance)
c) fodder yield
d) seasonality fodder production
e) palatability of fodder
f) nutritive value of fodder
g) additional products (fuelwood and nectare production)
h) vegetation growth underneath the trees

Type of research

On-station

Species selection and establishment trials including nutrient analysis and palatability analysis. The screening trials and analysis will take place during the entire project life.

On-farm

Species selection trials and establishment trials simultaneous with on station research during the entire life of the project. Management trials of the 'best bet' species and establishment methods in the last two years of the project (researcher managed, inputs supplied jointly by farmer and researcher).

6.2.4 Cut and carry fodder systems

Purpose: see 5.3.4

Variable factors

a) species
b) establishment methods
c) spacing
d) harvest management

Parameters to be monitored

a) labour inputs for establishment, maintenance and harvesting
b) survival and growth (termite resistance)
c) yield of different products
d) quality fodder, timber, poles or craftwood
e) nectar production

Type of research

On-station, On-farm as in 6.2.3.

6.2.5 Living fences around the grazing land

Purpose: see 5.3.5

Variable factors

a) species
b) establishment methods
c) in-row spacing
d) trimming frequency

Parameters to be monitored

a) labour inputs establishment, maintenance
b) survival rates and growth (termite resistance)
c) additional products (including nectare production)

Type of research

On-station

Species selection and establishment trials

On-farm

Species selection and establishment trials simultaneously with the on-station research. Both research activities will last for the entire project life (researcher managed, inputs and evaluation jointly by farmers and researchers).

The addition of an upper storey may be treated in the same way as the hedgerows in the cropland.

6.2.6 Windbreak around the home compound

Purpose: see 5.3.6

Variable factors

a) variety/cultivars of mango
b) in row spacing
c) tree management

Parameters to be monitored

a) labour inputs for establishment, maintenance
b) survival rates and growth (termite resistance)
c) wind speeds
d) additional products (including nectare production)

Type of research

On-farm only

Selection of variety, in row spacing (researcher managed, inputs and evaluation jointly by farmers and researchers).

6.2.7 Fruit trees in the home compound

Purpose: see 5.3.7

Variable factors

a) variety/cultivar

Parameters to be monitored

a) labour inputs for establishment and maintenance
b) survival rate and growth (termite resistance)
c) additional products (including nectare production)

Type of research

On-farm only

Selection of variety (researcher managed, inputs and evaluation jointly by farmers and researchers).

6.3 Initial experimental designs

The following experimental layouts have been designed for on-station experimentation on the hedgerow/mulch farming system (6.2.1). Other experimental designs are being created as the project progresses.

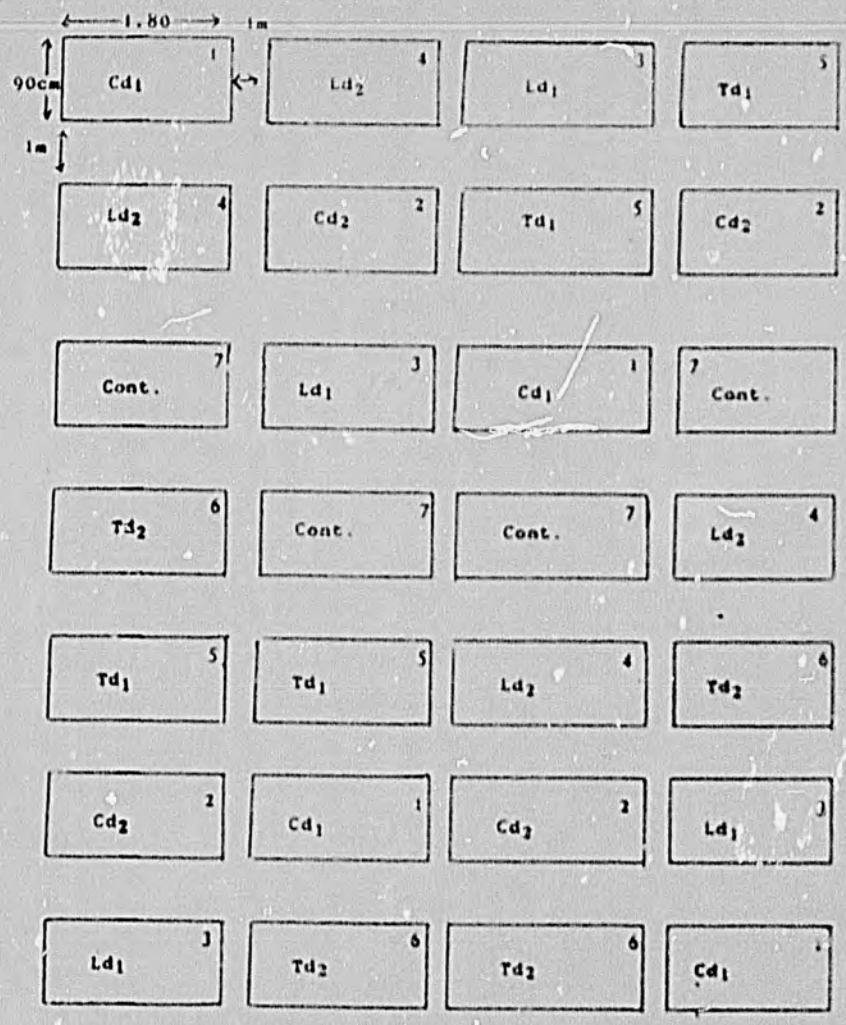

Figure 9. Plot design for maize/mulch-green manure trial.

Treatment Combinations

1. Cd_1 - Cassia siamea ● 1 kg/m²
2. Cd_2 - Cassia siamea ● 2 kg/m²
3. Ld_1 - Leucaena leucocephala ● 1 kg/m²
4. Ld_2 - Leucaena leucocephala ● 2 kg/m²
5. Td_1 - Terminalia brownii ● 1 kg/m²
6. Td_2 - Terminalia brownii ● 1 kg/m²
7. Cont. - Control (maize only, no mulch applied!)

Total amount of mulch require Leucaena) Cassia) 19.44 kg of each Terminalia) (fresh weight)

Each plot will have 1 row of maize in the centre, in-row spacing - 30 cm (6 plants):

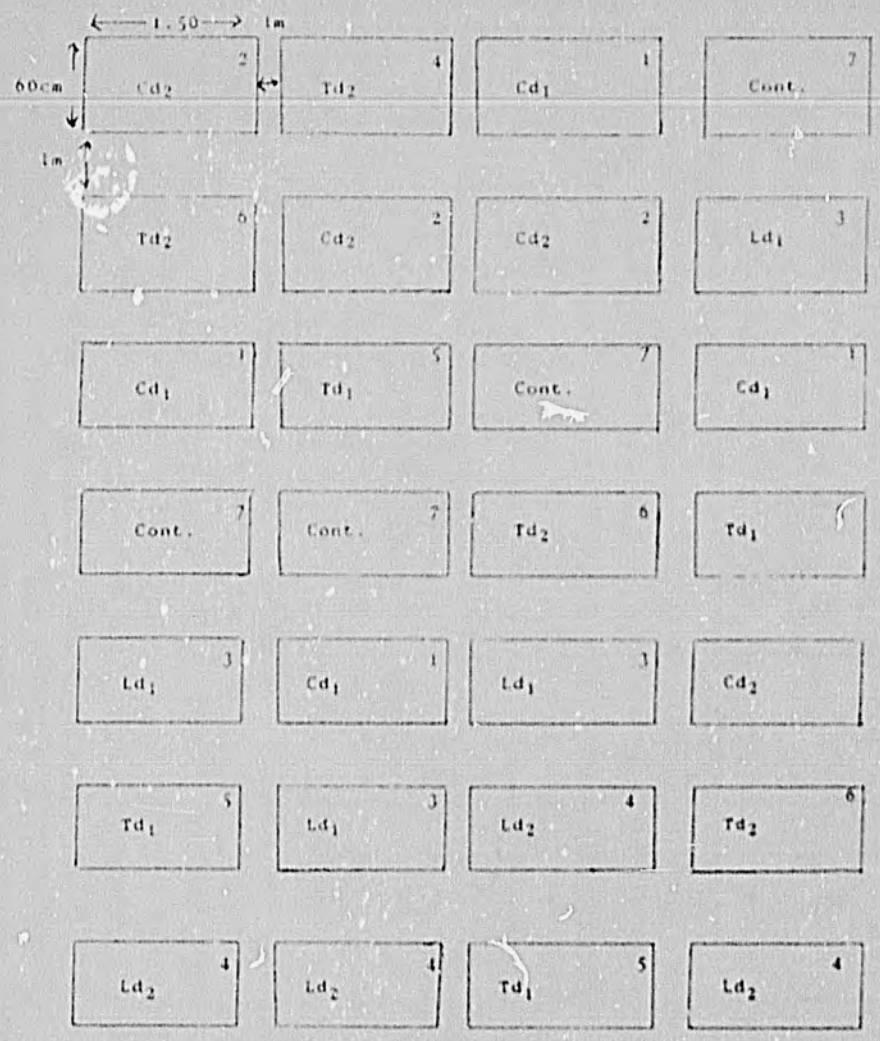

Figure 10. Plot design for beans/mulch-green manure trial.

Treatment Combinations

1. Ld_1 - Leucaena leucocephala @ 1 kg/m^2
2. Ld_2 - Leucaena leucocephala @ 2 kg/m^2
3. Cd_1 - Cassia siamea @ 1 kg/m^2
4. Cd_2 - Cassia siamea @ 2 kg/m^2
5. Td_1 - Terminalia @ 1 kg/m^2
6. Td_2 - Terminalia @ 2 kg/m^2
7. C - Control @

Total amount of mulch required/10.80 kg of each! (fresh weight)
Each plot will have 1 row of beans spaced 15 cm apart (10 plants)

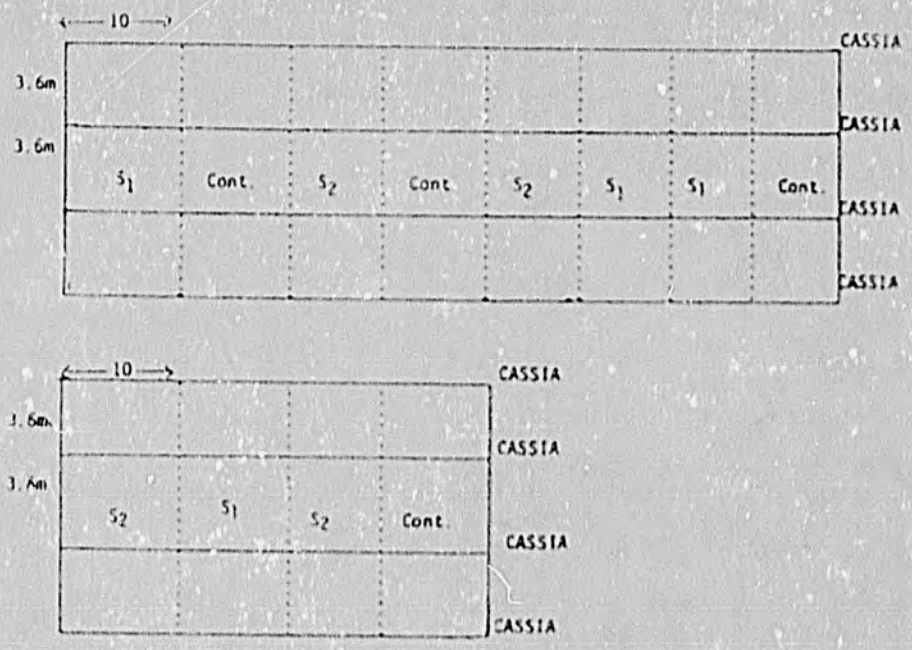

Figure 11. Plot design for hedgerow trial

TREATMENTS

S_1 - *Cassia siamea* in furrows at 0.25m spacing

S_2 - *Cassia siamea* in holes at 1m spacing

Cont. (Control) (Maize only)

Three rows of maize are planted between each 2 rows of Cassia (90cm between rows). In the control plots, each cassia row is replaced by a maize.

Note: These experimental plots are designed to provide information only on relative differences between treatments. Experiments with larger plots will be conducted in the second phase of experimentation to obtain yield data on the most promising treatments.

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