MULTIOBJECTIVE RURAL LAND USE PLANNING: POTENTIAL FOR SOCIAL FORESTRY IN MAPUTO, MOZAMBIQUE

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For Quito

This will not give us back the time we stayed apart, but I hope you will one day understand and appreciate why you and your mum had to sacrifice so much!

Declaration

I hereby declare that this thesis has been composed by me, and all the work presented is my own unless stated otherwise.

August, 1997

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Abstract

Maputo-city has a very high population density and sources of domestic energy such as electricity, gas or even kerosene are not yet available for the majority of the population. Demand for wood products is high both in the rural and urban areas for consumption and generation of income. Coupled with agricultural expansion, this raises concerns over the sustainability of use of natural forest resources. Nevertheless, the government has limited financial and human resources to establish plantations which can satisfy the increases in wood demand, especially in the urban areas. The 1991 Reforestation policy adopt, as strategy, the involvement of the users, especially the rural community, in the replacement of exploited forest resources. However, reported failure in implementation of this strategy has suggested that there is a need to develop a decision support tool, which would encapsulate the multidisciplinary nature of the problem, at both farm and regional levels. The underlying hypothesis of this research is, therefore, that despite data scarcity and/or unreliability, it is possible to develop a planning framework applying a relatively sophisticated planning tool such as Mathematical Programming. The aim of the thesis is to perform an *ex-ante* analysis of the impact of the strategy, stressing a bottom-up and integrated planning procedure and including decision makers at the two levels. Both single and multiobjective mathematical programming methods are applied, preceded by the use of Geographical Information Systems in the analysis of the spatial distribution of resources. The results show that by integrating agriculture, forestry and animal husbandry activities and constraints in the farm planning framework, it is possible to assess the individual potential responses to reforestation alternatives. Furthermore, conflicts among national goals are assessed using aggregation techniques. This provides policy makers with information on the opportunity cost that may be associated with changes in government priorities.

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CHAPTER 1

Introduction

1.1 The Country

Mozambique is situated in the east coast of Africa, between latitudes 10°27' and 26°52' South, and longitudes 30°12' and 40°51' East (Figure 1.1). It covers approximately 801,509 km^2 with 1.6% of that area being represented by inland water and 2,515 km of coastline which plays a very important role in the country's economy.

The terrain of Mozambique is lowland at the coast, upland in the centre, high plateau in the North and mountainous to the West. The climate is tropical and subtropical, but relatively more humid at the coast where the rain increases because of the unstable and strong inflow of deep moist air masses in that zone. The rainfall varies from 800 to 1400 mm/yr in the North and coast, achieving a maximum of 2,000 mm in Manica Province (West-centre). The rest of the central and southern provinces are drier with only 400-800 mm/yr, the driest being Gaza Province with 200-400 mm a year. Weather systems, such as tropical cyclones in the Indian Ocean and east coast of Africa, although rare, affect Mozambique causing between 10 and 100 thunderstorms every year as a result of surface heating and vertical convection. Furthermore, during recent decades, Africa has had less than 40% probability of having 10% of the mean rainfall of the preceding year, increasing the potential for severe drought, desertification and seasonal floods in the South of the country (Grove, 1990).

The country's population is around 17 million, growing at 2.7% per year and it is highly concentrated in an area approximately 50 km from the coast. While in 1970, the urban population was just 6%, twenty years later it rose to 27%, and is estimated to be 41% by the year 2,000 (World Statistics in Carolyne, 1993). This will require development of the cities infrastructures damaged during the civil war. Consequently, planners have to identify potential areas that can provide job opportunities in the rural areas in order to minimise further massive migration to the cities.

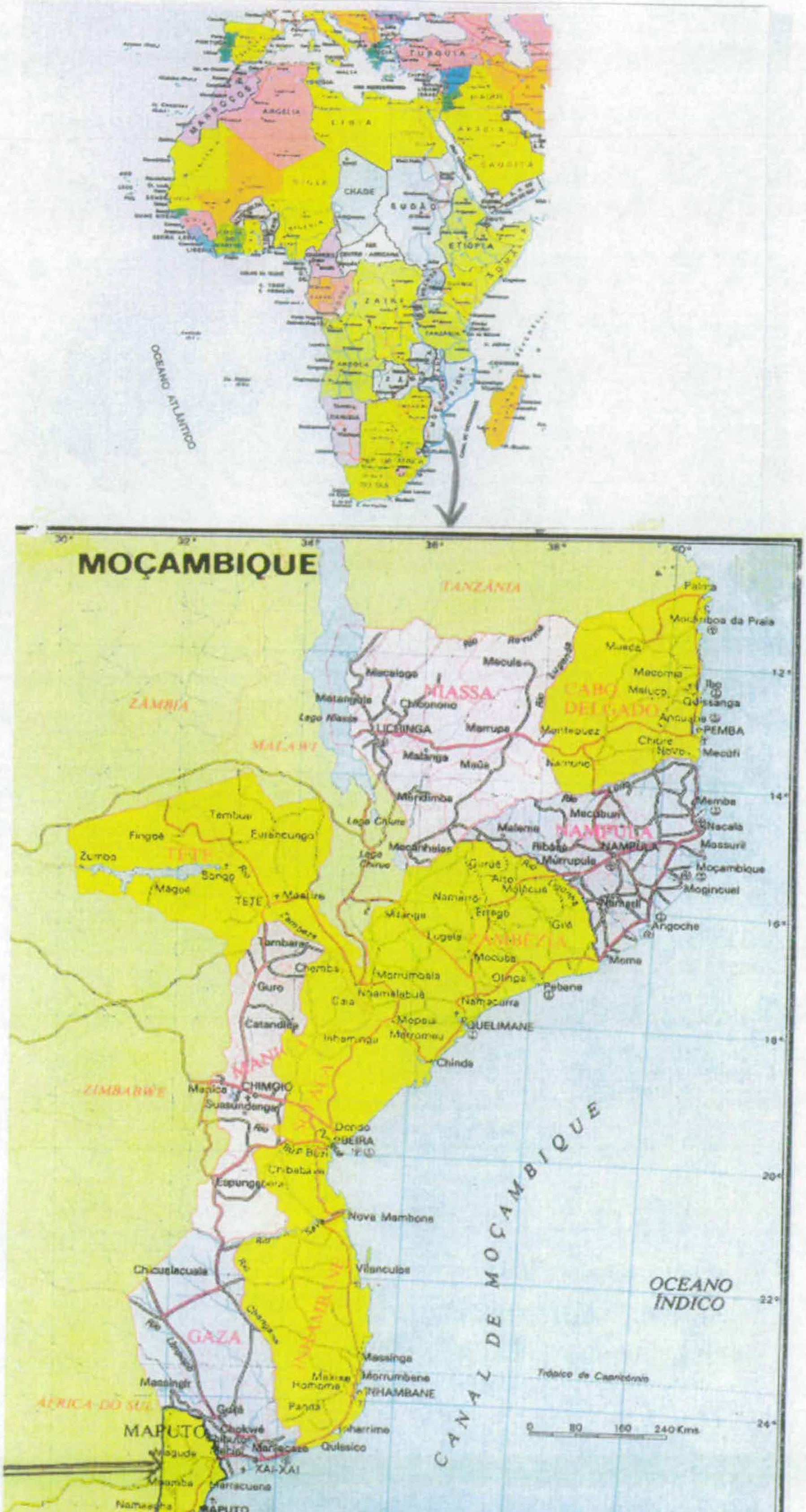


Fig. 1.1 Geographical location of Mozambique and Maputo

Mozambique is essentially an agricultural country whose main primary products are cereals, cashew nuts, cotton, sugar, tea, fruit, sisal and groundnuts. Its main industries are textiles, chemicals, mining, food processing and fishing. In 1960, 81% of the labour force was working in agriculture, having increased by 4% in 1980. This was associated with a decrease of jobs in the industry and services.

Due to certain factors, the country has become poorer and poorer during the last two/three decades. On one hand, civil war, which started a few years after independence (1975), lasted for about 16 years (until 1992). Additionally, drought which has affected all the southern African countries has contributed to the dramatic diminution of production, even in villages situated in relatively safe areas. For instance, the GNP in 1991 was only US$1,131 million with a negative change of 3.5% from 1980 to 1990. The corresponding income per capita was US$80 which although low does not quite give the real picture of the distribution of resources in the country, because about two thirds of the population lives in absolute poverty. Also, an inflation rate of more than 40% has dramatically reduced consumers' purchasing power. Furthermore, the unemployment rate of over 50% denotes lack of working opportunities and contributes for deterioration of people's life.

Even though the agricultural sector provides the major source of jobs (accounting for about 80% of total labour) and it generates 64% of the GDP, the majority of the rural people and other in urban areas cannot meet their daily calorie requirements. According to UNDP (1990), the average production of cereals in 1986-1988 was 26% less than the production in 1976-1978. Therefore, cereal aid donations were 9 metric tonnes per capita per year in 1975-1977 and 23 metric tonnes by 1985-1987. Even with this assistance, the average calories available met only 71% of the needs (1985-1987). Moreover, the fact that only 50% of the urban population and 12% of the rural population have access to safe water explains the high infant mortality of 141/1000 live births and high child death rate (<5 yrs) which was 241/1000 live births during 1985-1990.

However, another serious problem in Mozambique concerns the demand for wood. According to the National Directorate of Forestry and Wildlife (DNFFB, 1991) wood consumption in Mozambique is estimated at 18 million m^3 of which about 15 million m^3 are in form of fuelwood. It further predicts that by the turn of the century, this demand will increase to about 24 million m^3/year. Firewood demand has and will continue to increase, because alternative energy sources are expensive since oil or electricity supplies have to be imported. In fact half (300,000 Mwh) of the electricity consumed in the country is imported from South Africa. Subsequently, renewable resources will remain the main energy supply for a long period. Although the country has some fossil fuels: oil in the North and gas in the South, this still requires exploration. The whole country is affected by the energy problems. The centre and North has been defined as a zone of 'scarcity' with a positive balance of only 0.24-1.1 m^3 of wood per individual and, the South is considered a zone of 'acute scarcity' with a negative balance of 0.2-0.9 m^3 per head (SADCC, 1988).

Within Mozambique, these problems are particularly acute in large urban areas. Maputo Province in general (and Maputo-city in particular) is thus one of the main priority areas defined by the government of Mozambique as needing alternative sources of energy. Maputo Province therefore provides the focus of this thesis.

1.2 Problem summary, objectives and hypothesis

Problem Summary

Maputo, as the capital of Mozambique is expected to offer better living conditions in terms of health, education, and employment opportunities than rural areas. This, and the fact that the country had been in civil war for over a decade and half, led to overpopulation of the city by people both seeking the superior facilities and safety from war. Presently the population in the province is over 2 million, of which about 72% live in Maputo-city. From the total urban households only 38.5% have electricity with about half using it for cooking. 71.6% of the families use woodfuel while 11% use alternative sources such as kerosene, oil and gas (IE, 1991). The low level of consumption of electricity is mainly because a considerable proportion of families have an extremely low income. For example, around 73% of the households in the Maputo-city spend less than $34 a month (IE, 1994). Consequently, the high demand for relatively cheap sources of energy, such as firewood and charcoal which comprises, according to IE (1994), about 10% of the average monthly expenditures. Therefore, the high level of demand for forest products in the urban and rural areas, has led to an unsustainable demand for wood from the natural forests.

In an attempt to mitigate this, and other problems facing the forestry sector, the government designed the 1991 Strategies for Forestry Development which among others aspects, includes a Reforestation Strategy. This stipulates that the involvement of the local community is essential in order to replace the natural resources exploited while continuing to satisfy the demand for wood products by the growing urban market.

However, there were some shortfalls in the implementation of the strategy as reported by Getahun (1991). One of the reasons was the implementation of the Government's Reforestation Strategy (1991) with community involvement in some zones (Maputo) without a detailed *ex-ante* analysis of the technical and socio-economic issues involved. Prominent issues regard farmers preferences, land tenure issues and the analysis of the potential ability of the farmer to reallocate the limited resources (land and labour) to include the new activity. In addition, a lack of co-ordination between agriculture and forestry extension services in taking new technology to the rural farmer combined with scarcity of data for integrated land use planning, and uncertainty over potential farmers response to the policy and uncertain climatic conditions, were issues that needed to be considered prior to implementation. Therefore, general and specific objectives of this study are identified as follows.

Objectives

General

The aim of this study is to offer an *ex-ante* analysis of community involvement in reforestation for fuelwood and timber production in order to reduce pressure on the natural woodland while providing food security.

Specific

a) Bottom-up identification and analysis of social forestry alternatives suitable for each ecozone based on socio-economic data.

b) Evaluation of the alternatives through mathematical programming with integration of cropping, forestry, and marketing activities and constraints at both farm and regional planning levels.

c) Identification of data needs and gaps for future model application in rural land use planning and how it can be generated.

d) Assessment of the usefulness of the methodology as a tool for forestry policy and strategy analysis in Mozambique.

These objectives intend to address the following hypotheses which highlight the problems and form the general framework for the study.

Hypothesis

One of the main issues highlighted as a problem referred to the top-down approach adopted by the government as regards the implementation of the Reforestation Strategy. However, it is being increasingly recognised that a bottom-up planning approach is potentially a better way forward, i.e., the imposition of solutions on people is not always the best way for making progress in rural development. In fact, in many cases it creates conflicts between planners and/or researchers and the community. It weakens co-operation and mutual understanding of the problem and potential for joint identification of possible solutions. Projects fail sometimes not because of poor technical design, but because farmers are not involved in the decision making and planning processes.

Therefore, instead of being part of the project or program, they view the project or program as for outside interests (government or any other organisation). Evans (1992) states that whether development means economic imperialism or it intends to help poor rural people, as individuals and as a nation, it is important to understand and seek their ideals and wishes. This suggests the need for eliciting farmers ideals and solutions for their own problems and, application of a bottom-up planning approach. Hence, the first hypothesis highlights the micro level problem.

1. Traditional land use systems are sustainable and can be maintained so that traditional socio-economic environment is not disrupted.

Another aspect is the lack of co-ordination between institutions in information gathering and dissemination to assist rural planners and researchers. Furthermore, the fact that the study is conducted just two years after the cease-fire (1994) means that the primary information is also highly affected by the level of political instability that the farmers have been subject to. Therefore, the planning method is designed in a particular period of data scarcity and low reliability. This led to the definition of the second hypothesis.

2. It is possible to develop a multiobjective planning methodology for integrated rural land use in a data scarce environment and foresee the opportunity cost of changing traditional land use systems to satisfy both farm and regional goals.

It is already an empirical fact that social forestry offers ecological, economic and social advantages (Rocheleau, *et al*, 1988; Sinclair, 1995). Nevertheless, the objectives and hypothesis outlined, highlight the need to assess the potential farm response towards the Reforestation Strategy. Therefore, farmers goals and constraints should be assessed in terms of the likely influence on the decision making process for the achievement of the regional goals envisaged with the strategy.

1.3 The background to the problem

i) Natural forestry resources

Natural forests are the major supplier of wood for various purposes in Mozambique. This ranges from domestic and industrial energy consumption to construction materials and furniture both for local market and export. The natural forest is also rich in various wildlife species. However, there are also about 42,000 hectares of plantations of *Pinus* spp. and *Eucalyptus* spp. which supply the industry and domestic energy requirements, respectively.

Approximately 71% of the country is covered by a form of forest or woodland vegetation and is classified as gallery forest, montane forest, sub-hygrophilous forest, open forest, savannah and mangroves (Burley, 1989). However, valuable commercial species are found in the relatively closed and high productive forest of nearly 15 million hectares. Savannah and miombo forest are important sources of fuelwood and construction materials for the whole rural area and 65% of the urban population. In addition, mangrove species covering 455,000 hectares provide a very important micro climate for the early stages of development for shrimps and other shellfish. However, the mangroves are also exploited for firewood due to their high calorific value. This generates an economic threat as they provide a major source of foreign currency and also represents a serious environmental impact on the already fragile coastal ecosystems. There is also large area of forest land with potential either for agroforestry or animal husbandry, and 98,000 hectares of sand dunes.

The forestry sector, like the other sectors of the economy has suffered the consequences of long political instability. Against this scenario, the Maputo Province occupies the smallest area of the country, and contains only a small area of natural woodland. However, an important aspect is that over 80% of its natural forest has a low productivity (0.5 m^3 of wood/ha/yr compared with 1.85 m^3/ha/yr average for the country) (Saket, 1994). This offers a great potential for investigation of perhaps more productive alternative land use systems.

ii) Wood demand

Household consumption of energy

Average firewood consumption has been reported as 1.0 m^3/p/yr in the rural areas of Maputo Province, and 0.827 m^3/p/yr in Maputo-city (Bila, 1992) or respectively, 0.858 and 0.820 m^3/person/year (SADCC, 1988). These figures can be taken to illustrate some of the implications of biomass use on deforestation. Roughly, Maputo Province consumes over 800,000 m^3/year just about half of the annual increment of the natural forest. This of course seems a balanced supply and demand for wood products, because the annual allowable cut is over the demand. However, concern arises since the quality and growth of woodland is low.

Furthermore, besides the illegal production of charcoal, forest land is also cleared for agriculture, housing and other development purposes. Therefore, the harvesting of wood for energy or production of fuelwood combined with the fact that forest resources are the main source of income for the rural people during periods of drought and political unrest represents a serious drain on resources.

Another important issue pointed out by Catterson *et al* (1991) is that the peace process would mean a return of the farmers to their villages. The use of fire to clear the fallow land for resettlement may produce negative consequences. Experience has demonstrated that non controlled fire (as traditional land preparation for agriculture), burns more area than the farmer initially intended to, with negative impacts on the forestry resources and wildlife.

The above information suggests that the dependence from firewood both in the city and rural areas is likely to continue for quite a long time. While urban inhabitants have very low incomes and thus cannot afford to use alternative sources of energy, the farmer has no choice but to harvest the natural woodland in order to meet consumption needs, and more significantly, for generation of income. Hence, participatory reforestation becomes imperative to sustain the supply in the medium and long terms.

Industrial use of firewood

Wood is also exploited for industrial purposes. For example, 587,000 m^3 were harvested in 1982 for firewood (SADCC, 1988). Biomass demand by the industry was 170,000 m^3 in 1980 and it was estimated to be 568,000 m^3 by the turn of the century (Bila, 1992 quoting Pereira, 1990). The figures presented above are not consistent considering the tendency of demand to increase. If Pereira's estimate is more realistic, then it could be inferred that, on one hand, the processing industries could be more efficient in using the energy leading to a decreased input. Secondly, the industry would have adopted new technologies or alternative fuels. Nevertheless, it seems rather optimistic to expect such changes in the medium term, because the economy has been deteriorating progressively, and most of the processing industries are not reducing their production costs in order to be competitive. Therefore, this sector is likely to continue to be dependent on firewood.

iii) The Reforestation Plan in Maputo

In 1978, Maputo Province (as well as Sofala and Nampula Provinces) were considered priority areas for reforestation with *Eucalyptus* spp. to supply firewood and poles to the urban markets. The National Plan of Reforestation for the short and medium terms involved 24,000 hectares in Maputo, 18,000 hectares in Sofala and 10,000 hectares in Nampula.

Ten years later, just over 4,000 hectares had been planted in Maputo, whereas the figures in the other two major provinces were respectively, 1,880 and 490 hectares (SADCC, 1988). The latter figures increased to 4,170 for Sofala and 1,760 for Nampula as reported by Catterson *et al* (1991). Whatever the definition of short and medium terms, it is clear that the rate of planting has not as yet fulfilled the objective. This is despite the selection of fast growing species. However, unlike Maputo, other provinces have both a high percentage of low productive forests and over 80% of the population in the rural areas. Consequently, the density of population in the cities is relatively low, and in rural areas, people and forest resources can coexist in relative harmony.

Attempts to introduce agroforestry have not been successful due to local resistance towards *Eucalyptus* spp. firewood because of its low calorific value and smoke (Burley, 1989). This author also reported slow growth of the *Eucalyptus* spp. introduced as a result, probably, of misselection. Moreover, the low planting figures contribute for non immediate satisfaction of the demand for wood products in Maputo. Also taungya systems in the Project FO2 in Marracuene, for instance, failed because farmers were keen to reduce competition tree-crop thinned the plantations. Catterson *et al* (1991) stress that successful planting programs require excellent co-ordination of activities, starting from high quality seed, available on time, seedlings produced at the right size and vigour for transportation, and plantation according to the biological calendar. The lack of strict observation of these requirements is responsible for the mediocre plant survival (about 40%).

Fraser & Karkari (1987) pointed out that at least the country needed 100,000 to 120,000 hectares of plantations to supply firewood in the absence of substitute fuels. However, they also recognised a need for massive investment to fulfil the objective at more than US$1,000/ha plantation cost. This solution does not appear viable as the government investment in this sector was never significant.

In 1987, for example, the National Plan of Reforestation (PNR) already recognised that the government would not be able to satisfy the demand for firewood in the urban areas. Furthermore, PNR identified the establishment of extension networks and demonstration fields as priority for energy production in the rural areas. However, this plan was not complemented with sufficient research activity and due to severe lack of information, did not succeed.

1.4 Change in strategy: the community involvement in reforestation

The observation of the deteriorating forestry sector contribution to the economy led the DNFFB to formulate policies and strategies in order to identify alternatives for overcoming the present difficulties, and promote the development of the sector and its role in the economy as a whole. This represented a clear change in the energy policy which was once the expansion of reforestation programs and mobilisation of the rural community for conservation and rational use of the forestry resources (Government communication (1980) quoted by SADCC (1988)). The role of the farmers in creating their own source of energy for domestic usage and income was not addressed then or at least did not seem a priority.

However, the 1991 Reforestation Strategy showed a change in the government's approach to deal with the energy problem. It recognised that forest users should contribute to reforestation through social forestry projects. The expected outcome being the provision of food and wood for the rural community by promoting its own involvement in the activities, creating jobs and above all increasing the potential for improvement of the rural household income and sustainable use of natural resources. In addition, this would take pressure off from the natural forest, and would permit longer regeneration periods for the natural forest.

Economic policies and other macroeconomic decisions have also affected energy use and the exploitation of forestry resources. The Economic Rehabilitation under the Structural Adjustment Program adopted in 1987, aimed to increase production for export, liberalise producer prices, and encourage intensive and high profitability agriculture. However, in the forestry sector, price liberalisation, for example, benefited timber merchants at the expense of the producers who could not afford the high transport cost required to sell their produce directly in the Maputo-city markets. This suggests that a positive impact of integrated land use systems and conservation of the natural woodland will not only depend on the farmers, producers or sellers' willingness to participate in the process, but will also depend upon the policies adopted by the government.

1.5 Specific issues in the implementation of the reforestation

i) Land Tenure

All land and natural resources are state owned by the constitution (article 8 of the Land Use Legislation, 1987), and it is therefore the State which determines its use. However, the State includes workers and farmers, hence the land belongs to the people and it cannot be sold, leased or seized. Moreover, it is stressed that the use of land for social welfare is a right for all and every Mozambican citizen.

However, traditional practices consisted of communal properties mainly of forest and pasture land, and family or individual customary ownership (Bruce, 1990) where the right for use is only transmitted due to death to the partner and heirs. Bruce also points out that property rights are a very important incentive for agriculture investment by farmers, particularly as to introduction of sustainable land uses such as agroforestry. Although the state has changed its intervention in agriculture, with co-operatives again replaced with the traditional subsistence farming, there is a need to conduct detailed studies concerning rural social relationships as to different land ownership and mechanisms of conflict resolution.

Carilho (1992) states that although land sales or rents are illegal, a black market for land exists. Furthermore, as Negrão (1997) points out, the State contradicts itself when, for instance, it evaluates its shares in joint ventures having the land as its own capital. This procedure confuses people as to the right to use land and land ownership. It is argued that the government deliberately did not strictly set the boundaries of the extent to which land users have only rights to use or own the land. In fact, recently, the government started leasing land in the north of the country for a minimum period of 50 years to South African farmers.

As a result of this lack of transparency on the law, fertile land ownership is granted to private companies at the expense of smallholders. For example, Changalane in the Namaacha district is a case where land (400 ha) was given to a private investor which was not developed for many years. Consequently, farmers were denied access to that land. This is an extremely important aspect to take into account, because land tenure is an important aspect that can influence the farmer's decision on whether to adopt social forestry (village woodlots, agroforestry, etc.) or not. Evans (1992) pointed out that land ownership is one of the considerable obstacles in rural development and insecurity over land ownership can be used by the government as a condition for development, that is, if the farmer does not follow this condition, he/she can loose the right to use the land.

Generally, land is 'owned' by men who are the head of the families, whereas women cultivate it. Therefore, if women accept introducing tree species in the agricultural fields, this may create potential problems as there is a clear distinction between land ownership and tree ownership, food and cash cropping. Therefore, the redistribution of benefits is likely to be cumbersome and men may see it as a threat for losing their land (specially in polygamy cases). Fortman (1984) recognises that rights over tree and land in terms of ownership, inheritance, ability to dispose trees or exclude others from using them and their products, has serious implications in agroforestry adoption. Land owners (private or state) always have advantages compared to tree owners only. Also Carilho (1992) stresses that the existence of land policy in Mozambique will promote the smallholder to contribute towards food security. It would encourage job creation in the rural zones, eventual development of cropping systems to supply existing processing and exportation activities. Furthermore, it would reinforce the use and management of the natural resources.

Despite the need for revising the Land Tenure Law in Mozambique being well established, in 1997 the new proposals for change are still to be discussed in parliament, meanwhile conflicts between rural dwellers and the private sector seem to be increasing.

The problem of land availability is even more critical than the need to satisfy rural and urban demands for wood. The reason is the fact that, in agriculture, apart from the subsistence sector, the private sector becomes more important and problems of land property rights arise when farmers are prevented from using the land they think belongs to them. In the Boane district of Maputo the state and private farmers own large areas of land where they grow citrus trees and vegetables even though figures for the actual land area under cultivation were not available. In Matutuine, the private sector which was growing mainly rice is not operating at present, because the infrastructure was destroyed during the war. It has to be noted that the land problem will increase as the rehabilitation of the infrastructure proceeds.

Therefore, unless the law is clear, agriculture and forestry planners and researchers will be limited in terms of delivering sound plans for undertaking successfully rural development projects. Myers (1992) stressed, for instance, referring to the impact of Chóckue State Irrigation Scheme for rice production that ambiguous, weak or insecure land tenure is likely to lead the users to short term decisions or short planning horizons aiming to derive high profits which can result in land degradation. Consequently, the unclear Land Tenure law means that farmers' willingness to plant trees and mitigate environmental problems may not be readily implemented.

ii) Planning institutions and sources of finance for the DNFFB

With regard to planning and decision making processes, they are the responsibility of the government institutions or Ministries. Forestry is under the Ministry of Agriculture and Fisheries, being headed by the National Directorate of Forestry and Wildlife. There is the National Commission of Planning which has the overall responsibility of planning in the country. The public budget is allocated to each sector for a period of three years 'Three yearly Public Investment Plan'. For the period 1991-1993, over US$7,3 million in local currency and more than US$8,4 million of external input from the UNDP, World Bank, IFAD, CIDA and others, was assigned to the National Directorate of Forestry and Wildlife (DNFFB) for developing activities such as research, reforestation, forestry extension, and management of wildlife. The fact that there is more external money input, shows the governments limited capacity to invest in its economic development and the likely limitations in funding the implementation of the Deforestation Strategy.

Provincial services, where the implementation of policies, programs and projects takes place, have two sources of budget: the province itself and the sector (Catterson *et at*, 1991; SADCC, 1988). This duplicated subordination causes a lack of accountability of the provincial services and it is an obstacle for an efficient use of resources.

iii) Potential issues of the reforestation policy strategy and rural development

Rural development planning is a very complex issue. The policy and strategy for reforestation was set to minimise the problem of wood shortage, while ensuring rational use of the natural resources. However, the current exploitation of the resources cannot be looked at in isolation of the farm decision environment. This includes food security issues primarily, but also concerns the need for animal restocking after slaughter during the war and other socio-cultural aspects. This suggests that both technical and socio-economic questions have to be addressed in the planning of the participatory Reforestation Strategy:

- which tree species, with their spatial or temporal requirements are suitable for the local conditions;
- what impact the system may have on the allocation of land and labour among farming and non-farming activities;
- what technical assistance is necessary for the farmers to plant and manage the trees; capacity of nurseries and their location to minimise the cost of transport and assure that seedlings are planted at the right time;
- who will have responsibility for the maintenance of the nursery. If it is local people, what incentives to compensate the fact that they may give up other activities;
- adequate identification of beneficiaries and redistribution of benefits in the household;
- potential for development of other activities such as carpentry, carving, building, etc.
- land conservation benefits;
- transport and marketing facilities.

In other words, the need to know what the opportunity costs of land, labour and capital associated with the adoption of this strategy by the farmers.

Furthermore, alternatives should take into account not only the farmers preferences but also consumers preferences, i.e., the level of demand for the farmers' produce is an important consideration. This is because the ultimate measure of benefit or welfare improvement for the farmers will be the generation of income net of subsistence.

As it will be shown later, farmers prefer woodlots to any form of intercropping. Catterson *et al* (1991) highlighted that although there is great potential for agroforestry, planting fruit trees is preferred since it is traditional practice. Furthermore, live fences and boundaries are more adequate due to lack of experience in complex agroforestry configurations and the need for in-depth understanding of local farming.

The implementation of a social forestry policy strategy may encounter obstacles at two levels. First, the present institutional framework does not permit ready access to information for planning. Therefore, the organisation of the Forestry and Agricultural sectors, particularly the National Program of Rural Development have to introduce some changes to accommodate the new service demand for integrated rural development activities. Social forestry implementation needs a broad provision of technical expertise, because it includes issues not strictly related to forestry, agriculture or animal production. Second, there is no data system or a reliable source of information that can be used by planners at different levels of decision making. Moreover, there is also often discrepancies in published data which makes it difficult to decide rationally on the figures to use.

There is therefore a need for a regional and national study of the potential impact which may result from assessing the farm level present conditions and consequences in order to provide a planning basis that can be modified as detailed information becomes available or problems change over time.

As far as the scope of this study is concerned, farmers constitute the major protagonists, because they are the ones whose participation in improved agricultural production will play an important role in satisfying their own needs and produce surplus for other sectors of the population. The availability of firewood at a lower price may also alter the income allocation by the urban users. They may buy food for better nutrition or allocate extra income to education, health or leisure.

Having looked at the potential issues to be considered in the investigation of the possible response to the Reforestation Strategy, it is important to mention that answers to some of the issues raised may be given by monitoring and evaluating the impact of the social forestry on rural people's attitude towards resource allocation to integrated land use, and attitude towards different products and income allocation priorities: household expenses; investment in farm; education; health. There are many aspects involved in the benefits accruing to education. In most rural areas and even in the surroundings of the cities, there is a different value given to formal education and its usefulness is still 'gender biased'. This extends to administration of the family income, and it is perhaps not possible to predict to whom the final benefit of reforestation may accrue.

Nevertheless, it is important to evaluate the present situation to accommodate the changes that may be necessary. Macdicken & Vergara (1990) consider agroforestry an integration of trees with crops/animals which offers a potential for diminishing the risk (biological and economical) of crop failure, increasing simultaneously the total productivity. Although they emphasise agroforestry as providing risk reductions as the major objective of inclusion in the indigenous mixed cropping systems, they consider the claims of increased productivity, cited in some agroforestry literature to be unfounded, because few comparisons of agroforestry technologies and monoculture have been done so far. An important consideration they also make is that the benefits of agroforestry systems should not be seen purely from the development planners' point of view, i.e., increase in production. Despite the fact that this may be true, another issue arises: the farmer's primary objective, in Maputo and elsewhere, is to increase the production and income within a set of resource constraints. Therefore, the farmer would hardly adopt an agroforestry option that had considerable emphasis on conservation alone; or one which would lead to a decline in food production, even though the farmer may benefit from a more stable and sustainable distribution of production over long period, supply of fuelwood and fodder for the animals, besides wood material for other applications.

Risk consideration is an important aspect in the implementation of the reforestation strategy. However, data on variance-covariance of yields and prices of food and forestry products are not available in Mozambique. Therefore, farm risk aversion has been incorporated into the farm model through Lexicorgaphic Goal Programming denoting food security for the household as first priority as indicated by the farmers (survey).

These aspects, including soil improvement objectives and erosion control which may be outwit the understanding of the farmer, suggest that a compromise may have to be reached between the potential benefits from introduced changes in the traditional land use systems and other non agroforestry alternatives that may be useful to tackle the energy problem.

iv) Status of knowledge of the alternative farming to the traditional practice

Agroforestry systems can be complex. Therefore, biological and socio-economic advantages and disadvantages of agroforestry systems, which have been pointed out by many authors and are summarised by Macdiken & Vergara (1990) and Combe (1983) may be difficult for farmers to understand. Also, since there is no thorough understanding of the effects of the technologies in different specific conditions, the impact of tree intercropping with agricultural crops may be unclear.

For example, some questions are still to be answered. First, to what extent does alley cropping increase agricultural crop production?, how much influence does competition above ground (modification of temperature, wind speed and interception of light and rainfall) and below ground (water and nutrients) affect the performance of both crops and trees? which is the best spacing for tree and crop inter and intra rows to minimise the competition? or what intensity of management (pruning, e.g.) is optimal to get the best return from the crop? These aspects also include the potential introduction of fruit species, alternative management of natural woodland, and location specific conditions (soil, micro climate, dietary habits of the community, or the importance of natural resources for rituals, medicinal plants and other products).

Although social forestry is perceived to be a way forward for rural development, because of its promising future as an integrated land use system, it also has some limitations. Some aspects have already been considered. Not least important is that its impact will only be as good as the commitment of the community in planning and co-ordination in its implementation. As Nair (1989) stresses, any attempt to solve the problem of fuelwood has to be integrated into a wider context of satisfaction of basic living conditions as well as ecological sustainability. It is in that context that an *ex-ante* analysis of the potential planning framework for implementing social forestry in Mozambique is absolutely necessary to ensure the consideration of various relevant issues.

1.6 Maputo: the study region

i) Introduction

Within a planning framework one of the most important steps is to decide the level at which the model is representative. In general, there are three levels in which decision making can take place. The lowest is the farm where the farmer allocates the limited resources to produce food and income for the family. The second level is the province or regional level where broader decisions, both in terms of area and population involved, are made. This means aggregation of representative farm models within the planning unit to a provincial/regional planning level. At a higher level, the decision process has to take into account macro resource limitations, public human and financial resources, to allocate to macro objectives that will affect, the society/country as a whole. In this case, the study is carried out at the regional level, the Maputo Province.

ii) Description of Maputo Province

Geographical situation

Maputo Province has a surface area of 22,931 Km^2. Its latitude ranges from 24°15'00" to 26°51'45" South, while the longitude varies between 32°02'25" and 32°58'46" East . The province is, in general, at low altitude (under 200 m), however some peaks are observed, for example M'Ponduine (West border) is the highest at approximately 800 m above sea level. Mainland districts include Moamba, Manhiça, Magude, Marracuene, Matola, Matutuine, Boane, Namaacha, and Maputo-city. There are also three islands: Inhaca, Xefinas and Elefantes. The major river is the Maputo river although the Incomati, Umbeluzi, Matola, Tembe and Futi rivers also have an important role in irrigation of traditional farming as well as providing drinking water for domestic and industrial applications. Some of the rivers have their origin in the neighbouring countries, which is the case of Incomati and Umbeluzi. This makes water availability dependent on the other countries consumption (SADCC, 1988). However, there are other sources of water provided by lakes Pati, Maundo, Chingute, Pili and Satine.

Climate and geomorphology

A generally hot environment is suggested by the annual average temperature of 23.4° C. However, maximum and minimum temperatures can achieve, respectively, 40.9° C (January) and 10.4° C (August). Average annual precipitation is just 586.8 mm (IE, 1991). The climate is classified as Tropical Humid in the coast and the small parts of Southwest and centre-West. In addition, a very small area in the West has a modified climate by the altitude (Pequenos Libombos). The major proportion (over 50%) of the province, however, has a Tropical Dry climate.

The geomorphology of the province (centre to the East) is mainly plain from accumulation of material; part of the centre to the South is depression of accumulation, whereas the centre to North is characterised by slopes and river valleys. The West (up to the border with Swaziland and South Africa) is mountainous and lava surface.

Soil types and suitability for agriculture

Around 50% of the soils in Maputo Province have an excessive drainage, 45% have no major limitations, and 5% are either saline or have high potential for flooding (INIA, 1991). The summer rains fall between October and March, varying from 500-800 mm in over 75% of the province, with 20% of the province having 800-1000 mm; the remaining with less than 500 mm. During the winter (April to September) the rainfall is very low. In 1991, for example, it varied between just 0.1 mm in August to 40.2 mm in June with a total of 97.2 mm.

The land seems to have great limitations in terms of suitability for traditional agriculture, which characteristically has low levels of inputs. In addition, subsistence farmers deal with constraints such as the lack of basic agricultural tools. This suggests that the application of organic fertilisers, and provision of agricultural tools may play an important role in improving food production systems of the smallholders. Moreover, the fact that the population is increasing, makes farming more sedentary. Therefore, as the intensity of land use increases, it becomes more vulnerable because of irregular rain and potential for drought. Consequently, medium term concern should be the creation of conditions for sustainable production. This is possible with a change in focus for the forestry sector where changes from timber production to a more integrated land use might improve the productivity of the traditional farming system (Catterson *et al,* 1991).

Six soil types can be identified in the province. In the Southeast 'primitive' sandy soils exist in the coastal dunes, and further Southeast white sandy soils with low fertility and low water retention capacity can be found. Along the Maputo river in the South and Incomati in the North of the province, there is a predominance of fluvial soils, with high fertility, but are however difficult to till, sometimes holding excessive water and/or salinity. Part of the areas to East and West of the Maputo river and the central part of the province through the North, have sandy soils with very low fertility indeed, and low water retention capacity. Moving to the West, the altitude above the sea level increases, the soils are red clay with medium to good fertility. Finally, in the far west to the border, the soils are shallow, rocky and inappropriate for agriculture (MINED, 1986).

A more detailed characterisation of soils is necessary as to match them with particular farming and management systems. For instance, the Boane district with basaltic colluvial materials have weathered to chromic luvisols and eutric fluvisols whose texture is medium to heavy. Moving to the hills, the soils tend to be lithosols - shallow and stony. Conversely, in the flat areas, especially in the flood plains and river banks, soils are heavy, despite existing sandy soils. Getahum (1991) considered soil fertility to be good and with a deep profile, slope, texture and nutrient status suitable for agriculture and tree planting. However, the short wet growing season limits crop production, especially beans and maize.

In contrast, Marracuene in the North of Maputo has mainly sandy soils and is poor in nutrients, limiting agricultural production. This results in pressure on the valleys of the rivers where the soils are relatively fertile and promise better crop yields. Again this benefits commercial producers rather than smallholders (Macucule & Bila, 1991). In this area, there is a high potential for intercropping leguminous species with agricultural crops, while in other zones, planting in the boundaries is perhaps more appropriate.

Current Land use systems: crops, potential and limitations

Maputo Province has the widest coastal plain in Southern Africa with plantations of coconuts and sugar cane on the alluvial flats (Grove, 1990). In general, farmers grow maize, beans, groundnuts, cotton and cashew nuts on dry land, while vegetables are grown in irrigated fields either using surface water or wells. Other main food supplements are meat, fish and fruit. They also rear animals, with cattle being the dominant enterprise, but also including pig, sheep and goat production, grazing in mixed natural pasture (sweet and bitter). Tse-Tse fly affects areas with abundant livestock (MINED, 1986). A large proportion of animal husbandry is owned by smallholders.

The size of farm holdings ranges between 0.5 and 2 ha despite estimates that each family needs 2.6 to 11.5 ha (Burley, 1989) to produce enough for its subsistence. There is no tradition of soil fertilisation and traditional practices involve subsistence agriculture based on rainfall, which is becoming more intensive because of shorter wet seasons. In addition, pastoralism is a common activity and large areas are allocated to grazing involving a high mobility of people and animals.

Farm labour is mainly supplied by the women and children of the farm family but hired labour is used during the peak seasons (soil preparation and weeding). In some zones, a number of families join together and alternatively cultivate the land of each of the participants. This is a very important and efficient traditional use of labour without involving extra costs for the farmers.

In general, farmers have two or more farming plots, one of which will be in fallow. This enables burning just before soil preparation providing relatively good crop harvests which often does not last for more than a couple of years. Within the farming plots, trees are always present, although small in number. They provide an important function, not only for supplying fruit and wood, but also shade as socialisation places, village meetings or traditional courts for community problem-solving.

Agricultural tools and inputs

Hoes, axes and machetes are the most commonly used instruments although some farms own or hire draft power. In some districts, where there is a concentration of the private sector, it is possible for some villagers to hire tractor services. For example, in Boane district there are large areas of private plantations of vegetables and citrus and the nearby communities can benefit from the existing infrastructure (Getahun, 1991). The majority of the farming is done without using chemical fertilisers, which means there is potential for planting leguminous species that can fix nitrogen and perhaps provide better crop yields.

Farmers contribution to commercialised food products

Although the amount of food production by the farmer is not precisely known, it is certain that the farmer has a share in commercialised products for the urban population (Table 1.1).

The figures suggest that, besides satisfying their food requirement, farmers aim to produce surplus in order to sell and obtain income applied in supplementary products (sugar, soap, clothing, etc.) as well as for children's education and health care.

Table 1.1 Farmers' contribution towards food supply to Maputo-city (1990 Tonnes - IE, 1991)

Crops	Total traded products	Private sector	Farmers contribution
Beans	399	393	2%
Cashew nuts	19	-	100%
Cassava	2188	788	64%
Cotton seed	-	850	0%
Groundnuts	102	82	20%
Maize	6395	4475	30%
Sorghum	1	-	100%
Sugar	129218	129218	0%
Sunflower	5	-	100%
Hardwood	-	7158	0%

It can be seen that despite being low in quantity, cash crops like cashew nuts and sunflower are totally supplied by small farmers. As far as beans and maize are concerned, farmers sell small quantities because they constitute the major staple food. Integrated and efficient land use may improve production and contribute to the economy as a whole. This aspect will be illustrated both in the discussion of farm and regional model results (Chapter 6).

Forest cover and potential for reforestation

Maputo vegetation can be categorised in four different groups: coastal vegetation along the Ocean, open miombo forest in the centre, arboreal savannah in the West, and a mixture of alluvium herbaceous and arboreal savannah along the rivers Maputo and Incomati. *Acacia* spp. and *Strychnos* spp. are the most common tree species. The mean annual increment in tree growth is very low (0.5 m^3/ha/yr) and trees are thus subject to continued pressure due to the demand for fuelwood (Burley, 1989). Besides human activity, climatic conditions and soil characteristics may also be responsible factors of the relatively low quantity (and quality) of forest resources in the province, estimated at 0.8 million ha (Catterson *et al*, 1991).

The potential land for reforestation in Maputo was estimated by PNR (1987) at about 15% of the total area of the province. The total reforested area in the North of Maputo (Project FO2) so far is about 4,500 ha mainly of eucalyptus. However, technical problems such as tree survival rates as low as 40% and lack of subsequent management (Catterson *et al*, 1991) are reasons for both low quantity and quality of the plantations' production: mean annual increment varies from 7.5m^3/ha in the marginal areas, whereas nearer the coast increments of 10 m^3/ha/yr may be achieved (PNR, 1987).

In short, the problem of wood supply for the city remains unresolved. It is unlikely that the government alone can fund both maintenance of the natural stock and expansion of the forest resources. It is also not probable that current government funding (Fund for Agrarian Development) of nearly US$100,000 to the Energy and Biomass Unit with external assistance from the World Bank, of over US$3 million, will continue long enough to produce observable benefits for the community. Moreover, there is no guarantee of continuity of the projects once the funding period is over, examples of similar cases are the previously mentioned plantation projects. Therefore, a more sustainable expansion of the resources seems to rely on the users participation in the process.

Existing extension services

There is an agreement among the planners that integrated land use is necessary, but the limitation of funds and qualified personnel seems to prevent research and extension activities.

In Maputo, only the district of Boane benefits from extension services being funded by FFA with above US$210,000 (1991-93) and US$102,000 provided by IFAD for two years (1991-1992). A Diagnose & Design done in Boane district (Getahum, 1991) showed that farmers would be willing to plant trees if they owned the land. However, those who had started planting trees encountered problems of low survival rates, because of scarcity of water to irrigate the seedlings, inadequacy of species selection according to their ecology adaptation, poor introduction of new species and no clear use and management explained to the farmers. This situation calls for better planning of extension activities and above all the services should be extended to all districts in order to conduct objective assessment of the problems related to the use of natural resources and potential interventions.

iii) Social forestry/agroforestry research in Maputo

Investigation previously done has so far consisted of surveying the main crops and tree species existing in the farmland. This provides a basis for species selection and for further study on-farm and/or on-station research to obtain technical data of the productivity as well as economic viability of the alternative land use. Two districts, Marracuene and Boane, have been devoted that attention. Getahun (1991), Macucule and Bila (1991) and Bila (1992) observed that there is predominance of fruit species, in the farming systems of the two districts. Nevertheless, scattered native firewood species were also common in agricultural fields.

It is essential to select adequate multipurpose trees/shrubs for each particular location/district in Maputo considering the ecology of the species, silvicultural treatments, productivity, uses and rotation. Some tree species like *Leucaena* spp. are nitrogen fixing and can be planted in the poor soils to improve fertility. Nevertheless, the decision-making process should combine the advantages viewed by rural planners as to the use and potential benefits of particular species with priorities of the community. This necessity is illustrated by Barrow (1991) who considers building on local knowledge, a challenge of agroforestry with particular reference to Pokot and Turkana pastoral communities in Kenya, and Sukuma in Tanzania. These communities developed sustainable management of the natural woodland to survive the drought in East Africa. The author also adds that rather than emphasising a disconnected introduction of tree planting programs, it is better to emphasise conservation and sustainability of natural resource utilisation.

Another important issue is the allocation of female labour to many activities including domestic, farming, collection of firewood and water and others. Fortman & Rocheleau (1984) stated that the role of women in agriculture and forestry is ignored by both donor agencies and local personnel because of certain myths such as their minor involvement in agriculture production or tree planting and the fact that, they have less influence in public affairs. However, women in Maputo play an important role in the household economy as it will be shown in Chapters 5 and 6. Although the attitude of donor agencies has been changing, there is still a lot to be done locally to overcome this obstacle to rural development. This is a very important social aspect to consider when looking at participants and beneficiaries of social forestry activities.

iv) Role and importance of social forestry

Social forestry is an integrated land use system in which local inputs are used to produce output to develop a particular region. It may be in the form of different agroforestry techniques, farm forestry, community forestry or woodlots plantation (discussed in Chapter 3). They can be distinguished by the combination of tree and annual crops, tree growing by individual farmers in owned land or in public/communal land, or block/row tree planting in marginal land (Nair, 1989b). Production objectives can be combined with environmental purposes.

Tiwari (1986) defined social forestry as culturing trees by the people, for the people, aiming to increase the forest area, and rehabilitate wasteland while producing biomass for the industry and local uses. While agreeing with the participants and beneficiaries of social forestry, it seems very restrictive to consider that the only purpose of social forestry is expansion of the forestry area and wood production. Most of the traditional cultivation systems, where scattered trees are found in the agriculture fields or in the forest itself, are also sources of food. The use of agroforestry systems, for instance, was identified by Bene *et al* (1977) as a necessary shift from forestry to a broader land use concept in order to minimise hunger, inadequate shelter and environmental degradation (Nair, 1989a).

It is recognised that multidisciplinary and multidimensional (forestry, agriculture, animal husbandry, aquaculture, fisheries, land resource management and others - Maydell *et al*, 1983) approaches are required to solve the multiple problems faced by people at different levels of decision making: family, village, region, or nation. The remaining question concerns the identification of the best alternatives for a specific problem and socio-economic conditions, Maputo being a case in point. Districts differ in terms of resource potential and distribution including water (some have rivers nearby, or lower water tables that enable opening wells, in other zones people walk long distances to have just 20 litres of water, often not treated. Some water sources are inaccessible due to land mines planted during the war. They also differ in terms of the range of crop and trees/shrubs combinations. These disparities will determine the identification of suitable social forestry options.

Baumer (1990) presents information about areas with risk of desertification in the African, Caribbean and Pacific countries from FAO/UNDP 1984. Mozambique has 0.1% of its territory with high risk of desertification, 20.1% with moderate risk and about 79.8% with low or nil. The dominant factors of potential desertification are mainly movements of sand by wind and the existence of stony and rocky surfaces subject to deflation scouring or sheet erosion. Extreme erosion results in the formation of desert pavements, laterized horizons and rocky outcrops. The wind is an important factor in moving sandy soils and dunes along the coast of the country. This is particularly acute in the southern region. There is also risk of drought which is climate related and it can be an effect of complex global events not necessarily originated in the affected region. Heathcote (1983) states that it is a result of reduced moisture available to satisfy specific demands: for people, plants and animals. Baumer (1990) emphasises that the agroforestry crop production evaluation should not be simply based on average rainfall and it is essential to look at development options towards sustainable production even though uncertainty related to climate change may remain. As mentioned before, this aspects requires consideration and assessment during planning for rural development in Maputo.

One of the social forestry options that will be given particular emphasis in this study because of the variety of options and complexity in management, are agroforestry systems. Lundgren and Reintree's (1982) ICRAF refined definition of agroforestry is "a land use system and technologies in which woody perennials (trees, shrubs) are deliberately planted on the same land management units as agricultural crops and/or animals, in spatial or temporal sequence where there are, simultaneously, ecological and economic interactions between the components". Both the productive and protective role of agroforestry are outstanding in the definition of the role of incorporating perennials with annuals (Torres, 1983).

As to ecological interactions, agroforestry is a very complex management system, but it has the advantage of spreading agricultural risks among crops than in case of monoculture, where pests, diseases or mismanagement may damage an entire crop. Moreover, agroforestry systems enables agricultural and forestry plants as well as animals to use different strata. Above ground, leaf systems of agriculture crops/pasture and tree/shrubs require and use different amounts of light, whereas bellow ground the different root systems facilitate the species to explore either the surface soil moisture and nutrients or go deep into the soil. This implies an efficient use of the conditions offered by the environment. Nevertheless, not all interactions have been positive, as will be shown in the Chapter 3.

As regards socio-economic aspects, these can be analysed from two points of view. On one hand, this system gives the farm a range of products to harvest and obtain different levels of satisfaction of its multiple objectives, whereas demanding from him to accept a technological change/improvement that may have social implications. On the other hand, the introduction of integrated land use requires planning institutions to integrate themselves before they can achieve their purpose as to this new development route.

Subsequently, the achievement of this purpose in the Maputo Province, and Mozambique in general, will require, to a certain extent, transformation of the actual planning process at both farm and governmental levels. The incorporation of trees in the agriculture fields or woodlots will need a different concept, for the farmer, of land use and of natural resources use. Furthermore, government institutions, represented by the agriculture and forestry services will have to learn to look at their disciplines, not as the most important, but as one of the major contributors for economical development. This will require joint planning, policy making and implementation of rural development projects, including other relevant experts in the process. As Lundgren (1991) commented, inter-institutional programmes facilitate problem identification, priority setting and resource allocation besides bringing positive economic, ecological and social results. However, they call for a deep change in the approach of policy-makers.

Integrated land use systems in Maputo Province is a way in which farmers can minimise the problem of food, pasture and wood shortage in the short term, with a long term prospect to solve it. Baumer (1990) states that where there are trees, there is life, because these and other perennials survive from one season to another, and the farmer can use them to measure harsh climate conditions. The author clearly recognises that agroforestry can help in ameliorating desertification, managing arid and semi-arid zones even though it cannot be claimed to be a panacea against them. Maydell *et al* (1983) also stress that it is not possible to deny the possible negative impact of competition between components in agroforestry. The level of demand and available resources, instead of over exploitation, requires optimisation and sustainable management. Agroforestry may be as good as any other land use, or even not suitable at all, but it can be the best solution for problems of rural development in specific sites or regions. Therefore, an adequate choice demands a careful consideration of economical and ecological factors.

Agroforestry has an important role to play in the Maputo districts. For instance, were there is lack of water as it is the case of the dryland, it can improve infiltration by increasing deep root system trees, or by reducing evaporation through windbreaks. Soil erosion (water and wind) can be minimised by using multipurpose tree windbreaks, hedges, nitrogen fixing or trees providing large quantity of organic matter. In areas where agriculture productivity is low, agroforestry, in a form of improved fallow, land used for multipurpose use hedges can be a better option. Where reduced animal production is a problem, then forage trees and shrubs as well as reserves of standing grazing and protein rich woody plants may be a solution. Finally, for energy and other woody problems, the solution may be combined with the previous situation in selecting species that apart from satisfying other objectives also provide valuable firewood and charcoal.

Well planned social forestry and agroforestry in particular offers a highly efficient rationalisation of resource use (land, labour and capital), simultaneously addressing multiple objective problems. This is important from the farmers point of view. It offers a range of options for food and wood production as well as potential for income generation. From the National planners point of view, it will mean a more wide participation of people in reforestation, conservation of the natural woodland, and a possible application of public funds in managing the natural ecosystems.

Village woodlots and other tree plantations are also an option to solve not just the farmer's immediate problem, but as long term measures against erosion and for dune fixation, plantation for pole production or wood for processing (sawmill), with the added potential of offering job opportunities and subsequent amelioration of income and consumption of the village/district/region as a whole.

Selection of adequate species to address a range of ecological and economic (fodder, energy, poles and cash) problems have to be coupled with clear explanation given to the villagers as to management requirements and use of newly introduced species. In addition, the plan should be socially acceptable, i.e., species introduced or land use changes should be accompanied with a clear local understanding of the gains and losses that can be associated with people giving up traditional practices.

The importance of social forestry interventions in Mozambique, or Maputo Province in particular, can be supported by the fact that experience from many African countries demonstrates their application for solving a variety of problems: risk of desertification, food, wood and energy security. However, caution has to be taken to avoid errors in planning because not all reported examples have been successful. Difficulties have ranged from preconceived assumptions about farmer's problems without conducting a survey beforehand that would have helped to focus on the relevant issues; a lack of monitoring and evaluation of the implemented projects. Other problems include the technology transfer without a preceding local research of better alternatives and farmers preferences; lack of combination of both on-farm and on-station research to reflect the complexity and variability of the local farming conditions; lack of account of the risk averse nature of the farmer with regard to new technology, unless they are convinced of their advantages. Finally, problems in setting up the extension procedures (whether group or individual farmers, men or women) and institutional framework between NGO and the government or the agriculture and forestry authorities, are also responsible for the failure of agroforestry projects in Africa (Kerkhof, 1990).

These problems illustrate the importance of the integrated land use systems and the inherent complexities involved. Some examples of different degrees of success and failure can be found in a number of identified projects with various purposes (Chapter 3). For example, tree growing for fuelwood and other products in Rwanda, Kenya, Zimbabwe and Ethiopia; village forestry projects in Mali, Burkina Faso, Tanzania and Senegal; tree growing to increase productivity of dry land areas in Niger, Mali, Burkina Faso and Zambia; projects to promote natural regeneration in Tanzania, Kenya and Niger. Baumer (1990) also quote examples of The Gambia, Senegal and Chad as countries that viewed agroforestry as a promising strategy to combat desertification while increasing production.

Other examples are given by Nair (1989a) citing papers on the Chagga home gardens on multi-storeyed agroforestry cropping systems on mount Kilimanjaro in Tanzania whose diversity is an insurance against drought, pests and economic risks; Rwanda in Bugera-Gisaka-Migongo identified the role of agroforestry as a measure to cope with expanding food demand and rapid population growth. In the Jebel Mara highlands in Sudan, *Acacia albida* is planted as a source of food, wood and fodder. There are also indigenous mixed cropping practices that can be encouraged to solve food and wood security problems, illustrations of these are the evaluation of the *A. albida* traditionally mixed with cereals, vegetables and coffee in Eastern Ethiopia; the shamba system which is an indigenous food production from forest areas in Kenya or the compound farms/home garden systems of Southeast Nigeria are in danger due to indiscriminate clearing of forests and woodlands.

So, how much good can social forestry bring to Maputo? The thesis addresses the presupposition that this option has an undeniable role in minimising malnutrition problems among the rural and sub-urban areas which is responsible for the death of children below the age of 5, to address the energy and wood shortages, to give a sustained food and forestry production and long term socio-economic security.

The introduction of trees in the agriculture practices have potential advantages (FAO, 1989): dietary supplement and diversity, seasonal food resources, emergency role as a source of energy during drought period, famine or war; also, some tree species can improve water quality. *Moringa* spp for example, is used to clarify turbid water in Sudan and Egypt. *Swartzia madagascariensis* has been reported to contain saponin which is lethal to snails, intermediary host of bilharzia which affects populations living close to waterways that they use for drinking, bathing and cooking. Depending on the intensity of tree planting and management, this may also be a valuable employment opportunity. One of the sources of off-farm income in

Maputo comes from artisan wood processing by local artisans. Planting may provide a sustainable source of raw material.

This chapter has, therefore, described the problem, the objectives, the hypothesis and, potential and limitations of social forestry in Maputo Province. Chapter 2 looks at specific land use planning issues and methods. Chapter 3 then considers some of the roles of agroforestry in more detail, potential options, their management, problems and success/drawbacks registered in undertaking similar options elsewhere. The kind of data used for planning and sources or procedures to elicit it are then discussed in Chapter 4, and in Chapter 5 the planning framework at both farm and regional levels is discussed. Chapter 6 presents the results of single and multiobjective solutions of the farm and regional planning models, whereas Chapter 7 discusses the policy implication of the results, particularly concerning the regional model before concluding.

CHAPTER 2

Geographical Information Systems and Mathematical Programming in Land Use Planning

2.1 The Spatial Nature of Land Use Planning

Land is defined by Cloke (1989) as a simple form of property that can be traded at will or used as a form of common property. The author adds that land use is influenced by history, institutions, politics, technology, society and economy, all of which can vary across different nations. Land use planning in Mozambique, specially regarding the implementation of the Reforestation Strategy, aims at discouraging irrational exploitation of the natural forest and its potential environmental hazards while providing the level of output that satisfies the increasing demand for wood products and income in both rural and urban areas.

McCarl (1992), looking at policy formulation for environmental and natural resources, stresses that multiple objectives are relevant both for the farmer and the policy maker (PM). This is because the policy making process should be followed by an analysis of the farm response and implications in order to maximise the satisfaction of the PM according to such a response. This is relevant for the reforestation policy in Mozambique whose strategy is to involve the forest product users in the expansion of forest resources. However, people's willingness to accept the strategy, and participate in its implementation first needs to be established.

The nature of this planning problem thus demands a bottom-up planning approach as indicated in Figure 2.1. It is recognised that a top-down approach in decision making is not always the best planning approach for many rural development projects. Therefore, emphasis is being given world-wide to the involvement of the target group in the decision making process. There has been an evolution from an application of planning models such as Goal Programming (GP), at regional level where average individual preferences were put together with information generated from simulation models into model formulation, to the stage where the aim of the research is to include farm level models into regional planning. The problem associated with that is to preserve the individual farm's preferences at the regional planning level (McGregor *et al*, 1996).

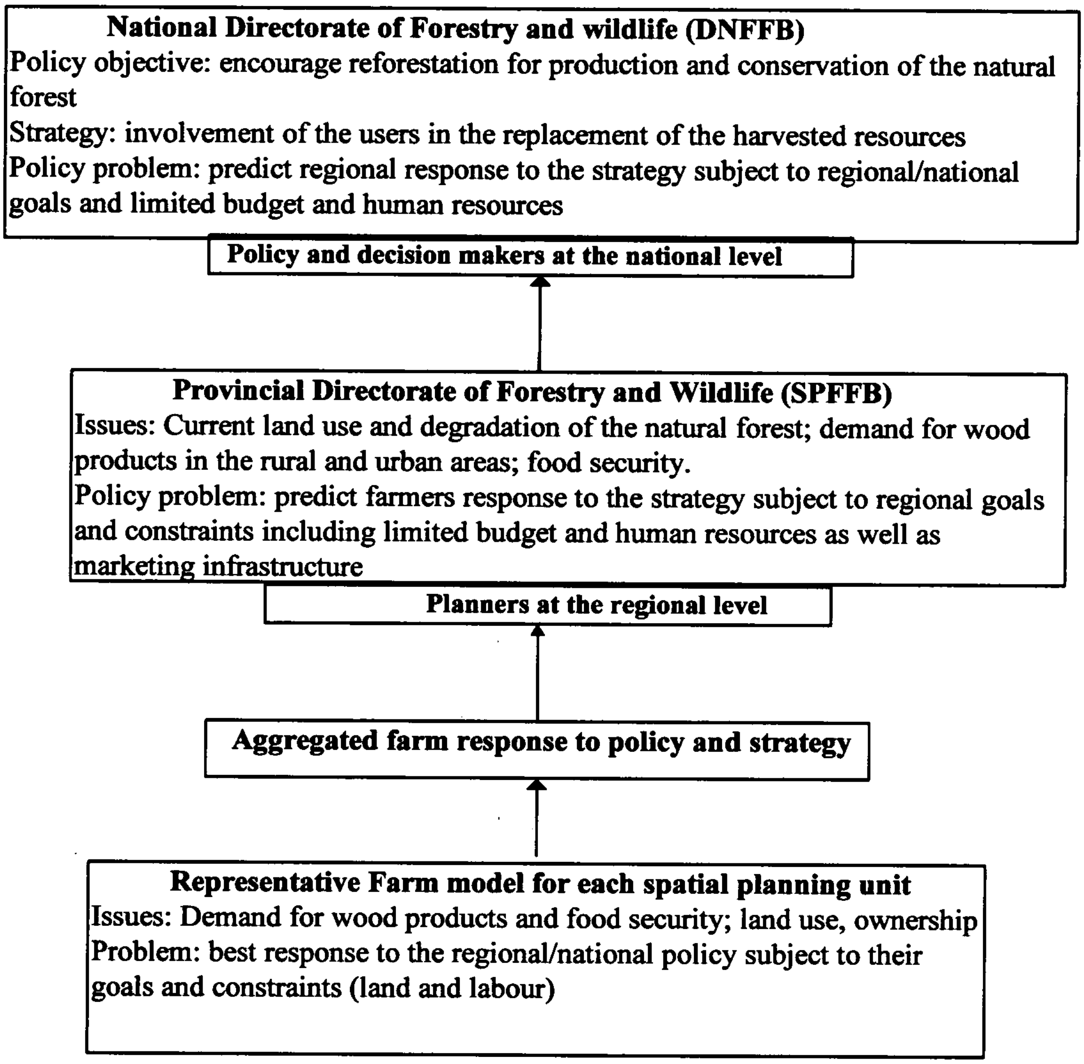


Fig. 2.1 Reforestation: a bottom-up planning problem

Planning at two or more levels, according to Mallawaarachchi *et al* (1995), raises the need to evaluate trade-offs between conflicting and non-overlapping goals and objectives as well as consideration of spatial and temporal aspects in the policy analysis. Furthermore, the framework shows that policy responses by farmers in the different planning units defined by geographical regions or land use patterns will be affected by their distinct resource endowments. Hence, the need for their individual modelling first. The level of sophistication of this planning approach is high, but its development and application may be worthwhile.

Cowen and Shirley (1991) describe the nature of planning as involving the following aspects:

1. Central intelligence comprised of socio-economic and land use information;
2. Detailed analysis of existing conditions;
3. Policy clarification based on comparison of different scenarios rising from policy issues;
4. Detailed development planning in which policy makers should prepare zoning maps to direct development balancing the economic development with social services; and
5. Feedback and review involving public opinion in a democratic society.

According to Cowen and Shirley (1991) this means that, on one hand, planning is inherently spatially oriented. Consequently, Geographical Information Systems (GIS) can assist in assembling information in an integrated format to improve the ability of the planner to visualise land use trends or ideally, serving as a sophisticated decision support system. This is because, according to Calkins (1991), policy statements lack specificity and the objective of using GIS is to present high quality information to the decision maker, describe important relationships, predict the impact of selected decisions and evaluate results of such decisions. Maguire *et al* (1991) summarise the functions of GIS as descriptive (what and where) and analytical (why and what if). On the other hand, planning involves a great deal of *ad hoc* decision making based on the evaluation of alternatives.

Mendoza and Sprouse (1989) state that there are two critical stages of planning: firstly, the generation of alternatives through fuzzy decision making approaches; secondly, the evaluation and prioritisation of the alternatives. They consider that for the first stage, the analyst is the major catalyst, whereas for the second stage it is the decision makers' (DM) role. This evaluates the merit of the alternatives based on tangible and intangible factors. Thus, in agroforestry planning, forest managers, agronomists and animal producers (as analysts) have to provide information about the resources and production techniques available so that a mathematical programming model can be built. Alternative optimal solutions can be suggested to the DM who can then select according to his/her preference.

Calkins (1991) underlines that public policy sets the development of public programmes and intends to influence individuals to a desired direction according to policy goals. This is clearly the case for the Reforestation Strategy: the government envisages to rationalise the use of natural forests by involving the community in the provision of alternative sources of wood products. Calkins (1991) also adds that setting public policy should be a process within a rational framework (Figure 2.2) and the model for public decision making should start with definition of goals and objectives, proceeding to decision space bounded by resources and constraints, leading to a set of alternatives for evaluation and, finally, evaluating solutions using previously defined criteria.

The framework (Figure 2.2) highlights four important aspects. First, at level 1 the need for monitoring the significance of policy measures and indicators is stressed. Second, level 2 represents public analysis of the problem and identification of appropriate action. Level 3 is where the planning activity occurs and detailed specification and analysis of alternative solutions are carried out. Fourth, the importance of feedback of the results of planning for rational policy decisions. In general, there is congruence between this and the framework for planning using mathematical programming presented by Dent *et al* (1986) and also with the general steps of the planning process as shown by Cowen and Shirley (1991).

Moreover, it is clear from Figure 2.2 that level 3 could be carried out using a planning approach such as mathematical programming. Mallawaarachchi *et al* (1995) illustrates the potential for integrating GIS with other behavioural and process modelling tools such as LP. The authors defend that despite not widely appreciated, LP models can be useful for repetitive applications and data manipulation and they quote McCarl and Nuthall (1982) saying that after model formulation and validation, re-application becomes clerical and can be handled using simple procedures.

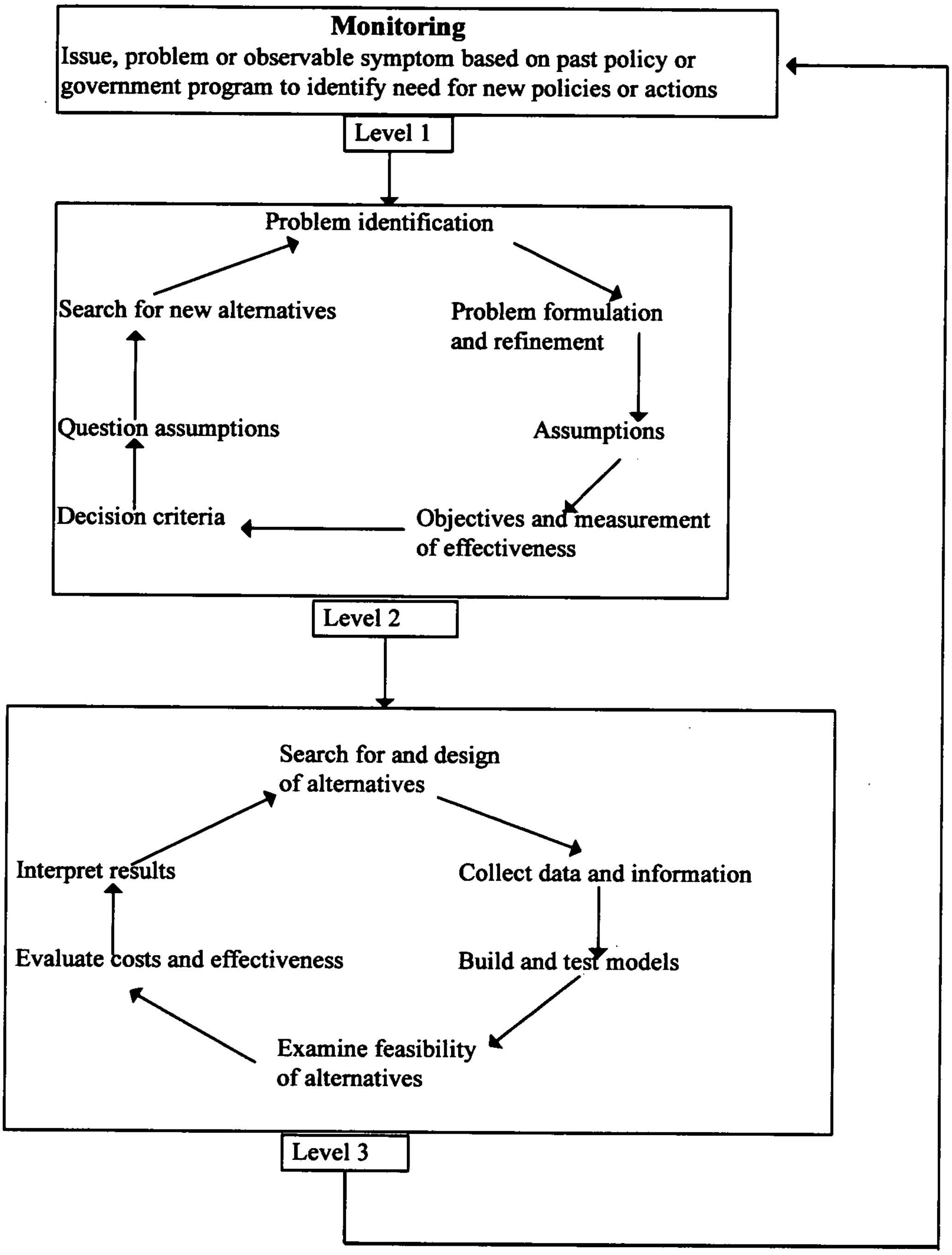


Fig.2.2 Paradigm for policy analysis using GIS (Calkins, 1991)

Chuvieco (1993) also uses LP to optimise spatial distribution of resources and as a guide for the integration of variables. Hastings and Clark (1991) explain the potentials for wide application of GIS in Africa. The increasing usefulness of GIS in planning land use and resource management in Africa and other developing countries is further illustrated by examples such as Taylor (1991), Nkambwe (1991) and ISLtd & DGUL (1996).

For the reforestation policy problem, GIS and mathematical programming are the main techniques used to analyse the distribution of resources, evaluate potential land use alternatives and assess the opportunity costs associated with variation of policy goals and priorities. Despite the fact that applying GIS in Africa still represents what Hastings and Clark (1991) called a challenge influenced by history, culture, politics economics, needs and resources, there is evident need to explore its application to aid planning and decision making.

2.2 Traditional Mathematical Programming methods: definition, scope and limitations

Reforestation Strategy represents what Norton and Schiefer (1980) refer to as decision problems in which policy bodies attempt to influence the economic pattern of agricultural activities by restricting decision possibilities. In this case, introduction of the tree component in the farming systems is determined by individual farming units who are allowed a certain degree of free choice subject to economic and technological constraints.

Policy makers have to forecast farmers reactions to the policy or strategy and select an adequate combination of potential options given policy goals and constraints and the conditional forecast of outcome which is a central issue in realistic policy planning (Norton and Schiefer, 1980). These authors state that econometric models are useful for solving forecast problems since they extract the maximum amount of information out of statistical data and provide indicators on the reliability of the estimates. However, they also list four main disadvantages. First, there are rarely enough degrees of freedom to estimate cross-price elasticity measuring the interrelationships between production levels of different crops. Second, parameter estimates are unlikely to be applicable for analysis of policy changes that depart from historical trends which is in fact the case of the current problem in which the impact of the participatory Reforestation Strategy is to be analysed. Moxey *et al* (1995) also stress that econometric models are unsuited to project situations where production conditions do not follow historically observed data or where it is necessary to predict spatial distribution of land use and land use changes. Third, econometric models do not consider inequality constraints such as seasonal land and labour restraints and, finally, they do not supply complementary information on movement of other variables of interest.

Statistical information is not always available for agriculture and forestry planning in Mozambique. For example, volumes and values of wood production, trading, and contribution to GDP for the same year are different when collected from the National Directorate of Forestry and Wildlife or from the National Planning Commission. It is, therefore, not easy to decide on the best information source. Planning is a way of forecasting future performance when there is certain degree of uncertainty in its realisation. However, if the intrinsic uncertainty of the situation modelled is coupled with data scarcity, unreliability and discrepancy, then the outcome of planning is likely to be unreasonably questionable.

Econometric models, therefore, are unlikely to address the current rural land use planning problem. However, there is a need to provide decision support information to policy makers to minimise the risk of adverse outcomes accruing to farmers due to drought or structural adjustment policies. This may have a long term impact when the policy or strategy involves the introduction of perennial crops and negative outcomes may not be assessed until it is too late. It is not appropriate either to perpetuate the situation where, according to Mucavele (1994) Mozambique most often relies on common sense to obtain micro and macro indicators for planning and policy formulation (due to high cost of collecting and keeping government statistics) when production and consumption policies are not even known by the majority of policy makers. An alternative policy analysis tool must be provided. Mucavele

(1994) also agrees that mathematical programming is one of the best tools to monitor data collection and evaluate factors affecting agriculture. This conforms with earlier observation by Hazell and Norton (1986) who stated that developing models, in data scarce situations gives impetus and help towards setting priorities for data collection.

Mathematical programming (MP) encompasses a set of analytical techniques which optimise particular objectives subject to specified constraints on resources allocated to alternative activities (Warner, 1983). Techniques include linear and non-linear functions, and one or more goals, expressed in the same or different units.

Linear Programming (LP) is one of the MP techniques used to solve optimisation problems using the simplex method developed by G. Dantzig in 1947 (Winston, 1995). Hazell and Norton (1986) define LP methods as a way of determining a feasible combination of farm enterprises with respect to a set of fixed resources. The model can be represented as:

$$\text{Maximise } Z = \sum_{j=1}^{n} C_j X_j \qquad 2.1$$

Subject to

$$\sum_{j=1}^{n} a_{ij} X_j \leq b_i, \text{ all } i=1 \text{ to } m \qquad 2.2$$

and

$$X_j \geq 0, \text{ all } j= 1 \text{ to } n \qquad 2.3$$

where,

Z = the objective function

X_j = level of the j^{th} farm activity

C_j = forecasted gross margin per unit of j^{th} activity

a_{ij} = quantity of the i^{th} resources required to produce a unit of j^{th} activity

b_i = amount of the i^{th} resource available

n = number of possible activities

m = number of resource constraints

To apply LP methods in planning, a number of assumptions have to be satisfied (Warner, 1983; Hazel and Norton, 1986; Winston, 1995):

- the objective function has to be maximisation or minimisation (optimisation)
- at least one constraint should have a nonzero right-hand side
- the number of activities and constraints within which the solution n is sought should be finite
- c_j, a_{ij} and b_i coefficients should be known with certainty (determinism)
- the decision variables should be continuous (continuity)
- all units of same resources and activities should be identical (homogeneity)
- contribution to the objective function from each decision variable should be independent (additivity)
- contribution to the objective function from each decision variable has to be proportional to the value of decision variables (proportionality).

There are some criticisms on the LP regarding, for instance, the fact that it considers only one objective and the assumed certainty of knowledge of coefficients which is not always possible. Furthermore, the optimum solution is only applicable for short run planning and it is simply a guide for long run planning rather than a prescribed plan. This is due to the dynamic nature of certain assumptions as well as demand patterns and prices. In addition, when a large number of constraints and variables are included, interpretation of the results becomes expensive and difficult (Warner, 1983).

Dent *et al* (1986) also recognised that despite the fact that LP has been proven to be a useful planning technique in the majority of the developed countries by generating valuable information for the decision maker, it was not being routinely applied as a planning aid. To the limitations mentioned by Warner, Dent *et al* (1986) include scarcity of planning data which can be minimised through sensitivity analysis, high costs of planning applications, and above all, the authors point out the main possible shortcomings in Mozambique, i.e., the limited availability of personnel with appropriate skills and lack of awareness among potential users and demand for planning assistance. However, they also highlight the fact that LP is a methodical, flexible and powerful planning technique which can be cost-effective when applied for representative plans of a similar group of farms. Subsequently, extension officers could modify the plans for individual farms. This may be further enhanced if LP is linked to computer assisted tableau construction and result reporting.

The additivity and proportionality assumptions are essential for the LP problem to represent real life situations (Winston, 1995), because they define linearity of the problem which implies that the aggregate whole farm production function relating value of Z to fixed resources, b, has constant returns to scale, hence satisfying Euler's Theorem (Hazel and Norton, 1986). These authors also state that early applications of LP methods assuming profit maximising behaviour, a single period planning horizon and certain environment, did not deal with planning problems realistically, hence the need to introduce some flexibility in the model without violating the basic assumptions. For example, piecewise linear approximation can be used for non-linear relations, dynamic specifications relax fixedness. Determinism can be relaxed by applying methods to model stochastic c_j, a_{ij} and b_i coefficients and incorporate less perfectly inelastic input supplies. In addition, activities defining mixed enterprises can relax the additivity requirement and permit joint production, complementary and supplementary relationships between crops. This is of particular relevance in the subsistence farming system in Maputo, and Mozambique in general, where mixed cropping is a common practice and an adequate modelling framework should address the issue accordingly.

Rural land use planning is multiobjective and multidisciplinary in nature, and includes subject areas such as forestry, wildlife, agriculture, economics and animal husbandry. Thus, the planning methodology should integrate these subjects in order to provide sound alternatives both from the point of view of the farmer and the regional planner. This suggests that any technique selected should deal with the real problems as closely as possible: scarce resources, several objectives expressed in different units.

All levels of organisation of society, whether at farm, regional or national levels, decision makers (DM) have to deal with a range of often conflicting objectives and they have to make trade-offs amongst them. Hence, DMs look for a compromise result. These trade-offs represents, according to Romero and Rehman (1989), a measure of an opportunity cost, or the value foregone by the DM for not selecting the next best alternative presented to him by the analyst.

In general, Mozambican farmers face problems like limited and low productive land, lack of even basic agricultural tools, poor quality seed, low income levels, no water, no health or education facilities, drought and subsequent reduction in animal grazing areas. Although there is a difference from one district to another in terms of the intensity of these problems, the common line is that the rural people are living in precarious situations that urge intervention. Farm goals are thus likely to be quite diverse incorporating: increased profit from the whole system; the possibility of cropping a larger area to meet food demand; increased land productivity; food security; the availability of wood products and of land for planting trees to supply both firewood and construction material demands; employment; minimum use of casual labour, and other aspects deemed important by the farmers. In fact, the actual number of objectives and tolerable deviations (negative or positive) will depend on the specific farmer's decision environment.

Furthermore, the same set of goals may be ranked differently according to the level at which the decision is made. Individual preferences hardly coincide with government's preferences. At the regional level represented by the Provincial Directorate of Agriculture, particularly the Provincial Services of Forestry and Wildlife, are responsible for the implementation of the policy and strategies designed at National level. As far as social forestry is concerned, there is a need for more co-ordinated work within the province between the agriculture and forestry departments. This is important in order to work towards the efficient use of resources.

The major regional objectives of the Reforestation Strategy is to reduce the deforestation rate, simultaneously expanding the forest resources in order to meet the rural and urban demand for wood and food, conserving the natural woodland and to avoid the erosion problem caused by deforestation.

These may create a conflict between regional institutions and the farmers because of the different attitudes towards tree planting. For example, farmers may be concerned with possible reduction of land available for crop production, of the extra time needed to be allocated for planting and managing trees, etc. These issues have to be addressed at the planning stage of social forestry interventions so as to forecast the possible rate of adoption. Even though there are these potential conflicts, it is clear that both are aiming for satisfaction of basic human needs and improvement of social conditions. Adding to that, the regional planners' long term objective should be a more sustainable land use system. Therefore, there should be a way of combining both interests and making trade-offs to evaluate the opportunity costs that each decision level may incur if some of its goals are foregone.

It is clear that decision makers in such situations have particular interest in having trade-offs among alternative farm plans and objectives instead of optimum solutions. As Dent & Jones (1993) pointed out, the advances of social science are questioning the validity of traditional mathematical programming, because as observed by Hazell and Norton (1986), it is difficult to formulate household models in which farmers goals are summarised as a single utility maximisation problem. Linear Programming (LP) also failed to include non monetary expressed objectives. Dent & Jones (1993) point out that despite generating a mathematically optimum solution, a single-criterion optimisation does not guarantee a realistic or correct representation of the decision making problem and an attempt to improve their effectiveness as well as working towards a more realistic model of the phenomenon under consideration is essential. Therefore, it is prominent to develop a planning methodology which takes into account the multiobjective and multidimensional natures inherent to the decision making process in land use planning.

2.3 Multiple Criteria Decision Making (MCDM) methods

2.3.1 Concept

Multiple criteria decision making (MCDM) methods are planning approaches which depart from the traditional practice of optimisation of one objective to more realistic approaches accounting for several objectives associated with decision making process. Their application can be as simple as selection of one objective to be maximised while the others are held as inequality constraints (Hazell and Norton, 1986) or more complex in which case any of the methods discussed in this section have to be used.

Cohon (1978) recognised that multiobjective approaches imply explicit consideration of value judgement implied in single objective planning approaches and it assigns adequate roles to analysts and decision makers. While the first generates alternative and objective trade-offs, the second, makes value judgement concerning the relative importance of the goals. Rae (1994) also emphasises the difference between goals and objectives as the fact that goals state a specific attribute level or target to be achieved. Moreover, goals differ from constraints because they represent desires or aspiration levels of the decision maker which may or may not be achieved, whereas constraints must be satisfied to secure feasible solutions (Romero, 1991).

As explained earlier, a bottom-up planning approach has been adopted in order to incorporate the goals at the two planning levels (farm and region) intrinsic to the problem under consideration. The aim is to offer a co-ordination platform between the two planning levels and provide information to facilitate the decision making process.

Forestry and agriculture are complex systems. Besides involving biological processes, they respectively produce a variety of products - fuelwood, timber for construction and other uses, consumption and cash agricultural crops, livestock, fodder, etc. Forests can also be planted simply for environmental purposes such as erosion control. Furthermore, forestry and agriculture involve the use of scarce resources such as land and labour. Shifting these resources from one land use alternative to another can only be justified if it is cost effective. So, it is necessary to apply techniques that will measure the trade-offs between DM's objectives and facilitate rational decision-making. Subsequently, DMs have to consider not only economic, but also social and environmental goals.

Kazana (1988), states that MCDM starts with the definition of 'best' which differs in meaning for each individual in society (its main distinction from LP). For example, while one farmer may be interested in maximising the production of cash crops, another may be interested in food security for his/her family. Preferences differ more as the planning goes from the farm level needs and wants, to the policy or DM at regional and national levels. Thus, there is no one best solution when dealing with real life or multiple objectives problems. Nevertheless, a compromise solution can be obtained.

Although MCDM methods have a potential to deal with these problems, it is important to stress that they are not applicable in all situations. Each method has its own limitations including the amount of data it requires, the size of the problems it is able to handle, and its computational work and assumptions. This illustrates that in selecting a research methodology, the analyst has to consider its suitability or its cost-effectiveness to solve a particular problem (Veloso, 1990 quoting McGregor, 1986).

One of the aspects of suitability of MCDM is the data availability, its quality and the time necessary to collect it. This is an important issue which may compromise any action in agroforestry research in Mozambique. Most farmers are subsistence land users and they have no tradition of keeping records on their activities and performance. Therefore, identifying a mechanism to elicit sufficient information for planning is an important stage of the development of a decision support tool.

2.3.2 Classification of MCDM methods and potential role in social forestry

There are several MCDM methods (Figure 2.3 and 2.4) which have been used for a number of decades in planning and they are divided into mainly two decision making categories: the multiple attribute and multiple objective decision making approaches. Multiple attribute decision making methods (MADM) are based on ordering a finite set of alternatives using a multi-criteria ranking system set up according to the DM's preferences.

One of the limitations preventing wide application of MADM, at least in agricultural systems, is their theoretical and empirical difficulties including rigid assumptions about the attribute's interdependence and independence (Rehman & Romero, 1993). Sharma (1990) also points out that MADM do not provide opportunity cost information, and require a large number of value judgements from the DM. From the point of view of agriculture and forestry this is considerably important, because the major resources (land and labour) are scarce and the cost associated with any decision should be assessed. Therefore, a method offering only a range of alternatives without analysing the value foregone from choosing one, instead of any of the other options, fails to account realistically for the problem.

However, the elimination and choice translating algorithm (ELECTRE) is an approach that minimises the limitation regarding dependence of variables. The method evaluates the level of fulfilment resulting from a certain choice (concordance) or the level of dissatisfaction caused by the exclusion of other alternatives (discordance). These levels are estimated using the 'payoff' matrix and relative weights. Rosato & Stellin (1993) contrasted this method with the Weighted Average Method (WAM) in territorial management of the Caorle and Bibione areas. They pointed out the superiority of the ELECTRE in terms of better utilisation of the payoff matrix and weights information. However, the difficulty associated with certainty of obtaining weights for discordance and concordance could not answer the question of preferable alternatives when varying the weights, the WAM was then used to resolve the problem. This illustrates the difficulty of selecting and identifying a suitable method for a decision making problem: this is itself a problem solving process.

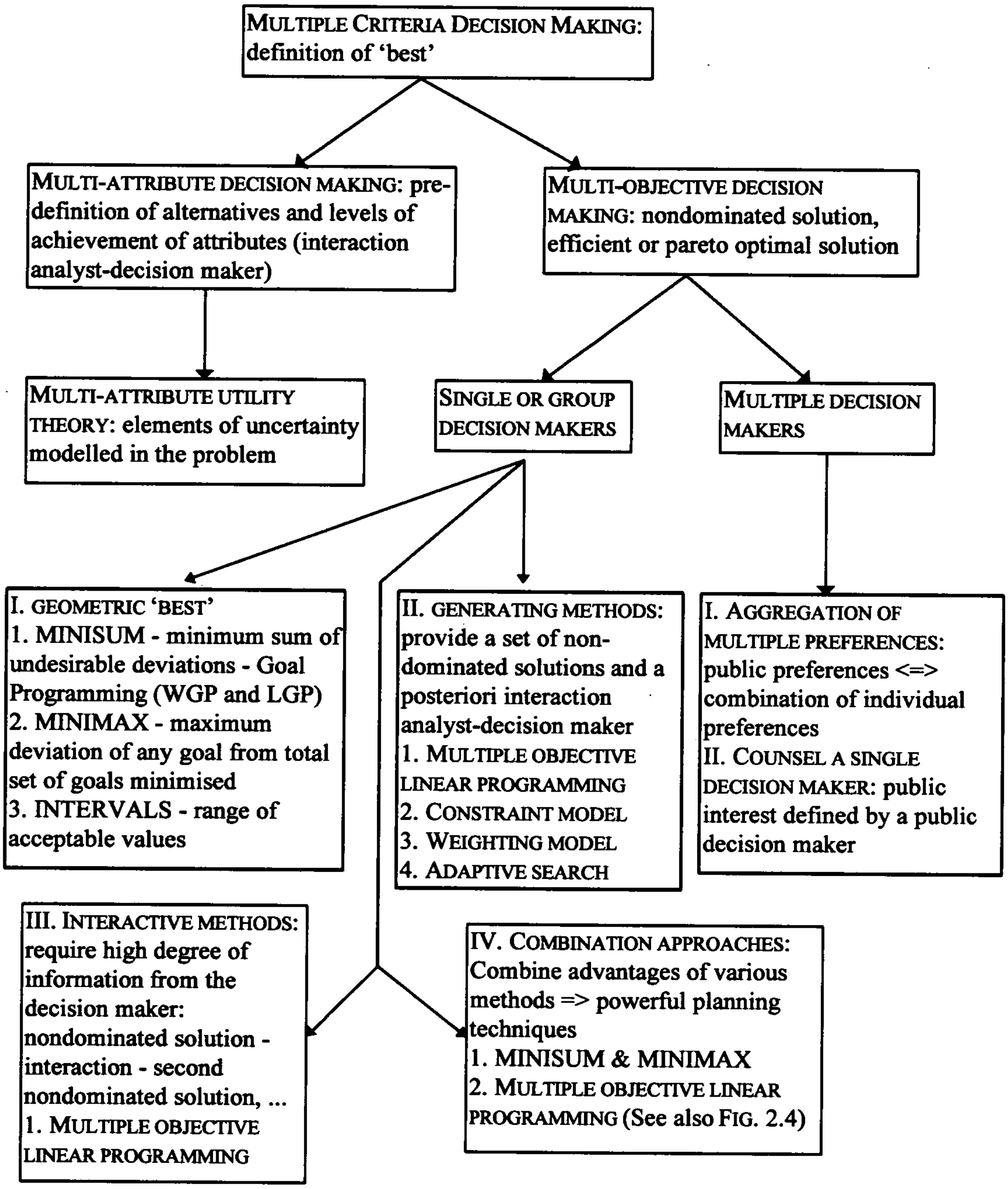


Fig.2.3 Multiple criteria decision-making methods - adapted from Kazana (1988)

The second category, multi-objective decision making methods (MODM) includes four methods as shown in (Figure 2.3). The methods essentially generate alternatives by building a model which incorporates a set of decision variables, constraints and objectives. The result of the interaction between constraints aids rational decision making. These methods also have a number of advantages and disadvantages that should be born in mind in their application. Romero & Rehman (1989) emphasise the size of the problem or number of attributes as determinant for the approach to be adopted in agricultural planning.

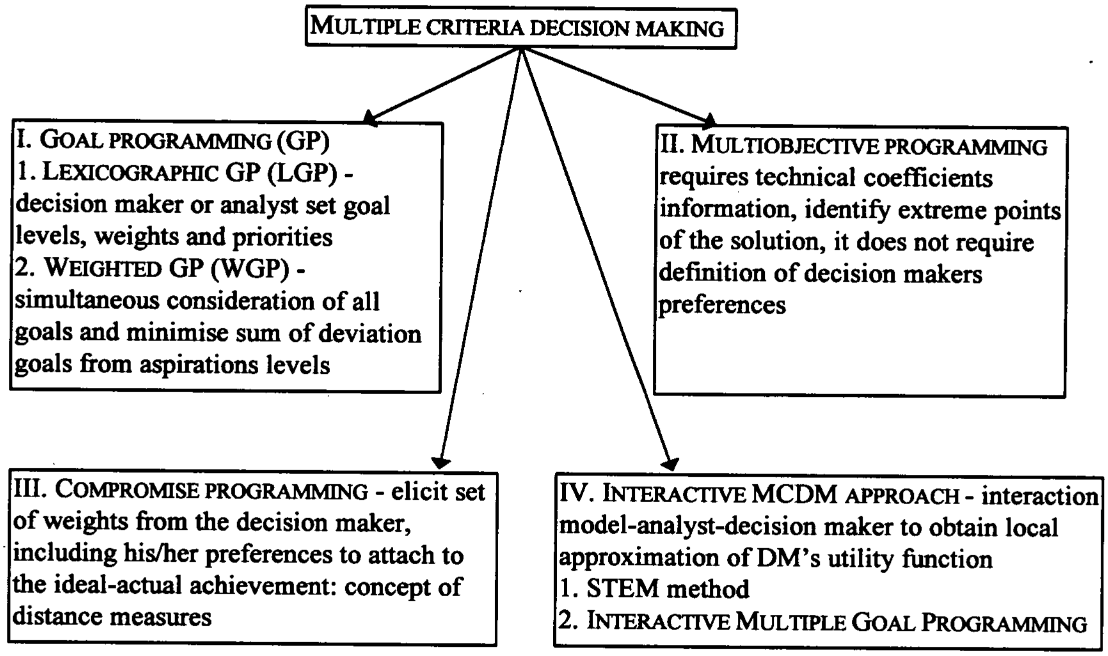


Fig.2.4 Another MCDM classification including multiobjective programming and compromise programming.

1. Single or group decision maker methods (Figure 2.3)

a) Methods based on the Geometric Definition of Best

MINIMAX is also considered a fuzzy approach generating method whose advantages are flexibility in generating satisfactory alternatives, specifying the range of different solutions as well as expressing the interval of target levels for each goal (Mendoza & Sprouse, 1989). The methods are classified as regular, selective, additive and weighted and their general formulation is as follows:

$$\text{Max } \lambda$$

$$\text{S.T. } (S^u - S^l)\,\lambda + \sum_{j \in J} X_j < S^u \tag{2.4}$$

$$-(Z_k^{\,o} - Z_k^{\,P})\,\lambda + Z_k(x) > Z_k^{\,P};\ k = 1,2, \ldots .p \tag{2.5}$$

$$x \in X \tag{2.6}$$

where,

S^l and S^u are the lowest and highest levels of the surrogate measure of difference between two generated solutions

j is the index of all basic variables

Z^o is the optimistic target value of the objective k

Z^P is the respective pessimistic target value

Z^o and Z^P should be based on initial estimates or *a priori* analysis.

The regular MINIMAX (model 1) generates maximally different and simultaneously satisfactory alternatives. The selective method (model 2) provides the analyst or DM with a set of decision variables to choose from maximising the probability of including the preferred ones in the generated solution. On the other hand, the additive method (model 3) has the same principle as goal programming, and it is considered as a version of fuzzy GP. Finally, the weighted method (model 4) is considered as hybrid of the regular and additive models, where the membership functions are weighted.

An example of an application of forestry planning in fuzzy environmental decision making is discussed by Mendoza & Sprouse (1989). They specify model 2 in a multiple use forest planning situation where the goals are to maximise economic return, the area suitable for wildlife habitat and the area for non-monetarized semiprimitive recreation. This is a clear example of a potential conflict between economic, environmental and social goals that a forest planner has to deal with and reach a compromise solution.

MINISUM, has relatively more examples of application in natural resource planning. Its underlying principle is the minimisation of undesired deviations (under or overachievement) from goal levels. Goal Programming (GP) represents this method and according to Rehman & Romero (1993), the DM sets targets aiming for minimisation of deviations instead of optimising a set of objectives. This method is one of the oldest approaches of MCDM (Romero, 1991) and was introduced by Charnes *et al* in 1955. Rehman and Romero (1989) state that GP does not necessarily produce a pareto optimum solution. Therefore, it is regarded as a model that operationalizes the Simonian approach of 'satisfaction' to the fulfilment of the DM's objectives.

GP can be applied for a single goal problem, for multiple goals and subgoals, even in a situation where these are incompatible and incommensurable (Barlett, 1976). This introduces an important advantage since not all goals in rural land use planning or indeed in the Reforestation Strategy are measurable in monetary units alone. For example, conservation of wildlife or water resources or minimisation of erosion or change on landscape that may result from tree planting are not always readily expressed in monetary terms.

Despite the difficulty in gathering information related to goal levels and of setting weights and priorities in the agricultural sector at the family level, Weldu (1992), for example, used GP at farm level integrated land use planning in a semi-arid (Machakos) environment. He pointed out the need for finding adequate information as well as understanding the major goals, weights and priorities set by the farmers as still an important aspect to be considered in the application of GP. In Mozambique, and presumably in many other countries, even published information can be somewhat contradictory and since there is limited research in crop simulation models, forestry data and the impact of combining multipurpose trees and crops has still to be thoroughly identified before reliable data to evaluate the effect of competition and interaction between crops can be incorporated into the planning models.

Romero (1991) considers that important steps in defining a GP model starts with the establishment of attributes, determination of targets and introduction of deviations or the number of units in which the i^{th} goal can be under or overachieved. When both positive and negative deviations are equal to zero, then the goal has been exactly satisfied. If the goal is expressed as

$$f_i(x) + n_i - p_i = b_i \qquad 2.7$$

then, when $f_i(x) > b_i$, the objective is to minimise n_i,

$f_i(x) < b_i$, the objective is to minimise p_i,

and $f_i(x) = b_i$, minimisation of both positive and negative deviations is desirable.

GP includes two groups of methods: lexicographic goal programming (LGP) and weighted goal programming (WGP) (Figures 2.3 & 2.4).

LGP assumes that the DM can articulate pre-emptive or absolute weights to be attached to goals' achievement as well as assign respective priorities. If Q_j priority is preferred to priority Q_k, this will be maintained even if bigger multipliers are associated to Q_k. Therefore, the fulfilment of goals in a specific priority Q_j is immeasurably preferred to the fulfilment of any other goals at lower priorities (Romero, 1991). Hence the fact that the solving process starts from the higher priority goals. The immediate disadvantage of this is the fact that the last priority goals tend to be redundant, in other words, they are not included in the optimal solution. The model of LGP is to find a lexicographic minimum of the objective a:

$$\text{Lex. min. } a = [h_1(n, p), h_2(n, p), \ldots\ldots h_k(n, p)] \qquad 2.8$$

$$\text{s.t.} \quad f_i(x) + n_i - p_i = b_i \qquad 2.9$$

$$x \in F \qquad 2.10$$

$$x \geq 0,\ n \geq 0,\ p \geq 0 \qquad 2.11$$

where,

n_i = negative deviational variable attached to the attribute i^{th}

p_i = positive deviational variable attached to the i^{th} attribute

h_k = k^{th} priority involving a certain combination of the vectors n and p

$f_i(x)$ = mathematical expression of the i^{th} attribute

b_i = target for the i^{th} attribute

x = vector of the decision variables

F = feasible set or region satisfying rigid constraints

a = lexicographic optimisation process

In contrast, WGP considers simultaneously all the goals embodied in a composite objective function minimising the sum of all unwanted deviations from the aspiration of the DM. The weights attached to the goals are relative rather than absolute as in LGP (Romero, 1991). Also the variables in the objective function represent percentage deviations from targets inasmuch as goals are measured in different units. Hence, absolute deviations produce a meaningless and biased solution due to the assignment of artificial extra weight to goals with higher targets (Romero and Rehman, 1989). The WGP model can be represented as:

$$\text{Min} \quad \sum_{i=1}^{k} (\alpha_i n_i + \beta_i p_i) \qquad 2.12$$

$$\text{s.t.} \quad f_i(x) + n_i - p_i = b_i \qquad 2.13$$

$$x \in F \qquad 2.14$$

$$x \geq 0,\ n \geq 0,\ p \geq 0 \qquad 2.15$$

where,

α_i = relative weight attached to negative deviations (n_i) and, $\alpha_i > 0$

β_i = relative weight attached to positive deviations (p_i) and $\beta_i > 0$

One important aspect to note in this procedure is that the priorities elicited from the decision makers have to be expressed in the form of weights. This is important in the case of the regional planning level where many decision makers are involved at national, provincial, district and local levels. Goals and priorities from each level have to be drawn out and it is fundamental to adopt a procedure to encapsulate the different views. As Yoon and Hwang (1995) state, the role of weights is to express the importance of each attribute relative to the others. These authors describe two methods of derivation of weights: from ranks and from ratio ratings.

a) Derivation of weights from ranks

This method consists of arrangement of attributes in a rank order starting from the most important which is assigned value 1, to the least important assigned *n*. Then the cardinal weights can be obtained from any of the following formulas.

$$w_j = (1/r_j)/(\sum_{k=1}^{n} 1/r_k) \qquad 2.16$$

or

$$w_j = (n - r_j + 1)/\sum_{k=1}^{n}(n - r_k + 1) \qquad 2.17$$

where,

r_j = rank of the j^{th} attribute

When the first formula is used the ranks obtained are called rank reciprocal weights, whereas by the second they are termed rank sum weights.

b) Ratio weighting

This method consists of the comparison of two attributes at a time and requires elicitation of the decision makers' preference ratio between the two. The question asked is 'how many times is X_i attribute more important than attribute X_j?'. This means that (n-1) pairwise comparisons have to be made in order to establish the relative importance of the n attributes. Yoon and Hwang (1995) stress that such comparisons may have a high degree of inconsistencies in human judgement, which mean that approaches to reduce such disparities have to be used. However, applying this method on the analysis of the Reforestation Strategy, may be ambiguous. The reason being that planners envisage to satisfy the market while ensuring environmental protection. Therefore, asking whether conservation is more preferable than provision of wood for rural and urban consumers may produce unrealistic and artificial answers without practical use.

One of the strong criticisms of the GP is that it requires a large amount of information from the DM (targets, weights, priorities). Nevertheless, Rehman &

Romero (1993), consider that such criticisms have no substantial effect since sensitivity analysis can be used to generate information and reduce the amount of input from the DM, while allowing him/her to make rational decisions. An illustration of such application is shown by Njiti and Sharpe (1994). Furthermore, the analyst-DM interactive approach can improve the reliability of the information and provide satisfactory solutions.

GP has the potential to offer a 'best' strategy for combining activities in a multiobjective planning framework. It is a method capable of handling multiple objectives and dealing with the multiple disciplines involved in planning real world problems associated with land use. Piech and Rehman (1993), Berbel (1992) and Berbel *et al* (1992) discuss the usefulness of various MCDM techniques including GP to agricultural and environmental planning. Moreover, Howard (1991) states that MCDM in general are proficient for poorly-structured problems that encompass many of the more complex problems currently affecting forestry and the author recommends techniques to be applied in the different forestry problems. Also Krawiec *et al* (1991) compare the results provided by different MCDM techniques to a simulated multipurpose forestry farm in NE Tuscany, Italy and observes that WGP gave extreme results between options, MINIMAX GP and IMPG gave similar and more balanced results whereas STEM method appeared more suitable for solving forest management problems. Specific applications of GP include irrigation systems in farm planning (Romero & Rehman, 1984), water allocation in New Zealand (McGregor, 1986), crop farm development in Brazil (Veloso, 1990), farm level integrated land use in Machakos (Weldu, 1992); modelling land use options for smallholder farms in Zambia (Holden, 1993 and Nkowani, 1996); application of WGP to predict resource allocation of farm in irrigated land of Tauste, Spain (Zekri and Romero, 1992).

b) Generating Methods

Within these methods the analyst provides a set of nondominated solutions without DM's goal preference information (Bare & Mendoza, 1988). Afterwards, the DM gives a preference structure to obtain the best compromise solution. Some of the widely known generating techniques are multiple objective linear programming (MOLP), weighting, constraint, noninferior set estimation and the adaptive search method (Kazana, 1988).

In agriculture, the analyst can collect information about specific land use systems. For example, the crop mixture and the likely yield and costs on the basis of which adequate alternatives may be offered to the DM. Nevertheless, consistency on the DM's judgement is determinant of the outcome, but it is difficult to assure such consistency at regional and national decision making levels and it can be critical at the farm level.

c) Interactive methods

The rationale of these methods is based on a progressive articulation of DM's preferences, generation of non-dominated solution by the analyst and subsequent DM's reaction and input. As illustrated in the diagram (Figure 2.5) the analyst has a role of transmitting the message from the model to the DM, who simply states his/her preferences as to the solution instead of eliciting weights to attach to each goal.

Fig.2.5 Interactive decision making process

The DM can provide three types of information: one is the articulation of the values of his local trade-offs among goals, however the DM may not be committed to assigning specific values; he/she can accept a certain set of trade-offs or not; or another possibility is to seek the opinion of the DM's as to a particular plan, if he/she suggests any improvement when not satisfied with the feasible efficient solution.

These methods require a substantial amount of DM's input information, which suggests problems in the application of the methods. In the case of farm modelling for the Reforestation Strategy in Mozambique, this is even more cumbersome because of dealing with farmers with little or no education at all. Consequently, there would be the need for an extremely simplified language to explain the model output as well as eliciting its rational judgement by the DM (subsistence farmers).

Romero & Rehman (1989) state that the information required is modest as the objective of the approach is to obtain an approximate utility function for the DM or the point of maximum utility. However, mathematical sophistication of some of the models constitutes the major limitation in their application. Some of the interactive methods are the STEM, Zionts and Wallenius (ZW), and interactive multiple goal programming (IMGP).

The STEM method was proposed by Benayoun *et al* (1971) and can be considered perhaps the oldest of interactive approaches (Romero & Rehman, 1989). It has two steps: calculation and decision. The first derives a pay-off matrix to obtain the ideal and anti-ideal values of each goal followed by an approximation of the solution closest to the ideal point. The decision follows a successive presentation of alternative solutions and the indication of the attributes to be worsened in order to improve others, leads to a satisfaction of the DM's preferences.

Bare & Mendoza (1988) illustrate through an example on land use planning, an application of MOLP (STEM method) on forest land management planning. The major advantage they pointed out is that the method can deal with the usual size of problems in that field and generate a solution more close to the ideal as aimed at by the DM.

Unlike the STEM method where decision making seems difficult, ZW has a rather complex calculation which facilitates decision making. The calculation involves a solution of a LP problem to optimise a linear composite function where the goals under consideration are assigned equal weights. After this process, non-basic variables are divided into efficient and non-efficient variables. The latter leads to an adjacent extreme efficient point. The DM then decides on the acceptability of the trade-offs. This method's rationale is that the convergence of the method is ensured, because at least one extreme point is eliminated in each interaction within a finite number of extreme points. It assumes that the DM's utility function is a linear combination of q concave objectives whose weights are not explicitly known.

Finally, the IMGP is a relatively more recent application and it was proposed by Nijkamp & Spronk in 1980. The general aim is to obtain aspiration levels from the decision maker interactively. It starts with the derivation of the 'potency matrix' whose first row is composed by the ideal or optimum points, whereas the second row contains the anti-ideal points; each column represents the interval of definition of targets of the attributes. Then the interaction starts and the shift from one potency matrix to another is considered the opportunity cost among the alternative solutions, for which the DM indicates the attributes to be improved.

From the above exposition, the difficulty of using these models comes out despite their desirability. STEM's major advantages are the operational simplicity, not requiring an anticipated generation of efficient set, non restrictive assumptions as to DM's preferences or utility functions apart from partially defining his local preferences at each step during the decision process. Its major weakness is the requirement of intensive analyst-DM interaction.

The ZW approach is the opposite of STEM as it has a very complex calculation phase where several auxiliary LP problems have to be solved. Furthermore, it considers that the DM makes choices consistent with an unknown and implicit utility function which brings a major decision process when the DM has to deal with many trade-offs.

The IMGP is considered by Rehman & Romero (1993) to be relatively simple both in terms of the information required and calculation phase. Nevertheless, it also presents difficulties when it comes to the decision phase where the DM has to deal with a large number of questions, increasing the possibility of inconsistent answers.

These methods may also be costly both in monetary terms and time. For instance, in agricultural planning, the farmer is the DM and he/she may be in a difficult access location, thus implying high costs of transport. Despite representing a way forward on the bottom-up planning approach which stresses the importance of incorporating farm level models into the regional models, its application will depend much on the cost compared with the usefulness of the information and the solution obtained. Furthermore, aspects like culture, education, mathematical abilities are likely to influence both the model and the analyst in generating the solution and particularly the interaction between analyst and DM.

d) Combination approaches

Kazana (1988) points out some examples of combination of the MINISUM and MINIMAX approaches with generating techniques. Rehman & Romero (1993) extensively analyse GP, multiobjective programming (MOP) and compromise programming (CP) (Figure 2.4). MOP requires technical data concerning the constraints of the problem and its mathematical expression in the absence of the DM's knowledge. It looks for mutually exclusive solutions: nonefficient versus the feasible, efficient or pareto optimal solution. This is then expressed in economic terms through a production possibility frontier (2-3 objectives involved) which allows the identification of trade-offs between objectives.

On the other hand, computational problems make it impossible to determine a complete set of feasible solutions unless the problem is small. This contradicts the fact that MCDM aims to resolve problems which involve a relatively large number of conflicting objectives such as the potential goals of the Reforestation Strategy.

CP elicits from the DM a set of weights, preferences and the level of discrepancies between tolerable ideal and actual achievements. The rationale is that human preferences are usually close to an ideal point and the analysis should consist of defining the distance function between the two levels. They consider MOP as a first stage of generating efficient points and CP as the second stage where the DM sets the levels he/she is aiming for. The combination results in a powerful tool. However, further consideration is necessary: in order to avoid generation of an infinite number of points by MOP, filtering mitigation techniques can be used to produce a manageable and informative cluster of extreme points.

2. Multiple decision makers

The aggregation of multiple preferences is apparently adopted by democratic political systems, which supposedly take into consideration individual preferences in decision making.

However, methods which counsel a single decision maker assuming that public decision makers can define the public interest is the type of approach frequently adopted in Mozambique. This leads to top-down approach in planning: experience of negative impacts of such decisions, calls for a change when appropriate, and the need of a more participatory approach. In the agricultural and forestry sectors where the poor farmers are the potential beneficiaries or otherwise, they should be incorporated in the planning systems. This would hopefully reduce the frequency of failure of projects because of lack of adoption.

2.4 Some remarks

There has been increasing recognition that forestry and agriculture as well as animal production no longer have strict boundaries. Mendoza *et al* (1986) and Rehman & Romero (1993) consider agricultural systems as multidimensional (spatial and temporal) because they offer a number of products and services, and they depend on complex biological processes and managerial techniques. Furthermore, public and private interests are both likely to affect the decision process and can generate conflict in resource allocation.

In Mozambique, the population is concentrated in the coastal areas or around the cities because of its natural growth or displacement by the war. The resources face very competitive uses: land for agriculture, land for animal grazing, forest/savannah woodlands for collection of fuelwood and poles all of which contribute for their rapid depletion. For example, the household farming land in Maputo, the focus of this study, is 1-2 ha. A small scale study done in Maputo by Macucule & Bila (1991) in one of the northern districts (Marracuene) where the major agricultural crops are peanuts, maize and beans (in the dryland), has shown that the major source of fuelwood is gathered from the neighbouring woodlands (65%), whereas the second largest source are scattered trees (32%) in the agricultural fields. In contrast, construction wood is mainly purchased (61%). This means that any intervention in order to minimise the problem will have to consider several and conflicting goals from the farmer's point of view and planners point of view.

Planning of such a wide range of possible economic, social and environmental benefits and costs demands methods able to generate a solution which reflects farmer's preferences into a wider planning framework. Goal Programming seems applicable for this study in this respect. It is necessary to set the weighting (marginal trade-offs towards one objective to another - Goodman, 1984) for each goal, specify the level of achievement required and also the respective priorities. Sensitivity analysis of priorities, weightings and even change in goal levels, reduce the amount of interaction with the DM.

Another important aspect in the construction of a regional model is associated with the selection of representative farms or regions. This is necessary because it is impractical and infeasible to include every individual farm model in the regional planning framework (Hazel & Norton, 1986).Therefore, the authors add, there is a need for aggregation and minimisation of bias which may result from overstating resources when combined in proportions that are not available for each farm individually. Hazel & Norton (1986) further suggest a classification of farms in order to avoid such tendency. They propose the following rules: firstly, proportion according to resource endowment, that is, group the farms in size classes according to land-to-labour ratios; secondly, similar yields - for example classify the farms according to irrigation or non-irrigation, climate, soils, elevation, slope, etc. (all these factors will dictate a distinct output level); finally, according to similarity in technology, since this determines the predominant crops and the options available to the farm as to what to produce.

In the Mozambican, and particularly, in the Maputo situation, even at the subsistence farm level where the land does not exceed 2 ha, there may still be some differences. For example, having draft animals means a different farm welfare situation due to the possibility of increasing production. Or, whether the land is classified as alluvial or dryland; different soil types or nutrient composition will ultimately determine the crops that can be grown.

Integrated land use systems are associated with many elements of uncertainty such as climatic changes. The drought which affected most of the farms in Maputo and elsewhere during recent years, implies that the planned outcome of social forestry, may well be affected by those natural changes. Despite that, there is no doubt about the increasing demand for food and wood products. Therefore, linking GP and CP to transform the problem with multigoals into a compromise problem to deal with uncertainty may be an option (Romero & Rehman, 1989).

LP is a powerful tool which has helped foresters and agriculturists in planning. It provides the best allocation of resources in order to achieve an optimum profitability. In contrast, MCDM seems an even more powerful tool because by considering simultaneously several objectives, a more realistic analysis of the planning problems is provided. Therefore, such models are used in this study to elicit goals and make trade-offs between farmers' preferences, to incorporate farm models into the planning framework and to derive a more satisfactory solution at both levels.

CHAPTER 3

Farmers choice: potential Social Forestry alternatives

3.1 Risk in Social Forestry

From the discussion in Chapter 2, it seems that an integrated planning approach of rural development projects may help not only in minimising food and wood shortage, but also may create job opportunities and motivate people to work for their better welfare. Social forestry in general and in particular agroforestry, enables an integrated land use that suits the farmers' level of input scarcity (land, labour and capital) while providing a wide range of products and services. It is a measure which aims to provide food security, that is, financial and physical access to food, for all people, at all times. However, this depends on the reliability of production, sustainability and equity: people's access to supply (FAO, 1989). Sustainability of the land use system can be achieved when production objectives are combined with conservation measures of the resources on which production relies on, a condition for increasing productivity (Young, 1989).

However, every option towards rural development or at least to minimise the non fulfilment of basic human needs, is associated with a certain degree of risk due to the uncertainty of future events, both natural and manmade. Therefore, before analysing social forestry itself, it is first important to underline the general conceptualisation of risk and risk attitudes that farmers as decision makers, and representatives of the government or non government institutions as policy makers, will choose to take/avoid. Schaefer (1992) highlights the importance of risk analysis by quoting Hazell (1971) who says that the exclusion of risk from economic development planning and evaluation models is the major source of bias and overstatement of development analysis.

It is not possible to dismiss uncertainty concerning economic, technical and social aspects in planning, the socio-economic guidance of development projects cannot be a risk-free process, therefore the public decision makers have to take risks associated with economic or financial failure of projects (ODA, 1988). Although this may seem irrelevant because of the size of the targeted farmers, if social forestry is adopted in the provinces with high demand for firewood, surely in the long term this will impact on the economy of the country.

The incorporation of risk analysis at the planning stage of agroforestry is necessary because farmers in developing countries face great uncertainty and they are strongly risk averse (Lilieholm & Reeves, 1991). An example in Papua New Guinea (Anaman, 1993), stresses that risk analysis of the economic performance of projects is also necessary to deal with the impact of diversion of government funding to other areas of the economy at expense of on-going projects. These and other aspects, such as the possibility of selecting inadequate technology for a certain area, selection of inappropriate species, non adequate appreciation of the socio-economic situation (Gittinger, 1982), are important for the case of Maputo, and Mozambique in general, whose decision-making process operates in a very uncertain economic and political environment.

ODA (1988) and Price (1989) define uncertainty as a range of states of nature whose outcome can be estimated but the probability of that outcome is unknown. When the probability of any event is known, then the situation becomes a risky one. Fleisher (1990) goes beyond that by considering risk as a resolution of uncertainty (one action with more than one possible consequence) which is likely to affect the decision maker's well-being, because of its association with loss or gain. Fleisher also considers the components of decision problems under risk. These involve first the choice of alternatives. This issue will be of relevance when looking at the types of social forestry that can be selected in addition to the variety of possibilities of crop combinations over space and time with a range of potential outcomes.

Second, the set of possible events generated by human action. For example, the future direction of the policy legislation and how administrative officers will carry out program provision. Although it is unlikely that changes (elections) in government in Mozambique, may have an immediate impact on the food and energy crisis, it is important to consider that monetary and fiscal policy may change, in turn affecting rural development projects, either positively or negatively. Other aspects such as price stabilisation, subsidies and institutional arrangement of markets may also affect the outcome of social forestry projects designed with some assumptions about possible income sources for the farmers. Moreover, natural events, either rare natural disasters or weather instability also need consideration. Uncertainty about the rainfall in Maputo, will affect the possibility of obtaining the aimed gains from an integrated land use system but its analysis reduces the risk of overestimating the benefits.

Third, the probability associated with each event is not known, despite the knowledge of the states of nature as previously indicated. Fourth, the set of possible (although unwanted) consequences, for instance, the risk that tree arrangement may result in decreased agricultural crop yield because of competition (Marshall *et al* 1992; Kerkhof, 1990) which is not quite what is desired when taking the technology to the farmer.

Finally, the decision rule which should, according to Selley (1984), mainly include a selecting criterion reflecting the DM's goals, his attitude towards risk, a description of the alternatives, as well as the decision choice. The latter should be easy to understand and apply. According to the land available for cultivation and their priorities, farmers will be able to select technologies that are suitable for their conditions.

However, when making these selections, (Young, 1984) adds that three classes of decision rules apply: first, one requiring no probability information, second, called the safety-first rule, and third, the maximisation of expected utility. The first, requires consideration of action with the worse possible outcomes and to select the one whose worse outcome is less harmful. In the safety first model, the decision maker selects among distinct alternatives, satisfying first a preference for safety or risk minimisation, then following a profit oriented objective. The third requires definition of the decision maker's utility function which is dependant on expected income levels and their associated probability. Safety first is the rule applied in the model where the social forestry option chosen by the farmers (Chapter 4) suggests that they minimise the risk of crop yield loss possibly associated with intercropping. Therefore, there is potential that planting solely trees in separate land is likely to maximise income.

Whichever discussion rules apply, however, only three attitudes towards risk can be elicited. First, risk-aversion which comprehend individuals preferring less risky sources of income, i.e., those who forego possible gains to reduce the probability of loss (individual risk premium). Generally, it has been noted that farmers look only a few months ahead to the harvest period (Price, 1989). Thus, they may not be willing to accept a change of the traditional practices (risk aversion), because of the need for technology change, with unknown outcomes.

Second, risk preferres (or adopters) can be classified. In lay terms this refers to farmers who would not forego an opportunity to gain income for the fear of loss; they would take even the most risky alternatives. An example is given by Sidney & Kawdia (1991) in an article referring to a successful Kenyan farmer agroforester who planted more than 60 tree species by developing a seedling watering method (tin and stone). This enabled the farmer to plant during the dry season and prevent high evaporation. In this case the farmer took the risk and got the reward. However, adverse results, in other situations may be observed.

The third category comprises risk neutral individuals who tend to select the highest expected value alternatives independently of the distribution of the consequences.

Farmers are generally considered as risk averse agents (Babu & Rajasekaran, 1991; Lilieholm & Reeves, 1991 and many others), i.e., they are more likely to forego a possible increase in income to ensure less income variation (Oglethorpe, 1996). However, it is important to bear in mind that the same individual can have different attitudes towards risk in the presence of distinct circumstances. Farmers income levels, expectations (adaptive or rational), time interval investment and return or price forecasts may all create different problems for farmers when making land allocation decisions (Fleisher, 1990).

Land and tree ownership, as well as the distribution of the benefits, are crucial for the achievement of the purpose of social forestry objectives. For instance, a study in Ghana demonstrated that native land owners were more willing to adopt agroforestry systems than the migrant land tenants. The latter did not own land neither had they secure rights to use the land (Owusu, 1993). Babu & Rajasekaran (1991) studying risk aversion among farmers in irrigated and dry land areas in the South of India, found out that risk aversion decreased as the land holdings increased in size in both farming situations. Moreover, in irrigated farming, farmers took up more risky enterprises because *Leucaena* spp. supply green manure and farmers would increase the area of cash crops and reduce the area under vulgar grain. In dryland farming, the small farmers also took more risk and increased the area of cash crops as a result of introducing the legumes. The larger farmers allocated more land to cash crops than the smaller ones. For this, each situation/decision environment has to be accounted for accordingly.

The public sector will also express distinct attitudes towards integrated land use system risks resulting from price stabilisation, credit facilities and assistance programmes (Barry, 1984). For example, in Mozambique a farmer who may be willing to invest in farm forestry through a bank loan would face restrictions of the criteria of eligibility and high discount rates (43% in 1994 - Bank of Development) which may discourage the participation of the smallholder in a long term investment. Therefore, the National Directorate of Forestry and Wildlife faces an impasse in complying with macroeconomic policies which seem likely to reduce the benefit stream of reforestation to farmers and simultaneously encourage them as to the benefits of undertaking tree planting activities. The effect of the high discount rate is illustrated in Chapter 6. Thus, what measures would the public sector have to adopt in order to encourage the farmer to take the risk of change, while ensuring that public and private funds will be usefully applied?

Risk can cause losses if they lead to the inefficient allocation or misapplication of resources and, premiums are required by farmers to undertake the risk. Barry (1984) underlines that risk is not bad or good, but it has to be evaluated according to the benefits it may provide, and the cost of reducing it. This means that farmers have to weigh the potential welfare improvement if they successfully implement selected alternatives, and potential failure due to inadequate management of the system.

Once potential risks have been considered, choice can be made as to the type of social forestry which will be adopted: farm forestry, community forestry, village woodlots and agroforestry systems. It is important to stress that besides risk, market analysis is also one area which has been given little attention in farming system research. While there is evidence of research into production problems, the same observation can not be made as far as market research is concerned (Fleming, 1990). Whichever integrated land use option the community or individuals may choose, it is likely to be affected by the availability of transport to take the products from the farm gate to the market. Such facilities are little or even non-existent in most of the remote villages of Maputo. This means that there is a need for assessing the extent to which farmers can expect to generate cash income by finding a market for their surplus produce. The issue becomes even more important, because it may affect the definition of the beneficiaries of the project: farmers or traders. whilst the prices at the farm gate should ensure the generation of profit for the farmer, if a marketing channel is identified, the trader will ensure he also gets a beneficial return.

3.2 Social forestry options

i) Farm Forestry

Farm forestry is characterised by farmers growing trees, usually for cash, on their own land (Nair, 1989a). Nair also distinguishes two situations: one in which the farmer is resource-rich, hence more concerned about maximising profits, even if it means reducing labour inputs, low local supply of fuelwood and fodder, and depletion of the soil capacity to fulfil this objective. The other situation concerns resource-poor farmers with low-input systems, whose main objectives are to plant a small number of trees and get a better return for their investments. The author concludes that farm forestry should apply for the latter. Nevertheless, given the fact that there are industrial users of wood fuel in Maputo, who are financially capable of investing or taking a loan to develop this option, it also seems applicable for them. It would give them a sustainable wood supply, and for the country the benefit of natural woodland conservation and provision of jobs.

It was indicated in Chapter 1 that farmers prefer to grow fruit trees both as cash crops or for land tenure consolidation. Aiyelaagbe (1992) states that selection of the right fruit species can also provide fodder, poles, timber, germplasm conservation, fertility maintenance, cash for farmers with access to the market, and offer food security. More importantly, it strengthens land tenure in the remote areas. So, there is scope for successful integration of different tree components for efficient exploitation of the site.

Resource poor and rich farmers can be distinguished according to the crops they grow. While citrus crops, for instance, are present on the poorer farms, coconut predominate the wealthier farms, mainly because of land restrictions, and market facilities. This suggests that tests are needed for particular conditions of each location in Maputo to derive the best crop combination intervention, selection of species for eventual improvement of the current practices.

ii) Community forestry

Community forestry is a term given to the growing of trees on public or community land (Nair, 1989a). It can be a single large tree with religious or cultural value (Rocheleau *et al*, 1988). It is a practical approach to tackle problem of degradation of common lands, resulting from competing demand by the local people (Foley & Barnard, 1984).

In Maputo, natural woodlands and grasslands are common property with open access to the entire community. They provide a source of wood for fuel and construction as well as an important source of medicinal plants. In addition, they are places for traditional rituals and pastoral activities. If the rural people can share and manage these natural woodlands, they may participate in extension of the resources by planting community forestry. Rocheleau *et al* (1988), for example, states that although the traditional practices are not agroforestry, they can be used as communal demonstration places for production and cash generation.

Nair (1989a) considers community forestry as having a great potential to fulfil a wide range of community needs, but he recognises the difficulty in effectively designing and implementing them. The reason being that, the identification of real common interests is not straightforward, and there is a high possibility of creating differences among the villagers. It does not seem appropriate to think of similar results/impact, so farm stratification can help in addressing the problem accordingly. It is not possible to ensure an even distribution of resources, hence there will be merit in introducing technologies which have potential to diminish the poverty level, simultaneously benefiting those already enjoying a non critical standard of living.

Despite considerable difficulties, efficiency may be dependent on the area or number of households included in the program, and the objective of the plantation. For example, in zones where there are serious environmental problems, like sand dune movement in the coastal zones and others with risk of erosion, farmers may possibly be persuaded to collaborate. These are problems that do not affect a particular farmer but the community as a whole. An example of such common interest was seen in Swaziland (Study Tour, 1990) where erosion control is combined with production objectives. The community owned a sawmill which also provided jobs. Organisation of the community and responsibility for administration of the resources can prove this as better land use in particular conditions. Demand for poles is a common problem for farmers in the Maputo Province. Therefore, it would benefit all to embark on a community forestry programme rather than individual forests. This may be more advantageous for the farmer in terms of not reducing the area of agricultural land, efficient use of labour, sustainability of the systems and any associated multiplier effect. Some of the species may be *Casuarina* spp., *Cassia* *simaea*, *Eucalyptus* spp. and *Melia azadirach* which are found in Maputo. Ultimately their choice will depend on the farmers' objectives of the forestry: productive, protective, or both.

iii) Woodlots

Woodlots are tree plantations in blocks which may be defined as either of the above types. Nair (1989a) considers that these can make better use of marginal degraded land unsuitable for food production. The plantations can be in blocks or plot boundaries. This can be used to supply fuelwood, other wood materials, fodder or staple food for the village. Perhaps, as plots boundaries they can provide a communal space for animal rearing mainly during the cropping season preventing animal invasion to agricultural fields and consequent crop damage - which happens very often and creates conflicts among the villagers. This system would then be silvopastoral, one of the agroforestry systems to be considered later.

Combination of *Melia azedarach* woodlot with *Leucaena leucocephala* and annual crops in Paraguay, for example, has proven to be a successful alternative to traditional agriculture systems (Evans & Rombold, 1984). This is attributed to the fact that *Melia* is a fast growing tree, has a deep root system, adds organic material to the soil through leaf and litter fall, is compatible with agricultural crops, and produces high value sawlogs, poles, furniture, plywood, veneer and firewood. This multiple purpose tree has potential for integration in Maputo where according to Bila (1992) it has been used for fuelwood, medicine and poles, producing up to 62.5 m^3/ha of wood in an 8 yr. rotation.

Risk associated with the social forestry alternatives

The three described systems include a certain amount of risk depending on the selected species. Through diversification into farm forestry the farmer can reduce the risk of failure of an entire crop and the associated significant economic impact. Community forestry and woodlots reduce the impact of any ecological or economic hazard, since the risk is spread among all the villagers. Benefits are potentially high, and the investment in labour or capital will be more evenly distributed than otherwise.

Uncertainty of rain in Maputo, mainly in the dry zone, can lead to very low seedling survival rates even for species resistant to harsh conditions. Climatic changes can affect productivity and timber price and diversification investments may be an adequate response to reduce such risks (Price, 1989). However, Price refers particularly to diversification of activities to include agriculture, housing, and others, but the principle can be applied equally to diversification in terms of selected forestry species. For example, the risk of a fire in a mixed forest reduces dramatically with the inclusion of fire resistant species. This is particularly relevant in Maputo where large areas of forest plantations have been lost, very often as a result of weed burning without proper control, during land preparation for crop plantation. Also, if the money invested is from a bank loan, the interest rate will have to be low because of the inherent characteristics of tree plantations (which do not produce ready return as do annual crops). Even if subsidies are provided, it is important to allocate public money minimising the loss: for example Getahun (1991) reported that one of the reasons for very low seedling survival in the Boane extension program was because of their late supply; this is an organisational problem that can be avoided if resources are properly allocated and responsibility assigned, so that individuals can be held accountable.

The above potential land uses offer possibility for taungya practice (intercropping during the first years of tree planting). The villagers or owners of forests or woodlots would benefit from increasing the chance of tree survival with weeding, while getting other benefits and reducing their own forest establishment costs. The system has been applied by northern Kilimanjaro farmers having shown high survival rates, although this decreased after a certain period when the farmers deliberately damaged the trees in attempts to reduce competition. This resulted in increase in maize and beans yield in the first year but which declined afterwards (Chamshama *et al*, 1992). Although this may seem negative, it is important to note that crop performance depends on the species selected, their canopy and rooting systems and their ability to increase the soil fertility. Hence the main objective in a taungya system is to derive additional income from agricultural crops through successful tree management (Macdicken & Vergara, 1990). Another, possible adverse response is soil erosion under taungya systems during the dry season because of the removal of vegetation cover (FAO, 1989; Hudson, 1987) which can be minimised if harvest aftermaths are left in the field. However, in certain conditions, taungya systems can last a long time, rural Kenya being a particular case in point. The shamba system is a modification of shifting cultivation introduced at the beginning of the century by the forestry authorities, with the objective of providing part-time employment to the villagers and to reduce the maintenance cost by allowing them to cultivate under plantations. This was a sustainable system with optimum food and forest products production, income source and more or less full employment for the villagers (Oduol, 1989).

Taungya is considered to have great potential for dryland Africa to rehabilitate grazing land, or establishment of woodlots where deforestation and land degradation can be solved by mixing temporary crops with trees. It can offer security for the rural community and aid long term development.

3.3 Agroforestry Systems options

Agroforestry systems can be defined as all practices involving the close association of trees and/or shrubs with crops, animals and/or pastures. The components have both ecological and economic interactions. This coexistence may be in the same place at the same time (intercropping) or, in the same place at different times (rotational). Rocheleau *et al*, (1988) further advocate that agroforestry will best serve people if it is seen as one of the several approaches of improving land use, rather than a particular combination and arrangement of trees and crops. Subsequently, planning has to deal with agroforestry as a multiple use system, with various users and within an entire pattern of rural landscape change and enormous variety of indigenous practices as well as technical knowledge.

Agroforestry systems are associated with biological and socio-economic advantages and disadvantages. Biological advantages comprise the increased utilisation of the space below and above ground, improvement of soil chemicals and biological characteristics through the concept of nutrient pumping. This has potential to increase productivity, reduce soil erosion, reduce micro climate extremes and decrease the risk of complete crop failure associated with less diversified systems. However, disadvantages may include competition between trees and crops for space, nutrients, water, and light and risk of loosing nutrients resulting, for instance, from intensive rainfall and subsequent interruption of nutrient cycle. Damages to plants may also occur when carrying on management activities or by livestock. Furthermore, there is potential for allelopathy and provision of habitat or alternative hosts for pests.

Socio-economic advantages include the minimisation of food and energy crises, increased employment and income generation opportunities, possible settlement of the shifting cultivators which tend to migrate when they cannot afford long fallow, and provision of multiproducts and services. There is also potential for improvement of human food quality and reduction of the risk of price changes associated with single crops enhancing trade opportunities, diminution of establishment costs and reduction of labour demand for weeding activity due to shade effect on weeds.

Beldt (1990) presents agroforestry systems for the semiarid tropics which include a great part of Mozambique excluding Gaza and Inhambane provinces classified as dry tropics. Other classification (Hudson, 1987) only includes part of the Tete province as semi-arid. Nair (1989) presents an agroecological classification which includes the South coast and the northern provinces as subhumid to semi-arid, whereas the Northwest and centre as highlands and the rest of the country as semi-arid. As a result of this classification, the author points out that the most promising agroforestry systems for the country are the silvopastoral systems, homegardens, multipurpose trees in cropland, and particularly *Acacia* spp. based systems. In spite of the difference in classification, approximately 50% of the province has a dry climate (MINED, 1986), especially the area of the study, and this will be borne in mind for the discussion of the potential alternatives that can be offered to Maputo farmers.

There are four criteria for agroforestry systems categorisation: structure, function, socio-economic and ecological characteristics (Macdicken & Vergara, 1990; Nair, 1989a, 1993). The first two reflect the spatial and temporal distribution of the woody components and the latter two reflect the productive or protective role. Hence, they form the basis for the classification presented in Figure 3.1.

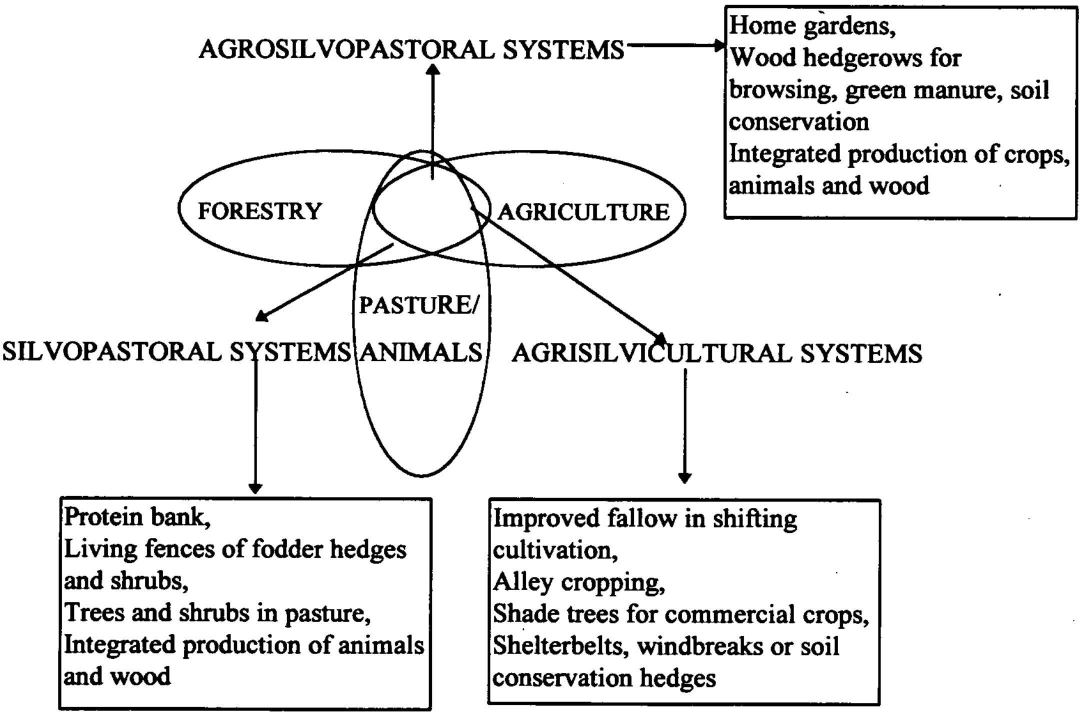


Fig.3.1 Classification of agroforestry systems and subsystems or practices according to the nature of components (Source: Nair, 1989)

The selection of the systems will be based on the objectives of a particular group's socio-economic situation as well as ecological conditions. Scherr (1991) states that the weak scientific knowledge of socio-economic and technical aspects of agroforestry, its complexity, and farmers' indigenous knowledge, make on-farm research an essential part of agroforestry. This will be important in evaluating the present conditions to derive potential interventions.

On farm research may consist of setting of objectives, criteria of site selection, identification of target groups, including description of the current systems, and the constraints and opportunities for improvement. It plays an important role in the development and validation of technologies while assessing their relevance for the resource-poor farmers. Moreover, such research assists in problem identification and provides a source of technical and production data across different farm conditions (Atta-Krah & Francis, 1989).

Although agroforestry research has been focused mostly within a tropical environment, it is also explored as an option in temperate regions (Anderson, 1991; Teklehaimanot, 1990). The association of trees and crops can yield positive or negative consequences which can be measured through experiments on-station or on-farm. However, this involves a long costly process and produces results limited to restricted circumstances. Subsequently, the use of computer models may help in simulating a wide range of interactions between tree and crops regarding water, nutrient and light availability. An example of such an application is the development of a model whose assumption is that the interception of light by trees has an influence on pasture growth (Anderson, 1991). Tree spacing and the effect of rainfall interception has also been investigated by Teklehaimanot (1990) and the results are shown in Figure 3.2 suggesting that the bigger the spacing, the lower the rainfall interception.

Huxley (1989) emphasises the need for thorough investigation using modelling (for example in alley cropping), because the removal of biomass from the site may diminish the long term benefits to the soils. The ability of the woody perennials to recover the nutrient from the lower soil horizons is determined by the root volume and its activity. Furthermore, nutrient cycling also depends on the capacity of the plant to accumulate nutrients, longevity of leaves and fine roots. The magnitude and nature of interactions of integrated agriculture and forestry towards sustainable development are necessary before generalisations concerning improvement of production can be made (Robinson, 1985).

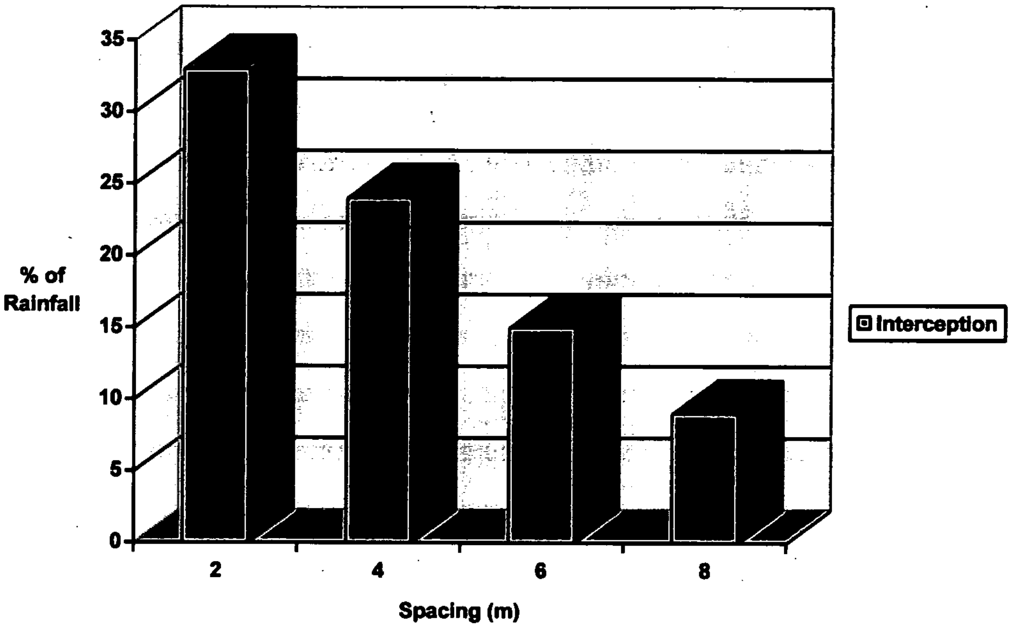


Fig. 3.2 Rainfall interception with trees planted at different spacing

Agroforestry can be used for the primary objective of food producing trees, trees for biomass/fuelwood production, trees for soil productivity increase and protection (Nair, 1989a; Young, 1989); trees for fodder and silvopartoral systems (Torres, 1989; Cameron *et al*, 1991). These different objectives will be considered for agrisilviculture, silvopastoral and agrosilvopastoral systems.

i) Agrisilviculture systems

This system basically comprises trees and annual crops in the same land management unit, with systematic or random spacing. It has been practised over the centuries as traditional farming practices in Maputo (Bila, 1992; Getahun, 1991; Macucule & Bila, 1991), and other parts of the country.

It is also a common practice in other African countries: Chitemene and Fundikila cultivation systems are used in Zambia (Dalland *et al*, 1993) and in Zimbabwe, farmers are known to conserve indigenous fruit trees both in the cropping and grazing fields (Campbell *et al*, 1991). In Swaziland, farmers plant woodlots, fruit and ornamental trees (Allen, 1990) and in the eastern highlands of Ethiopia, *Acacia albida* have been traditionally planted or grown with cereals, vegetables and coffee underneath or between; the registered improvement in yield achieved 56% under tree canopy than away from it (Poschen, 1989). This traditional agroforestry practice has been recognised as adequate for poor grassland, reclamation of wasteland and soils with low drainage.

The objective of having dispersed trees (either single or in clumps) is the provision of valuable tree products as well as improving soil productivity and water conditions (Rocheleau *et al*, 1988; Fodden, 1986). However, management of these traditional systems has been intensive, mainly because of population pressure (and subsequent land shortage for longer fallow) combined with low levels of capital investment and inputs. Short bush fallow periods for natural regeneration of the soils has become a dilemma in all developing countries (Drecshel *et al*, 1991). As referred to in chapter one, farmers do not have even the simplest agricultural tools in some districts. The result being non-sustainability of the systems and the need to identify other efficient land management options. While peanut yield, for example, is over 2500 kg/ha in the developed world, in the semiarid and arid tropics it is just under 50% of that due to low rainfall and the incidence of disease (Beldt, 1990 quoting Gibbons, 1986). While little can be done to directly influence the first factor, there may be chances to minimise the effects of the second.

ii) Improved fallow

Fallow is cropland without crops for a period between one season to several years. The aim is to control insects, pests, diseases and weeds associated with previous crops. It also allows the soil to recover from depleted nutrients. Improved fallow, on the other hand, may involve selective harvesting and weeding of natural vegetation or addition of natural herbaceous, plants, shrubs or animals. This process accelerates soil recovery compared to recovery under natural fallow (Rocheleau *et al*, 1988).

It is a sequential/rotational woody species (fast growing and normally leguminous) planted and left to grow during the fallow stage and agricultural crops. The objective of this shifting cultivation practice is twofold: soil fertility improvement and provision of wood products (Macdicken & Vergara, 1990). Despite this, the improvement of soil is dependent on the composition of the tree species. For example, a study of nutrient composition (N, P, K, Mg) of *Leucaena leucocephala*, *Gliricidia sepium* and *Flemingia macrophyla* after 42 months indicated a significant difference between the species (Budelman, 1989). Planted *Gliricidia sepium* fallow increased organic matter, nitrogen-nitrate and potassium concentration in the soil (Adejuwon & Adesina, 1990). A comparison of leaf fall and nutrient addition to the soil under *Cassia siamea* and *Gliricidia sepium* were also investigated in southern Nigeria (Ghuman & Lal, 1990). The results indicated that *Cassia* provided 113 kg/ha/yr. of N, 91 of Ca, 13 Mg and 40 of K. In contrast *Gliricidia* N input was 81 kg/ha/yr.

Improved fallow represents a promising substitution of the natural bush/grass fallow, because planted fallow permits quick and reliable soil cover besides producing firewood and poles. This was stated by Drecshel *et al* (1991) who conducted a five year fallow experiment with *Cassia siamea*, *Albizia lebbek*, *Acacia ariculiformis* and *Azadiracta indica* in the Central Togo. They observed a general positive response of the tree species to soil fertilisation, even though there were differences between the species. *Cassia* and *Azadirachta indica* enriched the sandy-loamy topsoil with Ca and increased pH; under *Acacia* both parameters were low suggesting that it was less favourable for soil improvement purposes, despite being suitable for firewood production as it produced high biomass. *Albizia*, on the other hand, presented the advantage of low C/N and C/P ratios which facilitates the mineralization of its organic matter.

Tree spacing is also important to fulfil their demands for soil resources. Verinumbe (1993) reports a trial carried out in Nigeria looking at the soil and growth of *Leucaena leucocephala* under *Faiderbia albida* and *Ziziphus spina-christ*. The results showed that *Leucaena* production increased at twice the crown radius distance inferring that this would be the optimum spacing between the trees and that crop yield was higher under *Ziziphus* which had higher concentration of P, although N concentration were similar for both species. This suggested the ability of mixed species to ameliorate soil fertility and provide insurance against pests and disease outbreaks.

This system has potential for application in Maputo provided that farmers have more than one field crop, however small, and may result in sustainable land use and improve soil fertility.

iii) Alley cropping

Alley cropping or hedgerow intercropping is a land use consisting of a combination of crops between managed perennials, preferably leguminous trees and shrubs, hedgerows spaced at regular intervals (Nair, 1989a, 1993; Siaw *et al*, 1991). The hedgerows are pruned during the cropping season to minimise the effect of competition. They are either used as mulch, fodder, fuelwood or other. This incorporation of pruning has a significant impact on soil erosion control (Young, 1989), but it also depends on a proper timing for incorporation. The first pruning has to be late enough to allow root development and resilience, as well as being soon enough to avoid the shading effect on crops. Results of an experiment of maize and yam under *Leucaena leucocephala* and *Gliricidia sepium* showed an increase of maize production from 1.3 to 3.2 t/ha which is equivalent to an application of 100 kg of N/ha (Rocheleau *et al*, 1988). It is even hypothesised that a combination of hedges and dispersed trees may provide better products and a greater impact on surrounding crops than simple alleys.

Small farmers in Ghana have been practising minimum tillage, a technology which minimises land disturbance, where land is not ploughed nor hoed, and instead, high levels of chemicals and mulching are used to control weeds. However, its substitution by alley cropping as a special form of minimum tillage farming has the advantage of enhancing land fertility while decreasing the requirement of the imported and expensive inputs over the years (Fodden, 1986). This suggests a cheaper production system which saves foreign currency to the country. In Maputo, few small farmers can afford to use high levels of inputs such as fertilisers, therefore it is important to devise productive farming systems which will be in accordance of the level of available resources to the farmer.

According to Rocheleau *et al* (1988) tree orientation is also very important in providing sunlight to the crops, hence the East-West direction of alleys is the most appropriate. They also recommend the use of spacing 4 to 8 m and 25 cm to 2 m between and within rows, plus double hedgerows which would increase competition between the hedges and reduce the effect on the adjacent crops. Moreover, a combination of trees whose leaves decompose quickly and release N to the soil with long lasting leaves for soil cover is useful for enhancing nutrients to the crops while protecting the soil.

Nair (1989b) has pointed out that although the hypothesis behind agroforestry systems regarding their ability to improve soil physical properties, maintain soil organic matter and promote nutrient cycling have not been fully tested as yet, experience shows that agroforestry systems overcome some of the drawbacks of monoculture. The question is, how much improvement can these technologies offer to the subsistence farmer who do not practice monoculture for generations, but whose practice is not efficient nor sustainable.

An experiment of alley cropping with pigeonpea has been conducted in a dryland region in India (Marshall *et al*, 1992). The aim was to compare the level of peanuts production under traditional or dispersed pigeonpea with that in hedgerow intercropping, looking at fodder and food production. It was shown that during the dry season, scattered perennials produced 6 t of fodder per ha, twice the production in the hedgerows. Nevertheless, as to groundnut production, there was no difference during the first year. In the second year, production declined by 40% under the traditional cropping system whereas production only fell by 20% under the intercropping system. This did not demonstrate necessarily an increased production, but a minimisation of a decline if particular tree arrangement was adopted. Some

rural projects have this objective (Gittinger, 1982; Hoekstra, 1990). Therefore, there is scope for trade-offs depending on the farmer's objectives: fodder first or food.
Ong *et al* (1992) states that tree-crop competition can have significant effects on yield. They undertook an experiment of intercropped *Cassia siamea* and maize at Machakos and analysed the competition above and under ground. It was evident that tree canopy intercepted about 20% of the seasonal rain, although it did not result in diminution of crop yield. They also observed that over 5 years, *Cassia* could spread its roots to a distance of 14m with potential to increase under ground competition with agricultural crops.

Another experiment at the same field station, of *Leucaena leucocephala* and maize alley cropping, analysed the effect of pruning on crop yield. This decreased the closer the rows were from the alleys in both pruned and unpruned systems, although it was slightly better in the former situation. In the unpruned rows there was more interception of rainfall being approximately 45% when the rainfall was 10 mm/day compared to 25% when rainfall increased to 30 mm a day. This resulted in a significant decrease in maize yields. The shading effect extended to 3-8 m reducing about 25% of the solar radiation. These aspects increase the risk on production that extension officers/researchers would have to be prepared to take when introducing the technology to the farmer, and farmers' willingness to take such risk particularly considering the harsh environment. Macdicken & Vergara (1990) stressed the advantageous application of alley cropping in humid and semi-humid environments, but its application has not yet proven adequate for the semiarid and arid tropics. Its role in these regions will depend on the development of management methods to control the sources of competition, and the authors add that even intensive and frequent pruning of the alleys will not perhaps increase production since the root competition for soil moisture is significant. It is not possible to conclude whether this agroforestry alternative will be successful or not in Maputo. However, farmers reported continuous decline of production over the years which may be caused by free access and environmental degradation resulting from intensive use as well as drought. Therefore, the present system is no longer sustainable and tests (on-station and on-farm) of alternatives are absolutely crucial.

Another experiment (systematic spacing design) concerning the intercropping of *Acacia albida* with maize and green gram at Mtwapa (a low fertility site) in Kenya, was reported by Jama & Getahun (1991). In this study, three different between row-spacing (2, 4, 8 m) and four within-row (0.5, 1, 2, 3 m) were adopted. No difference in tree survival was observed between treatment and control crops, the height difference was not significant in contrast with diameter at breast height (dbh), and crop performance declined rapidly under the trees, having been substantial in the smaller spacing (2, 4), whereas the within-row spacing had little impact. Weed control was greater with smaller spacing which also registered considerably lower levels of Ca, K, Mg, Mn. Good tree performance was attributed to the fact that *A. Albida* responds positively to weeding and to fertiliser even though this species is expected to fix atmospheric N for crop benefit. The decline in crop yield was unexpected due to the belief that the 'physiological anomaly' (loss of leaves during the rainy season) diminishes the shading effect on crops. This demonstrates how adverse/uncertain the expected agroforestry outcomes can be.

An analysis of the effects of alley cropping of *Cassia siamea* (deep-rooted, non nitrogen fixing) and maize on production and soil fertility in The Gambia was done using a latin design experiment (Danso & Morgan, 1993a). The treatments consisted of control plots, only prunings applied, prunings plus half of recommended fertiliser and pruning and fertiliser. The results showed that the latter treatment produced the highest yield, whereas the third produced the best grain quality, and in all cases there was negative effect of proximity of the crop from the hedgerows. Soil fertility (measured in terms of N, K) did not differ before planting and after harvesting in all cases, whereas the P quantity was significantly different among the treatments. Danso & Morgan (1993) also conducted an experiment of alley cropping with *Cassia siamea* and *Orysa sativa* (rice) analysing soil fertility and crop production. No significant benefits were obtained, however, from using pruning as organic fertiliser in rice fields.

Hedgerow intercropping has potential for food production, but it reduces the land available for cropping. Thus, the spatial arrangement of trees and their number have practical and economic implications and form important parameters to analyse (Karim & Savill, 1991). Competition between trees and crops is probably the most frequent cause of declined crop yield under alley cropping, despite the evidence that alleys have the potential to increase soil nutrient availability (Haggar & Beer, 1993). These are important questions that must be faced whenever this integrated land use is to be implemented.

Karim & Savill (1991) conducted experiments in Sierra Leone with maize and *Gliricidia sepium* looking at tree biomass production at 4 different spacing (2, 4, 6, 8 m) between rows and three (0.25, 0.50, 1.0 m) within rows. As a result there was greater per unit area biomasss between the nearest hedgerows: about 2.8 times more in 2 m and over 4 times in 4 m spacing. However, there was a reduction in nitrogen implying potential decreases in maize production. The production per plant decreased within the rows.

To support their point, Haggar & Beer (1993) conducted an experiment in Costa Rica comparing maize yield under *Griricidia* spp. and *Erytrina* spp. alleys. The results were significantly different for biomass than for N content under the two tree species. The biomass close to *Erythrina* was 44% lower than in the middle of the alley and had 35% less N content. Maize yield close to *Gliricidia* was unaltered while the N content increased by 56% compared to the centre of the hedgerows. Nevertheless, in general the N available was higher in the alley than in the sole crop. Some of the reasons given for this different trend is that *Erythrina* after pruning tends to compete strongly with crops, whereas *Gliricidia* has more upright branching and slow growth after pruning. This reduces both the shade and below ground competition, resulting from distinct rooting systems. *Eucalyptus tereticornis* intercropped with mustard and wheat, extracted water five times more than mustard from 0 to 150 cm profile and production fell by 47% and 34%, respectively (Malik & Sharma, 1990). *Leucaena leucocephala* interspersed with 12 crop rows (sunflower and sorghum) in each side resulted in suppression of yield of the 4-6 first rows (1.8-2.7 m) which was particularly significant in sunflower (Ong, 1991). The negative effects sometimes can be manifested in both components (crop and tree). For example, *Eucalyptus* spp. wood yield increases when intercropped with cassava and groundnut. Conversely the green forage of *Leucaena* spp. is adversely affected by cassava and tree root systems are inhibited to spread by cassava, and as a result production of the tuber is decreased. Monocropped cassava is found to increase soil fertility and the content of P and K increase when the crop is associated with trees, although this effect reduces after 3 years (Ghosh *et al*, 1989).

As much as the spacing, pruning height may also have an impact in the biomass available for incorporation into the soil. This is illustrated by Karim *et al* (1991) who analysed the effect of cutting height as well as its interval (one and tree months during six months) on dry matter production of *Leucaena leucocephala* in Sierra Leone. They found out that not only the biomass increased with the highest prunings (75 cm and 1 m) but also the longer cutting intervals (3 months) allowed the plants to recover and produce twice as much total yield of monthly cutting for equal period.

The above examples show attempts to introduce new cropping systems resulting from a breakdown of traditional practices. Even though almost nothing can be done to prevent the rainfall problem, it is neither possible to alter its unreliability nor its unpredictability, and the occurrence of droughts is inevitable (Hudson, 1987). The author proceeds saying that the abuse and mismanagement of land and people over the centuries, cannot be corrected in a period of less than at least 5 years. Subsequently, despite considering that the traditional systems have been sustainable as far as there was not as much pressure as today, it is sensible for both farmers and innovators not to expect quick positive response to the changes. Some studies have also shown a decrease in crop yields after agroforestry. For example, the perennial pigeonpea in strip or blocks with sorghum, sunflower and chickpea registered a decline in crop yields, because of shading. Further measurement of the root system showed high competition for moisture with chickpea reducing its production. A simulation study of photo exposure of *Erythrina poeppigiana* with sequential maize-beans cultivation have demonstrated that minimisation of shade while maintaining the supply of organic matter and N would be possible with wider between-row and low within-row spacings (Nygren & Jimenez, 1993).

Nevertheless, not all trials failed to demonstrate the hypothesis of high production under alleys than in sole crop. Hedgerow intercropping with *L. leucocephala*, *Acioa barteri* maize and cowpea, in Southern Nigeria, is a case in point. Siaw *et al* (1991) indicated that tree combination with crops increased the yield of maize and cowpea compared with the control. The two species were not compatible for the same hedgerow, once this resulted in suppression of dry matter production and nutrient yield of *Acioa*. Prunings of *Sesbania*, *Leucaena* and pigeonpea as well as maize stove were incorporated (every 2 months for a year) into the soil as green manure and compared with fallow plots (Onim *et al*, 1990). Soil improvement was tested using maize and beans. As a result *Sesbania* and *Leucaena* provided nutrient conditions to improve maize yield and beans by 76.6% compared to fallow plots. What is more the tree species provided a residual effect that continued for three seasons. Leaf mulch of *Flemingia macrophyla* was best in retaining water and lowering temperatures than *Leucaena leucocephala* (Budelman, 1989a). In water shortage conditions then the *Flemingia* would be appropriate for maintaining water at the surface for the crops. Nair (1989) reports that *Leucaena leucocephala* mulch had a significant impact on the effective cation exchange capacity and exchangeable Ca & K than bush fallow, in Nigeria.

The selection of species should be based not only on the definition of the homoclimate although this is important as a broad guide for selection (Wood, 1990). Trials should be undertaken to identify the ideotypes. Different intercrops with 4 m alleys of *Sesbania* spp. and potato, pole beans, dwarf beans and maize were tested. As a result, pole beans were most appropriate whereas maize production was too low, especially when *Sesbania* spp. was over 6 months.

So, in the presence of these contrasting results, what outcome can farmers expect? This certainly requires experiments to be carried for local conditions with trees species appropriate for the environment, i.e., select more suitable species for the farmer and the land (Wood, 1990). What is more, there is a need to adopt experimental designs (on-station or on-farm) that minimise the edge effects (neighbour or border) on crop yield. This can be done through computation simulation of neighbour effects, use of guard areas, systematic designs, use of neighbour terms or neighbour balanced designs (Langton, 1990).

Maputo farmers are definitely aware of the problems of decreasing production and the longer distances between the households and source of fuelwood. Besides the problem of lack of resources, or diminishing capacity of the soil as to production, lack of enough food may be itself responsible for decreasing the production. Farmers may be inefficient because of lack of sufficient energy supply from food. Therefore, finding alternatives to improve the system at the current farmer's energy levels, may bring potential for further improvement when he/she becomes self-sufficient.

iv) Shelterbelts and windbreaks

Shelterbelts and windbreaks consist of perennial arboreal shelterbelts designed to decrease the wind speed to an optimal beneficial for the crop (Nair, 1989a). If they are well planned, they can provide wood, fruit, fodder, fibre, honey and even grazing ground (FAO, 1989). They change the agrometereological environment (air temperature and relative humidity).

In the protected zone (leeward and windward) the wind declines by about 20% below incidence speed. Practical windbreak distance can be 15-20 H (tree height) leeward and 2-5H windward or 5-10H windward and 30-35H leeward (FAO, 1989). Therefore at least every 15-20H there should be parallel windbreaks perpendicular to the prevailing wind (Beldt, 1990). The effectiveness of a windbreak depends on its density/porosity. Very dense windbreaks can damage crops as much as thin windbreaks. The first can reduce the wind speed quickly and sharply, while the second, because of gaps, wind is funnelled and concentrated in small areas (Figure 3.3).

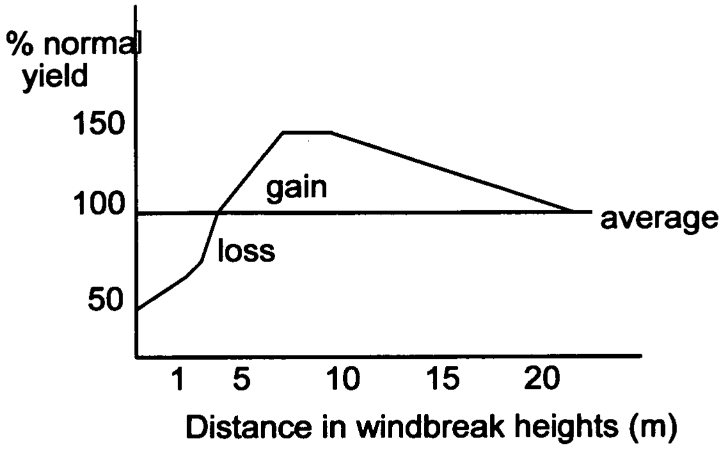


Fig.3.3 Possible impact on crop yield as result of using windbreaks, and the distance in which they are effective(Source: Macdicken & Vergara, 1990).

Oboho & Nwoboshi (1991) reported results of a study on the windbreak effectiveness in Nigeria which showed no change in rainfall in the leeward compared to the open field. The air and soil temperatures were slightly higher near windbreaks, relative humidity slightly higher close to the windbreaks (1H) because of open understorey and minimum resistance to air passage, 5H effective and at 10H they were less effective. This means that it is important to experiment the optimum windbreak density, species, layers to obtain the desired effect.

As it was mentioned in the description of the region, Maputo is affected by wind blowing from the Indian Ocean (humid) and from the continent, which tend to be very dry. There is a need for use of multipurpose windbreaks to reduce its effect on crop production. They also have an important role in soil erosion control: *Casuarina equisisetifolia,* for example, is one of the species that has been widely used for this purpose. *Eucalyptus* spp have also been used, although it is necessary to analyse their effect on water availability and crop productivity in their proximity. Other species such as *Annacardium occidentale*, *Acacia* spp and *Azadirachta indica* may also be investigated, since they are common in the region, and have significant economic role which would give them more probability of acceptance. However, *Annacardium occidentale* (cashewnut tree) has a wide crown which may reduce its effectiveness in obstructing the wind in the understorey, this means perhaps that shade tolerant trees may be used for overcoming this disadvantage.

An analysis of the impact of neem (*Azadirachta indica*) as a windbreak for millet (*Pennisetum typhoides*) in the Sahelian region was done by Brenner (1992). Wind speed diminution changed over seasons, because millet reduced the porosity at the lower level; the maximum shelter decreased from 6H at the beginning of the cropping season to half at middle and end of the season. The initial growth of millet was delayed due to the shelter. The influence of the competition on millet extended to a distance of 1.5H while the windbreaks consumed more water than millet, and 10-15H was identified as the appropriate windbreak spacing.

There are also a number of other possible benefits from windbreaks apart from preventing mechanical damage of crops by high winds, and reducing water loss rate by lowering evapotranspiration. It also reduces physiological changes such as leaf area and photosynthesis of crops exposed to high winds, protect livestock and hives from strong hot and cold wind, stabilise dunes, protect crops from salt sprays along the coast lines, reduces evaporative losses of lakes and irrigation canals, promotes insect pollination of crops. Moreover, windbreaks or shelterbelts have potential to increase crop production by diminishing the incidence and severity of pest damage problem which also affect the Maputo Province.

Although trees have a protective effect on soil from erosion, stabilisation of hill sides, exposed coastlines and other fragile land, resulting in preservation of agricultural land, a number of controversies still remain. Conviction of gains from trees (for example in increasing or decreasing water yield in streams, influence in rainfall, water erosion, etc.) cannot always be supported by scientific evidence (FAO, 1989 citing Hamilton, 1983). The author says further that agroforestry systems will not prove a panacea for erosion problems if the land is left bare most of the year. Since one of the major strengths of agroforestry introduction is the distribution of crop harvest year round, the negative or positive impact will always depend on the design of the land use pattern: the shade effect on crops is diverse, while cocoa, coffee and tea plantations may benefit from shading, other crops/pasture may reduce their photosynthesis ability and yield. Scattered *Acacia albida* in West Africa, leafless during the cropping season and full-canopied in the dry season, offers shade and fodder for livestock and it can break up wind patterns giving similar results as conventional windbreaks. The possibilities of this are to be explored and mixed species windbreaks may create an efficient barrier to wind with long life and less risk of attack by disease or insects.

Agroforestry practices on boundaries and border spaces as live fences and living fence posts has been used in Africa to protect people, dwellings, crops, pasture, water, soil and animals. Counter vegetation strips are also used for erosion control along the slope. Their effectiveness is known to depend on the rainfall in the region, the soil type, width of the strips as well as the intervals between them. The management of this system varies from intensive lapping and fodder grass cutting to an irregular harvesting of tree products and allowing animals to graze. It has been reported that on savanna, the strips can produce as much as 200 kg of dry weight firewood and 250 kg of fodder per year (Rocheleau *et al*, 1988).

Windbreaks are extremely essential in regions affected by strong winds. FAO (1989) states that even if they reduce the wind speed by a small amount, significant impacts on soil erosion can be observed due to reduction of the drying rate after rain. This is particularly important for Maputo because of the low amount of rainfall and high temperatures; hence the need for efficient use of water. The options here presented may not all be practical for the situation if Maputo, however, they offer a range of opportunities whose application can be further investigated.

v) Silvopastoral Systems

Silvopastoral systems have been widely applied in Southern Africa. They involve selective protection and management of naturally occurring trees and shrubs with value as animal fodder (Rocheleau *et al*, 1988). Other practices consist of trees planted with existing grasses individually or in clumps. The objective is to produce high protein fodder for livestock as well as providing wood products, fruit and cash income.

These systems can be divided into two forms, with and without tree component. Nair (1989) point out that in the Southern African tropical grass production under tree cover is considerably high and the same pattern is observed in the case of crops, but the former benefit from being rather competitive. The success of tree-pasture combination is also influenced by spacing. Cameron *et al* (1991) showed a negligible difference in above ground biomass production during the first year of plantation (5-7 kg/tree) whereas the peak was achieved at just over 100 stems/ha in 2.5 years (Figure 3.4). Torres (1989) considers the browse plants as drought reserves and protein-rich fodder for both domestic and wild animals.

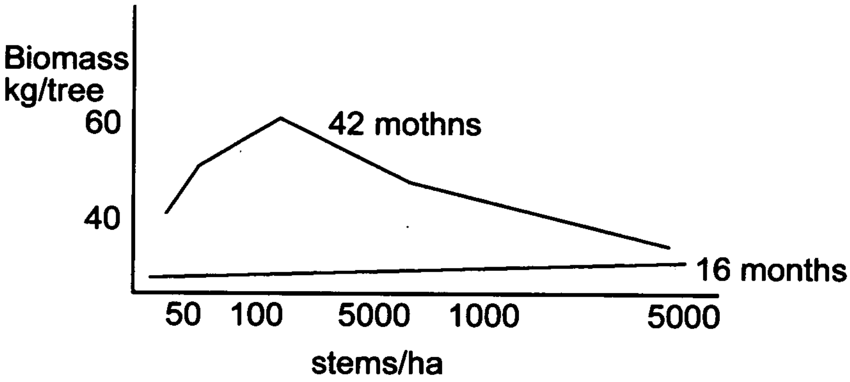


Fig. 3.4 Effect of spacing in above ground biomass production in a silvopastoral system in Australia (Cameron *et al*, 1991)

Silvopastoral systems can be protein banks or living fences, boundaries made productive by using tree/shrub for this purpose. An example of such practices is the adoption by Somali farmers of *Prosopis cinerea* for animal feed. Cattle grazing under *Pinus caribaea* for pulpwood production reduce the costs of weeding (Somarriba & Lega, 1991). This approach would be useful to apply in community forestry projects, where live fences or other tree planting arrangement would provide animal feed from grass or leaves of the planted trees.

Again an example of the importance of building on local knowledge is given by Bayer (1990) who reports that Fulani pastoralists in central Nigeria identified 39 tree species and ranked them according to the importance for cattle diet. A subsequent chemical analysis demonstrated that the pastoralists rank, reflected both plant relative abundance and nutritive value. This shows that it is important to understand the current silvopastoral systems in Maputo districts and seek from the farmer, possible improvement.

vi) Agrosilvopastoral systems

This represents a very high level of crop, tree and animal husbandry production in the same land management unit and has been in practice in Maputo for generations. During the cropping season, animals are taken to feed in the natural grassland, but after crop harvesting, the grass regenerates and animals are kept in these fields to graze. This also reduces the amount of labour necessary for land preparation for cropping. It has enormous advantages in terms of labour that can be allocated to other activities, during this season. However, as the other traditional practices, this needs an improvement which would come from an increase of fodder producing tree species in the agricultural fields. This would ensure enough feed during the dry season.

Agrosilvopastoral systems have also been practised elsewhere. In the Jebe Mara highlands of Sudan, *Acacia albida, Cordia abyssinica, Ziziphus spina-christi* are planted in terraced village fields with semi-permanent millet and subsistence crops - system also threatened by shifting cultivators (Mieche, 1989). In India a mixture of *Leucaena*, sorghum and livestock has been recognised as bringing the future value of timber, to the present value of sorghum grain, fuelwood and fodder (Hocking and Rao, 1990). The reason being that for example, in a year with less than half of the seasonal rainfall, fresh fodder production reached 4.8 t/ha/yr, firewood production was 3.8 t/ha/yr and the standing crop increased by 1.8 t/ha/yr and sorghum grain yield was retained at 46% of pure cropping.

Homegardens is a land use practice which involves deliberate management of multistoreyed trees and shrubs in association with annual and perennial crops as well as livestock. This is developed within compounds of individual houses managed by family labour (Nair, 1989a). According to Rocheleau *et al* (1988), this labour is mainly provided by women who combine the management of the system with other domestic activities. They consider that the use of this system and multipurpose trees plantation, offers advantages in alleviating conflict of women's fuelwood versus men's timber or women's versus men's priorities, e.g. Kakamanga and Kisii districts in Kenya, respectively.

Homegardens are widespread in the tropical and subtropical countries. They occur in almost every ecological zone and farming system in Africa (Rocheleau *et al*, 1988), ranging from a small vegetable and herbs garden to a dense multi-storeyed plot of fruit, vegetables, cash crops, trees for timber, firewood and fodder. They also serve as decorative and shelter plants around the homestead. It is known as economically efficient and ecologically sound as well as being biologically sustainable agroforestry practice. Although the land allocated is normally less than a hectare, there has been evidence that fruit and food production provide substantial calorific and nutritive value. Javanese (Indonesia) homegardens, for example, supply around 40% of the calorific requirements of the community in that zone. In the Philippines, the population practising homegardens can provide all the vitamins A, C, Fe and Ca daily required, but they can satisfy only half the requirement of thiamin, riboflavin and niacin needs (FAO, 1989). The Chaga homegardens in mount Kilimanjaro in Tanzania constitute another example (Fernandes, 1989). From an area of 0.68 ha, the Chagga produce 125 kg of beans, 280 kg of unhushed coffee, 275 branches of bananas, home fruit consumption, 5 kg of honey per year, and 1-3 m^3 of firewood, which satisfies about a third of the annual household needs. Besides meeting family needs, homegardens surplus production is also marketed and constitutes a very important source of income between the harvests and is a safeguard against crop failure.

Most of the traditional practices have been sustainable as far as their management did not exceed their carrying capacity. Homegardens can also cause adverse results when mismanaged. In India, West Kerala, for example, where natural forest were cleared by landless immigrants, highly mixed homegardens were established. There are signs of erosion caused by the ground cover and intermediate storey (1-4m), specially under cardamom, pepper and mixed cultivation (Moench, 1991).

In some regions it is also a practice to plant multi-storey tree gardens, in which forestry species are combined with other commercial species at a certain distance from home. FAO (1989) indicates that such practices are evident on communally owned land in Indonesia.

Such mixed cropping systems can be found in Maputo mainly close to the valleys where water availability is not a constraint. For example, in green belt fruit trees such as avocado, pear, banana, papaw, palms are cultivated together with vegetables and the main animal component of the farm systems are pigs. In the dryland areas it is also traditional practice to plant fruit trees occupying different layers, though this system is not as closed as the conventional homegarden.

3.4 Some remarks

Although application of social forestry alternatives in Maputo have been illustrated, it would be over optimistic to consider that the systems can simply be transferred or incorporated into the actual cultivation practices. There is no doubt about the need for an action to reactivate the production system in Maputo in order to reduce farmer dependence on the government or outside aid. Food security is the major problem for the farmers and the lack of food may have greater implications for the farming system than it appears.

Detailed analysis is necessary to make sustainable recommendations. Potential alternatives have to be tested and farmers have to participate in the process. Appendix (1) illustrates some of the possible tree species for social forestry alternatives. This is not a definitive nor a comprehensive list however, it gives an idea of the potential species, their management requirement and uses. It is important to point out that even the species known for their ability to improve the soil because of nitrogen fixation, do so in appropriate conditions. Roughley (1986) emphasises that it is important to determine the degree of host specificity on *Acacia* spp. since the Rhyzobia exhibit such specificity. Therefore, not all *Acacia* spp. can be nodulated with one bacteria strain. This knowledge is also necessary to predict the need for inoculation.

Social forestry (farm forestry, community forestry and woodlots) need a high level of commitment from farmers to invest, and the need for a clear identification and aggregation of farmers interests so as to share the labour input and ensure equitable distribution of the benefits.

Agroforestry systems have been long practised but a change is necessary. They are complex systems economically, ecologically and socially. However, use of knowledge based expert systems may help in planning and designing agroforestry interventions. Although they are not a solution in themselves, they may provide a useful device.

Most of the alley cropping experiments presented looked at the effects of the trees of crops which are not mixed (monocrop between rows). This means a suggestion of a complete break from the actual cropping systems which is based on mixed cropping system: maize, beans, cassava, peanuts, pumpkin and other crops. In an article drawing lessons from African projects, Kerkhof (1990) states that there are no easy agroforestry solutions with instant results. Agroforestry is an approach to be looked at in a wide sense, and its implementation should be sensitive to address the needs of local farmers.

CHAPTER 4

Implementation of the Reforestation Strategy: planning process

4.1 General framework

As mentioned in Chapter 1, the Mozambique government have concluded that the way forward for effective reforestation is the involvement of the rural community. The reason being that the present macroeconomic situation of Mozambique does not allow for massive government investments in forestry plantations.

However, effective involvement of farmers in the Reforestation Strategy calls for their participation in the planning process not only because it is socially desirable, but also to ensure successful implementation.

Consequently, the purpose of this research is the development of a methodology for analyzing the impact of participatory policies and strategies of rural land use, particularly reforestation. In fact, it is an *ex-ante* analysis of community involvement in social forestry implementation in Maputo Province in order to reduce the pressure in the natural forest while providing for food security. Therefore, the analogue model with physical representation of real system resource distribution (Geographical Information System) in Maputo Province, the regional planning level is combined with a symbolic model representing the system in algebraic terms (Mathematical Programming) to analyze the impact of such strategy in the farm organization as it is shown in Figure 4.1.

GIS is a multiple objective decision tool which displays the results of overlaid information, and it provides the planner with an understanding of the spatial interrelationships of resources, and hence improves the ability to make sound plans. Mendonza and Sprouse (1989) state that the critical stages of planning are the generation of alternatives through fuzzy decision-making approaches and their evaluation as well as prioritization. GIS is used for classification of ecozones or the planning units, from which representative farms are selected.

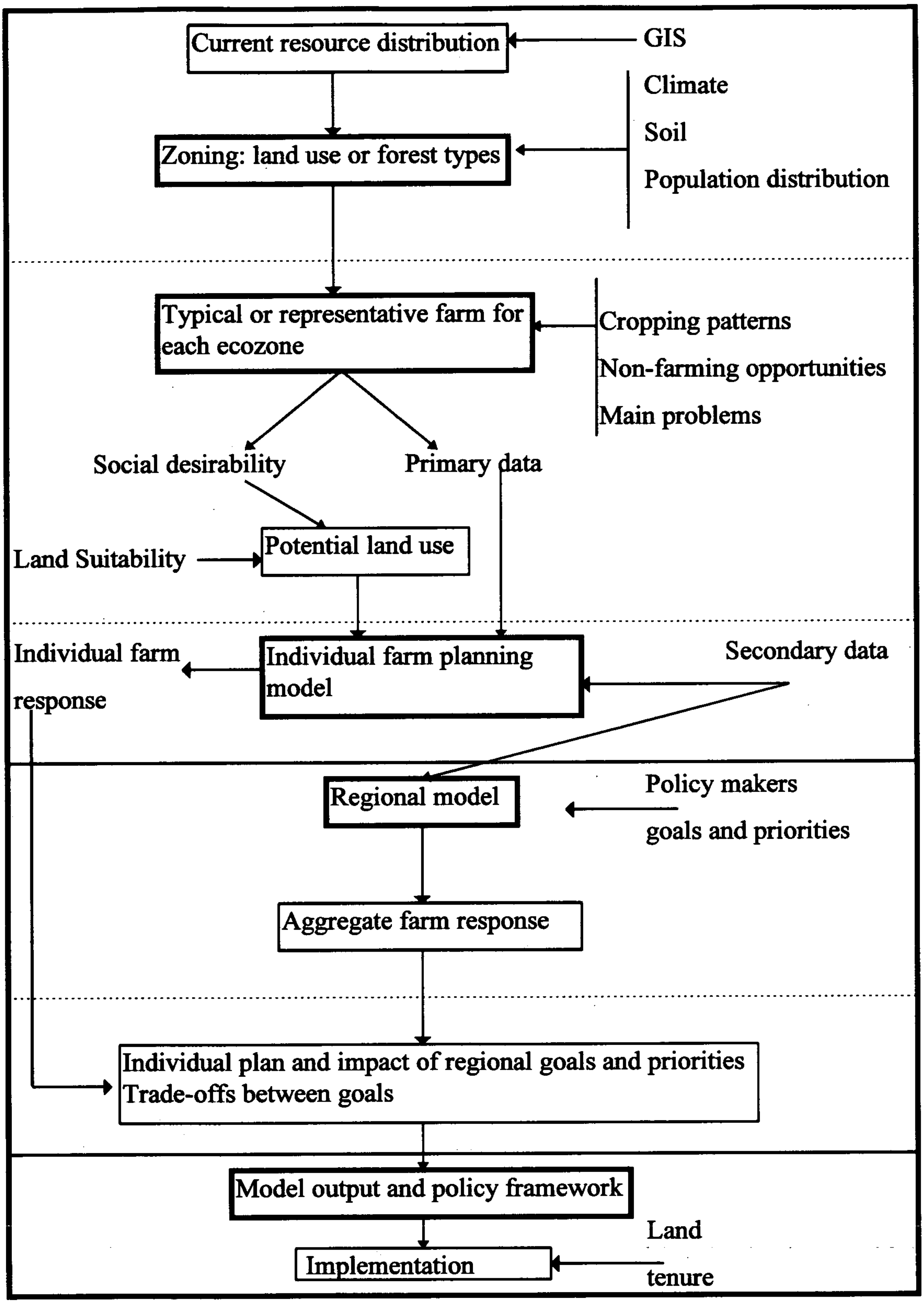


Fig.4.1 Planning framework highlighting the use of GIS for spatial analysis and mathematical programming as a planning tool at farm and regional levels

The integration of GIS and multiobjective planning methods seems an adequate planning methodology for policy analysis at both farm and regional levels. This connection of methods presents a further step in the approach to rural land use planning. For instance, the approach of Veloso (1990) was to use simulation models as data generation for LP/MOTAD to formulate the farm and regional GP models. Sharma (1990) used primary data and Knowledge Based Systems to perform SCBA and formulate a regional GP of social forestry in India, whereas Nkowani (1996) applies GP in land use planning for agroforestry purposes in Zambia.

Primary data on socio-economic situation and farm performance are elicited. This includes information regarding willingness to plant trees and the farmers preferences as to the system to be adopted. One of the aspects highlighted in the framework is that social desirability of the potential land use is as important as the land suitability for undertaking them. The data are used to develop both linear and multiobjective farm programming models. The structure of the ecozone representative farm models is aggregated in a regional model run as a multiobjective problem in order to assess the conflicts between regional goals as well as their trade-offs.

Rural land use planning is multiobjective and multidisciplinary in nature, and in this case it includes areas such as forestry, agriculture, and animal husbandry besides a need for economic analysis. It follows that the planning methodology has to integrate these subjects to provide sound alternatives for the farmer and regional planning level. This demands that any technique selected should deal with the real problems as closely as possible: scarce resources and, several objectives expressed in different units.

The details of the framework presented in Figure 4.1 will be discussed in following sections: 4.2 highlights data needs and provision; 4.3 describes the use of GIS for differentiation of the planning units or ecozones; 4.4 looks at the data extracted from survey and secondary sources to represent the typical farm information used in the model; 4.5 analyses the resource distribution and flow of wood products to Maputo-city in general from within the province and imports. Leading on from this, chapter

5, section 5.1 describes farm level planning matrixes highlighting their main activities, constraints and goals while section 5.2 looks at the integration of farm models with the Maputo-city market into a regional planning model. This section gives special attention to aggregation issues, and the impact of regional goals on the farm plan.

In the final step, the model output and possible application of the proposed methodology is looked at within the context of policy framework and different institutions dealing with rural development issues. One of the aspects highlighted here, also regards the decisive role that the pattern of land tenure will have on whether and how the strategy of reforestation may take place.

4.2 Data requirement and provision

Mozambique has been significantly affected by two calamities: the war, and the drought which affected both humans and animals throughout the Southern African countries. The severe residues of war such as the existence of land mines limited the access to remote zones and thus the data collection. On the other hand, official data gathering is still also highly constrained by the lack of financial and qualified human resources to systematically provide detailed statistics useful for planners or decision-makers and researchers. Consequently, the development of a planning methodology using mathematical programming techniques is quite demanding in terms of the quantity and quality of data required. In fact, one of the hypothesis tested is that despite data scarcity, it is possible to use Goal Programming, a relatively sophisticated planning tool, to analyze the impact of the Reforestation Strategy in rural Maputo.

Various sources of information, both secondary and primary (Figure 4.1) were used to obtain data to derive numerical coefficients or constants for the farm planning framework or to cross check it. Figure 4.2 shows the main data, including technical data for agriculture, forestry, livestock and supplementary activities carried out by the farmers; prices of products in rural and urban areas, and other socio-economic data collected for the development of the planning methodology.

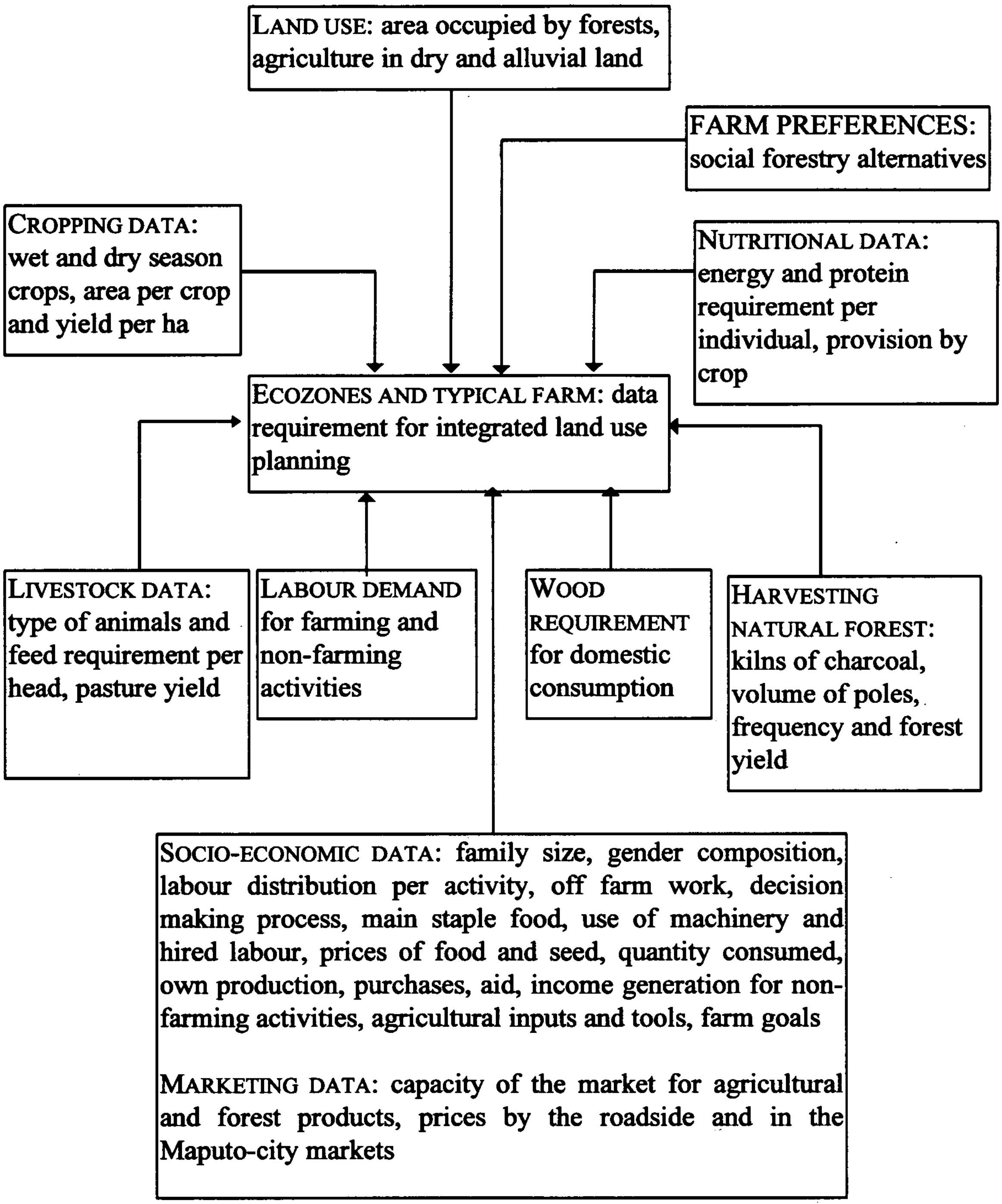


Fig. 4.2 Data requirement for integrated rural land use planning

Different mechanisms were used for data gathering including consultation of documents, informal interviews with senior technical staff of agriculture, forestry and livestock, members of staff at the Ministry of Agriculture and Fishery (DEA, DNDR, DNFFB), inspectors of flow of wood products to Maputo-city located at different points of the main roads, Ministry of Health (Nutrition Unit), the National Commission of Environment (CNMA), the Provincial and District Directorate of Agriculture and Forestry (DPA & DDA), Medic Sans Frontier, and a field survey of farmers.

The definition of land use was based on 1988 mapped information of administrative division and, road and railway access based on information from 1966-1970. This was supplied by the Instituto Nacional de Planeamento Físico. The maps lacked detail in terms of road access to the remote areas where many lorries extract wood products since, in general, near the main roads the forests have already been cleared. This is significantly important in locating how far inland the deforestation has gone. Soil maps were also obtained from the Instituto Nacional de Investigação Agronómica (INIA, 1991) which carries out research on soil classification, land suitability for agricultural crops and productivity. Forest types/land use maps were produced by the Direcção Nacional de Florestas e Fauna Bravia (1994) based on information of satellite image taken in 1972 and 1990/1991. The latter represents the most up to date information available.

Since this research is analyzing (*ex-ante*) the impact of implementing the Reforestation Strategy with community participation it was essential to elicit the goals that planners aim to achieve. Therefore, in a first step, two questions where put to decision makers at provincial and national levels (with University training, at the University of Eduardo Mondlane, Ministry of Agriculture and associated institutions) who direct or indirectly decide or influence on policy and strategic changes in the agrarian sector as a whole.

The questions were mainly on what they perceived as the main goals of integrated land extolled by the above mentioned strategy as well as quantifying the objectives

(Appendix 2.1). Thirty questionnaires were distributed, however only 16 were returned completed, the majority being from foresters. The reason given by some of the agriculture staff and by the Director of the then National Commission for Co-ordination of Environmental Actions was that the strategy concerned the forestry sector, hence it was difficult for them to provide the answers (Nhantumbo *et al*, 1996). Such comments helped also to evaluate the understanding of sustainable and integrated rural land use planning process and whether the planners perceive it as such or not. The fact that the responses were few and subject oriented, it implicitly suggests that planners still look at agriculture, forestry and livestock as separate disciplines. Academically this may be true, however, when dealing with a situation where extension officers have to introduce technologies for improving crop yields, for better management of livestock and introduction of trees in the cropping system, the target group is generally the same (farmers). Therefore, these disciplines cannot be looked at in isolation of one another so that the farmer can be provided with a clear measure of the opportunity cost associated with his/her choices and possible alternatives.

The second step was to conduct informal interviews in the DPA and DDA. The DPA (Appendix 2.2) gave an overview of the figures on crop production, the use of forest products for energy and building, and wildlife resources within the province. At the DDA, the questions were more specific in terms of how much land was sandy or alluvial, whether it was used by commercial or subsistence farmers, and details regarding main crops, production per locality, sources of income, problems with wood and water availability and the prioritization of goals already stated. The latter could not be left as an open question as most of the officers were unable to give a list of goals and priorities.

Furthermore, inspectors of wood and wildlife flow were given forms to register information on quantity of firewood, poles and charcoal transported, the origin and destination markets (Appendix 2.3). These were filled continuously for about 12 months. This is a monitoring system designed for this research, which hopefully will proceed in order to provide the trend of resource drain from different forestry/biomass types.

Finally, socio-economic data were collected using Rapid Rural Appraisal (RRA) with an informal, mostly open-ended questionnaire. This was conducted in two phases before and after the zoning. Exploratory data collection (Appendix 2.4a) provided essential information for definition of a criteria for selection of a typical farmer per ecozone.

It has to be stressed that RRA was the only feasible mechanism to gather primary data in the post war situation given the unstable conditions that farmers and the infrastructure were relegated to. Therefore, random sampling was not possible where lists of farmers may not have been available or correct. This coupled with the difficulty of access due to land mines and road conditions strongly restricted what could be achieved in terms of approach for data collection. Recall data from farmers were only applicable for qualitative judgment and therefore could not be used in quantitative or statistical analysis.

This led to the conclusion that the typical farmer within each ecozone (defined as each land use) would be best represented by the range of optional activities that the farmer could undertake in order to supplement the family income. Non-farming activities are important for the actual situation where people are just resettling after several years of war, and those who have never left, faced severe drought (1990-1994). Furthermore, the alternative activities, in some cases, represent a threat to forest resources as it is the case of exploitation of wood for firewood and charcoal or simply the availability of raw material may affect activities such as pottery, reeds collection, and traditional beer production. What is more, the number of current activities and their sustainability is likely to influence farmers decision on the allocation of resources to tree planting.

Farming is the basic activity in all ecozones; so, it was not used to define the typical farmers but the difference in cropping patterns. Every land use type is unevenly distributed in terms of area among districts and localities. Consequently, the sample was taken from the locality where a particular ecozone is best represented - 'representative locality for ecozone'. In other words, the sampled typical farm was located in the locality with a large area of a certain land use. Apart from that, the distance from Maputo-city and road access to a particular location were considered.

The questionnaires for typical farmers included farming and non-farming sections (Appendix 2.4b). The second section gathered information on input-output aspects of each activity. For example, exploitation of firewood/charcoal was concerned with species, quantity, kiln capacity, man-hours in each step, tools used, road access, price and production per month. General household information is as indicated in Figure 4.2. Families with more than one non-farming activity had one/two pages more to answer. The interview took between 30 and 45 minutes depending on the farmers willingness to talk about associated issues. The interview was not structured and was conducted as a conversation, a feature crucial for the provision of relatively comprehensive answers by the farmers.

As mentioned earlier, this was not a random survey. Further reason being that it was conducted at a regional level whose physical boundaries were more than 22,000 Km^2 and where political instability would not allow intensive sampling. Furthermore, the aim was to identify data needs and gaps for future application of the methodology in rural land use planning as an instrument for policy analysis. Interviews to provincial, district and in some cases local authorities plus the farmer (one exploratory and 'detailed' RRA) indicates that this objective can be met as well as being able to develop a relatively sophisticated multiobjective regional programming model.

It has to be noted, though, that government institutions are keen to create databases which can be used for research and planning. Since 1993, the Direcção de Economia Agrária (DEA) has been conducting national annual surveys of socio-economic data related to agricultural activities. This is planned to be continuous, and for the first year, only included two districts in Maputo (Boane and Moamba), defined as priority districts. However, the plan is to add one more district to the pool, every year. Therefore, information given by typical farmers located in these two districts is cross checked and the data is validated. The importance of this survey is that it is open for improvement, that is, planners may suggest inclusion of relevant questions to create a relatively serviceable database and it would reduce the lack of co-ordination in conducting surveys which make the farmers sceptical about the usefulness of the data they provide.

4.3 Geographical Information System and Zoning

4.3.1 General procedure

GIS is a computer assisted system for digital storage of maps, along with data associated with map features, that permit the user to produce customized maps, perform specialized data base queries, analyze complex relationships, apply models and assist in the decision making process (McKendry *et al*, 1992). These authors also highlight the importance of GIS in a forest management context: it requires data describing present and future forest resource conditions as well as geographical distribution. The tool was developed in Canada in the 1960's, but its expansion to developing countries started only in the 1980's (Taylor, 1991). In countries like Mozambique, the technology has only been imported recently and its use in planning is still limited and not accessible to all planners and researchers due to the high cost of using facilities.

ARCINFO, a GIS package was used to digitize and/or overlay mapped and non-mapped information. The original projection for all digitized maps was Universal Transverse Mercator and transformed to UTM using 'QUADRANT SE' and 'ZONE 36' to produce the relevant values for tic points.

Besides displaying the spatial distribution of resources, ARCINFO also provided quantified data on polygon area. This was done by projecting all digitized versions of the maps to *albers* equal area using the following parameters: -27°20’00’’ as 1st standard parallel (1/6 rule used); -24°40'00'' 2^{nd} parallel; 32°50'00'' as central meridian (approximate midpoint); - 25°50'00'' as latitude of projections and 0.0 as false easting and northing.

These data were used for further calculations of volume of timber in each biomass class, which is then linked with socio-economic information in order to explore the range of land use options both ecologically and socio-economically acceptable for each of the ecozones. Cowen and Shirley (1991) cite Goodchild saying that GIS links socio-economic data and land use so that planners can conduct exploratory analysis. Furthermore, Calkins (1991) stressed that quantification of GIS spatial display is a useful tool for public decision making support. GIS has been widely applied in rural land use planning including identification of environmental problems, area of protection and development, estimates of fuelwood supply, evaluation of land resources, forest evolution studies, deforestation, landscape changes, etc. (Yaakup, 1991; Gastellu & Sinulingga, 1988; Hutachareon, 1987; Simonet *et al*, 1987). In this research it has been used to assess resources, quantify resources, and support decisions on potential land use alternatives. Therefore, GIS in this context generates useful information for planning purposes as shown in the planning framework.

First an overview of the infrastructure distribution per district is looked at with emphasis on the road and rail network which ultimately influences the possibility for exploitation of the forest resources to Maputo-city markets.

4.3.2 Accessibility to localities

Maps of administrative division of scale 1:250,000 (1988), particularly highlighting district and locality boundaries, situation of main cities and towns, major and secondary roads, and railway infrastructure were overlaid producing a map of 1: 1,000,000 (Figure 4.3a and b) from six complete coverages. This shows the access that the different localities have to Maputo-City. There are also tracks not represented in the map used by many lorries and tractors transporting firewood, charcoal and poles to local towns. Other tracks are also sometimes only used by carts driven by animals (donkeys, cows) or man power.

Analyzing the map (Figure 4.3) from the South of the province, the district of Matutuine (Table 4.1) have predominantly secondary or minor roads, one just passing the locality 1 in the East, leaving the rest of the locality apparently without communications. A large area between localities 2, 3 and 5 is plainly without communication by road. Nevertheless, tracks have been opened by timber merchants and local producers in order to have their products transported. In many cases, tracks are in much better condition than the secondary roads due to holes made during the rainy season slowing the speed of the lorries to 10-20 Km/hr.

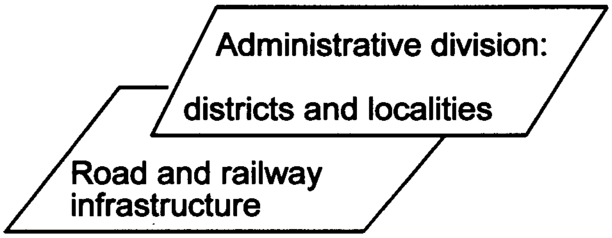


Fig. 4.3a First stage of information overlay

Table 4.1 Legend of districts and localities in Figure 4.3b and respective area

District	Locality numbers	Area of district (Km^2)
Matutuine	1,2,3,9	5,242
Namaacha	5,6,7,12,13,14,15,16	2,190
Moamba	17,18,21,22,13,27,28,29,30,40	4,597
Boane	8, 11	806
Magude	32,39,41,42,43	7,000
Manhica	26, 33, 34,35,36,37,38,	2,494
Marracuene	19, 20, 24, 25	709
Maputo-city	10	621

In the West of this area lies the Namaacha district which is very important economically, as it is the main entrance to Swaziland where both local residents and Maputo-city informal and formal traders, buy goods to supply the district and the city, respectively. The importance of this district is shown by the main road from Maputo-city passing through localities 12, 13 and 14. Residents of these localities

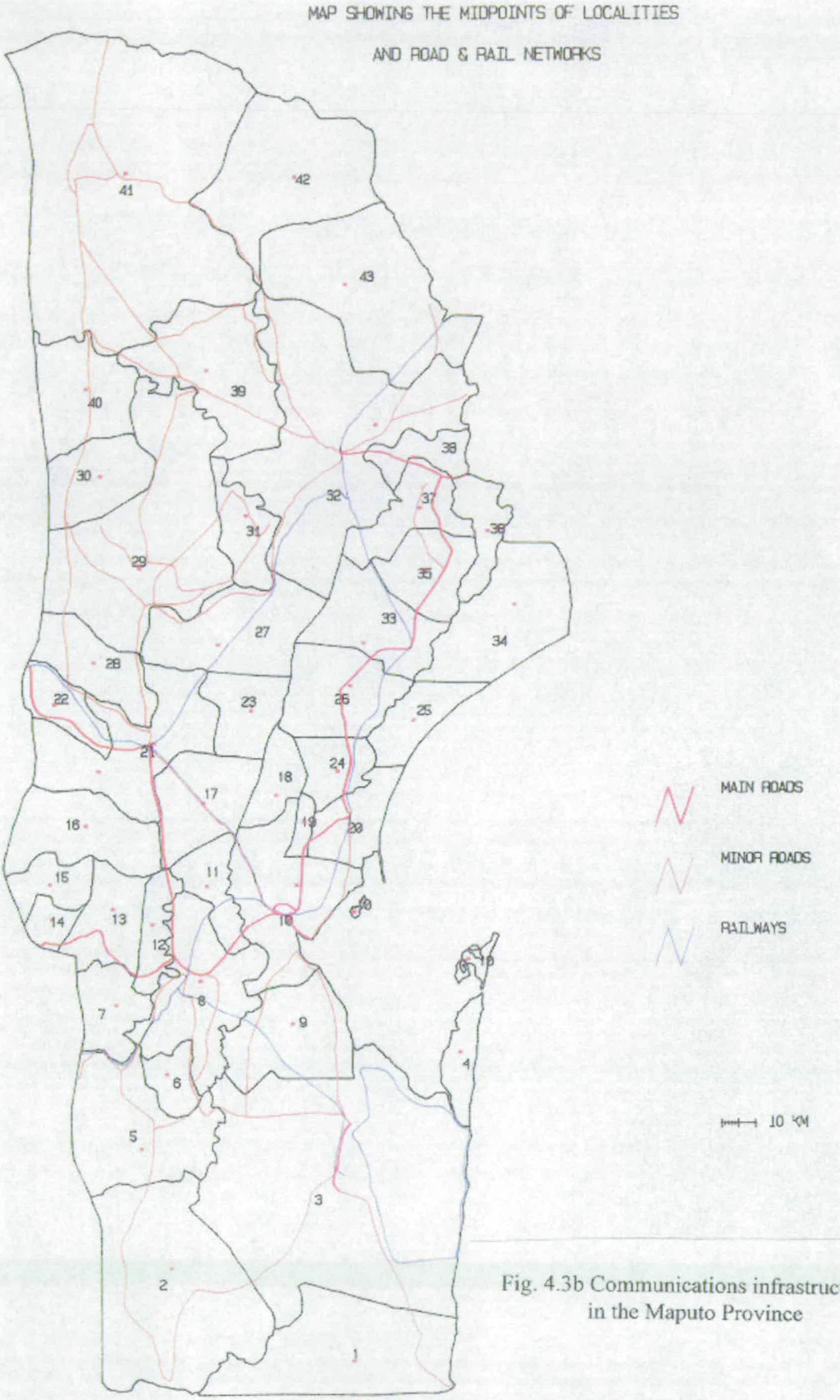


Fig. 4.3b Communications infrastructure in the Maputo Province

practice commercial activities as well as agriculture, whereas in the North at locality 13 plus localities 15, 16, 7, 6 and 5, residents mainly supplement agriculture with firewood and charcoal production - locality 5, during the civil war, was the main supplier of wood products to Maputo-city and it is already facing the consequences of intensive exploitation. The railway is not used for transporting wood in significant amounts. The recent shift to harvesting in the Northern localities, has opened up many tracks giving access to the local and migrant harvesters from the city. These districts are also important for wildlife hunting, the results of which is sold in the border area of locality 16 on the main road from Moamba. However, this component is not included in the planning model due to insufficient data, as explained later.

Moamba is also economically important, because of irrigated agriculture in Sábié (29) and the Corumana dam between this locality and Tonganhane (30) (Figure 4.3b). Therefore, apart from the main road and railway passing through localities 17, 21 and 22, there is also a relatively good network of secondary roads in northern localities. However, access to localities 18, 23 and 27 (all wood producers' localities) is basically via tracks used by lorries, and others only used by tractors due to sandy soil. The transportation of wood to the city is by train, and the wood products remain in their production locality for weeks before they can be transported.

Boane, is the main transit area or concentration point of wood products transported to Maputo-city, either from Matutuine, Namaacha or Moamba.

In the far Northwest of the province we find Magude district, the biggest district in terms of land area (Table 4.1). Besides harvesting wood products, pottery is one of the most important economic activities due to an abundance of clay soil. As can be seen later in the flow of wood products by road, there are comparatively very few lorries transporting wood from Magude. The main reason is that the source is very distant; about 390 km for a round trip to the market at a speed of 20 km/hr. Therefore, this district uses the railway far more than the road to transport wood products.

Manhiça district in the Northeast, is very important in terms of agricultural activity. It is the main supplier to the urban markets of cassava, sweet potato, banana, and maize. Rice and sugar cane were also important cash crops in years before the drought. Because of the war, forest harvesting became extremely important as a ready source of income. The main communication with Maputo-city is via the main road EN1 as well as by train. The soil in the eastern localities (34, 36) is mainly clay and almost impassable during the rainy season, preventing transit by tractors, which are the main passenger and goods transportation means. Since the train from Magude is usually already full when it arrives, Manhiça goods are not transported immediately.

Finally, Marracuene, although mainly agricultural, as Figure 4.4b shows, has environmental problems associated with the existence of salt in the alluvial land, and inland dunes in localities 20 and 24. Moreover, the soils are predominantly sandy, hence low in productivity. Fishing is affected by drought and the remaining resource is the Thicket, the main supplier of firewood, charcoal and poles to urban Maputo and source of income for the farmers. This district is close (15-20 km) to Maputo-city hence, many lorry drivers transport producers to city markets or retailers from Maputo-city who buy the products themselves. The limitation that producers face is the transportation from the source to the local market, which is through tractors and boat or simply carried on people's heads.

The road and railway infrastructure is important because currently transport costs form a significant part of price structure, and influence the profit the farmer obtains. Therefore improving marketing facilities is the only way to secure a beneficial effect of farmers undertaking tree planting activities.

4.3.3 Land use, zoning and typical farmers

The aim of this section is to discuss the use of the GIS results for zoning and for the selection of typical farmers forming the basis for the planning model.

The administrative division map was again overlaid with the forest cover/land use maps of the same scale (Figure 4.4a), based on satellite imagery and aerial photographs (DNFFB, 1993). The scale of the map was 1:1,000,000, which made it possible to digitize the original map in one step, highlighting inland and coastal dunes apart from the land cover (Figure 4.4b).

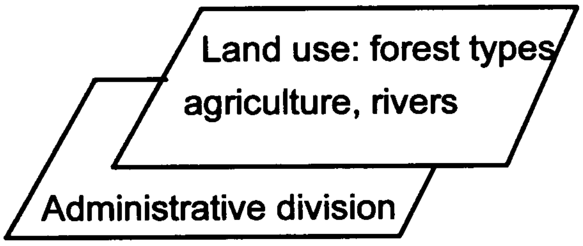


Fig. 4.4a Overlay of land use and administrative division

STATISTICS/ARCINFO was used to calculate the area of each locality and of each forest type within the locality (Table 4.2). This overlay visualizes the distribution of resources in each district which is important for general assessment of potential wood supply from each forest type.

The overlay results (Table 4.2) show that the province is poor in terms of availability of high quality forest types. Only 0.5% of the land is covered by low dense forest, which is found only in the Matututuine district in the South of the province. A further 7% of land is classified as low medium dense forest, with around 56% of this area found in the Moamba district; and, finally, 4% of land area is classified as low open forest made up of sparse trees, again with 63% of this area being concentrated in the Matutuine district.

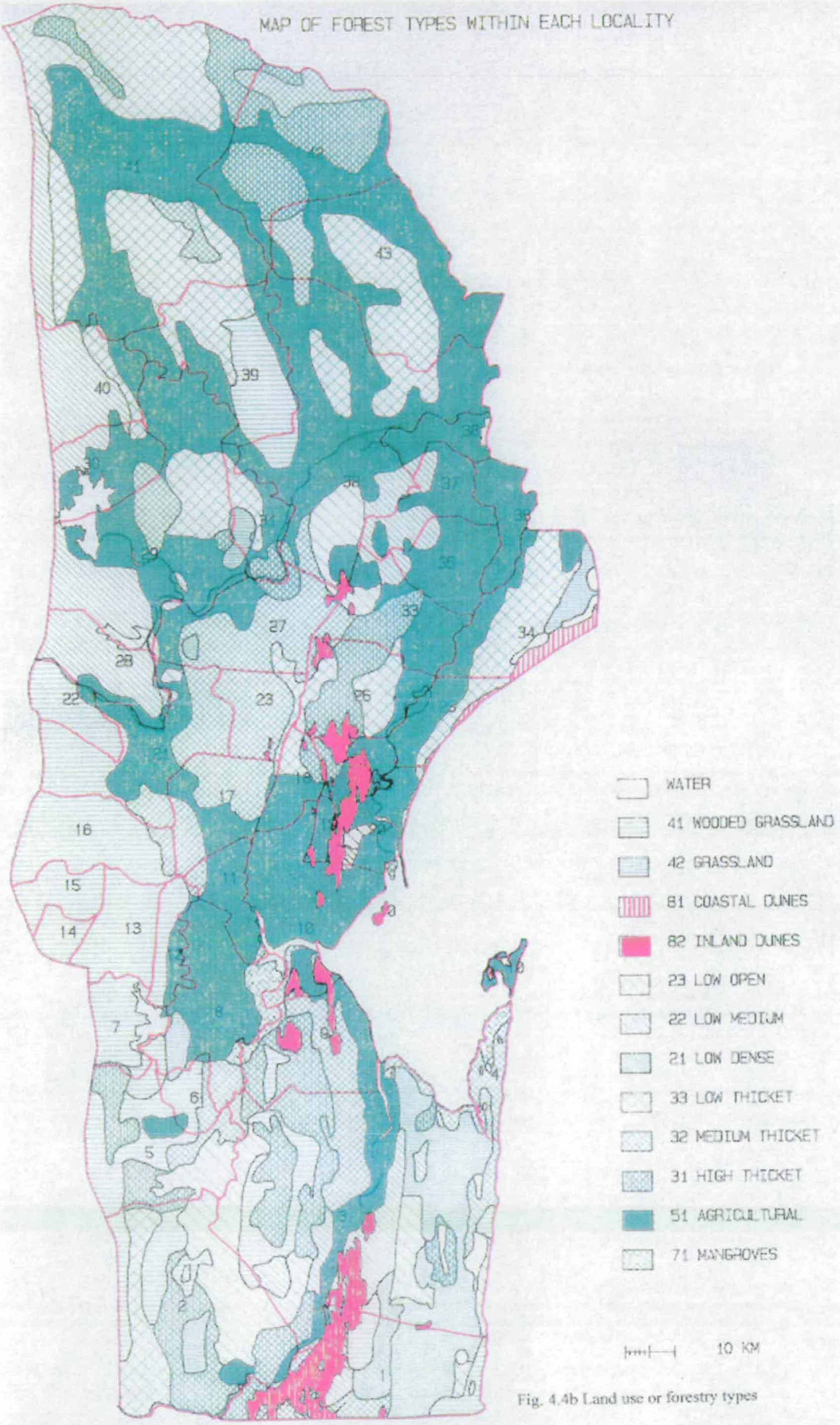


Fig. 4.4b Land use or forestry types

Table 4.2 Distribution of forest types per district and locality (km^2)

Forest District	Locality	F1 2.	F2 2.2	F3 2.3	F4 3.1	F5 3.2	F6 3.3	F7 4.1	F8 4.2	F9 5.1	F1 6.1	F11 7.1	F12 8.1	F13 8.2
Matutuine	1-Zitundo	89	42.5	0.1	36.	93.4	19.	121.1	248	3.2	9			181.
	2-Catuane		0.3	317.	34	3.6	24	242.8	56.1	37.4	5.9			0.5
	3-Bela Vista	29	285.	309.	46	256.		225.4	515.1	225.5	73.	47.7		74.7
	4-Machangulo					83.8			17.2		4.8	41.1		
	9- Catembe				16	139.		30.6		95.1	0.7	24.9		41.2
Namaacha	5-Changalane			119	17	65.1		272.3		29.4				
	6-Chigubuta					32.5		82.2	6	10.6				
	7-Mafavuca				4.8			192.4		42	0.2			
	12-Mafuiane					4.9		99.4		55.9				
	13-Mandevo							288.4						
	14-Namaacha							89.6						
	15-Macuacua							168.5						
	16-Matsequenha					33		417.7						
Boane	8-Boane				1.4	55.1		26.5	48.3	391.6		74.5		
	11-Matola Rio					23				167.4		4.7		
Marracuene	19-Michafutene									46.6				
	20-Marracuene		8.4	20.5			11.			160.9	12.		0.9	34.7
	24-Nhonginhane				25.		0.3			90.1	4.2			68.8
	25-Machubo						74			129.9	2.5		13.8	
Moamba	17-Pessene					263.	3	0.2		116.1				0.1
	18-Mahulana				27.	0.6	42.			95.1				3.2
	21-Moamba		5.6	11.3		214		195.3		232.2	6.7			
	22-Ressano		2.3					176.6		10.1	3.2			
	23-Vundica					222.	30.							2.4
	27-Malangane		12.7	4	33.	344.	20.		14.4	125	0.6			5.7
	28-Rengue		278.	4.2				0.3		38.1	4.7			
	29-Sabie		266.	22.1	12	98.7	20	0.1	21.6	617.5	48.			
	30-Tonganhane		80.6			21	12.			160.7	58.			
	40-Macaene		300.				59.			62.5				
Manhica	26-Maluana				16	15.1	15			56.3	3.7			33
	33-Manhica		32.4	35.9	10	35.3	6.2			189.4	0.1			5.1
	34-Calanga						28		72.9	148.4	37.		57.7	
	35-Mwatibjana		39.3		1.1					250				
	36-Xinavane									188.7				
	37-3 de		112.	0.2						175.2				
Magude	31-Eduardo				43.		65.		34.1	80.9	5.6			
	32-Magude		63	143.	11.	55.6	20	53.9		991.8	7.9			6.6
	39-Panjane						20	252.8		207.3				
	41-		161.		19	84.3	12			984.9				
	42-Mahele				48	116.				272.5				
	43-Motaze				16.	80.2	39			515.6				
Total		11	169	987.	23	234	33	2936.	1033.	7003.	29	192.	72.4	457.

F_1= Low Dense Forest; F_2= Low Medium Dense Forest; F_3= Low Open Forest; F_4= High Thicket; F_5= Medium Thicket; F_6= Low Thicket; F_7= Wooded grassland; F_8= Grassland; F_9= Agriculture; F_{10}= Water bodies; F_{11}= Mangrove F_{12}= Coastal dunes; F_{13}= inland dunes

Source: GIS output

The most common type of forest cover are thickets, occupying nearly 35% of the province, being 10% of high, 10% medium and 15% low thicket. These are respectively more abundant in Matutuine, Moamba and Magude districts. Wooded grassland makes up approximately 13% of land area, of which 55% is in the Namaacha district and 21% in Matutuine. On the other hand, grassland covers 4.5% of the land in the province and close to 81% in Matutuine.

The forest types in Maputo Province tend to be open, which gives an optimal environment for pasture growth. This province, before the war and severe drought, used to be very rich in cattle because of the predominance of sweet pastures, even though water has been the limiting factor for animal rearing, particularly for subsistence farmers.

Agricultural land accounts for approximately 31% of total land area. The remaining area is occupied by water bodies (1%), mangrove vegetation (0.8%), coastal dunes (0.3%) and inland dunes (2%). The resource distribution per district is likely to influence the location of the representative or typical farmers for each ecozone.

In order to highlight some of the soil limitations and potentials, the land use map was overlaid with a soil map (Figure 4.5a). This distinguishes two types of agricultural land: dry and alluvial. Only five types of soil were extracted from the soil map (1:250,000, INIA) with the legend in Table 4.3 essentially to differentiate the alluvial land. Furthermore, rocky and shallow (RI) soils, predominantly in the western hills, were included. Consequently, the areas either of forest type or agricultural land were subdivided using these details, grouping Fi and Ft to highlight the flood problem and Fe, Fa and Fs as mainly having salinity limitations (Table 4.3).

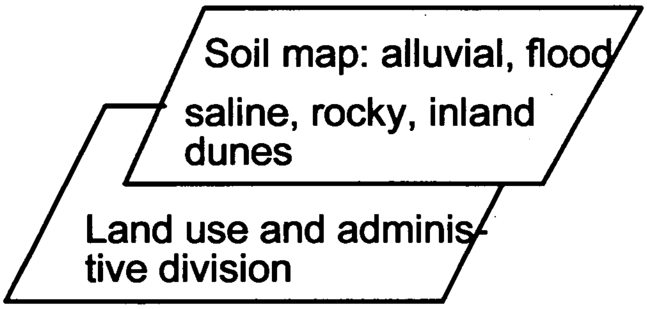


Fig. 4.5a Land use highlighting soil limitation

Table 4.3 Types of soils in the alluvial land (Legend of soil map -INIA, 1991)

Type of soil	Characteristics
F_i	alluvial with flood propensity and drainage problems
Fs	alluvial stratified, drainage problems and concentration of Na
Fe	salinity, marine sediments, bad drainage and flood problems
Fa	clay, drainage problems, salinity and sometimes flood
Ft	high propensity for flooding

As a result, the map (Figure 4.5b) and numerical information in Table 4.4 reveal the forest land or agricultural land with propensity for flooding, salinity problems or shallow rocky soils. Within the agricultural land classified as alluvial nearly 15% (of agricultural land) can be flooded and 21.5% have salinity problems as well as poor drainage. The salinization of Maputo river borders has been moving further Southwest during recent years, partly as a consequence of low rainfall and the entrance of sea water through the river mouth. The fact that the population is concentrated in the alluvial land, especially in the Bela-Vista locality, suggests that around 36% of the population, either farming in the river margins or collecting water to drink, face the problem of salinity. This affects labour, specially the women's labour who have to walk long distances to buy water for drinking.

Table 4.4 Land with major limitations to agriculture

District	Area with propensity for flooding (%)	Area with salinity problems (%)	Inland and coastal dunes (%)
Matutuine	19	1.6	6.1
Marracuene	9	37	2,15
Manhiça	7.6	35	2, 1.6
Moamba	2		

Source: GIS output

To the Northeast of Maputo-city, the Marracuene and Manhiça districts' agricultural land is highly affected by salinity problems along the Incomati river and/or propensity for flooding. These land limitations, predominantly on agricultural land, affect about 40% of the population in Marracuene and 38% in Manhiça.

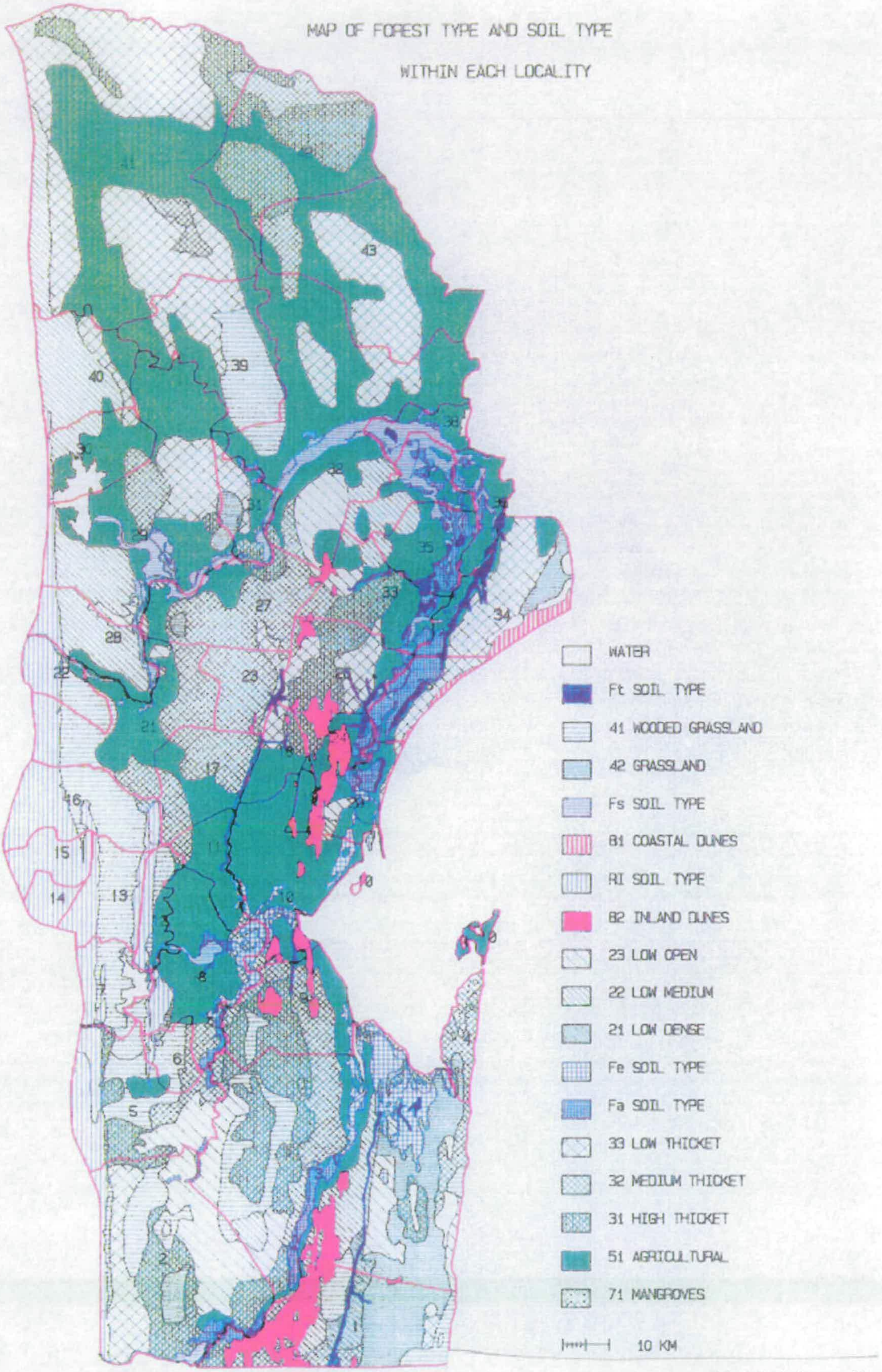


Fig. 4.5b Map of land use highlighting soil limitations and potential

As far as the Moamba district is concerned, some of the forest land is under rocky soils which presents a high propensity for erosion in the event of clearance, while approximately 2% have drainage problems, which is positive in terms of forest growth. This is illustrated by the fact that 90% of the land with drainage limitation is covered by low medium dense forest in this district and the same trend can be seen in Matutuine. Furthermore, the occurrence of this forest type in Magude is associated with a predominance of clay soil which also has a low infiltration rate. In fact, this soil type, as it will be shown in the discussion of the farm model outputs, has a very important economic role as pottery is one of the activities augmenting farm income.

As to shallow soil limitations, this is substantially observed in Namaacha district which reaches the highest elevation (800 m) in the West of the Maputo Province. The Libombos hills extend to the Moamba district in the North (21,21, 28) and only a narrow strip in Matutuine (2). The forest cover in this land is wooded grassland offering good pasture for cattle, one of the major components of the farming system in the district. At least each family in this region owned 5 to 21 cattle in the early 80's (Lexa, 1985).

The information above was important for classification of homogeneous zones which could then be specified as separate planning units within a mathematical programming model. Therefore, the seven districts were defined across five non-contiguous zones of ecological homogeneity and similar opportunities. The classification was based on forest types, but also took into account the different limitations faced by farmers in the dryland and in the alluvial land areas and also considered road access. Associated to this, other criteria were based on the first exploratory socio-economic data collected in the districts at three levels: administrative authorities, agricultural authorities and a sample of 22 individual farms and two group interviews (Appendix 2.2 and 2.4a). This preliminary survey provided the basis for definition of the main agricultural and non-agricultural activities associated to each ecozone which were later used to select representative farmers from which information was elicited to use in the planning models.

There are various criteria for selection of farmers for planning purposes which include the selection of a representative farm for each stratum of land size, family size or income size, or a representative farm according to land/labour ratio and other types of selection. Nevertheless, this research is mostly based on RRA data, which does not satisfy statistical requirements. This is due to the fact that, the objective of this research is not necessarily to produce quantitative outputs, but to develop a planning methodology in a data scarce environment for strategy/policy analysis whose final application shall justify more sophisticated data collection methods.

In this context, it seemed more appropriate to select a representative typical farmer rather than an average farmer in each land use or ecozone. The first step consisted of analyzing the average land and family size which in fact were not from a representative sample due to the reasons presented before. The second step was to list the main activities in each locality and district (Table 4.5).

Table 4.5 Definition of criterion for typical farm selection

District	Average land size	Average family size	Main activities
Boane	1 ha	7	Farming, animal breeding, firewood harvesting, charcoal production and marketing, artisan work (bags, straw mats, etc.)
Magude	2 ha	10	Farming, pottery (bricks, bowls, vases and other domestic utensils) firewood harvesting and marketing
Manhiça	2 ha	5	Farming, firewood harvesting, charcoal production, reeds harvesting, straw mats, sugar cane local brand, pottery
Marracuene	2 ha	5	Farming, fishing, charcoal production, poles and firewood harvesting and marketing, wild fruit brand production (*Strychnus* sp.)
Matutuine	2 ha	6	Farming, reeds collection, straw mats, charcoal production
Moamba	2 ha	8	Farming, fishing, hunting, animal breeding , firewood harvesting and charcoal
Namaacha	1.5 ha	6	Farming, charcoal production and trading (border with Swaziland)

Source: RRA, Preliminary stage

The predominance of certain land uses in each of the districts (Table 4.2) enabled connection with the results of the preliminary survey in Table 4.5 to define the ecozones and the typical farmers. The rationale for using a range of activities as a basis for selecting typical farmers is their strong link with farmers' possible decision as to whether to adopt agroforestry in their farming system or not. These activities, above all the non-farming activities, have a significant bearing on the generation of income and guarantees for meeting a minimum daily food requirement, thus, it is likely that they would be decisive in determining resource allocation, particularly, labour.

The typical farmers (30, three in each land class in Table 4.7) were located in each ecozone using as primary criteria the cropping patterns defined in association to similar crop yields and same level of access to technology. For example, in some ecozones farmers attained very low incomes and used only basic agricultural tools whereas, relatively wealthier farmers in the alluvial land could hire tractors despite still using manual irrigation and claiming lack of fertilisers as limiting the production. Since ecozones are not spatially contiguous (Figure 4.5b), localities with larger areas of each of the land uses were listed and only one selected among them depending on the accessibility by roads and tracks (Figure 4.2b) as well as an absence of land mines. A scale of 1 to 8, with one denoting easy access or near the main road and 8 the presence of land mines hence no access at all; 2, 3, 4 representing relatively good access condition with tracks opened by producers and timber merchants, 5 less access to the interior, 6, difficult access due to clay soil which implies impossible transit during the rain season and very slow speed during the dry season due to difference in terrain levels (holes) and finally, 7 the more remote zones from Maputo-city. This information was overlaid to the land use map and road and rail infrastructure map and using IDRISI, another GIS package, the difficulty of transportation from any ecozone to the local market (town) and to the Maputo-city markets were produced as indicated in Table 4.6.

Table 4.6 Difficulty of transportation

Ecozone	Nearest market (km)	Maputo-city market (km)
Dryland	54	137
Alluvial	40	100
Thicket	89	169
Open Forest	52	108
Grassland	90	142

Source: GIS output

This table only indicates the average difficulty of access to markets expressed in terms of traveling distance. Both producers and timber merchants still have a choice to minimize the travel distance by tractor or carts to the local market, or by lorry to the urban markets. Despite the fact that the Thicket ecozone has relatively large distance to either of the markets, it is still the main supplier of wood products hence the prices in the urban markets are likely to be more influenced by the transportation cost from this ecozone. On the other hand, for food supply, the major supplier (Alluvial) of food is located at relatively short distance which is likely to have more bearing on the price at which tubers, cereals and some vegetables are sold at in the Maputo-city markets. The locations of the representative or typical farms are shown in Table 4.7.

Table 4.7 Location of typical farmers

Ecozone	Land use	Localities
Dryland	Dryland Agriculture	8- Boane
Alluvial	Alluvial Agriculture - saline	25- Machubo
	Irrigated Agriculture	29- Sábié
	Alluvial Agriculture	37- 3 de Fevereiro
Thicket	High Thicket	26- Maluana
	Medium Thicket	17- Pessene/Vundiça
	Low Thicket	34- Calanga
Open Forest	Low Open Forest	32- Magude
	Wooded Grassland	13/16- Matsequenha/Mandevo
Grassland	Grassland	1- Zitundo

Source: Outcome of the prelimiry stage of RRA and GIS output

4.4 Typical farm data

The problem of food security is both associated with land availability and its productivity. The latter depends on the soil type, rainfall patterns and access to mechanical tools and other inputs. As it was highlighted in Figure 4.4b, most agricultural land is dryland with mainly poor nutrient soils and the alluvial is mainly limited by salinity (Figure 4.5b). Consequently, most of the crop yields shown in the Table 4.8 are very low due to intrinsic land suitability conditions as well as climatic and political instability. As sensitivity analysis will show later (Chapter 6), it is suggested that in stable conditions the crop yields are likely to be higher than that reported in virtually all ecozones.

Table 4.8 also indicates that there is a very small variation of crops cultivated in the different ecozones. However, land capability dictates that larger proportion of the land be allocated to one crop or another. For example, cassava and sweet potato are important cash and consumption crops in the Thicket and Alluvial ecozones, while green beans are hardly consumed locally, being mainly cultivated for sale.

Table 4.8 Data used in modeling the typical farm

Ecozone	Crops	Crop yield ton/ha Per land class			Opportunities for generation income	Predisposition to plant trees
Dryland	Maize	0.473			Charcoal production	Fruit and wood species
	Beans	0.399				
	Peanuts	0.148				
	Cassava	1.183				
	Pumpkin	6				
Alluvial	Maize	0.7^{s}	3^{i}	0.8^{a}	Fishing Carving Brewing Reeds collection Charcoal production	Fruit and wood species (Food shortage causes deforestation)
	Beans	0.33		0.4		
	Peanuts	0.6		0.4		
	Cassava	6		8		
	Sweet potato	3.8		8		
	Green beans		4			
	Pumpkin	6				
Thicket	Maize	0.8^{l}	0.6^{m}	0.6^{h}	Charcoal production Harvesting poles	Farmers believe on sustainable natural regeneration, they can plant trees but reluctantly
	Beans	0.4	0.2	0.3		
	Peanuts	0.4	0.2	0.3		
	Cassava	9	4	6		
	Sweet potato	8	2	6		
	Pumpkin	6	3	6		
Open Forest	Maize	0.8^{of}	0.473^{wg}		Charcoal production, Pottery Brewing	Aware of consequences of deforestation, wood species and wind breaks
	Beans	1.4	0.4			
	Peanuts	0.4	0.2			
	Cassava	6	4			
	Sweet potato	8				
	Pumpkin	6	5			
Grassland	Maize	0.473			Brewing	Wood species for generation of income
	Beans	0.399				
	Peanuts	1.183				
	Cassava	0.48				
	Sweet potato	4				

s= saline, a= alluvial, i = irrigated; l= low, m= medium, h= high; of= open forest, wg= wooded grassland

Source: RRA, 2nd stage

Furthermore, the table shows the main non-farming activities which are currently the major supplement of farm income and are likely to compete for labour with tree planting activities when such opportunities are created. In general, farmers show more of a willingness to plant trees in the ecozones where wood shortages result in large amounts of labour having to be allocated to wood gathering (either for family consumption or commercial purposes).

Saket (1994) compared 1980 and 1993 forest inventories based on 1972 and 1990/1991 national satellite images. This showed a deforestation rate of only 0.24% per annum. The main reason for such a small percentage of deforestation is the inaccessibility of forests and natural regeneration of others in abandoned land during the war (1964-74 and 1977-92). However, in Maputo Province, the increase in agricultural land has been nearly 20% which represents a substantial loss of already low productive forests. Around the secure corridors, the pressure on forest resources has been high. Saket (1994) also recognizes that since the cease fire, in 1992, people resettling in rural Maputo, have been causing mass destruction of woodland due to the use of bushfires to clean land for agricultural purposes, and direct exploitation of wood for fuel. The author calls for an immediate action if drastic negative effects are to be minimized.

Table 4.9 presents information regarding the average land (or weighted average in the ecozones with more than one land class) and the number of possible cropping seasons. The typical farms in the Alluvial and Thicket ecozones, are on fertile heavy soils and are supported by the existence of rivers or wells (since the water table may be at a reasonable depth in these ecozones), which means that crops including vegetables for family consumption can be cultivated all year round. This is later illustrated in chapter six through the surplus produce sold to other ecozones and to the Maputo-city markets.

Table 4.9 Other farm data

Ecozone	Cropping land (ha)	Cropping seasons	Pasture land (ha)	Pasture yield (ton/ha)
Dryland	1	One	5	0.428
Alluvial	2.29	Two, rotations	15	0.300
Thicket	1.44	Two, rotations	15	0.75
Open Forest	0.78	One	10	3
Grassland	1	One	15	0.333

Source: RRA, 2nd stage and estimates of pasture yield from secondary data

The pasture land area assumed for each ecozone is simply made to consider the possible scarcity of pasture due to overgrazing. In reality there is no delimited pasture land for each farm, since cattle and other animals graze on common land. However, the distance that the herdsmen have to walk depends on the availability of common pasture and the size of the herds of other farmers. For instance, grazing in the Dryland ecozone may be limited due to water scarcity. This aspect is illustrated with the potentially low availability of grazing area compared to other ecozones. The Alluvial ecozone, despite not having much land for grazing, is surrounded either by any of the other ecozones, which provides farmers with possibility of sharing the pasture with inhabitants of these ecozones, while benefiting from the availability of water as well. Cattle grazing in Maputo Province (and Mozambique in general) is characterized by a high mobility of both animals and herders throughout the common land.

Apart from land, labour availability is a crucial aspect liable to dictate the success of adoption of the Reforestation Strategy by the farmers. Table 10 outlines average labour availability and highlights the fact that the female's day starts much earlier and finishes much later than any of the other members of the household.

Such a situation arises because women have to undertake both field and domestic activities, whereas the other family members participate only in either of these activities, or else men work off the farm which generally has a shorter day length and requires travel time. Some flexibility in labour exchange is created, though, in the structure of the planning model, to allow for realization of tree planting activities. In general, there is only one adult man in the family, however, children include both genders. Coefficients regarding nutrient demand were computed from the FAO (1993) database related to the 1985 population data as well as original anthropometric data from Mozambique which presents the demand for energy per individual. According to this source, the daily demand for energy is 2856 kcal per adult man, 2066 per adult woman and 2071 per children (average boy and girl children under age of 15), whereas the protein demand is respectively 78, 59 and 57 g. The nutrient content per crop used in the model is indicated in Appendix 2.5.

Table 4.10 Labour availability

Ecozone	Hours per year	Size of the family
Dryland		
Male	2,848	1
Female	3,784	2
Child	2394	3
Alluvial		
Male	3044	2
Female	3898	3
Child	2438	2
Thicket		
Male	3044	2
Female	3898	2
Child	2438	4
Open forest		
Male	3044	1
Female	3898	2
Child	2438	3
Grassland		
Male	3044	1
Female	3898	3
Child	2438	4

Source: RRA, 2nd stage

As to the use of the natural forest for income generation, Table 4.11 shows the importance of wood products for generation of income. In all ecozones, except Grassland, typical farm income includes charcoal production and the predominant size of the kilns clearly illustrates that importance.

Table 4.11 Exploitation of wood products and availability per ha

Ecozone	Charcoal production (bags/kiln)	Volume of wood per kiln (m^3/kiln)	Harvesting poles (m^3/trip)	Forest yield m^3/ha
Dryland	30	8.223	0	6.81
Alluvial	5	2.2	0	0
Thicket	50	18.3	36	29.45
Open Forest	40	12.2	0	25.68
Grassland	0	0	0	0

Source: RRA, 2nd stage

Overlaying the administrative division map with the biomass map (Figure 4.6a), scale 1:250,000 (1993) which was transformed to UTM and projected to *albers* and appended to create a finished and corrected coverage (Figure 4.6b), showed the approximate availability of wood biomass. This supplied very important information related to the areas of each biomass type within the locality through STATISTICS/ARCINFO. The data were further processed in a Spreadsheet (EXCEL) generating the total biomass per locality which is converted into volume.

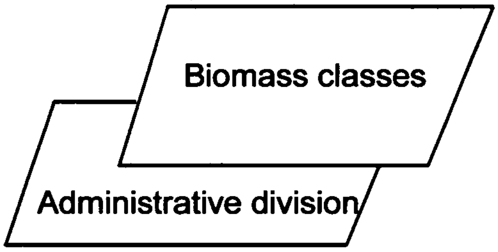


Fig.4.6a Forest productivity

Zero volume of wood products (Table 4.11) indicates either that only shrubs exist in an ecozone such as Grassland, or that farmers essentially have to travel some distance to the nearest ecozone to collect wood for various purposes, as is the case of farmers in the Alluvial ecozone. Since wood commercialization is not carried out in the Grassland, it is likely that household wood demand is met with existing shrubs. Nevertheless, this does not hold for the Alluvial ecozone since there is production of charcoal for cash even though at small scale. It can be inferred therefore that the volume available per household, particularly in the Thicket and Open Forest ecozones, is likely to be lower than indicated in the Table 4.12. For instance, the

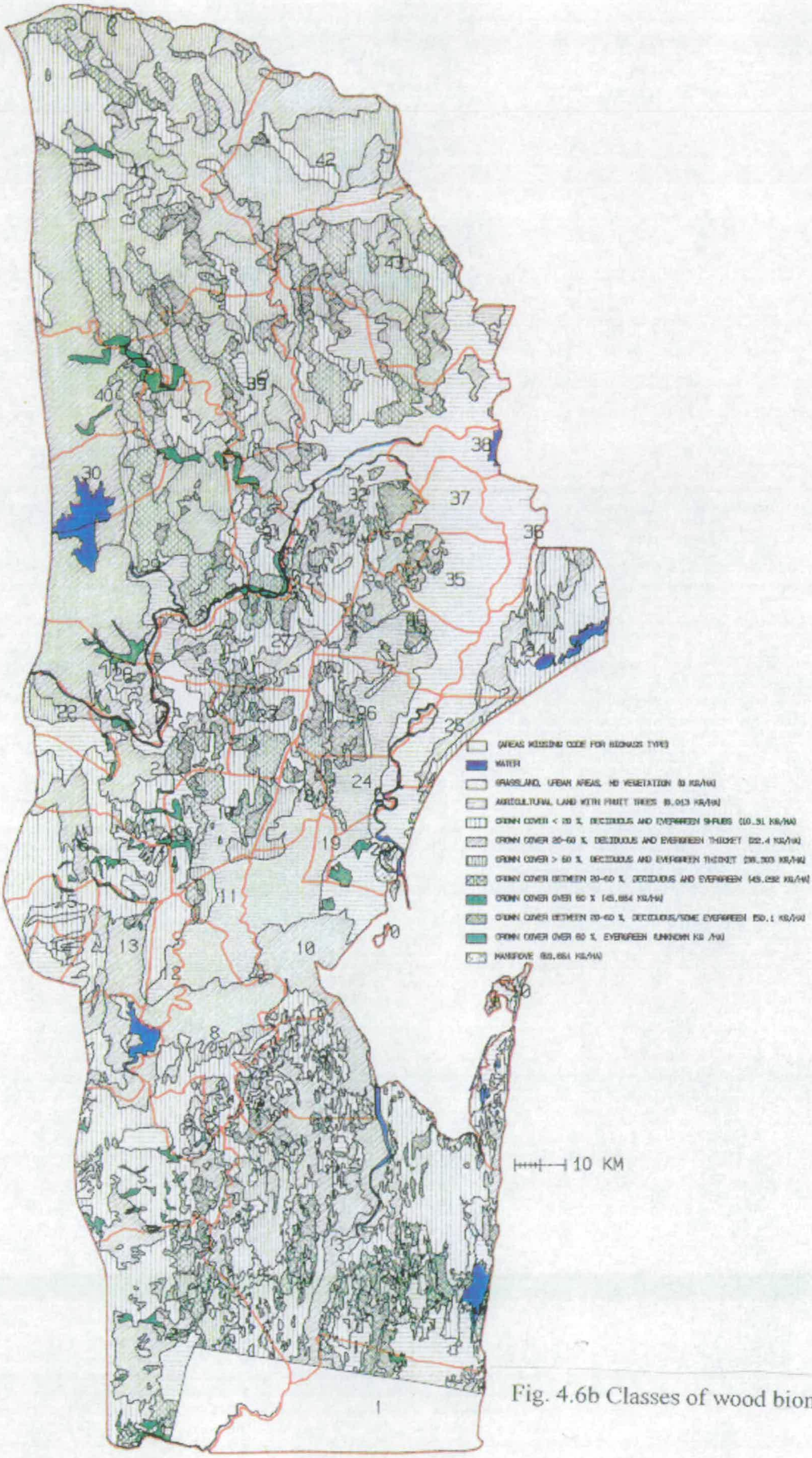


Fig. 4.6b Classes of wood biomass

Thicket has a lot of pressure from charcoal producers, who camp, harvest, burn and move on. Marketing of wood products by both locals and timber merchants from the city, makes it important to consider reforestation even in this ecozone, especially where harvesting has been intensive.

Table 4.12 Size of the ecozone and existing volume of wood

Ecozone	Area (ha)	Volume of wood (m^3)	Volume per household (m^3/hh)
Dryland	712,610	4,852,874	157
Alluvial	127,770	0	0
Thicket	649,860	19,138,377	715
Open Forest	372,550	9,567,084	1033
Grassland	103,370	0	0

Source: Estimates from the GIS output

The real abundance or scarcity of wood products in the ecozone depends on the quantity of wood exploited for commercial purposes and for domestic consumption against the existing volume as shown in the Table 4.12. The average domestic consumption of wood per head is between 0.85 (SADCC, 1988) and 1 m^3/yr of firewood (Bila, 1992), and 1 m^3/yr/household of building poles in houses with walls based on reeds in both the rural and urban areas (Nhantumbo and Soto, 1994). Some of the families interviewed in the Dryland ecozone, which has a negligible amount of biomass per hectare as indicated in Table 4.11, walk about 6 km to the nearest non farmed land or Thicket to cut firewood and transportation in a cart costs about $1.5 which is very expensive considering the limited opportunities for generation of income in this ecozone.

In the Open Forest ecozone, fuelwood is also significantly harvested to supply the pottery industry. In general, this ecozone is located far from the main roads and the deplorable state of the existing roads prevent timber merchants from intensive exploitation of the resources, since they would have to travel 350-390 km, half of which at a maximum feasible speed of 20 km/hr, hence making it a non-cost-effective business. However, as will be shown in the next section, many wood products are transported by train to Maputo-city, which is relatively cheaper. Moreover, exposure to wind causes concern and this explains the fact that, particularly in this ecozone, farmers explicitly expressed concern over environmental protection.

The agricultural land in both the Dryland and Alluvial ecozones has relatively good road access, hence the concentration of population. Wood is normally scarce, however, and the price of charcoal in some localities like Xinavane is nearly as high as in Maputo (about $2 per bag of 50 kg), and in many cases the population use forage from the maize harvest as a source of energy. This situation also increases farmers' awareness of the importance of tree planting, and in fact, some already have homegardens and live fences. The fact that firewood and charcoal production is necessary in the seasons of drought in the Alluvial ecozone, for instance, means that many farmers have to produce it at more than 15 km distance and transport it by head to the road side market.

It is important to point out that the analysis of GIS results provide some constants that otherwise would be complex to determine. Each ecozone model has a natural forest output coefficient and according to demand of wood for different purposes by the typical farmer, the level of forest exploitation is assessed (Chapter 6).

4.5 Wood flow to Maputo city: impact on potential land uses

Data on flow of wood to Maputo-city were collected especially for this study by 'Forest and Wildlife inspectors' in the main control stations (road side) of the Direcção Provincial de Agricultura (DPA) (map in Appendix 2.6). They are located in Michafutene (A), about 15 km North of Maputo-city which receives all products from Marracuene district, the northern districts (Manhiça and Magude) and Gaza province which has its boundary with Maputo in the North; Boane (C) at about 37 km to the South; Porto Henrique (D) at about 60 km South; Changalane (E) at 80 km Southwest and Chicochane (F) in the West. The other point is Gare de Mercadorias (B), in the Maputo-city, which is the railway station receiving wood products from some northern districts, particularly Magude and mainly from Gaza Province.

The data were collected over a one year period from September 1994. The recorded information was entered into a database to derive information on the main sources, markets, the average quantity of wood products daily transported and the average number of lorries doing so. In average, 33 lorries were found to pass through the check points every day to supply the urban markets with wood products, and the majority (20) transport charcoal, 10 transport firewood and the rest, poles. The capacity of each lorry is around 8-10 m^3 of firewood and just over 100 bags of charcoal. On the other hand, the train operates the equivalent of 5 months every year, even though the quantity per trip is relatively higher. Table 4.13 shows the total volume registered in each post per year.

The figures in the table suggest that only the equivalent to just over a million bags of charcoal enter Maputo-city markets. However, field observations seems to propound that much more charcoal is transported during the night when the officers are not on duty or through routes which escape inspection, and the reported quantity may be several times under the value that is really being transported. In general, the rail station wood shows the major contribution of the remote ecozones in remote districts such as Magude and imports from Gaza province.

Table 4.13 Wood products legally entering Maputo-city markets per year

Check point	Firewood (m^3)	Charcoal (bags)	Poles (m^3)
Boane	9,855	390,550	2,920
Changalane	3,190	141,255	7,838
Chicochane	6,898	78,110	
Michafutene	5,110	47,012	4,015
Porto Henrique	3,175	234,330	2,920
Rail station	8,343	135,681	2,574

Source: Wood flow registration for this study

The Thicket ecozone is dominant in terms of the availability of wood (Table 4.11), so it is reasonable to infer that it is the main supplier of the wood products registered at any of the check points outlined in Table 4.13. The registration of the destiny of wood products illustrates where the consumers are concentrated. It is confirmed therefore that markets in the suburban areas are the main destiny of wood products.

Nevertheless, the aim of such analysis is to identify the need and alternative land uses in the context of social forestry or participatory reforestation. This is the crucial part of this research which is concerned with a methodology design to evaluate social forestry alternatives. GIS results linked with socio-economic information provided a selection of options both ecologically and socially desirable. Experience has demonstrated that such links are necessary to avoid, for instance, misselection of species and population resistance to plant species like eucalyptus (Burley, 1989) or to use taungya systems. Catterson *et al* (1991) recommends co-ordination of activities as the way forward to handle the problem. In fact, as Mucavele (1994) points out, the government provides extension services based on what is perceived to be feasible to farmers whereas the designed techniques do not take into account farmers constraints and their behavior towards risk. This is worsened, the author stresses, by the lack of effective agriculture policies which would motivate farmers to increase their production and productivity.

The approach adopted here is an analysis of farmers preferences and goals, and incentives that may have to be created to encourage their participation in community reforestation. Farmers prefer village woodlots to intercropping as stated in the interviews and tree species included in the model are suggested in the forest zoning by Willan (1981). This alternative and its impact on the farm organization will be analyzed in Chapters 5 and 6.

Changalane was a large supplier of wood to Maputo during the war years. As a result, timber merchants are now moving to Matsequenha/Mandevo and Mafuiane. In Mandevo (Open Forest ecozone) people camp for wood harvesting. An interesting aspect to note though is the fact that this locality is a unique example of how local or traditional authority can play an important role in the management of the natural forest. Both local producers and producers from other areas, particularly Maputo-city harvesters, are given permission by the chief to exploit a limited number of tree species leaving some trees for natural regeneration purposes. However, such management has to be combined with other activities, because the regeneration rate is very slow compared to the harvesting rate.

Analysis of resource distribution in terms of wood availability per locality shows that Boane, some areas of Manhiça, Marracuene, and Namaacha districts have a significant wood shortage either from the point of view of local demand or if demand from Maputo-city is included. Moreover, districts like Magude, Matutuine and Namaacha which apparently have sufficient resources, have problems related to spatial distribution which puts a number of farmers under stress as to energy supply.

The above procedure aims at satisfying the first objective of this research which is the identification of social forestry alternatives. GIS and socio-economic data provided by typical farmers in each ecozone seems the way forward for addressing the current rural land use planning problem facing planners in the Maputo Province.

CHAPTER 5

Planning Matrices

5.1 Farm level planning framework

Chapter 4 has addressed the first specific objective of this research by identifying and analysing the social forestry options available to each ecozone. The second objective is the evaluation of these alternatives, involving farming and non-farming activities, tree plantation, animal rearing as well as marketing activities and constraints, through application of mathematical programming as a planning tool.

It was indicated in Chapter 4 that a survey was conducted with the aim of eliciting the farmers willingness to plant trees (WTPT) and collecting socio-economic data to compute the coefficients for a farm model in each homogenous zone. The predominant response concerning WTPT was positive in favour of either fruit or wood species, in a separate area from cropping. This suggests that intercropping may not be the best way to get farmers to implement the Reforestation Strategy in the Maputo Province. Therefore, the models described in this chapter assume that each farmer would have a separate area of land provided by the government as an incentive for reforestation. A group of farmers may own individual plots in village woodlots which they would manage independently.

Single and multiple goal planning situations, with and without tree scenarios are considered in two mathematical programming methods: linear and goal programming. Principles and application of these methods were discussed in Chapter 2. At the micro level, total farm gross margins of individual representative farms is maximized while other goals are taken as constraints. In this way, a singular farm objective can be used to analyze the whole farm model under the current decision environment and under the impact of changes that may result from the incorporation of tree planting activities. Further runs using Lexicographic Goal Programming whenever relevant, permit evaluation of possible conflict and tradeoffs between farmers goals. At a regional level, a Weighted Goal Programming model is applied to examine the extent of conflict between farmers and regional goals.

Representative farm-level planning models were constructed for each of the five ecozones, classified as: Dryland agriculture, Alluvial land, Thicket, Open Forest and Grassland. The general structure of the models representing each of these ecozones is similar. However, as shown in Chapter 4 the main differences concern the crops that can be grown on each land class, crop yields and the opportunities in terms of non-farming activities that can supplement the farm income. As a result, one ecozone model will be discussed in detail while only the main differences in the model in other ecozones will be highlighted.

However, before describing the model, it is important to detail the size of each of the ecozones and the assumptions made regarding population distribution per ecozone (Table 5.1). The Dryland and the Thicket ecozones are larger than the other ecozones. The Grassland zone is the smallest and has a very low human population density, partly due to a large area of this ecozone being within the Wildlife Reserve of Maputo. In addition, a significant proportion of the population were still refugees in neighboring countries at the time of the survey. It is anticipated that they will return to their original homelands with time.

Table 5.1 Ecozone and Population size

Ecozone	Area (ha)	Percentage of families in rural Maputo	Land classes
Dryland	712,610	30	1
Alluvial	127,770	28	3
Thicket	649,860	26	3
Open Forest	372,550	14	2
Grassland	103,370	2	1

It is also clear from Table 5.1 that the agricultural land (Dryland and Alluvial) accommodates nearly 60% of the total number of households in rural Maputo.

Comparing the land use or forest types classification (Saket, 1994) and the definition of level of intensity of farming, in what Snijders (1985) called small scale arable farming, it is found that there is complementarity of information. Both the Dryland and Alluvial ecozones are classified as generally high density farming zones. Snijders also adds that land use is associated with the presence of people which justifies that the arable land is where the majority of the population reside. The Thicket zone is classified as forest, because less than 30% of the land is cultivated. It is assumed to have a significant percentage of households since forest products offer income security to the farmers. This also conforms with high and medium density small scale farming. Therefore, the Alluvial and Thicket ecozones could potentially provide, a large share of both food and wood products to a regional pool from which other ecozones and the Maputo-city inhabitants may purchase.

This background will facilitate the understanding of the multipliers that will be associated with each ecozone when computing the total surplus (or deficit) of food and wood products (details in Section 5.2).

In general, the ecozones have one (Dryland and Grassland) or more land classes (Table 5.1). Alluvial land can be classified into three potential land classes: alluvial without major limitation (flood or salinity), saline and irrigated land. The Thicket ecozone includes low, medium and high thicket and the Open Forest includes open forest and wooded grassland.

Crop activities comprise cereals, legumes and vegetables grown with a range of yields dependent on land class (Table 4.8 in Chapter 4). In the case of the Alluvial and Thicket ecozones there is potential for a crop rotation during the two seasons whereas other ecozones cultivate mainly cereals solely in the rainy season.

Farmers practice farming and non-farming activities (Table 4.8) to minimize the risk associated with low harvests related with climatic instability and social unrest. These activities are not sustainable inasmuch as they either depend on the forest resources, which may be depleted as the population increases, or the existence of rivers which may dry out during drought periods. Saket (1994) indicated that large forest areas in Maputo have been converted into cropping fields or pure grassland at 1.1% a year. However, SADCC (1988) presented a rather dramatic picture by Kalbreg (1985) who estimated that Maputo forest resources would be depleted by 2010 due to population increases of 2.3% and 5.5%, in the rural and urban areas, respectively. Consequently, whichever estimation is more realistic, both suggest that directing land use towards tree planting has great potential to secure income which can minimize the impact of the climatic hazards, and more importantly, the conservation of soil and forest resources. Therefore, the main constraints of the model are land and labour which determine viable activities in terms of resource use.

In the first instance the individual ecozone models are run separately to highlight the different land uses and opportunities that could exist if each ecozone was considered in isolation (i.e. without interecozone trade and without trading opportunities with the Maputo-city). However, the main objective of this research is to analyze the overall impact of the Reforestation Strategy at the regional level. Therefore, the farm models described are the main building blocks for planning at the regional level.

An important aspect to note is that the data were collected just after a period of war which considerably disrupted the record keeping of socio-economic and agricultural data thorough the country. Despite the lack of hard data it is acknowledged that farmers are risk averse as to food security due to uncertain climate and that there may be spatial and temporal variation of data relating to crop yield. A sensitivity analysis is therefore carried out to deal with risk associated with farming and data uncertainty through variation of some of the assumptions related, for example, to crop yield and variability of land size. The following section discusses the model developed for the Dryland ecozone, and as mentioned above, rather than repeat aspects of model construction, the models representing the remaining ecozones are only discussed with regard to their differences from this model.

5.1.1 Dryland ecozone

As mentioned in Chapter 4, typical farms have been selected to represent each ecozone as a whole in terms of the range of opportunities for both farming and non-farming activities. Farmers provided socio-economic and technical information on the basis of which the coefficients have been determined. The organization of the typical farm in this ecozone consists of a unit in which the activities performed depend on the gender and age of members of the planning unit. In general, two activities prevail: farming and charcoal production. Because of the consequent narrow range of employment opportunities in this ecozone it is possible to identify a real individual farm which resembles the model. However, as it will be shown later, ecozones with relatively wider range of non-farming activities make the hypothesized model less identifiable on the ground.

The application of mathematical programming as a planning tool requires that a decision be made concerning the potential range of relevant activities, the resources available as well as the goals of the decision-maker. Figure 5.1 summarizes the basic farming model to which animal and tree components were subsequently added as illustrated in the Figures 5.2 and 5.3, respectively.

The basic model consists of the current farming and non-farming activities. Two situations of the model for each ecozone are described: without tree establishment and with afforestation. The without trees situation is further considered in two steps: with and without animals as part of the potential system. The reason is that a livestock restocking program is being encouraged by government and non governmental organizations independently of the Reforestation Strategy. Furthermore, tree species providing fodder supplement may be planted. This in turn may reduce the labour allocated to animal rearing and possibly increase the size of the herd.

Fig. 5.1 Basic typical farm model

Activities	Grow Crops	Sell crops	Store crops	Buy Crops	Labour sale	Domestic activities	Agriculture land	Wood for charcoal	Charcoal Production	Sell charcoal	Food consumption	Seed	Wood consumption	Hire labour	Family equivalent	Labour transfer	Sign	RHS
		D/W	W	D/W	D/W	D/W	D/W	D/W	D/W	D/W	D/W		D/W	D/W		D/W	Sign	RHS
Objective	-$/Ha	$/Kg	-$/kg	-$/kg	$/mnhrs	0mnhrs	0$/m3/ha	0$/kiln	0$/kiln	$/50Kg	0$/kg	0$/kg	0$/m3	-$/hr	0$/hr	0$/hr		
Constraints																		
Land per class	1																≤	ha
Land/crop	1																≤/≥	ha
Crops	-	1	1	-1							1	1					≤	0
Family Labour	+				+	+		+	+	+					-		≤	0
Hired labour	+													-1			≤	0
Limit on Hired labour														1			≤	Mhrs/season
Labour Sale					1												≤	Mhrs/season
Domestic activities						1											=	1
Family Size															1		=	No/sex and age
Energy											-				+		≤	0
Protein											-				+		≤	0
Diet balance											+						≥	Kcal/crop (D/W)
Wood for Charcoal								-1	1								≥	0
Charcoal									-	1							≤	0
Limit on Charcoal									1								=	Kilns (D/W)
Limit on Wood Consumption													1				≥	m3 (D/W)
Seed	+											-1					≤	0
Use of Natural Forest							-	+					+				≥	0

D= Dry season W= Wet season + = Demand - = Supply

First the major components of the model are discussed: activities, resource constraints and farmers' goals.

a) Current situation planning framework

Current and Potential Activities

All ecozone models are based on the information provided by the sample farmers as indicated in Chapter 4. The representative model for the Dryland ecozone (Figure 5.1) is no exception. Allowance is made for potential activities such as selling the commodities which are surplus to requirement or, transferring adult female labour to male labour or child labour to female to allow flexibility in the exchange of labour during the peak periods within the broader planning period of the dry and wet seasons.

The features of the Dryland ecozone are:

1. The main cost component for crop growing activities is seed because, given the subsistence nature of the farmers in the ecozone, they tend not to use inputs such as chemicals. The cost per ha of cassava is very small, due to its vegetative reproduction and in the event of being bought, its price is very low. Pumpkin also demands a small quantity of seed at a very low price. Other costs include hired labour primarily for sowing and weeding. These activities have to be performed over a short time period: sowing before the humidity of soil is totally lost, and weeding to minimize the effect of competition.

2. The next group of activities involve selling and buying in both the dry and wet seasons as well as storage on farm. The prices (Appendix 3.1) of the main products are lower during the dry season, their main harvesting period, while the price of by-products tend to be lower in the wet season. The total value of sales either of surplus crops or from non-farming activities determines the farmer's capacity for buying food and agricultural inputs as short term needs, as well as the long run objectives such as investment in draft power, education for children, and better health care.

3. Domestic activities are also considered to account for the whole range of family time. They include fetching water, cooking, gathering firewood and other household daily activities. They vary between ecozones, mainly depending on the location of the source of wood and water. In the Dryland ecozone both water and wood are scarce, and considerable time is necessary for collection. Children participate in these activities together with the females in the household.

4. The next activity group in the matrix relates to non-farming activities. In the case of the Dryland ecozone, these involve activities concerned with charcoal production. According to the Forest Inventory (Saket, 1994), tree volume per ha is as low as 6.81 m^3 on dry agriculture land. Assuming that charcoal is produced with wood from the ecozone, about 1.2 ha would have to be harvested to provide an estimated value of over 8 m^3 of wood necessary to produce a single kiln of 30, 50 kg bags of charcoal.

It is assumed that apart from the opportunity cost of the labour input, there are no specific costs associated with timber provision for charcoal production. This is because, according to Chapter V.2 of the valid Forest Legislation (MA-DNFFB, 1987) the rural population can explore, for their consumption, 3rd and 4th class species for poles and firewood without licensing. In the event of infringement, i.e., clear felling of diameters greater than 30 cm for commercial purposes, fines can be charged with the amount varying between \$52 and \$155 depending on the type of forest exploited. However, perhaps the recognition of the fact that forest products were the only source of subsistence during the civil war and drought periods, led the government to a passive role in enforcing this legislation. Charcoal is assumed to sell in bags of about 50 kg and is more expensive during the rainy season due to difficult transportation and the fact that the combustion period is longer.

5. Food consumption activities in the planning model framework, ensure that basic food requirements are provided for. Food demand maybe met from crop output or from storage or from foods purchased from other ecozones or Maputo-city markets.

6. Seed activities account for harvested produce set aside for sowing the next crop. However, in many cases low productivity from such seed necessitates the purchase of new seed.

7. Wood consumption activities account for the family demand for fuelwood and building material in each year, both in the dry and wet seasons. In the rural areas, apart from cooking, the wood is used for heating and light since kerosene is expensive and not always available in the local shops. It is assumed that the demand for fuelwood is near perfectly-inelastic, i.e., families consume about the same amount even if it means a high opportunity cost of labour used for gathering wood.

8. The 'family equivalent' activities consider the family composition in terms of both gender and age (child and adult). This determines the available labour to perform the various activities previously listed and, the demand for nutrients. The latter demonstrates the degree to which the family is self-sufficient or dependent on purchasing. It is assumed that the maximum length of the working day for men, women and children is respectively, 8, 10 and 6 hrs in the dry and 9, 12 and 8 in the wet season.

The transfer of labour between child to female and female to male, is considered in the model. These activities aim to create flexibility in labour exchange during the periods of high labour demand. The survey has indicated that male to female transfer could not occur since traditionally or culturally, men assist in farming activities (particularly, land preparation), but will not engage in domestic activities which are defined quite rigidly as women's duties. Therefore, in this case, females will assist in the first stages of charcoal production and if their participation in this or any other activity has to increase, the children have to provide more labour for domestic activities.

At this initial stage of planning, it is assumed that the sole objective of the farm family is to maximize the annual total farm gross margin (TFGM). The reason being that the farm has to generate income not only to ensure food security in case of crop failure, but to attend for other family needs not included in the model. Therefore, running the LP model is considered the first step in deciding the best combination of farm activities (Makeham & Malcom, 1986) subject to the following constraints.

Constraints

In this mainly farming ecozone, production is limited by the prevalence of sandy soils with low fertility levels. The direct effect this has on yield is exacerbated by an irregular and increasingly short rain season. This, partly, explains the low maize and peanut yields of 500 and 150 kg/ha, respectively. Thus the extension of water capture capacity and improvement in soil fertility would certainly provide for greater farm output. There is potential for a tree component to contribute to soil improvement, for instance through the incorporation of leaf biomass into the soil to enhance nitrogen supply. However, the incorporation of new activities in the farming system such as animal rearing or tree planting requires an analysis of the current land and labour limitations.

The main constraints are as follows:

1. The area of land per family in this ecozone is approximately one hectare on average. Since there is only one farming season, mixed cropping is unavoidable to maximize the output mixture. A specific proportion of land is allocated per crop according to the traditional culturally determined consumption patterns. In fact, the land use and diet constraints seem to have reciprocal influence. Generally, more than 50% of the land is allocated to maize, about 20% to peanuts, 10% to beans and the rest is allocated to cassava, pumpkin and other crops. Therefore, this information was used to constrain the land allocation in order to produce a realistic model output.

2. Labour deployment is an important aspect in the model which determines the capacity for the family to adopt the Reforestation Strategy. The overall requirement for labour per crop was obtained from the 'Agriculture Norms' of the Ministry of Agriculture (UDA, 1982). The activities performed in the dry season are basically land preparation in which men participate. The participation of children in farming

in this ecozone is assumed to be negligible. Sowing, weeding and harvesting is mainly carried out by women. Consequently, during the periods of peak demand for labour, female labour is often hired to assist in farming activities.

Conversely, men allocate their labour primarily to charcoal production. Hiring male labour takes place during the periods of income or food shortage in the family, when production of charcoal in a relatively shorter period is indispensable. Also a bigger labour share is expected from the female labour. The corresponding cost per hour of hired labour is computed in the objective row.

Hiring labor is limited by the amount the family can afford to pay, the average being 60 hrs of female labour and 169 hrs of male labour per annum. It is assumed that within the ecozone there are some families with a smaller land area who would prefer to sell their labour to be paid in kind or cash. No exchange of labour among ecozones is incorporated, because the ecozone unit is assumed to be self sufficient in terms of labour supply.

3. Family size indicates the number of individuals by gender and age (child and adult) per average family which determines the total labour available to perform all the activities previously listed. This constraint also determines the total demand for nutrients.

4. Human energy and protein requirements, in kcal/kg and g/kg, respectively, are the essential nutrient components considered in the model. It is assumed that satisfying them will also provide for the essential micro nutrients with supplement from wild fruits and plants which were not included in the model. The energy and protein content of the main products and by-products was extracted from tables presented by West *et al* (1988) (Appendix 2.5).

The selection of crude values such as energy and protein does not account for the farm family endeavoury to select a balanced diet according to palatability.

Therefore, lower and upper bounds are specified for each season for maize and cassava (normally accounting for about 75% of the total energy demand) in the diet. Furthermore, since peanuts are an indispensable ingredient in the consumption of by-products such as sauce, constraints were included to ensure its entry in the food 'basket'. Pumpkin was limited to a low level of dietary inclusion for it is not a major component of diet in the region, despite its high energy value. All other crops can be included in the diet and the model selects a combination that meets the rest (25%) of the energy and protein requirement.

The nutritional constraint is essential in this research, because one of the objectives expected in social forestry implementation, is either to improve soil fertility and crop production or provide a cash income so that the farmer can purchase at least a satisfactory basket of food to meet the daily nutritional requirements - the short term farmer's goal.

5. Finally, 'the use of natural forest' balance constraint accounts for the area of natural forest that would have to be harvested in order to meet the wood demand both for household consumption and for income generation. It is an important constraint which may later be influenced by the size of the planted area. The area of plantation may enhance or substitute the current source of wood for producing charcoal or give preference to selling poles or firewood which would demand less labor. Further discussion is provided in the reforestation model framework description (item c, pp. 150).

Goals

One essential landmark of this research is that a bottom-up planning approach as illustrated in Chapter 2 (Figure 2.1) is used. That farmers views are taken into consideration is seen as a way forward in the research towards better understanding of the level of conflict between farmers' goals regarding the implementation of the Reforestation Strategy.

One of the questions asked during the survey related to listing and prioritization of goals that the farmers perceived as substantially important for the household to achieve with its resource endowment in the current situation and in the event of tree planting. There was a strong indication that farmers have two main goals which related to the achievement of food security and the continuous availability of wood for consumption and generation of income. The first goal means that crop output should vary as little as possible or that farmers should generate sufficient income to purchase food to satisfy their nutrient requirements. The second goal, means availability of wood close by and in quantities that could ensure generation of income. This ecozone has only scattered trees and these are unlikely to be able to make a significant contribution without further reforestation. Even though a reforestation target will be set in the regional goal programming framework, and its negative deviation minimized, it was found appropriate to include trees in the LP tableau to explore its impact on the farmers' planning framework. The option to dedicate land to trees has been constrained at a maximum.

Food security brings social stability and having a tree crop that ensures the generation of income also ensures the minimization of disruption of that stability. Therefore, the objectives put forward by the farmers have an underlying socio-economic component even though the environmental component is intrinsic to tree planting. The trade-offs between these goals will be analyzed with a multiple goal programming framework specifically Lexicographic Goal Programming run in LINDO following a sequential introduction of priorities as described by Winston (1995). According to Romero (1991) this could be a disadvantage as the model may have to be run as many times as the number of priorities. Nevertheless, given the limited number of goals and priorities listed by the farmers, such a limitation is irrelevant for the problem under consideration.

b) Incorporating the restocking program into the planning matrix

At the time of data collection for this research (1994/95), farmers were still resettling in their zones of origin after the civil war. They needed both short term expenditure on agricultural tools and other inputs as well as long term investment like animals and trees.

Animal rearing has always been an important activity in the Maputo Province. The animal population was over 432,000 head in 1974 of which 80% were owned in the family sector. In 1973, for instance, the average herd size per family in the province was 11.2 cows, which was above the country average of 9.5. However, the stocks decreased at a rate of 2.44% per annum during the period of 1974 to 1983 (Dionísio, 1985). This decline increased dramatically during the 16 years of war which ended in 1992. Many farmers had no animals at all when the survey was conducted. Therefore, it seemed appropriate to analyze the impact of restocking as well as the likely effect of multipurpose trees in the reforestation program on herd size.

The fact that animal production is traditional amongst farmers means that there are unlikely to be obstacles for adoption. However, farmers may have to repay loans at an average of 0.33 calves and 0.57 goats per year per animal borrowed. The actual possible size of the herd is limited by the grazing land available and its productivity. Supplementary fodder from trees although restricted by animal digestion limits, provides fodder security for the dry period when natural pasture is bitter and/or scarce.

Goats and cows are included in the model as they are very important from the farmers' point of view. They bring a measure of social prestige, a form of capital easily converted into cash, milk production and meat for consumption and animal traction. Average figures for the Southern African region indicate animal traction as the most important purpose (42%), followed by milk (29%) while consumption was only 5%. Dionisio (1985) also states that approximately 24,000 ha were cultivated in

Maputo Province using draft animals. Even though these uses are not individually included in the model, selling activities account for the opportunity cost associated with keeping animals for social prestige. Therefore, the base model described above was extended to include animal activities (Fig. 5.2).

Fig. 5.2 Tableau of the animal component

Activities Objective	*Leucaena* biomass 0$/ton/ha	Pasture 0$/ha	Cattle 0$/head	Goats 0$/head	Calves repayment 0$/head	Sell Calves $/head	Goats repayment 0$/head	Sell goats $/head	Sign	RHS
Constraints										
Lower land limit									≥	1 ha
Wood-leaf biomass tie									≤	0
Upper land limit									≥	ha
Pasture land		1							≤	ha
Pasture feed		-	2.25	0.197					≤	0
Leucaena feed	-12.8	-	0.75	0.022					≤	0
Calves			-0.77		1	1			≤	0
Goats				-1.7			1	1	≤	0
Limit on Calves					1				≥	0.33
Limit on Goats							1		≥	0.57
Maize Improvement									≤	0
Use of Natural Forest									≤	0

-= supply

Feed supply from common grazing land was estimated from Myre (1971) as 0.428 tons/ha. It was further assumed that the typical farm has access to about 5 ha of common land for grazing. According to Timberlake (1985) the source of feed is mainly native grass with trees and shrubs becoming more important during the dry season. The demand of pasture per cow is 3 tons of dry matter (DM) per year (Timberlake, 1985), whereas goats consume 3% of their live-weight per day (Williamson and Payne, 1978). Assuming an animal with an average weight of 20 kg, then the consumption is approximately 219 kg DM/yr/head.

c) Reforestation strategy in the planning matrix

As mentioned earlier, the analysis of the current model is a basis for determining the impact of adding a tree component to the farming system. The structure of the sub-matrix shown in Figure 5.3 is the same for all ecozones.

The survey information showed that farmers prefer reforesting in woodlots rather than intercropping. The reasons for this relate to the potential reduction of land available for crops and possible competition under and above ground between tree and crop components. Therefore, the model analyzes only the planting stands of forest species, however, their by-products can also be used for feeding animals and improving soil fertility.

The tree investment activities include *Leucaena* spp., *Eucalyptus* spp. and *Melia* spp. According to the ecological zoning these are some of the main species that can be grown in Maputo Province. It is envisaged that planting trees should be a sustainable activity, therefore, every year land equivalent to that harvested has to be replanted.

In the objective function only the cost of replanting is reflected, because harvesting is charged in terms of labour. It is assumed that the forestry authorities will provide the seedlings at a cost of production which includes the cost of purchasing seed and the labour involved in producing the seedlings. The projected costs per year were discounted to Present Value (PV) at 43%, the nominal discount rate for agricultural investments prevailing in 1994. A period of 16 years was taken to provide for at least two rotations for the longest rotation species (*Melia* sp. 8 years). The annuity of

Fig. 5.3 Tree component of the model

Activities	Mz	IMz	LB	L	LTP	LTC	N2	E	ETP	ETC	M	MTP	MTC	LF	LP	EF	EP	MF	MP	NF	HhWC	Sign	RHS
					D-W	D/W			D-W	D/W		D-W	D/W	D/W	D/W	D/W	D/W	D/W	D/W	D/W	D/W		
Objectives	-$/ha	-$/ha	0$/ha	-$/ha	0$/m3	0$/ m³	0$/ton	-$/ha	0$/m³	0$/m³	-$/ha	0$/ m³	0$/ m³	$/ m³	$/ m³	$/ m³	$/ m³	$/ m³	$/ m³	0$/ m³/ha	0$/ m³		
Constraints																							
Crop land	1	1																				≤/≥	Ha
Maize	-	-																				≤	0
Family labour	+	+	+	+				+			+											≤	0
Lower land limit				1				1			1											≥	1 ha
Wood-leaf biomass tie			1	-1																		≤	0
Upper land limit				1				1			1											≤	ha
Pasture land																						≤	ha
Pasture feed																						≤	0
Leucaena feed			-																			≤	0
Leuacena				-	1/-1	1								1	1							≤	0
Eucalyptus								-	1/-1	1						1	1					≤	0
Melia											-	1/-1	1					1	1			≤	0
Calves																						≤	0
Goats																						≤	0
Limit on Calves																						≥	0.3
Limit on Goats																						≥	0.6
Maize improvem.		+					- 0.0072															≤	0
Use of Natural Forest						-1				-1			-1							-	+	≤	0

D= Dry season W= Wet season Mz= Maize IMz= improved maize L= Leucaena spp. E= Eucalyptus spp. M= Melia spp. TP= wood transfer to poles

TC= wood transfer to charcoal production N2= Nitrogen content of Leucaena leaf biomass NF= natural forest HhWC= household wood consumption costs were amortized using one of three different interest rates (10, 20 and 45%) and an annual capital charge for each option was determined. This provided information for the decision maker, the planner in this case, to select the adequate interest rate to apply (from 3 scenarios) for the farmers, according to the rate of adoption expected. 10% and 20% were simply chosen subjectively, whilst 45% was chosen as an amortisation rate scenario close to that of the observed nominal interest rate.

Trees have long rotations whereas farmers have shorter planning horizons, therefore the different interest rates of lending capital serve to illustrate the possible incentive or disincentive to farmers to adopt tree planting. Furthermore, it means a very high price that the government may have to subsidize to secure the implementation of the Reforestation Strategy.

Leucaena spp. are fast growing and in a period as short as two years can be clear felled for firewood and/or small poles (8-10 cm). There is a market for such produce in the construction in the rural areas and the suburbs of Maputo-city. On the contrary, medium size poles (with diameter over 15 cm) can be produced from *Eucalyptus* spp. and *Melia* spp. at rotations of 7 and 8 years, respectively. Therefore, it is assumed that in every year half the area of *Leucaena* spp. can be harvested and the area subsequently replanted, whereas one fifth of the remaining species can be harvested. So, the annuity cost of planting 1 ha and replanting ½ from the end of the first year in the case of *Leucaena* spp., or 1/5 ha for *Eucalyptus* spp. and *Melia* spp. are considered. The revenue is given by annual prices for the sale of two types of products: firewood and poles. *Leucaena* spp. also offers fodder and leaf bioamss for soil improvement, however, costs are only computed in terms of labour demand, that is, opportunity cost of labour. The nitrogen improvement due to *Leucaena* spp. biomass is directed to the improved maize activity which competes, in terms of land, with non improved maize production.

Land is the major constraint on reforestation. An estimated range between 1 ha and an upper limit of 15 ha is explored to cover the potential each family could plant with trees in the Dryland ecozone. Planting may be on marginal land with extremely low crop productivity. Larger areas may only be planted if enough incentive is provided to farmers. The survey found that farmers are likely to achieve a target of 1 ha planted to trees even if no subsidy were paid.

The model also includes transfers for wood products from one season to another to enable sale in a more advantageous season, and transfers for wood from plantations to the 'use of natural forest' constraint. The objective of this constraint is to supplement the natural forest harvesting with wood which could perhaps be used in charcoal production or firewood for consumption. Is there a substitution of natural forest products with wood from plantations? If there is substitution, then it can be inferred that planting will immediately lead to conservation of the forest resources and possibly provide habitat for wildlife.

The main wildlife indicator species to benefit from tree planting in the medium term is the wild goat which is common in the province and is an important source of income for local people. However, it is not included in the model because of the reluctance of farmers to disclose the level of hunting. Perhaps an institutional enforcement, like having a harvesting license fee, may be necessary to encourage the farmers to use less of the native forest products.

Both animal and reforestation components of the matrix are similar in all ecozones, the only difference being the size of land available for grazing and reforestation. Therefore, in the following subsections the details of this part of the matrix will not be repeated and only issues unique to each ecozone will be discussed.

5.1.2 Alluvial ecozone

Unlike the Dryland, the Alluvial ecozone offers more opportunities in terms of the range of crops that may be grown in the three land classes (alluvial without major limitations, saline and irrigated), crop rotations and the relatively higher yields. The weighted average area for each of land classes for the representative farm is 0.26, 0.9 and 0.63 ha, respectively. Despite the potential for higher yields, and the fact that farmers employ machinery (such as tractors for land preparation), the use of chemicals such as fertilizers and pesticides are still limited by low supply and/or very high prices. As mentioned previously, only particular aspects of the planning framework will be highlighted since the general structure of the matrix is the same as for the Dryland ecozone.

Activities and constraints

1. Crops which are grown include, apart from the ones mentioned in Table 4.8, vegetables for local consumption. Green beans are cultivated in the dry season and provide for growing maize on the irrigated land. The total land for agriculture on the typical farm is about 1.79 ha.

2. Food surplus in this ecozone is sold in the local and Maputo-city markets. So a certain amount of labour is set aside in the model for selling activities related to agricultural products such as cassava, sweet potato and green beans. These activities draw on family labour and their corresponding costs include those on traveling to and from the markets as well as charges levied on selling produce in the markets. The difficulty of traveling during the wet season increases the traveling costs.

3. Fishing is the most important non-farming income earning activity. Fish is the main supplier of protein for the coastal districts and those living close to the rivers. During a 10 or 8 hour fishing day in the dry or wet season, about 10 and 20 kg respectively of fish species ('*corvina*' and '*serra*') are caught. The limit in terms of

the number of possible fishing days per season was calculated from the survey data as 103 and 88 days respectively in the dry and wet seasons.

Carving, collection of reeds, brewing of local beer from sugar cane and small scale production of charcoal also enhance farm income. The coefficients for these non-farming activities are computed using the same procedure, i.e., duration of the activities, output and the maximum number of days that the activity can be performed. It has to be noted that carving also draws on forest resources, even though in relatively small quantities normally averaging 0.001 m^3/unit. However, because wood is very scarce in this ecozone, any wood consuming activities increase the pressure on the nearest forest types, particularly Open Forest and Thicket.

The main cost of fishing comprises the payment that the fishermen have to make to their assistants and replacement of fish-hooks and thread. Costs are generally very small.

The costs of brewing local beer comprise of mainly the cost of ingredients such as sugar and family labour.

4. Food consumption activities differ from those of the Dryland model in only one respect. In the Alluvial ecozone there are additional crops available like sweet potato and vegetables which are not grown in the Dryland ecozone.

5. The same animal activities are included as for the Dryland ecozone, however, it is assumed that in the Alluvial ecozone the pasture yield is 300 kg DM/ha. It is further estimated that animals can have access to about 15 ha of grazing land. The higher productivity of land in this ecozone makes cropping a top priority, therefore it is possible that farmers will graze their livestock in the nearby ecozones. However, it is

assumed, for simplicity, that farmers graze their animals only in pastures found within their ecozones.

6. *Casuarina equisetifolia* as a salt tolerant tree species is also included in the model for this ecozone along with *Leucaena* spp., *Eucalyptus* spp. and *Melia* spp.. It may be a better choice for the Alluvial land, particularly at the river mouths, where, because of lack of regular rain during recent years, sea water flows into the river, leaving salt residues in the land irrigated with this water. This problem is particularly significant in the Catembe and Bela Vista localities of Matutuine (Maputo river) and Macaneta in Marracuene (Incomati river) as indicated in Chapter 4. An area of 2 hectares is assumed as the maximum land that can be allocated to tree planting.

Goals

The analysis of the question 2.10 in appendix A.2.4b indicated that farmers have four goals in the following order of priority: achieving the highest possible income, food security, being involved in wood production as a form of overcoming the shortage of income, and restablishment of animal production, which is the traditional way of savings.

The fact that crops have a reasonable yield in this ecozone may imply that family nutrient requirements can be met in most years. This therefore makes income generation an important goal the satisfaction of which could enable the farmer to have enough cash for purchasing inputs that would enhance the production in the alluvial and irrigated land classes and to create a strong basis for food security (the second goal). Additionally, farmers have to meet other demands such as those of education and health care, and for these they require cash. The third goal relates to planting trees to ensure that wood for family consumption is obtained from a reasonable distance. Finally, cattle are viewed as a form of capital investment in this ecozone.

5.1.3 The Thicket ecozone

In common with the Alluvial ecozone, the Thicket offers a range of income-generation occupations for the farm family. The most important ones relate to harvesting the thickets for charcoal and poles for construction.

There are three land classes in the Thicket ecozone referred to here as low, medium and high thickets. The representative farm is an average for all farms across these land classes in the proportion of 0.44 ha, 0.58 ha and 0.42 ha, respectively. The soil in the low and medium thicket is mainly clay and is relatively rich in nutrients and permits vegetables to be grown for family consumption. The common rotation is sweet potato with beans, peanuts, cassava and pumpkin. It is also possible to have two rotations of maize per year. This ecozone is known for its high output and quality of sweet potato and cassava which are sold locally mainly to dealers who eventually sell in the Maputo-city market.

The Thicket ecozone is the richest in terms of wood with a standing volume averaging 29.45 m^3/ha. Therefore, the non-farming activities are mainly concerned with forest harvesting, although traditional beer is also brewed. Farmers in this ecozone strongly believe in the sustainable regeneration of the natural forests not making them predisposed to planting trees. In a way, this is positive in that substitution of the natural forest with fast growing species is not a sustainable solution. Nevertheless, this reluctance to plant trees whilst continuing to exploit the natural resources means that the activity may ultimately be unsustainable. Therefore, tree planting activities are included in this ecozone to mitigate against an unforeseen shortage of wood. Charcoal production and cutting of small to medium poles are the most exploitative activities. Unlike the Dryland ecozone, the kilns have a capacity of 50 bags of charcoal each weighing, on the average, 50 kg. For this level of output, each kiln is estimated to use over 18 m^3 of wood. Also, about 13 and 23 m^3 of small and medium poles may be harvested 5 and 3 times a year, respectively.

The productivity of pasture in the ecozone is assumed to be 750 kg/ha, and the estimated common grazing land available for each farm averages 15 ha. It is estimated that each farm household can plant up to 6.5 ha with tree species.

Goals

When farmers were asked to articulate their goals and priorities they were unanimous in naming the following three goals: first, achieving food security; second, to continue wood harvesting - this goal allows farmers to use the natural forest as a source of income; finally, re-establish animal stocks, especially cattle with which farmers have a strong tradition.

5.1.4 Open forest

This ecozone has two land classes: the open forest and the wooded grassland, with a weighted average land area of 0.29 and 0.49 ha respectively, for the modeled representative farm. The yield prospect for most crops in the latter are lower due to poor soil fertility. Nevertheless, most of the open forest occurs on a relatively rich clay soil from which good yields may be sustained.

The main non-farming activities in this ecozone are brick production for local and Maputo-city markets, charcoal production and brewing a local beer based on pumpkin. The farmers produce about 1200 bricks per month using approximately 2.5 m^3 of wood for drying purposes. Labour hire is common to assist in this activity. Charcoal production is carried out by women and the kiln capacity is about 40 bags of 50 kg each using just over 12 m^3 of wood. The kiln is fired at least 10 times a year. Finally, brewing requires approximately 60 kg of pumpkin per 100 liters of beer with the major cost component being the added sugar. This activity is carried out for about two months only each year and is restricted to the harvesting season.

Common pasture land provides about 1500 kg DM/ha and a total of 10 ha is assumed to be set aside for grazing. This land is more favourable for grazing because of the mixture of sparse trees for shelter and sweet pasture. It is estimated that tree planting activity can be allocated to a maximum of 6 ha per representative farm household.

Goals

Like in the previous ecozones, food security and wood supply were expressed as the major goals in the Open Forest. However, people appear to be more aware of the role of trees in the protection of the environment in this ecozone. This is explained by the fact that conservation of the forest and soil is stated as the third priority, followed by the need for securing non-farm employment, the need to generate high cash income and finally to re-establish animal production activities. As far as employment is concerned, tree planting could provide an occupation for the family in addition to the other non-farming activities.

5.1.5 Grassland ecozone

The Grassland ecozone, like the Alluvial ecozone, has almost no trees, because woody vegetation is present in less than 25% of the total area (Saket, 1994). Furthermore, poor quality soils result in low crop yields. The problem is exacerbated by the political instability still experienced in this ecozone, two years after the civil war ended. At the time of the survey, most of the ecozone was still under the rebel movement RENAMO (Resistência Nacional de Moçambique) administration, and most of the families were still highly dependent on food aid. The only occupation for men was either small scale fishing in the lakes or production of a palm drink. Fishing has not been considered further because the information provided appeared highly unreliable. Further, the authorities and people living here were suspicious of us, which made the data collection particularly difficult.

Most of the labour involved in palm drink production is basically supervisory rather than physical work. No cost is involved in the exploitation of the palm trees apart from the opportunity cost of the labour involved. The production in the wet season is assessed at double that in the dry season, i.e., respectively about 40 and 20 liters of drink per week for sale per family.

Pasture is estimated to produce only 333 kg DM/ha and about 15 ha/family/ecozone are estimated to be available for grazing. Potentially, a maximum of 30 ha/farm can be planted with trees.

Goals

Again the main goals stated are food security, maintaining wood supply and rearing animals. There is probably more emphasis put on the food security goal here because farmers do not produce enough to meet the requirements making it necessary to improve agriculture production. There is potentially a large area that could be planted with trees, which could produce income to help ease the shortage of food. Planting trees would also ensure that local demand is satisfied, while the animal production goal would be met through the re-stocking program.

5.2 Regional model

The overall objective of this research is to provide an *ex-ante* analysis of community involvement in reforestation for fuelwood and poles production in order to diminish the pressure on the natural forest while simultaneously providing food security. This concern is based on the fact that natural forests supply the energy requirement of the urban and sub-urban population in addition to requirements by the industry and it is further predicted that this situation will prevail for many years to come. However, the ability of the natural forests to sustain such supplies is highly questionable because annual harvesting exceeds annual growth in these forests (DNFFB, 1991).

Reforestation is viewed as one way of containing future imbalances between wood demand and supply. As indicated earlier in Chapter 1, Maputo-city has the largest urban population and wood demand in the country which makes the study more relevant. The expectation is that knowledge and experience gained through the evaluation of the Reforestation Strategy in Maputo Province could be extended to the other provinces.

The energy problem in Mozambique, and Maputo Province in particular, is partly caused by the growing market in the urban areas. However, socio-economic and political as well as drought conditions have led to the situation where the main source of survival for farmers was through exploitation of the natural forest, which provided a ready source of income. The coexistence of these two issues led to deforestation which resulted in some zones having fuelwood shortages even for local consumption. Previous studies by Getahun (1991) and Bila (1992) and results of the survey for this study showed that farmers recognise deforestation as a problem and tree plantation as a possible solution as did the policy makers when they designed the 1991 Reforestation Strategy. Therefore, this suggests, as noted in Nhantumbo *et al* (1997) that the apparent disparity in the definition of the problem facing the meso and the micro level of policy making, in other words, what Janssen (1995) calls aggregation of private and public rationale, may not be significant. Consequently, it may be hypothesised that solving farm level problems may simultaneously solve a higher hierarchical level policy problem. This will be further addressed in Chapter 6.

A modeling approach has been employed in which typical farm models, already discussed in the previous section, are now aggregated into a regional model for Maputo Province. The Reforestation Strategy is therefore a two level decision problem, i.e., as described by Hazell and Norton (1986). Therefore, policy makers at the regional level are concerned with decisions about the best allocation of funds (e.g., for seedling production) and extension services. This is essential to support the implementation and monitoring of the management of the tree plantations/woodlots in the light of uncertainties about farmers responses to Reforestation Strategy. On the other hand, and at the micro level, farmers are concerned with the best response to the Reforestation Policy/Strategy in order to meet their own goals given resource provision, which comprise mainly of land and labour.

It was therefore logical that in the process of dealing with this problem, to start with the construction of models to represent typical farm situations as described in section 5.1. This allows us to understand better the farmer and his/her interaction with the environment. For example, running these farm models for different scenarios such as maintaining the current farming system as well as introducing tree planting activities, provides an indication of the potential farmer responses (adoption or not) to the Reforestation Strategy.

In order to investigate the second level of the decision problem, at the meso scale, a regional Weighted Goal Programming model was constructed. This model provides an aggregation of farm models, and is designed to investigate the responses to regional plans for meeting food and wood demands, as well as conservation policies for the natural forest. Such have to be met within regional budget constraint. This includes the cost associated with production of seedling as form of subsidies, and as mentioned in the section 5.1 the policy instrument that will allow farm to participate in the implementation of the strategy is land reallocation and assurance of ownership.

The following section discusses the main activities and constraints establishing the link between the farm level and the regional level as well as an explanation of how regional goals and their respective weights were represented.

5.2.1 Structure of the farm models within the regional matrix

The main feature of the regional model is that the individual representative farm models are preserved as separate units in terms of the specification of activities and constraints. In the regional model all ecozones are simultaneously inter-linked through aggregated surplus or selling activities supplying a "common pool" which facilitates inter-ecozone trade as well as supplying the Maputo-city market. There is no comparative advantage between the two groups of activities ("common pool" and Maputo-city market) in terms of price. This assumption was made to ensure that only after satisfying local demand for certain products within the ecozones can farmers or traders sell the same in the Maputo-city market. Also, to indicate that farmers always sell on the local market, traders from which will be active in transferring products to the capital city. Further, it is assumed that farmers trade between ecozones only to compensate for specific food deficit. This simplification is introduced by way of a "common pool", because the defined ecozones are not spatially contiguous and a local market permits farms from two or more ecozones to exchange products, at a certain price. Despite acknowledging this phenomenon, the fact is that representative farms were selected from a district where certain land uses were dominant, and further it would be reasonable to assume that each ecozone has a different selling and buying price depending on the farming and non-farming opportunity mix and capacity to supply a product. For example, it is cheaper to buy sweet potatoes in the Alluvial ecozone or Thicket ecozone than from the other ecozones where sweet potatoes are scarce and therefore expensive.

The structure of the representative farm model in each ecozone allows the sale of charcoal, and poles from the natural forest or from plantations/woodlots. It is further assumed that all food and wood surplus is sold. In the event that non-farming activities are prevalent, farmers have access to markets from which they can purchase food to meet their nutrient requirement as described above.

The individual farm model solution is not an end in itself if consideration is given to regional food security and environmental conservation. In addition to supplying wood products to the growing market in Maputo-city, farmers may clear more forests for agriculture for their own food production and sales of surplus for income to meet other demands. The question is then how the province can meet all these requirements on a sustainable basis without compromising environmental conservation. Essentially, this is a matter of what policies should be put into place and what their impacts are likely to be. The impacts would most invariably be on the land, the forests and on the farmers and other resources to which they have access. In this context the farm level models are therefore the major components of a regional model structure as shown in Figure 5.4.

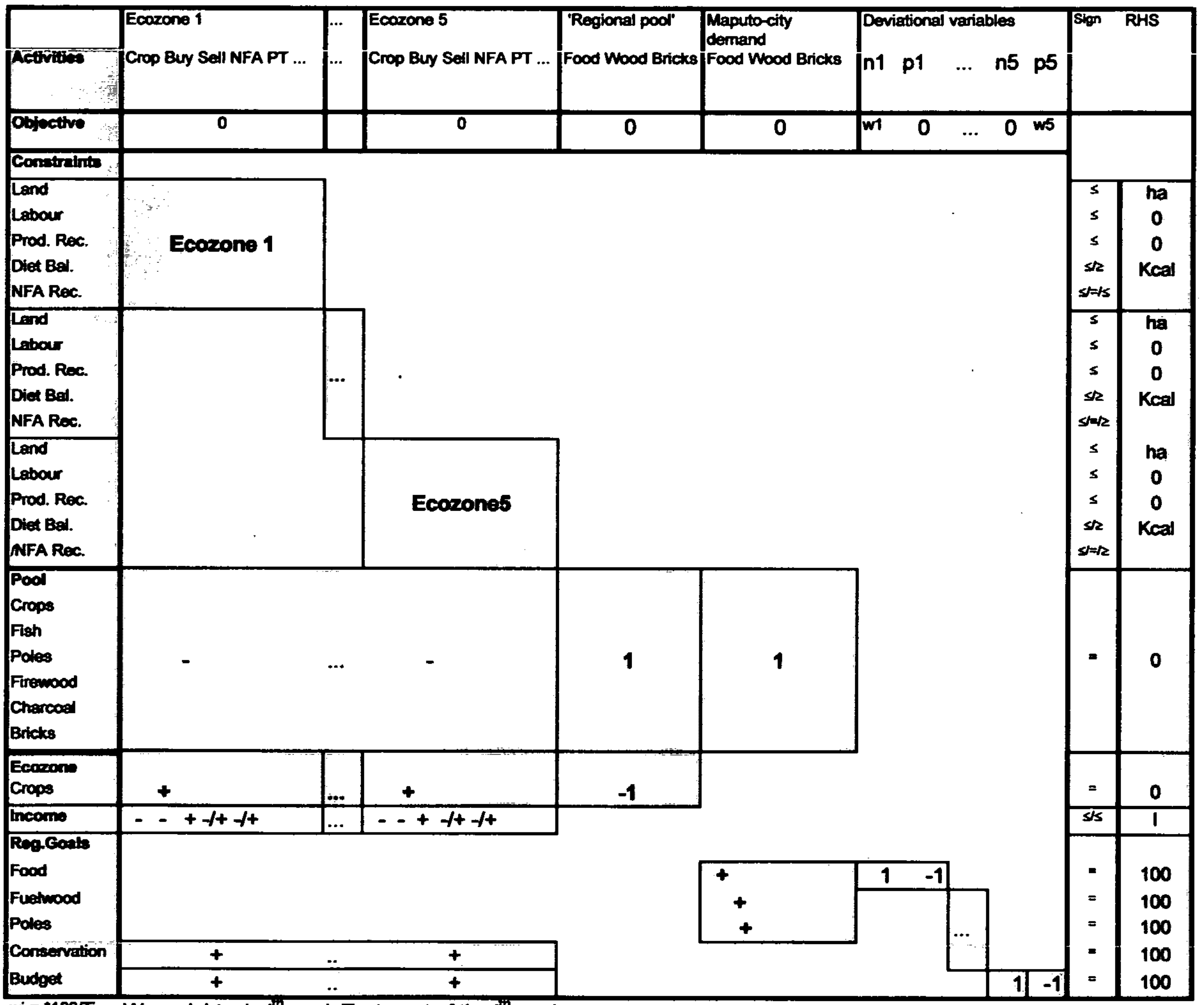
Since regional planners are concerned with reducing deforestation while ensuring food security at two levels (the farmers and the Maputo-city consumers), all farm level activity is aggregated by the number of farms in each ecozone using the following methodology.

5.2.2 Aggregation of individual models

The question of aggregation, especially the possible reduction of bias, has been widely discussed (Day, 1963; Norton and Schiefer, 1980; Hazell and Norton, 1986; Moxey *et al*, 1995 and Janssen, 1995). It is not intended to provide in this section an exhaustive evaluation of the associated theoretical and practical issues, rather the subject is briefly highlighted to justify the approach adopted in this study.

Aggregation becomes an issue because it is not feasible to construct models for every single farm and evaluate its individual response to a certain policy change. However, in the case of the Maputo Province, all subsistence farmers have a fairly similar decision-making environment given that they share the same unstable economic, political and climatic conditions. This suggests that modeling every individual farm would not only be costly (in terms of data and time), but it may not bring any further significant insights regarding farmers' reaction to the Reforestation Strategy.

Fig. 5.4 The structure of the regional model



	Ecozone 1	...	Ecozone 5	'Regional pool'	Maputo-city demand	Deviational variables	Sign	RHS
Activities	Crop Buy Sell NFA PT ...	...	Crop Buy Sell NFA PT ...	Food Wood Bricks	Food Wood Bricks	n1 p1 ... n5 p5		
Objective	0		0	0	0	w1 0 ... 0 w5		
Constraints								
Land Labour Prod. Rec. Diet Bal. NFA Rec.	**Ecozone 1**						≤ ≤ ≤ ≤/≥ ≤/=/≤	ha 0 0 Kcal
Land Labour Prod. Rec. Diet Bal. NFA Rec.		...					≤ ≤ ≤ ≤/≥ ≤/=/≥	ha 0 0 Kcal
Land Labour Prod. Rec. Diet Bal. NFA Rec.			**Ecozone5**				≤ ≤ ≤ ≤/≥ ≤/=/≥	ha 0 0 Kcal
Pool Crops Fish Poles Firewood Charcoal Bricks	-	...	-	1	1		=	0
Ecozone Crops	+	...	+	-1			=	0
Income	- - + -/+ -/+	...	- - + -/+ -/+				≤/≤	I
Reg.Goals								
Food					+	1 -1	=	100
Fuelwood					+	...	=	100
Poles					+		=	100
Conservation	+	..	+				=	100
Budget	+	..	+			1 -1	=	100

wi = *100/Ti W= weights, i= i^{th} goal, T_i= target of the i^{th} goal

Hazell and Norton (1986) state that aggregation bias results from the fact that the optimal solution of an individual farm differs from the optimal solution of the representative farm model. The authors also add that avoiding or minimising such bias may be possible by applying the demanding conditions set out by Day (1963) or by applying less stringent and simple rules which still keep reasonable conformity with Day's requirements.

Day's conditions for aggregation of farms include first, technological homogeneity which means each farm in the group should have the same production possibilities including resources and constraints as well as technology and managerial skills. The second condition is pecunious proportionality requiring that farms expectations to unit activity returns be proportional to the average expectations. Finally, institutional proportionality which requests that the constraint vector of programming model of each farm be proportional to the constraint vector of aggregate farm. The latter condition is only necessary for binding constraints which according to Hazell and Norton (1986), cannot be determined beforehand.

The approach taken in this research for classification of ecozones and farms (Chapter 4) was based on the forest types and land use resulting from a forest inventory reported in Saket (1994) including soil classification (INIA, 1991). Also, a preliminary survey provided information on the availability of non-farming opportunities in each ecozone facilitated classification of the farms. Therefore, in taking all this into consideration it can be argued that this study conforms with the three simple rules that, in practice, have been used for reducing aggregation bias, namely, having classes of similar yields, similar technologies and (fairly) similar land to labour ratios (Hazell and Norton, 1986). It can also be argued that the procedure complies with Day's conditions of technological and pecunious homogeneity. For example, the Dryland ecozone has low fertile soils, inadequate rains and farmers lack working capital to invest in agricultural inputs. All these conditions give the farmers only one cropping season and similar cropping patterns. Therefore, it can reasonably be assumed that the average farmer expects a return proportional to average expectations. Also, the fact that land for cropping is a binding constraint, then the existence of unemployed labour in the province as reported by the authorities which does not have incomes for purchasing staple foods, has the potential to be engaged in increasing the farmed land to provide food and in so doing, off-set regional food deficit. Even though there is relatively free access to land for farmers in Mozambique, explicit or implicit traditional rules makes it possible to argue for the existence of institutional proportionality (Nhantumbo *et al*, 1997).

On the basis of the preceding discussion, the aggregation process involved simple multiplication of the surplus and/or deficit activities by the corresponding number of farms (Table 5.2) in each ecozone. Therefore, trading between ecozones is based on these population figures.

Table 5.2 Number of farmers in each ecozone

Ecozone	No of farms
Dryland	30,864
Alluvial	28,806
Thicket	26,749
Open Forest	9,259
Grassland	2,057

Source: Estimated

The modeling framework presented in Figure 5.4 includes a spatial aggregation of farms which according to Janssen (1995) relates to the sustainability of resource use and natural resource management by allowing the modelling of resource modifications. This will permit an illustration of how the Reforestation Strategy is likely to affect the use of natural resources by the farmers. Also temporal aspects are included in the model to deal with the perennial (tree) crops despite the fact that the issue of which is the right discount factor to use was, of course, not resolved. However, a range of discount rates were used to provide the decision-makers with alternative scenarios which will hopefully facilitate decision-making.

5.2.3 Regional activities and constraints

The aggregation of the farm models to the regional level needed an introduction of what can be called regional activities and constraints. These activities are related to the "common pool" (Figure 5.4) which could be viewed as a surplus 'pool' or regional store from where ecozones and Maputo-city consumers could purchase their specific needs. These needs include agricultural crops as well as products from non-farming activities such as charcoal, poles and bricks. A final set of activities are the main components of the regional Weighted Goal Programming model, representing the negative and positive deviations of each of the stated goals (Figure 5.4).

The "common pool" reconciliation constraints are mainly related to agricultural crops and wood products. Each selling activity in individual ecozone supplies products to the "common pool" and Maputo-city market (both with coefficients 1 in the Figure 5.4). These constraints are set as equalities and therefore do not take account of potential imports, because the aim of this research is to evaluate the capacity of the region to contribute towards satisfaction of its own food and wood requirements.

While Maputo-city market activities demand the whole range of products supplied by the surplus of the ecozones in the 'common pool', the ecozones only buy crop products to offset their food deficit (Figure 5.4). The reason being that wood products for rural household consumption, are free goods obtained from the common land. Also this group of constraints (Ecozone, Figure 5.4) are set as equalities so that farmers purchases only meet farmers' demand and the level and mix in each ecozone is determined by the diet habits and the level of the output.

All the surplus activities supplying the 'common pool' and deficit activities purchasing from the 'common pool' back to the ecozones are aggregated to the corresponding number of farms indicated in Table 5.3.

The objective function of the original LP models of individual farms was set as a constraint in the regional model. The RHS of this constraint was determined by running the five ecozones together and maximising the regional TFGM. This constraint is not aggregated by the number of farms because this would imply an assumption of equity in the distribution of income within each ecozone which would introduce a significant overstatement of the total income generated in the rural areas. The non aggregation of income avoids an upwards bias due to overstatement of resource mobility amongst farm households (Hazell and Norton, 1986).

The income constraint is used in providing a policy instrument for ensuring the conservation, or rather rational use, of the natural forest while providing for the basic needs in the rural and urban areas. A harvesting fee is introduced (in the activities supplying wood for commercialization) as such a measure. However, infeasible solutions may occur due to the conflict: generate at least the stated TFGM and pay harvesting fee which obviously leads to reduction on the TFGM. Therefore, a lower bound (50%) on regional income was introduced providing flexibility in the model to generate a feasible level of activities. Two scenarios are considered using the income constraint: one running the regional model without fees (one income constraint) and one running it with a fee (two income constraints).

5.2.4 Regional goals

Regional goals, targets and priorities were elicited from policy makers across a range of disciplines including government administrative and research staff, at various levels and institutions in the light of the 1991 Reforestation Strategy as explained in Chapter 4. As indicated in Nhantumbo *et al* (1996), many agricultural experts and coordinators of environmental activities at the national level did not express goals and priorities/weights claiming that the Reforestation Strategy is a specifically forestry issue which demanded forestry expertise only. Therefore, it can be deduced that despite policy makers being aware of the need for integrated rural development and for a multidisciplinary approach in extension services, in practice, they were observed to be very orientated to either agriculture or forestry.

Seven main regional goals were identified and are prioritized in the following order:

- the desire to satisfy wood demand in Maputo-city;
- the need for securing the availability of food for both rural and urban dwellers;
- the need for introducing measures to ensure that the first goal is not achieved at the expense of conservation of forests and inland water courses (rivers);
- the need to generate regional income;
- to implement the Reforestation Strategy at least cost;
- employment generation for rural people;
- wildlife conservation.

The list is relatively long and the respondents did not associate any targets to the objectives. The availability of data that could be used to estimate coefficients for the model dictated that some simplification or interpretation of the goals was inevitable. This was done and only five goals emerged. These center on the production of fuelwood, poles and food, conservation of forests and operating within given financial limits (budget) in implementing the Reforestation Strategy (Table 5.3).

The income goal was not included in the model due to the difficulty in interpreting the policy makers rationale and their different implicit assumptions regarding income distribution in the rural and urban areas or whether such income generation also means increasing funds for the treasury through charges for using the natural forest.

Regarding employment, this issue transcends the boundaries of the region and is not solely an agricultural sector problem. However, the sector can contribute towards minimisation of rural unemployment through, for instance, planting trees in woodlots, the impact of which on reduction of slack labour is discussed in the next chapter.

Finally, wildlife conservation should be mentioned. This goal, together with the ones on conservation of forests and water resources, are dealt with indirectly, albeit insufficiently, through the assumption that every hectare planted with trees will, in the medium and long term, contribute to reducing the pressure on the natural forest and this will in turn provide habitat for wildlife. Hence, the target is set assuming that each typical farm household should plant trees on at least one hectare. This, it is acknowledged, is an indirect measure of conservation. The difficulty in setting target values for some social and environmental objectives, as it is in this study of modeling subsistence farmers, is considered by Cohon (1978) a limitation in applicability of GP in public decision problems. The goals and respective targets are summarised in Table 5.3.

Table 5.3 Summary of the goals and the desired achievement function

Goals	Targets	Deviational variables
Fuelwood	3,743 ,249 bags	Minimise under-achievement
Poles	44,146 m3	Minimise under-achievement
Food	11,214,310,020 Kcal	Minimise under-achievement
Conservation	97,735 ha	Minimise under-achievement
Budget	$1,530,530	Minimise over-achievement

Targets for fuelwood and poles were determined on the basis of estimates of the demand in the urban area as reported by Nhantumbo and Soto (1994), and estimates for firewood demand by the industry as estimated by Pereira (1990).

The food target is calculated based on the population information (IE, 1994) which indicates that there are over 1.5 million people in Maputo-city of which about 46% are children under 15 years and a gender proportion of 1:1. The nutrient requirement is assumed to be 2005 Kcal/day and 2367 Kcal/day per adult female and male respectively and, 1630 and 1830 Kcal/day respectively for a female and male children, respectively (Ministry of Health, Program of Nutrition). These values were aggregated to reflect yearly demand and consumption. It should be pointed out that the structure of the model in which the food surplus is directed to Maputo-city market will result in a solution where the province becomes self-sufficient in food. However, there are diet differences even within the urban area which are not captured by the model. Much of the diet of the sub-urban population is more similar to that of the rural population and details on diets in the city were not explored because the study objective was to indicate the extent to which Maputo Province could be self-sufficient in food and on a sustainable basis without compromising environmental conservation.

The conservation target assumes one hectare is planted per household and, the budget constraint is the cost of planting that area with any of the species included in the farm model.

Coefficients of food, fuelwood and poles for satisfaction of the corresponding goals are placed in the Maputo-city market activities (Figure 5.4). However, conservation and budget coefficients are associated with the contribution, through tree plantation, that each typical farm in each ecozone can provide towards the achievement of the conservation target under the budget limitation (Figure 5.4). The derivation of the coefficients were based on the formulas given in Appendix 3.3.

5.2.5 Goal Weights

Contrary to the farm model, where in each ecozone there was one decision maker (farmer), at the regional level, the policy making process involves many policy makers (PM) and decision makers (DM). While clear goal identification and respective prioritization was possible at the farm level and was dealt with through Lexicographic Goal Programming (LGP), at the regional level it appears more appropriate to rank the several goals of the DM/PMs and derive weights which encapsulate not only the DM/PMs preferences, but also reflect the relative importance attached to the goals as well as the relative significance of positive or negative deviations (Cohon, 1978).

The regional goals were ranked using the frequency with which each was placed in a certain rank by the policy makers. Weights were then determined using a procedure described by Yoon and Hwang (1995) as indicated in Chapter 2.

Weighted Goal Programming (WGP) as explained earlier (Chapter 2), considers simultaneously all goals in a composite objective function minimising the deviations between goals and aspiration levels. However, the goals in Table 5.3 are expressed in different units and the numerical values have considerable difference in range which may create scaling problem when running the model. As Romero (1991) explains, the objective function of a WGP model is meaningless when it aggregates incommensurable deviational variables due to artificial extraweights associated with goals with very high target values like the goal on food production as compared with the others. This author adds that arbitrary solutions which do not correspond to the actual preference of the DM can be avoided by using a kind of normalisation or scaling of the goals. There are two methods for normalization of the deviational variables: scaling based on percentage (equations 5.1 and 5.2) and the Euclidean norming. The first, provides meaningful result because the objective function is a sum of percentages, which are adimensional and the new sets of weights (w_i/b_i) do represent the preference of the DM. However, the problem that remains is the necessity to distinguish between the numerical value of a deviation and its corresponding geometric distance which is taken into account by adjusting each goal according to Euclidean norming (5.3) (Romero, 1991).

$$n'_i = \alpha_i n_i / b_i * 100 \quad (5.1)$$

$$p'_i = \beta_i p_i / b_i * 100 \quad (5.2)$$

$$n''_i = w_i n_i / (\Sigma a_{ij}^2)^{1/2} \quad (5.3)$$

where,

w_i = weights

a_{ij} = coefficients of all of the i^{th} goal

b_i = the absolute values of the goals

β=0 when the desired achievement is greater than the target, the case of the first four goals in the Table 5.3 and, α=0 if the desired achievement is less than the target, as with the budget goal.

The Euclidean norming procedure presents two problems. First, the achievement function still has different units, and second, it does not consider the numerical values of the goals which means solutions can still be biased due to artificial extraweight for goals with high numerical values. Because the percentage norming procedure reduces significantly the range of units which can affect results of models run in the simplex algorithm, it was adopted in this research.

This chapter has therefore discussed the structure of the farm and regional models in which problems of representation and aggregation have been highlighted, the following chapter discusses some validation issues and then presents the results.

CHAPTER 6

Results

6.1 Introduction: validation issues

In the previous chapter the planning matrixes for modelling the individual ecozones were described. This chapter presents the results for the representative farm models for each of the five ecozones under three alternative scenarios. As explained in Chapter 5, first, each model was run to represent the base situation in order to validate it as an appropriate component of the regional model. Second, the potential for restocking was evaluated. Finally, in order to assess the uptake of afforestation various tree options were added to the model structure. The farm model output is relatively detailed and later, the regional model results highlight the impact of change of government priorities on farm organisation.

Changes in resource use, especially land and labour use under the various scenarios, is explored, both 'with tree' and 'without tree' options in the model of the farming system. This *ex-ante* analysis addresses further the second specific objective of this research which is the application of mathematical programming in the evaluation of social forestry alternatives identified through farmers' expressed preferences. Furthermore, where appropriate, attention is drawn to data gaps that may have confined the scope of the analysis and prospects for generating new data for future land use planning (third specific objective). The results ultimately should provide, however, a response to an alternative hypothesis to the null hypothesis stated in Chapter 1. In other words, the current land use system is not sustainable and changes, such as tree planting, may not bring negative disruption of the traditional socio-economic environment.

An aspect previously highlighted is that this research intends to explore the application of a relatively sophisticated planning approach in a data scarce environment. The classification of the ecozones is based on land use and does not match any particular administrative boundaries. Even if it did, the lack of statistical information would still limit a formal validation of the model. At the time of data collection for this research, the National Directorate of Agrarian Economy in the

Ministry of Agriculture, had started what is to become an annual survey for gathering farm information. The process is planned to be gradual, each year adding one more district to the pool. The data are not as yet published and easily accessible and only aggregate data were obtained for the two districts already surveyed. The availability of desegregated information will certainly facilitate future development or application of advanced planning techniques.

As already explained in section 5.2, the farm models are just a first step towards a regional planning model. Hence, emphasis was given to logical model structure and reasonable representation of the farm situation and likely responses to the Reforestation Strategy. In this context, farm models were validated as to their adequacy in representation of each ecozone. McMeekin and Ross (1996), point out that the development of specific applications for predictive modelling should be based on an understanding of the intrinsic qualities of a fully validated model. Fonweban *et al* (1995) add that validation builds confidence in the use of the model and it enables its revision when deficiencies are identified. Beck e*t al* (1995), however, defend that such confidence can only be built through successful application of the model, which entails what McCarl (1984) calls operational validation. Furthermore, Katawatin *et al* (1996) more conclusively stress that a model should be validated for its accuracy, usefulness and relevance for the conditions for which it is designed.

Norton and Schiefer (1980) suggest that validation is not really such an issue when looking at single farm models, as it is in the case of regional and sector models. The authors advocate that coefficients and restraints can be directly verified and the objective function is determined by the farmer. Nevertheless, Hazell and Norton (1986) also call attention to the fact that data scarcity, unreliability and mutual inconsistency limits the validation process particularly in developing countries. However, the authors add that, 'it is better to use good logic for policy analysis than compound the problem of poor data with poor logic'.

Validation need not be totally quantitative in nature (i.e., checks on model output against real recorded data). In other words, in the absence of quantitative data, subjective judgement of the output assuming broad comprehension of the system represented (Dent and Blackie, 1979) is used. Therefore, a process whereby model results are judged against expert opinion or a 'validation by assumption' (McCarl, 1984), is useful for situations where statistical information does not exist or where it may be misleading due to a number of factors including inefficiencies in gathering information and inadequacies in data collected. Such is the case of this study: where statistically reliable data are absent, and an 'expert' based validation is presented instead.

Data collection involved many interviewees (Chapter 4), consulted with respect to information on various issues of land use including trends in crop yields, exploitation of forest products, goals of the Reforestation Strategy, main problems and constraints, and other relevant information. These qualitative data are used as 'expert' knowledge which provides the best available basis against which the results of the current modelling scenario can be analysed besides assessing the relevance of this approach as a potential planning tool. Furthermore, logical opinion is employed to evaluate conformity of the results of the predictive 'with trees' scenario with responses from the farmers.

Given the political and climatic instability prior to data collection the reported yields were possibly uncommonly low and the war environment is unlikely to be replicated in the future. Consequently, a sensitivity analysis was carried out specifically to analyse the effect on farm performance of variation in key parameters such as crop yield and farm size. However, the stability of the solution is looked at simultaneously with the basic solution. Change in relative prices of products/inputs alters the combination of activities for profit maximisation (Rae, 1994). However, this author adds that the nature of activity analysis and the production-possibility frontier in LP models, allows for a range of relative prices in which the solution is invariable. In other words, post-optimality analysis determines the stability or robustness of the optimal farm plan given uncertainty in data and assumptions made

(Hazel and Norton, 1986). Therefore, the decision maker is provided with information regarding the price range over which the model output could still be valid.

The reduced cost of non-basic variables and marginal value product of scarce resources further address such a question. The reduced cost shows the amount by which individual objective function coefficients must be improved in order for an activity to become a basic variable in the LP solution. The shadow price, however, denotes the potential improvement of the optimal z-value of the LP model if a resource constraint was increased by one unit (Winston, 1995). These aspects provide insights into the economic interpretation of the LP solutions in both the basis and when the opportunity for rearing animals and planting trees are incorporated into the model solutions.

The most pertinent questions that such values can answer in this study are:

- whether there is positive advantage in terms of total farm gross margin (TFGM) from the introduction of trees and animal restocking;
- whether the availability of tree activities has any effect on crop output, the level of purchasing and consumption possibilities;
- whether the introduction of tree activities will affect current land use due to substitution between family and hired labour.

The first part of this chapter presents the results of the representative farm models and the second part addresses the regional model output. Since much of the analysis is common to all ecozones, the Dryland ecozone is (again arbitrarily) discussed first in detail and other ecozones are discussed more briefly. The results of the typical representative farm models do not incorporate all constraints bearing on the farmer. Consequently, some of the outputs may appear unrealistic. For example, trade relations between ecozones and/or with Maputo-city are not considered at this level, but at the regional level. Therefore, some of the levels of output from the farm models may reflect the output potential given land and labour constraints assuming existence of market for all farm surplus. Hence, caution has to be exercised in evaluating and interpreting the individual farm model results as they are provisional results until the regional aspects are incorporated and these will complete the farmer response behaviour.

6.2 Individual ecozone farm models

6.2.1 Dryland ecozone

1. The LP farm model results and stability of the solution

The Dryland ecozone has a small range of crops and large proportion of land is allocated to maize (staple food), peanuts and beans (essential ingredients in the consumption of the by-products). In order to meet the minimum food requirement, the ecozone is a net purchaser of food. Table 6.1 presents the model results in the restricted basis (the 'base' solution), later changes in this output when animals and/or trees are incorporated into the model will be highlighted.

Current household welfare

The model has provided for satisfaction of the minimum daily requirement for food through production or purchase. Each individual has only about US\$49[1] per year for all other needs. The national income per capita is reported to be about US\$100 a year (NotMoc, 1996). If we assume that half of it is spent on food then the remaining US\$50 compares favourably with the US\$49 calculated above. Farm data could not be used to validate this result because the information was used in the characterisation of the representative farms used in the model.

Land use, Consumption and trading activities

Mixed cropping is a common practice in the subsistence cultivation sector, particularly when there is no possibility for rotation. The distribution of land conforms with consumption habits. Maize and cassava supply 75 per cent of the nutrient requirement of farmers (Table 6.1) hence the allocation of nearly 68% of

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[1] TFGM divided by the size of the farm household

the land to these crops. Beans and peanuts are supplements and are mainly used for sauces.

DNE (1992) indicates that 66.1 per cent of farmers in the Dryland are not self-sufficient in food because they cultivate less than 3 hectares which each family would need to meet food requirements.

Table 6.1 The base solution for the Dryland ecozone representative farm model

	Model Base Solution
Total Gross Margin ($)	293
Land allocation (Ha)	
Maize	0.6
Beans	0.1
Peanuts	0.2
Cassava	0.08
Pumpkin	0.02
Consumption (Kg/yr)	
Maize	700
Beans	71
Peanuts	31
Cassava	353
Pumpkin	8
By-products	778
Purchases (Kg/yr)	
Maize	431
Beans	32
Peanuts	13
Cassava	272
Pumpkin	0
By-products	480
Sales (Kg/yr)	
Maize	0
Beans	0
Peanuts	0
Cassava	0
Pumpkin	111
By-products	380
Charcoal (bags/yr)	360
Slack of Labour(Mhrs/yr)	
Adult	2579
Children	6717
Hired seasonal Labour (Mnhrs)	
Male	72
Female	60

Thus, purchasing activities as shown in Table 6.1 provide for the supplement of home produced food to meet family demand when deficits in production arise in the average year as it is the case of this ecozone. This explains the negligible sale of food surplus and the fact that the typical farm relies basically on charcoal as a source of income.

All land use variables enter the basic solution, however, some selling, buying and consumption variables do not. For example, selling activities for the main crops (maize, beans, peanuts and cassava) have positive reduced costs due to the demand for these crops to meet diet requirements. Additionally, buying and consuming cassava and pumpkin by-products have a relatively high reduced costs due perhaps to the existence of substitutes within the system like bean leaves. However, in the base solution, the total cropping land has a marginal value product (MVP) of $49 per ha, reflecting the positive TFGM generated.

Family and hired labour

As pointed out by the local authorities, unemployment is one of the major concerns in this ecozone. The labour slack (Table 6.1) illustrates the magnitude of the problem. However, female labour is still hired during the peak seasons of farming activities such as sowing and weeding, while male labour is hired for charcoal production.

The fact that there is a surplus of family labour after performing all farm activities implies a zero MVP for these activities. In addition, increasing the size of the family has a very high opportunity cost. However, Gittinger (1982) argues that economists now agree that the MVP of agricultural labour on an annual basis is more than zero and, at some point, in one season or another, the opportunity cost of labour is positive even if low. This is illustrated by the fact that despite the slack labour within the typical farm of the Dryland ecozone, in peak periods the family hires labour.

Having looked at the results and their possible interpretation as well as the stability of the solution, another question to be answered regards the extent to which the model of the system actually relates to reality.

2. Model validation

Evidence from the distribution of crops in the 1960's in Maputo Province (Snijders, 1985), shows that the Dryland ecozone falls in the region where maize alone or a maize, bean and peanut crop system forms the dominant agriculture. In addition, in this region a large proportion of land falls to maize production to provide the basic diet component, and together with cassava, provides two thirds of the nutrient requirement. In fact, Getahun (1991) states that cassava is one of the most important crops in the farming systems of this ecozone.

Table 6.2 presents a comparison of the percentage of land allocated to each crop in the model and results of the National Directorate of Agrarian Economics (DEA) based on the 1993 survey. There is some variation in land allocation, especially the fact that in the survey conducted in 1994 sweet potato was not mentioned as one of the crops present in a typical farm in this ecozone. However, maize and cassava together account for 66 per cent (68 per cent in the model) of real land cover, so this may be considered a fairly good result and broadly in-line with current practices.

Table 6.2 Land allocation per crop in the Dryland ecozone

Crops	Model (%)	DEA (%)
Maize	60	56
Beans	12	22
Cassava	8	10
Peanuts	20	7
Sweet potato		4

The minor differences in land use may be explained by the fact that farmers make small changes in land allocation to accommodate expected lower yields in one or another crop. The land allocation to cassava by the model, for instance, is generally small but it has higher yield. However, when maize output increases due to biomass incorporation into the soil, or due to favourable change in the climatic and social factors, cassava is easily substituted as one of the staple food products.

The crop yields used in the base model were three or four times lower than the maximum potential yields: maize yield is a case in point with respectively 473 and 2500 Kg/ha (UDA, 1982). This, however, was compatible with the view of the local authorities and findings by Getahun (1991), that crop growth is considerably constrained because subsistence farmers face the problem of erratic and poor rains, lack of adequate tools, and low capacity for hiring sufficient labour (especially for weeding). The DEA also reports that only a third of farmers can hire a tractor or plough for land preparation, and two thirds are limited to use only hoes and cutlasses. The limited availability of inputs such as seeds, fertilisers and tools are also pointed out by FAO/WFP (1995) as the major cause of a fall in cereal output in Mozambique and other Southern Africa countries.

3. Sensitivity of key parameters

The Dryland ecozone has farming as its major activity. According to local authorities, production has been low due to irregular rain and lack of adequate farm tools. Therefore, proposed future yield increases [25, 50, 75 per cent and the maximum yield attainable according to the agriculture specifications (Appendix 4.1)] potentially resulting from a combination of favourable climatic and socio-economic conditions as well as improved political stability, were introduced into the model to assess the sensitivity of farm returns to such changes (Figure 6.1).

Although the value of the total farm gross margin (TFGM), is not presented in Figure 6.1, a reduction of purchases and increases in sales would imply an increase in the TFGM under the scenarios in the figure, respectively, by 12, 20, 27 and 93 per cent compared to the current level. In fact, there is possibility of almost doubling the current income if stable conditions (rainfall, better seed quality and political and socio-economic) allow farmers to produce at the maximum production potential. Also the figure shows a slight drop (1 per cent) in the volume of consumption at the maximum level of yield, which is a result of cassava being substituted by maize; the latter being a more nutritious crop.

Farm size

In another scenario, representative farm size was doubled from 1 to 2 ha. This resulted in a reduction of the quantity of cereals purchased, especially maize. More by-products are sold and the TFGM rises by nearly 125% to US$659, however, this change does not offer a plan that can make the farm household self sufficient in food. Further increase of land to 3 ha, as suggested in DNE's report (1992), shows that, in fact, the TFGM increases and farmers meet their food requirement. However, this happens only if the current proportion of land allocation is maintained, otherwise cassava is produced to generate cash and maize is purchased to meet the household demand.

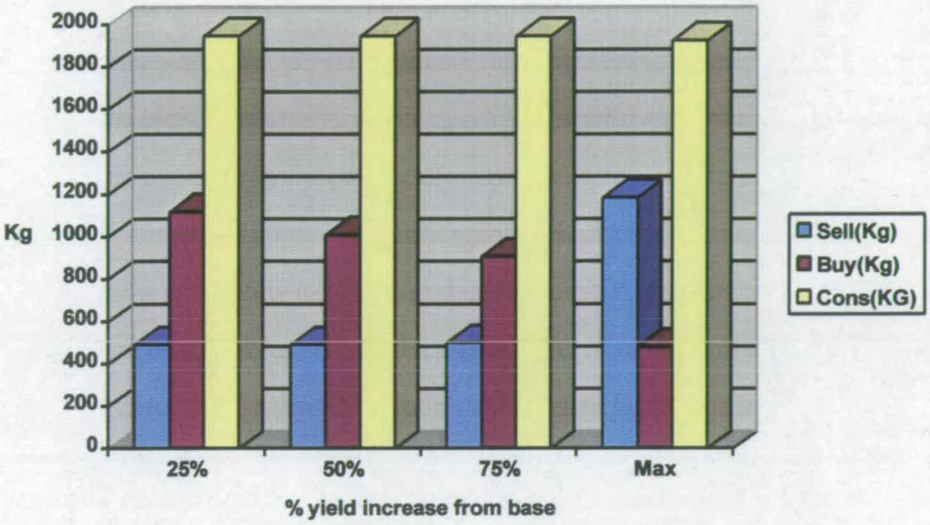

Fig. 6.1 Comparison of the quantity sold, bought and consumed across various yield increases for all crops

Trees are scattered in this ecozone and the traditional farming systems normally allow perennials to coexist with the agricultural crops. Therefore, increasing the land for agriculture would not have any significant environmental impact which could result from clearing the forest, for instance.

Change in costs of production

In a third scenario, a 50 per cent increase in production costs was examined. Despite the fact that the inflation rate has been reported to have dropped to about 22% in the last year, the 50 per cent is taken as the average inflation for 1993-1995. Fluctuations of prices of all products are due to the unstable economic situation following the devaluation of the local currency and the lack of price control. The result was a reduction in the current TFGM on a typical farm by 3 per cent. The significance of this value arises from the fact that the current farm TFGM is already too low ($293). However, land use does not change under this scenario.

The variations in the parameters studied and the analysis of the associated changes on the farm plan, show in a way, the level of confidence which can be attached to the results discussed in the previous section.

4. The impact of introducing animals and trees in the farming system

Impact on household welfare

Diversification into animals and trees improves the farm performance despite the fact that animals are generally not reared solely for cash or for consumption. Animals are a source of prestige and used for traditional ceremonies and special celebrations. In addition, they provide for socio-economic security in terms of availability of convertible capital. There is an increase of $97 which represents a 33 per cent increase on the TFGM of the base solution, as a result of rearing six goats.

When possibilities for planting woodlots is introduced, then the main differences are the ones highlighted in the Table 6.3. First, there is a significant improvement on the TFGM which is over twofold even under the scenario of the highest interest rate. The income per capita 'with trees' varies from US$132 and US$422 depending on the amortisation rate.

Land use, consumption and trading activities

In the base solution, the allocation of land for agricultural crops for the average family in the Dryland ecozone does not change when either animals or trees are available as options. This is basically because animals are reared on common grazing lands away from the crop areas, and trees are planted in woodlots separate from the agricultural fields as preferred by the farmers. However, when trees are introduced, there is competition for land between non-improved and improved maize.

The trees are not interplanted with maize or other crops, but as stated earlier they are planted in pure stands and leaf biomass can be harvested and transferred to the cropping farms and be used to improve soil fertility. This makes it possible in this ecozone (as well as in others) to retain the area under agricultural crops but increase maize yields when the tree option is introduced by using leaves from leguminous trees. However, this can only occur at the expense of a higher labour demand to incorporate the leaf biomass into the soil and other silvicultural activities.

Table 6.3 Changes in representative farm performance under the 'with trees' scenario in the Dryland ecozone

	With trees	Without Trees (Base solution)
Total Gross Margin ($)		293
Trees at 10% amortisation rate	2530	
Trees at 20% amortisation rate	2030	
Trees at 45% amortisation rate	795	
Land allocation (Ha)		
Trees	16	0
Consumption (Kg/yr)		
Maize	854	700
Cassava	183	353
Purchases (Kg/yr)		
Maize	0	431
Cassava	99	272
Sales (Kg/yr)		
Poles (m^3)	219	0
Animals		
Goats	10	0
Slack of Labour(Mhrs/yr)		
Adult	275	2579
Children	3916	6717

As explained in Chapter 5, 16 ha is the area assumed as potentially available for individual farmers to plant with trees. On the assumption that this may have been overstated, or that, in the medium or long term, with concession of land to the formal private sector and increases in population, the land available for tree planting may reduce by 50 per cent, then the TFGM 'with trees' can be expected to decline by 56% ($1108). Therefore, the improvement in the TFGM reported in the Table 6.2, due to tree plantation, may be drastically reduced, depending on land availability.

Regarding consumption, in the 'with trees' scenario, only cassava consumption reduces due to substitution by maize which has high yield and is more nutritious. There is no maize purchase and only a small quantity of cassava is bought. The income increases due to sales of poles and an increase in the number of goats occurring in turn as a result of fodder supplement from trees. Cattle are excluded activities unless forced into the solution. Selling calves has a reduced cost of $304 which reduces to $223 under the 'with trees' scenario, because of the availability of more pasture supplement. Therefore, the MVP of pasture land and of pasture production increases as a result.

Labour with animals and trees

One aspect to note is that labour demand for animal rearing was not included in the model. In spite of that, it is known to require between 1825 and 2555 hours per year which is currently available as child slack labour. When trees are brought into the solution, adult slack labour is significantly reduced (Table 6.2).

There is significant welfare improvement in terms of food security, employment, cash and capital when animals and trees are introduced into the model, irrespective of amortisation rates.

Plantation versus use of natural forest

Tree planting does not automatically induce conservation of the natural forest through substitution of natural forest harvesting activities, nor do plantations necessarily supply wood to increase the production of charcoal. The typical farm continues to harvest about 15.3 ha per year of the natural forest for firewood and 360 bags of charcoal. Selling poles is less labour intensive compared to producing charcoal, the reason why transferring wood from plantations for charcoal production have a high average reduced cost ($13.42/m^3). This result implies that these activities (harvest natural and planted forest) can only be mutually exclusive through administrative measures, such as through the introduction of a harvesting fee.

As can be seen in Table 6.4, for all three planted species, the reduced costs of firewood and using plantation wood for charcoal production (including domestic consumption) are very high. This is because it is more profitable to sell wood as poles in the wet season. The reduced cost of selling wood from plantations as firewood, poles or as charcoal (Table 6.4) could be used in the estimation of a potential fee for continuing the harvest of the natural forest for commercial purposes.

Table 6.4 Reduced cost of selling different tree products from plantation species

Tree species	Firewood ($)	Charcoal ($)	Poles ($)
Leucaena spp.	9.14	10.34 (0)	0.94
Eucalyptus spp.	10.8	12 (1.71)	1.75
Melia spp.	15.25	16.5 (6.16)	1.5

Figures in parenthesis are reduced costs when the model is run with a harvesting fee

Following this, when a fee of $91.39/ha [derived as the average reduced cost of *Leucaena* spp. and *Melia* spp. (for charcoal) which are basic variables in the model multiplied by the average volume of the natural forest wood per hectare in the ecozone (6.81 m^3/ha)] has to be paid for harvesting natural forest, then the reduced cost of charcoal production drops substantially (values in brackets). It is cheaper in terms of labour use, to sell poles rather than to produce charcoal. The overall impact of such an administrative measure is further investigated in the regional model.

Having presented the scenarios with and without trees and the impact on the farm performance, it is also necessary to consider the applicability of such a plan. There is evidence from the survey and a previous study (Bila, 1992), that farmers are willing to plant trees not only for fruit and shade, but also for fuelwood and poles. However, insecurity of land ownership and limited planting experience slows down the implementation of afforestation (Getahun, 1991). Therefore, the analysis of farm performance with this activity is not a top-down decision. Land tenure issues were looked at in the introductory chapter and further analysis under the policy aspects considered when the regional model results are discussed.

Despite the extensive analyses of the LP solution, the nature of the planning problem is multiobjective hence the need to consider the various farm priority goals.

5. Farm goals

In section 5.1, it was stated that a typical farm in this ecozone has two main goals: achieving food security and ensuring wood availability from short distances for sale and consumption. It is implicit, however, that maximum income is also an important objective, especially to ensure the achievement of the first goal and also harvesting wood products, the second goal, aims at generating income. Therefore, the LP output can be taken as representing fairly well the decision environment of the farm in this ecozone.

It can be argued that the incorporation of an energy requirement, dietary constraints and wood production constraints to the LP structure may be a simple way of dealing with this multiobjective problem. In balance, this approach is useful despite the fact that rigid enforcement of constraints can produce infeasible solutions (Hazell and Norton, 1986). This, or LGP, may be used in the other ecozones depending on the potential insights that can be brought in.

6.2.2 Alluvial ecozone

1. The LP farm model results and stability of the solution

Current household welfare

Soil conditions in the Alluvial ecozone are more fertile even though salinity in one of the areas limits output. In general, however, the crop yields are higher compared to the Dryland ecozone even in the saline land class. This ecozone also has a wide range of activities that generate income which provides for a relatively secure farming environment. The availability of inputs like fertilisers, that farmers claimed were in short supply, coupled by better climatic conditions and socio-economic stability can significantly improve the agricultural performance.

Unlike the Dryland, in the Alluvial ecozone farmers are financially better off (Table 6.5) due to the range of opportunities available. The TFGM per capita is \$673[2], which is over six times the average for the country (\$100) (NotMoc, 1996).

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[2] TFGM divided by 7, the size of the family

Table 6.5 The base solution for the Alluvial ecozone representative farm model

	Model Base Solution
Total Gross Margin ($)	4721
Land allocation (Ha)	
Maize	1.05
Beans	0.11
Cassava	0.11
Peanuts	0.5
Sweet potato	0.5
Green beans	0.63
Pumpkin	0.01
Vegetables	0.001
Consumption (Kg)	
Maize	638
Beans	93
Cassava	353
Peanuts	79
Sweet potato	772
Pumpkin	4
By-products	265
Fish	190
Purchases (Kg)	
Beans	59
Sales(Kg)	
Maize	1404
Beans	0
Cassava	313
Peanuts	197
Sweet potato	1543
Green beans	2520
Pumpkin	54
By-products	2371
Fish	2598
Charcoal (bags)	40
Halves (units)	614
Drink (l)	5000
Reeds (bundles)	360
Slack of labour (Mnhrs/yr)	
Adult	6238
Children	4876
Hired seasonal labour(Mnhrs/yr)	
Male	22
Female	35

Land use, Consumption and trading activities

Like the Dryland ecozone, despite higher soil fertility and opportunity for crop rotation, mixed cropping is still a common practice especially in the saline land class.

However, there is also monocropping and rotation in the irrigated and alluvial land where separate plots are allocated to either maize, green beans or peanuts. Contrary to the Dryland were staple food crops are cultivated on 68% of the land, in the Alluvial ecozone maize, cassava and sweet potato, both staple food and cash crops, are allocated to 57% of the total farmed land.

As stated earlier, the representative farm in this ecozone is self-reliant on food, all but one crop (beans) has to be purchased (Table 6.5). The diet composition is also richer in terms of energy and protein (fish) and, it also includes vegetables. The staple foods, however, are maize, cassava and sweet potato which provide for 75% of the diet requirement.

As with the Dryland ecozone, all variables utilising land and all selling activities (with exception of beans in the dry season) appear in the basic solution. Selling staple crops (maize, cassava and sweet potato) in the wet season is associated with high reduced costs because food stored is only for consumption, thus selling is not the most viable option.

The MVP of land under cropping varies for each land class due to its production potential. It is $664, $1020 and $1689 for the saline, alluvial and irrigated land classes, respectively. Therefore, a unit increase in land in each of the land classes would have a significant impact in the TFGM.

Family and hired labour

Despite the range of activities in this ecozone, under-employed labour, especially in the case of women (90%) is still significantly high.

The major constraints to agricultural activity within the model are land, labour and working capital. The limitation of the latter is endogenous to the model framework since apart from seed and hiring labour or tractor hire for land preparation, the farmer is limited in terms of his ability to purchase other inputs that would probably enhance the output. Labour, on the other hand, has a zero shadow price due to underemployment (slack) which conforms with the theory regarding shadow prices of rural labour (UNIDO, 1972, Gittinger, 1982).

2. Model Validation

A quasi-formal validation carried out for the Dryland ecozone, is not possible in this case due to lack of data. Therefore, subjective expert opinion must be relied up on. Local agricultural and administrative officers underlined that there is a wide range of activities that do not justify the existence of unemployment. According to the Director of the District Directorate of Agricultural in Manhiça (1995), 'young men as well as demobilised troops do not want agricultural jobs' and they migrate to neighbouring countries. The migration of men may explain the fact that a large proportion of slack labour is women's.

Agriculture can be practised all year round, permitting the supply of mainly maize, cassava and sweet potato to Maputo-city markets. Drink processing from sugar cane is an important source of household income besides reeds collection (Table 6.5). The contribution of these activities to the household welfare are well illustrated by the sales. However, drought, plague of insects and rats affected the yield. This supports the fact that yield in some land classes could be assumed to increase (Appendix 4.2) even with the current level of input. The improvement could be even higher if more tractor hours, instead of manual work, were used for land preparation, and better irrigation facilities were available. Therefore, the structure of the model seems to comply with land allocation patterns and other activities and limitations in the ecozone.

3. Sensitivity of key parameters

Change in yield

The current crop yields in the irrigated land class are higher than in the other land classes. Nevertheless, around 66% of the farmers in the Alluvial ecozone irrigate the land manually (DEA, 1993) which coupled with the use of low inputs and poor seed quality still allows for future improvement of crop yields. Therefore, Appendix 4.2 shows the allowed variations. The exceptions in yield increase are made because either the current level of yield reported is assumed to be the lowest likely or because obvious maxima would apply. For example, the average yield of beans on saline land (330 kg/ha) is assumed to be the lowest possible, therefore only possible increases are considered.

Generally, an increase or decrease of yield by 25 per cent does not change the land use from the base solution. Conversely, at 50 and 75 per cent yield increases, and when land is doubled (about 4 ha) a large proportion of it is allocated respectively to sweet potato and, maize and sweet potato.

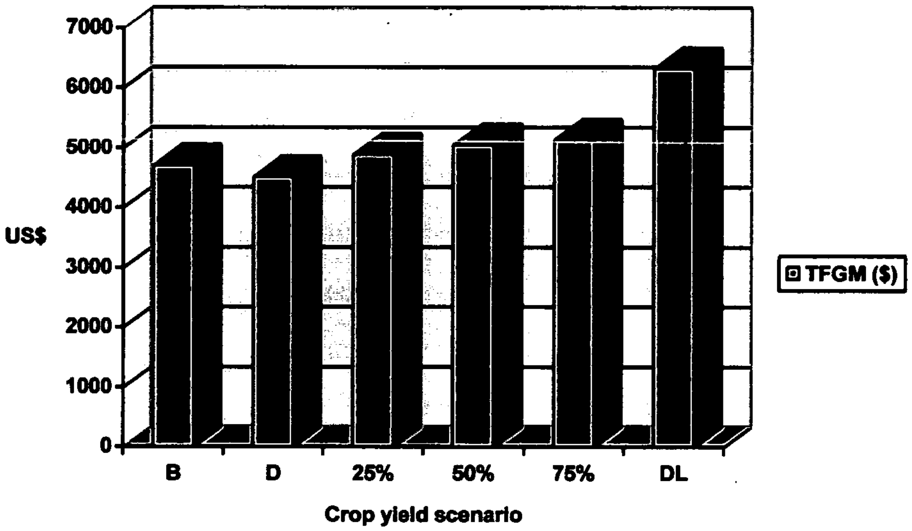

Fig. 6.2 Change in the farm Total Farm Gross Margin (TFGM) as a result of change in yield where B= basis, D= decrease by 25 per cent, 25, 50 and 75 per cent level of increase and DL= doubling the land available.

Figure 6.2 summarises the response in sales to changes in the yield and land coefficients on the farm performance in terms of TFGM. The response on parameters variation is looked at from a slightly different point of view from the Dryland ecozone, because the Alluvial ecozone is a net seller rather than purchaser and its impact is more in terms of farm income. There are relatively small differences in the TFGM, particularly related to levels of yield increase due to the assumptions made (Appendix 4.2).

Farm size

An increase in land available would substantially improve family income, however, land is a binding constraint in this ecozone which makes such an option unlikely. In fact, the MVP of land in the base solution is over $3300 per hectare. This ecozone is food secure, so consumption is not affected by changes in yield coefficients.

Change in costs of production

The most important coefficients of the objective function whose variation may have a significant impact on the land use and the TFGM are the costs of crop production, since all other non-farming activities are charged in terms of labour demand alone.

Within the group of cropping activities, production costs are of particular interest for maize, beans, green beans and peanuts because sweet potato and cassava are propagated vegetatively on farm. These crops have very low cost and additionally, pumpkin seed demand has little impact on the solution due to its marginality. It is worth noting that seed forms 100% of the production cost since, on one hand, no other inputs were being used (as reported by the farmers) and, on the other hand, labour and tractor hire are not a function of production but of land size and are considered independently.

Since decreasing further the current seed price does not seem likely, an increase in crop production cost would appear a more pertinent issue for investigation. Table 6.7 shows (under current) the cost of production used in the model, the cost if high quality (under potential) seeds were used and, finally, the maximum allowable increase in the cost of production as given by the model output for each crop and land class (saline, alluvial, irrigated). The average farm in this ecozone stores maize and peanut seed to plant in the irrigated land class. Therefore, the current cost in the objective function is nil which justifies an infinite possible increase (Table 6.6).

Table 6.6 Current, potential and maximum increase on the cost of seed per ha

Crops	Current ($/ha)	Potential ($/ha)	Saline ($/ha)	Alluvial ($/ha)	Irrigated ($/ha)
Maize	8.5	21.25	606	951	Infinity
Green beans	59.98	267			Infinity
Peanuts	55	80		765	Infinity
Beans	7.6	19.5	210	538	

The results in the Table 6.6 also imply that even if the price rose (due to inflation) or if farmers decided to purchase high quality seed (potential) the marginal value in the base solution would not change for all land classes, because such variations, and in the ranges specified, would be accommodated within the model output.

The following section proceeds with the impact of tree planting on changes in the farm objective function, land use, commercialisation of surplus and consumption.

4. The impact of introducing animals and trees in the farming system

Impact on farm welfare

Diversification of farm activities to include animals and tree planting has a positive impact on the TFGM (Table 6.7). The amount by which such an increase occurs falls as increases in the amortisation factor employed to the perennial crop are considered. This result provides both the micro level and meso level decision makers with information regarding, respectively, the interest rate that could be affordable for the farmer to adopt the Reforestation Strategy and, the potential level of subsidy that the government might have to provide to encourage such adoption.

At the individual level, diversification means a potential increase in income per capita between $726 and $758, i.e., 7% to nearly 13% higher than the one given in the base solution, dependant on the amortisation rate.

Land use, consumption and trading activities

Land allocation to crops remains unchanged irrespective of tree planting because separate land is assumed to be provided for trees and, labour is not binding.

However, when trees are introduced, a notable result is that non-improved maize is replaced by improved maize with a reduced cost of $10, $170 and $150 on saline, alluvial and irrigated land classes, respectively. Therefore, non-improved maize would have to improve by these values in order to enter the basic solution.

Table 6.7 Change in representative farm performance under the 'with trees' scenario in the Alluvial ecozone

	with trees	Basis
Total Gross Margin ($)		4721
Trees at 10% amortisation rate	5305	
Trees at 20% amortisation rate	5243	
Trees at 45% amortisation rate	5086	
Land allocation (Ha)		
Trees	2	
Sales(Kg)		
Maize	2583	1404
Poles (m^3)	27	0
Animals (heads)		
Cattle	1.82	
Goats	3	
Slack of labour (Mnhrs/yr)		
Adult	5564	6238
Children	4876	4876

The recommended planting of 2 ha with trees per household may be a reasonable long term objective. Such land may include rehabilitation of saline land with plantation of trees such as *Casuarina* spp.

Unlike the Dryland ecozone, the income from tree and animal options does not alter food tastes and preferences since this zone appears to be fairly well food self-sufficient. In the Dryland ecozone more income from these options made it possible for families to buy the more preferred maize in place of cassava. Instead, yield increases resulting from the incorporation of leaf biomass taken from woodlots with leguminous trees augments the sale of maize by almost 84% (Table 6.7). The food surplus of this ecozone has a significant impact on interecozone and regional trade as it will be shown later in this chapter.

Grazing land and the land planted with trees have a lower MVP compared to the cropping land. It is, correspondingly, 18 and $118 per ha because, in reality, only marginal land is allocated to the two latter activities whereas the most productive land goes to agricultural use.

Labour with animals and trees

Tree planting only reduce slack labour by approximately 11%, due to relatively small land allocated to trees.

Plantation versus use of natural forest

Again, like the Dryland ecozone, conservation of the natural forest needs an administrative enforcement, because the desire for increasing farm income may not be sustainable due to potential depletion of resources. Selling wood from plantations as poles appear the most profitable option, therefore, the reduced cost of selling that wood as firewood or transformed into charcoal is high (Table 6.8) compared to poles.

Table 6.8 Reduced cost of wood products

Tree species	Firewood ($)	Charcoal ($)	Poles ($)
Leucaena spp.	8.67	9.87	0.47
Eucalyptus spp.	9.71	10.97	1.06
Melia spp.	14.5	15.75	0.75
Casuarina spp.	34.7	36.00	41

However, *Casuarina* spp. produce very low volume yield and this explains the very high reduced cost for all possible uses. In fact, this species is more appropriate for conservation than for production and it was included in the model of this ecozone due to its tolerance to salinity.

Wood for commercial purposes can only come from the neighbouring ecozones such as the Thicket or Open Forest. This seems to suggest that the harvesting fee farmers would pay, would have to be the same as the inhabitants of these ecozones. Therefore, the reduced cost presented in Figure 6.9 is not used to estimate the value of that fee, because it would not be as realistic.

The solution analysed so far was obtained assuming that farmers have a single objective: maximisation of the TFGM. However, as mentioned in the last chapter, farmers are also concerned about food security and the availability of wood, particularly for domestic consumption. In order to deal with this, a multiobjective approach was adopted.

5. Farm goals

The typical farm has been reported (Chapter 5) to have three objectives lexicographically ordered with income first, the need to maintain the current level of food satisfaction as a second goal and, finally, the concern regarding the availability of wood at a relatively close distance. Unlike in the Dryland ecozone, in this ecozone farmers explicitly stated three objectives (income, food and wood). Trade-offs between the goals and the impact of their prioritisation in the farm organisation provide the measure of opportunity cost associated with achievement of several goals (Romero and Rehman, 1989; Romero, 1991; McGregor and Dent, 1993; Winston, 1995). Therefore, Lexicographic Goal Programming (LGP), was adopted to produce such measures. This approach assumes that the decision maker explicitly defines the goals and attaches respective priorities in a pre-emptive fashion (Romero and Rehnman, 1989).

However, farmers did not express a quantitative target to be associated with the objectives, rather, they expressed it qualitatively. Therefore, this qualitative information was transformed into quantitative, as shown in Table 6.9.

Table 6.9 Goals, targets and changes in priorities

Goal	Target	Run A	Run B	Run C
Income	$6000	First	Second	Third
Food	5,661,879 kcal	Second	First	Second
Wood	25 m3	Third	Third	First

The target level for the first goal (Total income) was generated by the initial LP solution while that for the second goal is the total demand for energy based on FAO data for a family of two men, three women and two children. Finally, the target for the third goal relates to ensuring the satisfaction of wood demand for family consumption and for cash generation, i.e., wood to maintain the current level of production of charcoal. The fact that farm goals and priorities are limited to three in this ecozone eliminates the problem of redundancy in LGP caused by excessive prioritisation of the goals (Romero, 1991). The LGP model was run in LINDO following a sequential method described by Winston (1995).

Table 6.10 shows the output of the LGP. The level of all non-farming activities remain unchanged irrespective of variation in goal prioritisation. However, an interesting aspect is that land allocation in Run A is in agreement with that of the LP model (2.29 ha) whereas, Run B and Run C produce the most inefficient land allocation with, respectively, 1.12 and 1.58 ha. The effect of this situation is a reduction in the level of sales and consequently in the income goal (Table 6.10) which aims to minimise the negative deviation. This can be justified by the fact that GP solutions are not necessarily pareto optimal, but offer information on the level of satisfaction of the decision makers' goals and the opportunity cost associated with non-allocation of resources in their next best option, i.e., change in priorities.

Table 6.10 The achievement function of the Alluvial ecozone

Deviational variables	Run A	Run B	Run C
Income			
n_1	$699	$2354	$2198
p_1	0	0	0
Food			
n_2	0	0	0
p_2	88,174 Kcal	620,057 Kcal	620,057 Kcal
Wood			
n_3	0	0	0
p_3	2.43 m^3	4.16 m^3	4.16 m^3

n1....n3: negative deviations ; p1....p3: positive deviations

The apparent underachievement of the income goal in Run A is expected because the target was set slightly higher than the one that led to the TFGM in the LP results, when in fact, the levels are exactly the same. On the other hand, when food or wood are the first priority, respectively in Run B and Run C, the income goal is underachieved by respectively, 39 and 36%, whereas there is overachievement of the food goal by an amount equivalent to nearly 25 and 183 Kg of maize.

Finally, as far as the wood goal is concerned, the current level of demand can be satisfied with a 2 ha plantation and even surpassed as shown in the overachievement of the goal (p_3) in all scenarios.

6.2.3 Thicket ecozone

1. The LP farm model results and stability of the solution

Current household welfare

The Thicket ecozone is characterised by relatively rich soils which produce a significant surplus of tuber production and wood products. Apart from cereals, the Thicket ecozone is particularly suitable for cassava and sweet potato production. The reported yield of cereals, which are more sensitive to shortages in rainfall, were low. Despite that, the level of output was still adequate to meet the demand with little supplement from purchases and contribute to the Maputo-city market.

The typical farm in this ecozone has a comparatively reasonable level of income (Table 6.11). The TFGM per capita is $438 in the base solution. This value is also more than fourfold higher than the average in the country.

Land use, consumption and trading activities

Like in the Alluvial ecozone, the soils are fertile and when there is sufficient humidity there is potential for rotation of mainly maize and/or sweet potato. Land allocated to the main crops (maize, cassava and sweet potato) is nearly 82 per cent. This is because the latter two crops are the main cash crops in this ecozone compared to maize and green beans in the Alluvial land.

This ecozone needs supplements of maize and beans, which explains the positive reduced cost associated with these crops in both dry and wet seasons. In addition, the MVP of land is respectively $1571, $1218 and $1635 per ha for the low, medium and high thicket land classes. Alluvial and Thicket ecozones offer the most profitable resources in terms of land, however, in the latter, the cropping land has an average higher marginal value product by $350/ha. This is perhaps due to more land allocation to high yield cash crops such as cassava and sweet potato.

Table 6.11 The base solution for the Thicket ecozone representative farm model

	Model Base solution
Total Gross Margin ($)	3507
Land allocation (ha)	
Maize	1.08
Beans	0.14
Peanuts	0.32
Cassava	0.7
S. potato	0.48
Pumpkin	0.04
Consumption (Kg)	
Maize	824
Beans	78
Peanuts	88
Cassava	291
S. potato	848
Pumpkin	11
By-products	589
Purchases (Kg)	
Maize	55
Beans	27
Sales (Kg)	
Maize	0
Beans	0
Peanuts	0
Cassava	3427
S. potato	2839
Pumpkin	188
By-products	5476
Charcoal (bags)	450
Sugar cane drink (l)	2400
Native poles (m^3)	154
Family labour (Mnhrs)	
Adult	0
Children	4600
Hired seasonal labour (Mnhrs)	
Male	18
Female	26

Family and hired labour

In comparison with the other ecozones, it can be argued that there is full employment in this ecozone, because all adult labour is used up even in the 'without trees' base scenario (Table 6.11). Also, the farmers hire a small amount of labour to assist on land preparation. The reduced cost, however, is nil and any increase in the family size with any gender and age has a negative MVP, i.e., it would reduce the TFGM.

2. Model validation

Farmers in the Thicket ecozone have traditionally relied on exploitation of wood products and animal rearing. However, war, scarcity of inputs and drought are deemed to have been more responsible for the high level of exploitation of the resources. The model fairly illustrates the importance of this activity on the household welfare. Also, the importance of the natural forest as an employment opportunity seems to suggest that perhaps the use of the resources for commercial purposes may be going beyond the only need to meet basic needs. Therefore, administrative reinforcement may be needed to prevent negative effects of deforestation.

3. Sensitivity of key parameters

Variation on yield

In order to deal with the problem of uncertainty associated with yield coefficients and other parameters, a sensitivity analysis is carried out. Because of variation on the current crop yield in the different land classes, different assumptions (yield increase or decrease) were made regarding potential variation (Appendix 4.3). Land allocation to crops does not change nor does the consumption as a result of yield variation. However, an increase in sales has a significant impact on the TFGM as shown in the Figure 6.3.

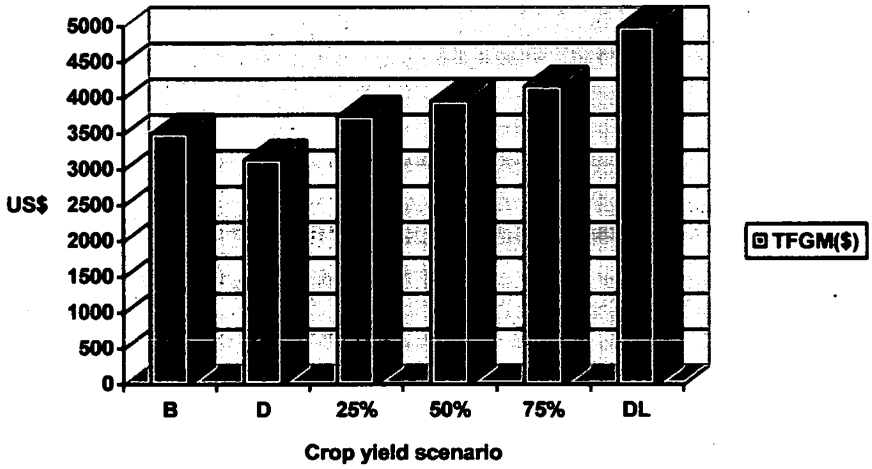

Fig. 6.3 Variation of the TFGM with change on yield coefficients and land size B= basis, D= decrease by 25 per cent, 25, 50 and 75 per cent level of increase and DL= doubling the land available.

Farm size

Doubling the land size results in more land being allocated to maize in the low thicket, and to cassava in the medium and high thicket significantly increasing the TFGM (Figure 6.3). This positive impact on the TFGM, can only be possible through slash and burn agriculture. This would have a serious impact on the environment of the ecozone as well as the potential availability of wood products in the future. Another option is by making use of the already harvested land to produce wood products, in which case the potential land allocated to trees would reduce.

Change in costs of production

The range of cost of producing maize, beans and peanuts are presented in Table 6.12 which is basically the seed cost component due to the low input nature of agriculture practice in this zone. For reasons explained in the previous section, the other crops are not included.

The lower price of seed per ha ('Current' column), specifically for maize and beans is due to the low quality of seed used in this ecozone. In general, the range of price increase is significantly high, which suggests that price variation, due to inflation or purchase of good quality seed at the cost indicated in the 'Potential' column can well be accommodated under the current land use pattern without changing the MVP of the scarce resources.

Table 6.12 Current, potential and maximum increase on the cost of seed per ha in the Thicket ecozone

Crops	Current ($/ha)	Potential ($/ha)	Low ($/ha)	Medium ($/ha)	High ($/ha)
Maize	5.4	21.25	Infinity	1136.8	1552.6
Peanuts	57	80	Infinity	1149.8	1471
Beans	3.23	19.5	Infinity	782	1222.8

4. The impact of introducing animals and trees in the farming system

Impact on household welfare

The pattern of change in the TFGM brought by diversifying the farm activities is no different from the other ecozones. The variation in TFGM is directly associated with increases in sales of improved maize, animal capital and/or trees. The TFGM varies between $565 and $655 under the different amortisation rate scenarios. Despite higher TFGM (Table 6.13) estimates for this ecozone, compared to the Alluvial ecozone, for instance, greater family size (averaging 8) reduces the value of income per capita.

Table 6.13 Changes in representative farm performance under the 'with trees' scenario in the Thicket ecozone

	With trees	Basic Solution
Total Gross Margin ($)		3507
Trees at 10% amortisation rate	5237	
Trees at 20% amortisation rate	5053	
Trees at 45% amortisation rate	4524	
Land allocation (ha)		
Trees	6.5	
Purchases (Kg)		
Maize	0	55
Sales (Kg)		
Maize	1675	0
Planted poles (m^3)	109	
Animals (Heads)		
Goats	8	
Cattle	3	
Family labour (Mnhrs)		
Adult		
Children	1792	4600

Land use, consumption and trading activities

In the medium term 6.5 ha per household are assumed to be available for tree plantation, as indicated in Chapter 5, since the high exploitation of wood products seem to suggest that the natural regeneration may not be significant in the cleared areas.

The typical farm in this ecozone is nearly self-sufficient in food and no food tastes and preferences are altered due to increased incomes from the introduction of animal or/and tree options. The diet composition is maintained irrespective of the diversification in the farm even though no maize is bought. In fact, in the 'with trees' scenario, maize sales increase from nil to 1675 Kg as a result of soil improvement with the leaf biomass. Surprisingly, the MVP of land under crops does not change in all land classes, and the pasture and tree plantation land have obviously low MVP, $46 and $118 per ha respectively. An aspect to note though is that the MVP of land under the introduction of tree crops is the same as in the Alluvial ecozone while it is higher for the pasture land due to greater pasture yield in this ecozone.

Labour with animals and trees

As mentioned before, there is no adult slack labour in this ecozone. Consequently, tree planting needs flexibility in labour exchange within the family, with children possibly undertaking more of the domestic activities to release adult labour to take on this activity. Furthermore, child slack labour (with trees) is not sufficient to cover the time necessary for animal rearing. Therefore, there is a need for a compromise of the two activities. Animal husbandry is a traditional farm activity and perhaps less risky in terms of the unknown outcome as is the case of reforestation. Thus, allowing only flexibility for exchange of adult labour in the model would free child's labour for animal rearing despite having an opportunity cost, i.e., loss of some of the household income. The reason being that less than half the previous amount of charcoal are produced and also there is reduction of harvesting natural forest poles to 115 m^3. The area planted with trees remains the same and child labour slack become over 8,000 manhours.

Plantation versus use of natural forest

Table 6.14 shows the reduced cost (RC) of wood products from planted forest. Like in the other ecozones, poles are the most favoured use whereas charcoal production is the least. *Leucaena* spp. and *Melia* spp. are the two species selected in the model and their average RC for using planted wood for charcoal production serves as the potential harvesting fee to be charged to farmers and timber merchants using the natural forest products for commercial purposes. In this case, the cost per m^3 is $12.81 or $377.25 per ha. This fee is considerably high compared to that reported by

Soto and Sitoe (1994) which is as low as \$0.06/m^3 harvested for firewood or charcoal production or \$0.56/m^3 for poles. These values show a significant undervaluation of the resources, despite the fact that it was observed during the data collection period that trees with more than 40 cm diameter at breast height (dbh) were also harvested to produce charcoal.

Table 6.14 Reduced cost of wood products in the Thicket ecozone

Tree specie	Firewood (\$)	Charcoal (\$)	Poles (\$)
Leucaena spp.	8.67	9.87	0.47
Eucalyptus spp.	9.98	11.23	1.06
Melia spp.	14.5	15.75	0.75

The impact of this (harvesting fee) policy instrument will be explored in the regional model. However, when it is introduced in the farm model, the result is a dramatic reduction on the activities relying on natural wood products. There is no charcoal production and only 13 m^3 of poles are harvested by the representative farm.

5. Farm goals

It was earlier mentioned that farmers have three goals which include food security, availability of wood and restocking with animals. The third is incorporated into the model as two constraints, one limiting the number of goats and the other allowing any number of cattle. The higher the size of the herd, the more prestige the farmer gets, therefore, the total size of the herd depends on the pasture productivity and availability of labour. Hence there is a difficulty in setting a reasonable target.

The criterion of the LP model is set as a maximisation constraint, because it is understood that the farmers would not prefer to give up income which is why they harvest large amounts of forest products.

The target values of the two goals and two permutations of priorities are given in Table 6.15. The target for the food goal was estimated using the gender and age composition of the typical farm and the daily nutrient requirement. The wood goals denote the demand for wood products for family consumption and the current level of wood harvested (charcoal and poles) for commercial purposes.

Table 6.15 LGP runs

Goal	Target	Run A	Run B
Food (n_1, p_1)	6,222,520 kcal	First	Second
Wood (n_2, p_2)	452 m3	Second	First

The associated trade-offs between food and wood goals given by the LGP model are shown in the Table 6.16. In Run A, the food goal is exactly achieved which conforms with the potential of the ecozone. Nevertheless, in both runs the wood goal is considerably underachieved. This means that the potential area available for plantation cannot sustain the current level of wood harvesting for commercialisation. Therefore, conservation may need another policy measure such as introduction of harvesting fees to restrict the exploitation.

Table 6.16 The achievement function of the Thicket ecozone

Deviational variables	Run A	Run B
n_1 (Food)	0	664 Kcal
p_1 (Food)	0	0
n_2 (Wood)	362 m^3	357 m^3
p_2 (Wood)	0	0

n_1 and n_2: negative deviations; p_1 and p_2: positive deviations

Also when wood is put as the first priority, not only it is not achieved as it results in the underachievement of the food security goal due to reduction on use of cropping land from 2.76 ha (in the optimisation problem and with food as first priority goal) to 2.13 ha. This scenario is unlikely to be preferred by farmers or policy makers.

6.2.4 Open Forest ecozone

1. The LP farm model results and stability of the solution

Current household welfare

Soils in this ecozone are characteristically fine clay and therefore offer great potential for cropping and for production of building material such as bricks and/or domestic utensils. Nevertheless, the shortage of rain during the period preceding the data collection resulted in underperformance of the agricultural activities which implied, farmers were still not self-reliant in food and relied on non-farming activities such as the production of charcoal and bricks to generate income.

As shown in other ecozones, the difference in the level of TFGM is dictated by the range of opportunities that the farmers can explore as well as the size of land available for the average family to plant trees.

The TFGM of the base solution (Table 6.17) has a significant component of charcoal and bricks sales. Also the importance of animal rearing can be shown by the number of head as well as their capital value. The corresponding per capita value of TFGM is $281.

Land use, Consumption and trading activities

Like in the Dryland ecozone, there is only one cropping season and mixed cropping is inevitable. The current farmed land is less than a hectare per household which also has an effect on the capacity of producing surplus. This explains the very high MVP ($1547/ha) for the open forest land class whereas the wooded grassland has a substantially lower value ($126/ha) because of a lower soil fertility associated with it.

The ecozone is deficient in food, therefore, the typical farm household purchases more than 0.5 tonnes of maize to supplement production. Hence, selling any crop has a relatively high RC value, whereas purchasing essential components of the diet such as maize and sweet potato have, respectively, nil and very low RC. However, like in the previous cases, all land use variables are basic.

Table 6.17 The base solution for the Open Forest ecozone representative farm model

	Basis
Total Gross Margin ($)	1686
Land allocation (Ha)	
Maize	0.33
Beans	0.14
Peanuts	0.1
Cassava	0.15
Sweet potato	0.03
Pumpkin	0.025
Consumption (Kg)	
Maize	855
Beans	60
Peanuts	33
Cassava	150
Sweet potato	350
Pumpkin	9
By-products	849
Purchases (Kg)	
Maize	665
Peanuts	16
Sweet potato	111
By-products	677
Sales (Kg)	
Cassava	646
By-products	609
Charcoal (bags)	400
Bricks (units)	14400
Family labour (Mnhrs)	
Adult	2743
Children	7935

Family and hired labour

Unlike all the other ecozones previously discussed, farmers were reported not to hire any labour for farming during peak seasons. There is slack family labour, with a high component of female labour. However, hired labour is the main component on the cost of brick production and its cost is expressed monetarily in the criterion rather than in physical units. It is obvious that labour shadow price is nil, perhaps even all year round since the typical farmer seems to suggest that family labour can still provide labour during the peak seasons.

2. Model validation

The Open Forest ecozone has fertile land which could be farmed in both seasons but rain shortage makes agriculture unreliable. Therefore, wood harvesting and pottery which employ mainly child labour generate income for farmers to purchase food. The officers emphasised the fact that wood harvesting is particularly important for the subsistence farm specially as a ready source of income during harsh conditions that made many families refugees in the neighbouring countries. The model output once more seems to address this issue.

3. Sensitivity of key parameters

Variation in yield

The assumptions made regarding the change in yield parameters are shown in Appendix 4.4. Despite the agricultural underperformance mentioned earlier, the current yield of some of the crops are not assumed to be the lowest, therefore the impact of their possible reduction is investigated.

Figure 6.4 illustrates the change on the TFGM as response to yield change and land availability. Decreasing or increasing yield by 25 per cent has no effect on the current land allocation. However, at higher increases, more land is allocated to peanuts and cassava to the detriment of other crops. The TFGM, as shown in Figure 6.4, decreases or increases compared with the basic solution in response to potential reductions or increases in yield. The absolute value changes are not substantial, however.

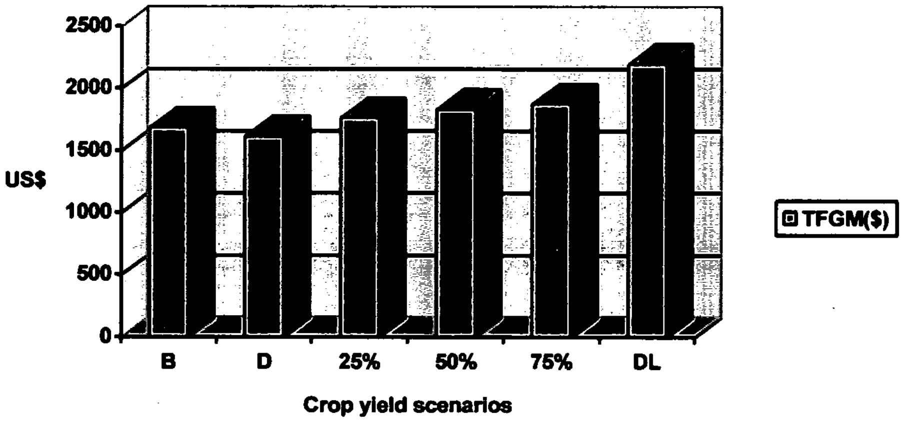

Fig.6.4 Effect of changes of yield on the TFGM B= basis, D= decrease by 25 per cent, 25, 50 and 75 per cent level of increase and DL= doubling the land available.

The main difference in relation to the Alluvial and Thicket ecozones, is that the positive change on the TFGM can be attributed to variation on the cassava output and sales and, as far as cereals are concerned, (especially maize) the output only offsets the deficit on family consumption. This results in a decline in the level of purchases.

Farm size

As a further scenario, land area is doubled, which seems a fairly feasible scenario considering that there is a substantial surface exposed to winds, and hence not currently explored yet, tree planting can serve as windbreaks and make such land suitable for agriculture. When this is explored, the model allocates more land to beans and cassava and TFGM increases. However, this does not alter the land allocation to maize and therefore maize has to be purchased for family consumption. This is due to the lower yields of maize in this ecozone.

Change in costs of production

Contrary to the other ecozones, the average prices in the Open Forest are comparatively high. This is essentially due to transportation. Nevertheless, the impact of a 50% increase in prices of seed is a negligible reduction of the TFGM by 0.6%.

Table 6.18 shows that in fact current seed prices do not differ very much from those of the high quality seed, which means the farmer could easily invest in better seed to increase yield within perhaps a lower permissible increase, compared to the Thicket, for instance (Appendix 4.3).

Table 6.18 Current, potential and maximum increase in seed costs per ha in the Open Forest ecozone

Crops	Current ($/ha)	Potential ($/ha)	Open Forest ($/ha)	Wooded Grassland ($/ha)
Maize	18.1	21.25	1398	71
Peanuts	75.5	80	494	552
Beans	7	19.5	1080	41.5

4. The impact of introducing animals and trees in the farming system

Impact on household welfare

This increases TFGM (Table 6.19) per capita to values ranging from \$463 and \$574 with trees and different amortisation factors. An important aspect to note though is that a significant component of TFGM is from animals even without trees (4 cows and 10 goats). This is so because animal rearing is one of the traditional farm investments in the ecozone. *Leucaena* spp. fodder supplement increases the size of the herd by 6. Thus, introducing animals improves the per capita value of the basic solution by about 47%.

Land use, consumption and trading activities

Land allocation to crops does not change with farm diversification, there is only substitution of non improved with improved maize. The MVP of cropping land remains constant despite increases in maize yield. Increasing pasture or land for tree plantation could increase the TFGM by respectively, \$92 and \$118/ha, i.e., the MVP. The 6 ha of land that would produce the reported gains in the TFGM is reasonable given the fact that one of land classes is wooded grassland, hence with low tree density. On the other hand, the harvesting of the open forest for charcoal and household consumption is likely to create large areas without trees which can be reforested. In fact, as mentioned before, one of the problems of low yield is the exposure of the agricultural crops to wind, implying need for improvement of the environment.

The advantage brought by tree planting is that improved maize reduces purchasing to about 38 per cent of the previous level and there is thus no impact on sales. However, the diet habits and level of food consumption do not change.

Labour with animals and trees

Tree plantation significantly reduces unemployment. Certainly, the reduction of even child labour slack in the 'with trees' scenario, suggest that children have to have greater participation in domestic activities. However, there is enough slack child labour to accommodate the labour demand for animal rearing.

Table 6.19 Changes in representative farm performance under the 'with trees' scenario in the Open Forest ecozone

	With trees	Basic solution
Total Gross Margin ($)		1686
Trees at 10% amortisation rate	3434	
Trees at 20% amortisation rate	3263	
Trees at 45% amortisation rate	2776	
Land allocation (Ha)		
Trees	6	
Purchases (Kg)		
Maize	513	665
Sales (Kg)		
Poles (m^3)	82	
Animals (heads)		
Cattle	4	
Goats	16	
Family labour (Mnhrs)		
Adult	1327	2743
Children	3998	7935

Plantation versus use of natural forest

Conversely, the reduced cost of transferring planted wood to uses like firewood or charcoal production is the same as in the previous ecozones, but a possible fee that farmers would have to pay for continuing to harvest the natural forest is $329/ha. Similarly, the response to the introduction of a harvesting fee is that there is no production of charcoal, but the TFGM is about the same. The reason being that 12 cows (high capital value) are reared instead of 4 cows and only 10 goats.

5. Farm goals

As stated in the previous chapter, farmers' goals in this ecozone include food security, continuous exploitation of wood products to generate income, employment and conservation. The last two goals can be properly addressed within the regional model framework rather than in the context of the individual farm. Contribution of the sector towards employment is provided by tree planting activities. Therefore, the slack of labour perhaps transcends even the regional and sector boundaries which limits its possible consideration. Like the case of the Dryland ecozone, a need for satisfaction of food and wood constrain the maximisation of the TFGM, which represents a simple way to deal with the multiobjective problem.

6.2.5 Grassland ecozone

1. The LP farm model results and stability of the solution

Current household welfare

The Grassland ecozone is the poorest in terms of the current agricultural output as well as in terms of limited alternatives for generation of income. It occurs in the less fertile mainly sandy soil with obvious limitations as to agricultural production. Nevertheless, farmers grow maize, cassava, sweet potato, peanuts and beans. The first three crops form the staple diet with a significant predominance of maize.

Besides the naturally inhospitable environment, the poor living conditions were aggravated by the war (Chapter 4). The results of the base solution (Table 6.20) illustrates how serious the problem is.

The current annual income per capita in this ecozone is extremely low ($8 per year), and the population of this ecozone can be considered to be under the category of absolute poverty.

Land use, consumption and trading activities

About 89% of the cropping land is allocated to maize, beans and cassava. However, the ecozone is dramatically food insecure and a large proportion of the food requirement (almost 84% of maize, for example) is met with purchases, which really account for the amount of food aid that each household is likely to have been receiving. Obviously, as a result, all selling food output activities even during the harvesting period are associated with a high reduced cost. Moreover, the low soil fertility justifies the relatively low MVP ($445/ha) compared to other ecozones.

Family and hired labour

The high adult slack labour demonstrates the lack of opportunities for rural employment in this ecozone. Therefore, the zero labour shadow price all year round is not refutable.

Table 6.20 The base solution for the Grassland ecozone representative farm model

	Basic solution
Total Gross margin ($)	66
Land allocation (Ha)	
Maize	0.4
Beans	0.19
Peanuts	0.1
Cassava	0.3
Sweet potato	0.02
Consumption (Kg)	
Maize	1105
Beans	79
Peanuts	44
Cassava	296
Sweet potato	288
By-products	1040
Purchases (Kg)	
Maize	926
Peanuts	35
Sweet potato	208
By-products	482
Sales (Kg)	
By-products	1175
Family labour (Mnhrs)	
Adult	9978
Children	8306

2. Model validation

The Grassland ecozone demonstrates a case where natural and manmade problems contribute to deterioration of the household economy. Drought and strong winds, lack of seed and (at times) cassava vegetative material, compound the problem. Making palm drink is the sole activity that supplements income in this ecozone. The structure of the model addresses this issue adequately.

3. Sensitivity of key parameters

Variation in yield

The current yield of crops is assumed to be the lowest and an increase of up to 75% is allowed for all crops. Contrary to other ecozones, change in crop yield has a negligible impact on the TFGM (Figure 6.5).

Farm size

There is a remarkable improvement of the TFGM when land size is doubled to 2 ha. The cultivated land can expand under stable political conditions given the low density of people in the ecozone. The TFGM increases due to the fact that more than a ha is allocated to cassava, resulting in sales of over a ton of the tuber and its by-products. This means that the TFGM per individual could raise to $64 (8 times the current).

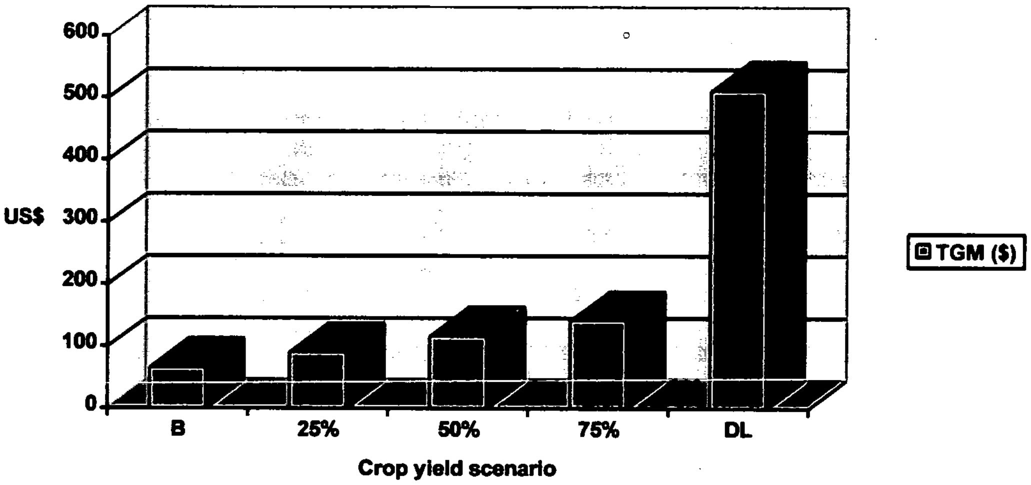

Fig.6.5 Effect of changes of yield on the TFGM B= basis, 25, 50 and 75 per cent level of increase and DL= doubling the land available.

4. The impact of introducing animals and trees in the farming system

Impact on household welfare

Reforestation Strategy appears to have a great potential (Table 6.21) to provide employment, and improve farmers' welfare in this ecozone. In addition, there is potential land per household that could be planted with trees. Whether such an opportunity will bring real improvement, will depend on how much land the farmers are willing to plant with trees.

The per capita income improvement can range from $85 to $495. Opposite to other ecozones, the high component of the TFGM is derived from trees. This is a good illustration of the potential impact of high interest rates: they are likely to act as a deterrent to farmers participating in a Reforestation Strategy.

Land use, consumption and trading activities

Land allocation to crops does not alter in the 'with trees' scenario. The assumption that each typical farm could have 30 ha of land available for tree planting does not seem unreasonable given the low density population and the nature of the ecozone. The Reforestation Strategy also has a significant impact on the labour, i.e., there is significant reduction of unemployment available provided that such an area is planted. Again, the MVP maintains as in the base solution despite incorporation of leaf biomass and hence relatively higher productivity.

Table 6.21 Changes in representative farm performance under the 'with tree' scenario in the Grassland ecozone

	With trees	Without trees
Total Gross margin ($)		66
Trees at 10% amortisation rate	3958	
Trees at 20% amortisation rate	3022	
Trees at 45% amortisation rate	677	
Land allocation (Ha)		
Trees	30	
Purchases (Kg)		
Maize	715	926
Sales (Kg)		
Poles (m^3)	411	
Animals (heads)		
Cattle	2	
Goats	8	
Family labour (Mnhrs)		
Adult	2115	9978
Children	6367	8306

Consumption levels do not change with trees, however, purchases of maize reduce by nearly 22% due to improvement on maize yield. The level of sales do not vary either.

Plantation versus natural forest

There is no production of charcoal in this ecozone, therefore, there is little change in the impact that farmers have on the natural environment. The RC of tree transference regards only firewood and poles. As in the case of all other ecozones, selling poles is more profitable, hence the significantly lower RC ($0.75/m^3).

5. Farm goals

Food security is clearly a primal goal in this ecozone. Also, farmers mentioned wood availability and animal production. Because the family requires a relatively small quantity of wood for domestic consumption (8 m^3 a year), and because there is no tradition of selling wood products from this ecozone, then there was no reasonable basis to set a target. Therefore, given that each farm household could potentially plant 30 ha, then it is up to the decision maker to decide on the area to plant and hence on the level of income to generate. The animal production goal is determined by the availability of fodder and the LP model output provides the number that can potentially be reared. Therefore, once more, a simple multiobjective approach was deemed appropriate to resolve the problem facing farmers in this ecozone.

6.2.6 Some remarks on the farm model output

One of the aspects highlighted at the beginning of this chapter regarded the fact that the farm models are simply a step towards the building of a regional planning framework for the Reforestation Strategy. Also it was mentioned that an expert validation focusing on the structure of the model would be used due to lack of statistical information. The Dryland ecozone was the only exception with a quasi formal validation done. Nevertheless, the situation could not be replicated for other ecozones and, the survey of the local administrative and agriculture officers provided some indication which served to validate the models.

In general, for many years rural Maputo was self sufficient in food and a lot of surplus was supplied to Maputo-city. Despite the fact that the results of the individual representative models show high food deficit, the political stability and the rainfall over the last two cropping seasons, show that the figures of yield can improve significantly.

At the beginning of this chapter it was also mentioned that the farm model output would be looked under the perspective of whether it responds to the second objective of this study which regards the analysis of the application of mathematical programming in the evaluation of social forestry alternatives. In addition, it should provide the answer to the hypothesis that the current land use is not sustainable and the Reforestation Strategy could not disrupt negatively the traditional socio-economic environment.

The survey of farm households showed that they were willing to plant trees for production of wood as long as it was in separate plots from the agricultural land. This is the reason why the only option looked at in the model is pure forest stands, or the social forestry options (Chapter 3), other than intercropping even though options for harvesting and incorporating leaf biomass to improve the soils have been allowed for. It can be argued that the results of the farm models provide the decision maker with better information on the basis of which to make decisions regarding the possible adoption of the Reforestation Strategy. The three scenarios show the contribution in terms of lowering the level of unemployment, increase in crop yields which result in savings from making less purchases and this increases the TFGM. Furthermore, considering that the multiple objectives generally numbered only two in most of the ecozones, it seemed that the LP approach could still adequately address the problem. In short, introducing trees does change the farm organisation, but such change is positive even if only looked at from the social point of view, that is, through a reduction in unemployment. Also the income generated contributes towards satisfaction of the food security goal through purchases from surplus ecozones. The socio-economic environment of the household/farmer is therefore strengthened by implementing the Reforestation Strategy.

In short, the typical farm planning frameworks are taken as valid given their family oriented goals. The next section, however, explores the changes on farm organisation resulting from the need for the farmers to incorporate inter-regional trading opportunities in their activities subject to meso-level or policy goals.

6.3 Regional model results

6.3.1 Introduction

In this two-level planning problem, first the results of the farm model planning framework were discussed. Individual farms were looked at as independent economic units which produce, consume, sell and/or purchase without being affected by the environment surrounding them. The impact of the Reforestation Strategy was looked at from the point of view of the farms' own capacity to respond subject to their land, labour constraints and goals. It was thus assumed that there was a market for all the produce. Nevertheless, a more realistic approach should look at the effect of individual farm reactions in the context of competition with other producers and the size of the market that their surplus is directed towards. The demand is determined by the regional goals set by policy makers (Chapter 5) in the province of Maputo.

This section explores the impact of the Reforestation Strategy in this wider context of coexistence of many producers aiming at the same market. Particular attention is given to the following aspects: the level of achievement of the regional goals with a change in priorities; the impact on land use of each ecozone; whether there is disruption in the traditional non-farming activities due to tree planting, (and whether this contributes towards reduction of unemployment); the interecozone trade and generation of surplus that goes to Maputo-city; and whether the strategy results in a sustainable use of the natural forest resources envisaged by the government. Addressing these questions should provide answers for the fourth specific objective of this research which is to assess the programming methodology in terms of its usefulness as an instrument for policy analysis. It should also address the hypothesis of whether it is possible to develop a multiobjective planning methodology for integrated rural land use in data scarce environments and foresee the opportunity for changing traditional land use systems.

6.3.2 Output from the regional model

1. The achievement function

Weights calculated from the ranks given by the sampled decision makers were used for the initial run of the regional model. Subsequently, these priorities were changed in accordance with the scenarios presented in the Table 6.22. Obviously, the primal objective of the Reforestation Strategy is to mitigate the problem of increasing demand for wood products in the urban areas and the drain of resources to generate income in the rural areas. Consequently, policy makers place wood production goals in high priority, whereas budget limitation is placed last. Planners are also aware that food security is a vital issue both in the ecozones and the region, hence its placement in the third priority. The ultimate gain of reforestation is going to be conservation of the natural forest and its intrinsic benefits. Scenarios B, C and D aim to explore the trade-offs associated with changes in the regional priorities, which is likely to occur since policy makers perception of problems and priorities is not static.

Table 6.22 Weights associated to the goals in each scenario

Scenarios	Run A (survey)	Run B	Run C	Run D
Fuelwood	1	0.33	0.3	0.16
Poles	1	0.33	0.3	0.16
Food	0.33	1	0.16	0.12
Conservation	0.16	0.16	1	0.3
Budget	0.12	0.12	0.12	1

The results of these scenarios are shown in Table 6.23, where target multiples represent the number of times over the targets were achieved. All goals are at least achieved in all scenarios. However, the goal regarding the production of poles for construction in the sub-urban areas is substantially overachieved (P_2) in all scenarios due to overachievement of the conservation goal whose indirect target is the area of reforestation. It also follows that more investment would have to be made by the government, hence the overachievement of the budget goal.

Table 6.23 Target multiples showing the level of achievement of each goal

Goals	Run A	Run B	Run C	Run D
Fuelwood				
n_1	1	1	1	1
p_1	2.17	1	1	1
Poles				
n_2	1	1	1	1
p_2	111.5	69.8	69.6	38.93
Food				
n_3	1	1	1	1
p_3	1.06	1	1.1	1.33
Conservation				
n_4	1	1	1	1
p_4	1.42	1.33	1.32	1.56
Budget				
n_5	1	1	1	1
p_5	1.34	1.24	1.25	1.49

Run A

The fact that wood products were given the highest priority by the policy makers led to a level of production of fuelwood twice as much as the demand. Harvesting and not being able to sell means an irrational use of resources without providing any benefit neither to the farmers nor to the environment. Nevertheless, it is also true that current fuelwood production may be more than the demand because the number of producers has increased over recent years. The high storage in the production places, in the markets by the road side and even in the Maputo-city markets seems to confirm this result (observed on survey).

As to poles, their value is substantially overachieved due, essentially, to a surpassing of the conservation goal. While the poles target is just over 44,000 m^3, the conservation goal is overachieved by over 41,000 ha, hence the high volume of stock. The target multiple of poles means that this volume can exist in the forest as a capital for the farmers and the region, because there is no market to absorb it. Another option would be to transfer the wood currently sold (in the model) as poles to the production of charcoal which would benefit for the bigger market and also harvesting the natural forest would diminish. Moreover, the overachievement of the conservation goal means a higher government investment is necessary (budget target multiple).

The food goal is also surpassed by a modest figure which illustrates that in fact there is not much saturation of the Maputo-city market with local produce. The overachievement of this goal also suggests that farmers are able to satisfy their food requirement as well as produce surplus for the Maputo-city consumers. However, it is important to note that the dietary habits are not homogenous across the region and also a significant component of the farmers' surplus are by-products which are not necessarily the main dietary components in the urban areas.

Run B

When priorities are changed, food security being first and wood products second, the result is that the food and energy goals are exactly achieved. This seems to suggest that the model provides the best land allocation to crops and farmers do not engage in an intensive harvesting of the natural forest over the demand.

This is also coupled with a lower level of overachievement of the rest of the goals in comparison to the first scenario. Therefore, having food as the first priority would not motivate farmers to plant a larger area for conservation as in Run A. Consequently, wood stock (poles) would reduce and the government would save more than $276,000 from the budget by changing priorities from A to B. There is a trade-off or opportunity cost, however, associated with change in priorities and it can be as much as 9,774 ha of reforested land.

Run C

When the conservation goal is placed as the top priority with wood products being the second, the overachievement is not as much as in the first scenario where perhaps the driving force for large scale adoption was the demand for wood products.

The food goal is again relatively, modestly surpassed, whereas the energy produced, exactly meets the demand.

In general, the opportunity cost of changing priority from scenario B to C is not that significant. Therefore, whether policy makers priorities are food security or conservation first is not associated with a high cost for the society compared with changing priorities from A to either B or C.

Run D

Putting the minimisation of a positive deviation from the budget target as the first priority seems to, ironically, produce the highest overachievement to the conservation goal. Moreover, wood stock is not necessarily harvested to supply the poles goal (shown by the lower target multiple). This seems a rather interesting outcome: the minimum investment possible should be used to maximise an environmental rather than an economic (selling poles) objective.

Another interesting aspect is that the level of overachievement of the food goal is also the highest in this scenario. This may be a consequence of the fact that farmers have to produce cash, and if it is not through a potential poles market, then it has to be from food surplus.

It is important to recall that the objective function was to minimise negative deviations for fuelwood, poles, food and conservation goals while minimising positive deviation of the budget goal. The results in the table may seem to suggest that Run A would be the best as far as the fuelwood goal is concerned. Nevertheless, policy makers are concerned with satisfaction of energy needs without depleting the natural resources, therefore, any of the other runs would be preferred.

As far as poles, conservation and food goals are concerned, Run D is perhaps the best solution since more area is planted with trees, there is less oversupply of poles and the food goal is over satisfied. However, as to the budget goal, only Run B allows the smallest investment.

Given the fact that most goals seem to be satisfied in Run D, then this may be recommended for the policy makers to consider the trade-offs with their current prioritisation given in scenario A.

2. Farmers response to change in regional priorities

Land use

Land allocated to crops and trees as well as changes in each ecozone under the different scenarios are shown in Table 6.24. If dietary constraints for Maputo-city consumers were considered in the model, changes in land use to accommodate both farm and consumer preferences could be a strong instrument that extension services could use to direct farm production to demand. Despite that, Maputo-city consumers' preferences were not rigidly imposed in the model structure. Therefore, the modification in land use provide the farmer with a possible choice on how to respond to the regional goals, whereas policy makers can analyse how much the farmer has to forego in order to satisfy their goals.

Table 6.24 also gives insights on the strategy that each ecozone could choose to best meet food and conservation goals. Land allocation to each crop clearly changes in all ecozones (see Tables 6.1, 6.5, 6.11, 6.17 and 6.20). However, an interesting aspect is that the planning model for the region, due to allowance for interecozone trade, enables the ecozones to exploit their best potential in terms of crop yield (highlighted in the Table 6.24).

In general, Run D seems to provide better land allocation in most of the ecozones, despite that apparently the Dryland ecozone may have to purchase all but two of the dietary components. In view of the current situation, securing the production of maize and peanuts may mean savings on the purchasing of other crops, because these crops are relatively more expensive and maize is staple. Particularly for the Alluvial land, Run D gives the best land use in terms of exploring the rotation option better than in the previous runs. For example, green beans in this ecozone are an important cash crop and a plan excluding it (first three scenarios), may not be acceptable for the farmers. In short, Run D would be recommended for it is also the best prioritisation to achieving the regional goals (as stated in the last section).

Table 6.24 Land allocation per household per ecozone and per crop

Ecozones and crops	Run A (ha)	Run B (ha)	Run C (ha)	Run D (ha)
Dryland				
Maize	**0.57**	**0.5**	**0.5**	**0.6**
Beans	0.1	0.1	0.1	0
Peanuts	**0.3**	**0.3**	**0.3**	**0.4**
Cassava	0	0	0	0
Pumpkin	0.01	0.01	0.001	0
Trees	1	1	1	1
Land for Trees	16	16	16	16
Alluvial				
Maize	**0.475**	**0.544**	**0.475**	**1.05**
Beans	**0.3**	**0.43**	**0.3**	**0.52**
Peanuts	0.0001	0.0001	0	0.0001
Cassava	0.01	0.06	0.01	0.06
Sweet potato	**0.43**	**0.252**	**0.43**	**0.16**
Pumpkin	0.0009	0.0009	0.0009	0.0009
Green Beans	0	0	0	**0.63**
Trees	1	1	1	1
Land for Trees	2	2	2	2
Thicket				
Maize	**0.61**	**0.54**	**0.54**	**0.64**
Beans	0.14	0.14	0.14	0.14
Peanuts	**0.89**	**0.79**	**0.77**	**0.77**
Cassava	0.15	0.11	0.12	0.38
Sweet potato	**0.64**	**0.6**	**0.6**	**0.6**
Pumpkin	0.04	0.04	0.04	0.04
Trees	1	1	1	1
Land for Trees	6.5	6.5	6.5	6.5
Open Forest				
Maize	**0.405**	**0.405**	**0.405**	**0.33**
Beans	0.07	0.06	0.07	0.02
Peanuts	**0.174**	**0.193**	**0.182**	**0.23**
Cassava	0.07	0.07	0.06	0.15
Sweet potato	0.03	0.03	0.03	0.03
Pumpkin	0.024	0.024	0.024	0.025
Trees	1	1	1	1
Land for trees	6	6	6	6
Grassland				
Maize	**0.588**	**0.612**	**0.588**	**0.4**
Beans	**0.301**	**0.257**	**0.301**	0.186
Peanuts	0.1	0.1	0.1	0.1
Cassava	0.01	0.01	0.01	**0.294**
Sweet potato	0	0.02	0	0.02
Pumpkin	0	0	0	0
Trees	20.85	16.82	16.15	27.44
Land for trees	30	30	30	30

As to land for trees, all ecozones but the Grassland plant only one hectare of *Eucalyptus* spp.. The area planted varies substantially between the results of the farm models and, when farmers' decisions aim at a specific market and conservation targets. For example, the typical farm in the Dryland and Grassland ecozones could potentially plant areas as large as 16 and 30 ha. The dramatic reduction in those levels of reforestation (Table 6.24) appear more realistic in terms of the potential farm response to the Reforestation Strategy.

However, the Grassland ecozone persists allocating considerably large areas to tree plantation. There is rationale for this output since (as referred to in the farm results, section 6.2.6) this ecozone has limited opportunities to improve the currently low living standards. Conversely, other ecozones, particularly those which harvest forest products for commercial purposes like the Dryland, the Thicket and Open Forest, or those with better agriculture conditions such as the Alluvial and the Thicket ecozones, may not need to embark on a large scale reforestation program.

Pure tree plantations in four of the ecozones may go against the fact that planting is necessary, but mixed tree species would be preferred in terms of landscape and management. The Grassland ecozone, is the only one providing for mixed plantations of *Eucalyptus* spp. and *Leucaena* spp.. It has to be recalled that in the results of individual farm, a constraint was introduced to ensure mixed tree cropping. Nevertheless, when regional goals are incorporated into the model, such constraints seem redundant, perhaps due to the fact that if less land (just 1 ha) is allocated to trees, then mixed cropping may further reduce the farm benefits (in the first runs of individual models, monocropping was more profitable than when mixed crops restrictions were introduced). Run D again seems to address better the reforestation goal with its wood and conservation targets because a large area is planted.

3. Non-farming activities and employment

The results presented in Table 6.25 give further insights into the level of disruption (hypothesis being tested) of the traditional socio-economic environment. When farmers are looked at as independent units they are able to make decisions which conform with their expectations and preferences within their resource constraints environment. However, if farmers have to produce to respond to the Maputo-city market then there are some changes that they may have to observe.

In general, a change in regional priorities affects the level of performance of non-farming activities in virtually all ecozones. This shows that fulfilling the regional goals is associated with a high opportunity cost that farmers have to incur. On the other hand, from a conservation point of view it is desirable that exploitation of the natural forest falls. This is the case in Run D, where only the Dryland ecozone produces charcoal at full capacity and, in the Thicket, the representative farm only produces about a 10th of poles compared to the level in Run A. There may be a predicament here facing the policy maker as to how much of the farmers preferences should be compromised with the market or regional preferences.

Table 6.25 Effect of change on priorities on non farming activities and labour surplus

	Run A	Run B	Run C	Run D
Dryland				
Charcoal (bags)	323	323	323	360
Labour slack (mnhrs)				
Adult	0	0	0	4754
Children	9099	9102	9101	9246
Alluvial				
Charcoal (bags)	40	25	25	0
Carving (units)	414	414	414	0
Brewing (l)	5000	5000	5000	5000
Fishing (KG)	1533	1533	1533	1533
Reeds (bundles)	240	240	240	360
Labour slack (mnhrs)				
Adult	7783	7966	7938	8422
Children	4876	4876	4876	4876
Thicket				
Charcoal (bags)	450	300	300	0
Native poles (m^3)	126	62	62	13
Brewing (l)	1600	1600	1600	800
Labour slack (mnhrs)				
Adult	0	0	0	3271
Children	0	4223	4208	8717
Open Forest				
Charcoal (bags)	400	400	400	0
Bricks (units)	9600	9600	9600	14400
Labour slack (mnhrs)				
Adult	5381	5382	5380	7709
Children	5529	5529	5529	5529
Grassland				
Brewing (l)	700	700	700	1390
Labour slack (mnhrs)				
Adult	2651	2841	2885	7502
Children	9839	10492	11075	10205

Dryland ecozone

Charcoal production in Run D is less than in the representative farm model and, change in land allocation to crops and trees justifies the increase on slack labour compared with the base solution and under the scenario 'with trees' (Section 6.2.1).

However, since charcoal production is crucial for generation of income, Run D may be the best farm response option.

Alluvial ecozone

Run A is the only one that permits farmers to continue with their traditional activities while contributing for the achievement of the regional goals. Moreover, this scenario gives the lowest slack labour of the four runs even though it is still about 34% higher than in the 'with trees' scenario (Table 6.25).

Thicket ecozone

Again Run A shows the same production levels as in the basic solution and full employment including zero slack for child labour. However, given the fact that animal rearing requires child labour, then perhaps the farm response is better depicted by the results of Runs B and C. Run D illustrates the importance of the natural forest as source of employment, i.e., when production of charcoal and poles reduce dramatically, then there is a significant level of unemployment.

Open Forest ecozone

There is no difference between results of Runs A, B, and C even though the production of bricks is not in full capacity as indicated in the basic solution (Table 6.17). However, as stated before, conservation of the natural forest was one of the goals indicated by the farmers as of primal priority. This means that Run D would be the best farmers response since no harvesting of wood products occurs, and the opportunity cost that the typical farm would have to pay is equivalent to around 19% increase in adult slack labour and decrease in income.

Grassland

The fact that the area planted with trees is different in all runs from the potential shown in the results of the farm model, has a significant effect on unemployment. Notwithstanding the high levels of overachievement of the target in all runs (more than 15 ha), the results seem feasible considering that this ecozone is poor and the government should provide alternatives to minimise the problem. However, as with the results of all other ecozones, these indicate the potential farm response and, an interactive planning approach would allow the analyst to explore other preferred options. Run D is perhaps the best option since it provides for the maximum exploitation of the only non-farming activity available and the level of tree planting indicated in the Table 6.24. The higher labour slack arises as a direct consequence of the higher proportion of land being allocated to cassava which is less labour intensive compared to maize.

4. Interecozone trade

There are village markets which reasonably reflect the predominant range of crops and other opportunities that distinguish the ecozones. Table 6.26 show the total quantity of mainly food products that remain in the rural areas through local market exchange. Because there was no allowance for animal trading, the quantity in the table only quantifies the existing (potential) number of head in all ecozones. On the other hand, charcoal is not purchased for consumption in the rural areas, and it only denotes the oversupply that remains in the production zones. It is a fact that due to increases in the number of producers, some cannot actually market their produce.

Table 6.26 Food trade between ecozones

	Run A	Run B	Run C	Run D
Maize (ton)	3707	3707	3707	7526
Beans (ton)	2358	2555	2053	3335
Peanuts (ton)	7624	7685	7646	7855
Cassava (ton)	13256	7483	15725	4526
Sweet potato (ton)	2333	18501	2542	1600
By-products (ton)	31102	33058	31116	30643
Charcoal (1000 bags)	18744	18679	18678	7365
Cattle (1000)	167	167	167	167
Goats (1000)	489	489	489	489

The channels of trade between ecozones are likely to be predominantly as shown in Figure 6.5. The Alluvial and Thicket ecozones experience a certain degree of goods exchange and, the same might happen between the less productive ecozones (Dryland, Open Forest and Grassland). However, the major flow of products is likely to be from the first two to the others which are mainly net purchasers. Table 6.27 also clearly illustrates this with a wider range and quantity of products supplied by the Alluvial and Thicket ecozones. Also, looking at the first three runs of the

Thicket ecozone (Table 6.27), it is outstanding that it supplies all the maize (Table 6.26) demanded by deficient ecozones.

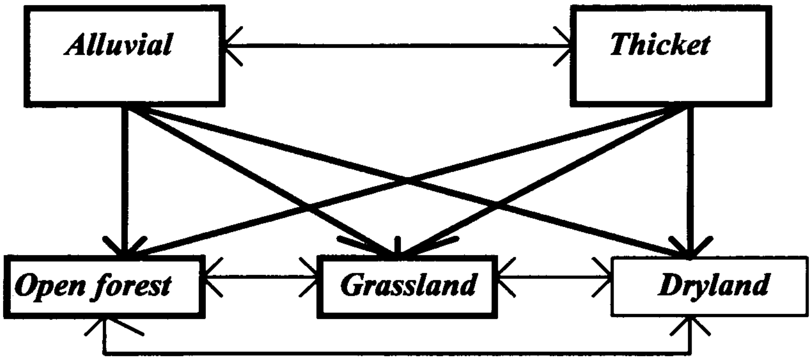

Fig. 6.6 Predominance of food trade (interecozone) direction (thickness of line indicates common trade direction)

Dryland Ecozone

Contrary to the solution of the individual farm models, by-products are no longer the major surplus, because more land is allocated to peanuts as a source of cash. Aggregated charcoal production to the level of ecozone suggest that the supply is substantially overestimated.

Alluvial ecozone

The results on the Run D seems to give better representation of the type of surplus products and it is more in conformity with the results shown in the farm model (Table 6.5) even though previously important cash crops such as cassava and peanuts are excluded from the regional model solution.

Also charcoal production is not an important activity since its contribution to income is not significant, therefore, excluding it from the farm plan (Run D) is not likely to have any considerable impact on farm household welfare.

Thicket ecozone

Once more, Run D represents the range of crops that this ecozone supplies both to other ecozones and to Maputo-city markets. The production or harvesting of forest products for charcoal and poles may have been overstated.

Table 6.27 Level of exports per ecozone and crop

	Run A	Run B	Run C	Run D
Dryland				
Peanuts (ton)	2,914	3,395	2,679	3,324
By-products (ton)	0	0	0	59
Charcoal (bags)	9,969,072	9,969,072	9,969,072	11,111,040
Poles (m^3)	308,640	308,640	308,640	308,640
Alluvial				
Maize (ton)	0	0	0	67,382
Beans (ton)	2,086	2,459	2,053	3,246
Green Beans (ton)	0	0	0	72,591
Sweet potato (ton)	32,119	18,501	32,464	7,190
By-products	25,085	29,301	24,134	18,467
Fish (ton)	44,175	64,967	64,967	74,900
Charcoal (bags)	1,152,240	720,150	720,150	0
Poles (m^3)	288,060	288,060	288,060	288,060
Thicket				
Maize (ton)	3,707	3,707	3,707	41,441
Beans (ton)	0	0	0	44
Peanuts (ton)	4,262	4,266	4,274	3,786
Cassava (ton)	13,256	7,483	15,726	43,420
Sweet potato (ton)	77,281	100,559	81,364	68, 496
Pumpkin (ton)	0	0	0	4,280
By-products (ton)	6,151	4,994	6,016	55,579
Charcoal (bags)	12,037,050	8,024,700	8,024,700	0
Native poles (m^3)	3,378,746	1,649,825	1,661,140	347,737
Poles (m^3)	267,490	267,490	267,490	2267,490
Open Forest				
Beans (ton)	272	65	0	0
Peanuts (ton)	0	21	0	234
Cassava (ton)	0	0	0	5,979
By-products (ton)	0	0	734	5,435
Charcoal (bags)	3,703,600	3,703,600	3,703,600	0
Poles (m^3)	92,590	92,590	92,590	92,590
Grassland				
Beans (ton)	0	31	0	42
Cassava (ton)	0	0	0	82
By-products (ton)	0	308	0	2,471
Poles (m^3)	588,631	474,961	455,728	774,460

Open Forest ecozone

Cassava and by-products were the two products supplied in the farm model (Table 6.17). These continue to be the main products (Run D), including peanuts. This run also appears to address the fact that farmers showed awareness to environmental problems caused by harvesting the natural forest, therefore, they may be prepared to forego the income generated by this activity altogether.

Grassland

Only by-products were sold according to the farm model output (section 6.2.6), and Run D represents a better situation despite also allowing for sales of relatively negligible amounts of beans and cassava.

5. The surplus to the Maputo-city market

Goals concerning food and wood products denote the level of demand in the Maputo-city market and do not include ecozone demand. This has been taken into account through intrinsic constraints on nutrient demand as well as diet composition in the farm model units.

In Maputo-city, both urban and sub-urban dwellers are supplied with cereals, tubers, by-products and wood products from the ecozones. This is supplemented by vegetables produced in the 'green belt' of the city and staple food (e.g. rice) from imports. However, the role of the ecozones in providing food supplements to Maputo-city consumers is not negligible (Table 6.28). In fact, the high price of meat ($1.8-$4/kg) and even fish ($0.7-$2.5) has forced low income consumers (who are in the majority) into vegetarianism.

It can be recalled from Table 6.24 that land allocation in the Runs A to C is not the most efficient: neither all the available land is utilised nor is the allocation directed towards the main crops of each of the ecozones. This only happens in Run D, hence the fact that the crop mixture supplied to Maputo-city in this scenario is more representative of the commercial transactions between rural and urban Maputo. Therefore, the plan given by Run D target better the consumers needs than any other.

According to the survey conducted in the different 'Check points' in the main roads to monitor the flow of wood products to the urban markets, approximately a total of 1,030 million bags were transported over a period of one year (1994-1995). This value is about a third of the target. There are at least two reasons for that apparent shortfall: first, as early observed by Bjerke (1990) quoting Mansur (1986), 92% of the timber merchants transport more wood than their license allows them to and declare less. Second, reports from the officers who collected data indicated that many illegal timber merchants do not go through the check points. This is possible due to the limited number of officers employed by the Provincial Directorate of Agriculture to control illegal exploitation of wood products and poaching.

Table 6.28 Supply of food and other products to Maputo-city markets

	Run A	Run B	Run C	Run D
Maize (ton)				101,297
Beans (ton)				
Maize seed (ton)				2880
Green Beans (Ton)				72,591
Peanuts (ton)				
Cassava (ton)				44,954
Sweet potato (ton)	107,075	100,559	111,293	74,087
Pumpkin (ton)				4,209
By-products (ton)		1,459		53,484
Fish (ton)	5,107	5,107	5,107	44,175
Charcoal (1000 bags)	8,142	3,745	3,745	3,745
Poles (1000 m3)	4,924	3,082	3,073	1,719

Furthermore, records of the same period show that nearly 20,000 m^3 of poles were supplied to Maputo-city. Again this value is about a half of the target which is not realistic given the high stocks of poles in many of the Maputo-city markets. A more adequate validation could be possible through recording all lorries entering each of the markets in Maputo-city. However, this was not feasible for this study due to the high cost both in terms of time and money.

6.3.3 Reforestation and sustainable use of the natural forest

According to the Strategy of Forestry Development (1991) one of the problems of the use of natural forest resources arises from the fact that besides satisfying the demand for energy in the rural areas, fuel must also be supplied to industry and to a large proportion of the urban population. Consequently, this increases the pressure on the resources and one of the principles for education of the user of the forestry resource is that reforestation should generate income or improve welfare of the community as well as being a mean to 'put back what has been taken from the nature' (DNFFB, 1991).

Therefore, when tree options were permitted to enter the model solution with activities regarding the transfer of wood for charcoal production, sell as firewood or poles or provision of firewood and poles for domestic consumption, the expectation was that the exploitation of the natural forest would reduce as a result. The reason being that the DNFFB is not keen on simple substitution of the natural forest with plantations, but rather on ecological conservation and rational use of the natural forest. So it was important to offer a devise that could be used by the government to ensure the realisation of these objectives.

It was indicated earlier that the cost of harvesting one hectare in the Dryland ecozone can be estimated at $91.39. This is taken as the amount that would have to be charged against farmers and timber merchants as a license fee for harvesting natural forest for commercial purposes. This is so assuming that harvesting for satisfying the family needs is not a threat as regards deforestation. In the Thicket and Open Forest ecozones, the likely charges are respectively, $377/ha and $329/ha.

The consequence of introducing such charges into the regional model are illustrated in Table 6.29 in terms of charcoal production and area of plantation. The Dryland ecozone exactly supplies the Maputo-city charcoal demand, without storage, in each of the first three scenarios. This is due to the relatively low harvesting fee in this ecozone.

Table 6.29 Impact of license fee on charcoal production and reforestation area

	Run A	Run B	Run C	Run D
Charcoal				
Dryland	121	121	121	121
Alluvial	0	0	0	0
Thicket	0	0	0	0
Open forest	0	0	0	0
Grassland	0	0	0	0
Plantation				
Dryland	4.7	3.8	2.14	1
Alluvial	2	1	2	1
Thicket	3.5	3.9	3.5	1
Open forest	6	6	6	4.9
Grassland	30	30	30	30

An interesting outcome shown in the table, however, is that when administrative measures are introduced, it is not only possible to save the natural forest, but it is also possible to expand (compared with Table 6.24) the area planted with trees which would be both economic and environmentally beneficial. However, decision makers at the planning level, either in the district or at provincial or national level, need to consider the social impact (employment) of such a measure: it is obvious that harvesting activities are an important source of employment and placing fees may create a bigger labour slack.

In order to provide decision makers or planners with some more information, the fees stated above were reduced by 50%. The result was that the Dryland ecozone continued to supply most of the charcoal with 120 bags provided by the typical farm, whereas in the Thicket, the representative farm only supplied 1.556 bags and 13 m^3 of poles. In another scenario, the fee was reduced to a third. Then the typical farm in the Open Forest produced at its full capacity (400 bags), while in the Dryland ecozone the supply increased to 157 bags per representative farm. This result shows clearly that free access to resources is associated with unsustainable exploitation.

Another scenario analysed the possible impact of applying the same level of fee irrespective of the forest type: the result is that no charcoal is produced at all. This may be another extreme which would not be desirable from the policy point of view, because many people will continue demanding alternative sources of energy to electricity or gas. Perhaps in the first stage, the harvesting fee could be just half of the one calculated from the reduced cost, because it ensures no depletion of the resources and it provides the government with some source of cash to reinvest in the implementation of the Reforestation Strategy or any other policy instruments.

Weighted Goal Programming applied in the regional model seems to have addressed reasonably well the various planning goals. It allows the analysis of possible farm responses to the potential variation of priorities. The individualisation of the representative farm models and their aggregation allows to simultaneously explore the impact at micro level of the macro policy goals. It can be argued that the potential private and public rationale conflict is negligible in this planning problem since the major farm concerns are food security and availability of wood products which were also identified as primal by the planners.

Having presented the farm and regional model results, the next chapter discusses the major assumptions of the regional model and the scope for its use in policy analysis.

CHAPTER 7

Discussion and conclusion

7.1 The Problem and Zoning

Reforestation Strategy is a dual decision problem involving private and public rationales. While farmers control and use natural forest resources to generate income and recognise deforestation as a problem, policy makers are concerned with satisfying the demand for wood products in the urban areas and guaranteeing a source of income for the rural population. This was the motivation behind the design of the 1991 Reforestation Policy whose strategy aims at involving the community as a way to try and minimise the consequences of deforestation.

The farm survey indicated that farmers in Maputo province are willing to plant trees. This suggests that there is, in fact, convergence as to perception of the problem and possible solution at the two planning levels (farm and region). Therefore, Janssen's (1995) proposition that aggregation from farm to regional level involves a shift in rationale may be refuted in this case.

Farmers are concerned with how to best respond to a changing policy environment subject to their own objectives and limits of action. However, at a macro level, the problem facing planners is to minimise uncertainty regarding these micro responses (Hazell and Norton, 1986). It was, therefore, essential to design a planning framework which could give a picture of farm organisation, when considered as an independent planning unit and, also provide an overall view of a more global farmer response to the regional goals. In other words, the planning framework highlights the need to tackle macro policies with micro level resource constraints.

Maputo province was initially divided into spatial categories based on land use or forest types. Ten planning units (ecozones) were then devised and data were collected for representative farms in each. This classification included three variants of the Thicket forest type (low, medium and high) and Alluvial (saline, irrigated and, with no major limitations), Open Forest, Wooded Grassland, Dryland and

Grassland. However, during the development of the methodology, it was concluded that grouping Thicket, Alluvial and Open Forest in single ecozones with different land class capabilities could perhaps reduce the structure of the regional model to a manageable size.

The final modelling framework comprises five ecozones, with one or more land classes. A weighted average land allocation across land classes was used which portrayed the agricultural potential that farmers could explore in the ecozones. It is not uncommon, for example, for subsistence farmers to have more than one agricultural plot. Therefore, a range of opportunities are explored through this planning framework.

A modelling approach was chosen to evaluate the impact of land use changes as a result of integrating trees in the agriculture systems in rural Maputo. This research makes use of both GIS and LP models to address the rural land use problem. As pointed out in Chapter 2, mathematical programming is used in the policy analysis due to the failure of econometrics to predict distribution of land use and changes (Moxey *et al*, 1995) and hence analyse policy changes that depart from historical trends estimated by these models (Norton and Schiefer, 1980). An outstanding goal of modelling is, as stated by Beck *et al* (1995), to facilitate extrapolation beyond a range of past observations. However, Stoorvogel (1995) also mentions that Linear Programming models have to be combined with georeferenced data in order to adequately investigate potential land use systems and technologies.

An aspect highlighted in this study is that the target group has to be involved in the planning process, especially regarding the identification of preferred land use options. Also highlighted is the fact that a policy cannot be impetuously implemented across the country: policy will affect the population differently depending on their current land use and welfare. Therefore, differential measures have to be addressed through design of a model structure which takes into account the specific conditions for which it is to be used.

Primary data collection indicated that farmers generally prefer woodlots to any kind of intercropping. However, extension services have been trying to get farmers to adopt intercropping systems instead. This clearly sets up conditions for medium or long term failure of the policy and its strategies. A step that was not explored in this study was to analyse the various possible options (farm forestry and intercropping systems) in order to provide policy makers and extension services with a measure of the advantages and drawbacks of each of the options compared with farmers' preferences.

7.2 Assumptions and aggregation issues

The basic model assumption for building the regional model was the homogeneity of the representative farms in each ecozone (not necessarily spatially contiguous) as regards land use patterns, access to technology, and opportunities to generate income. Furthermore, despite the relatively free access to land, traditional explicit and implicit rules create uniformity of land tenure conditions. This guarantees the proportionality of resource endowments, which according to Norton (1995), are probably the most relevant of Day's criteria for unbiased aggregation (Chapter 5).

Day's criteria are considered by Hazell and Norton (1986) as demanding. The authors defend that application of simple rules like similar proportions of resource endowments, similar yields and similar technologies not only permit reduction of bias but also comply reasonably with Day's conditions. These aspects were essential for the aggregation of the farm models into a regional planning framework. Nevertheless, bias was not totally eliminated as some of the results on production of charcoal with natural forest wood have shown. An upwards aggregation bias occurs which means there is an overstatement of resource mobility amongst the farm population (Hazell and Norton, 1986), which in this case is translated as the production of millions of bags of charcoal. However, as Janssen (1995) points out, aggregation bias either mathematical or due to simplification, interaction, control or resolution (which includes researcher subjectivity) is a fact of life and it cannot be avoided. However, Janssen adds, it is necessary to anticipate imperfections, especially when using programming models for policy analysis.

As it was highlighted earlier, the underlying hypothesis of this study is that it is possible to develop a planning framework in which a sophisticated mathematical programming device could be used in a data scarce environment. An optimisation algorithm was therefore used to solve the farm and the regional model problems. It was observed in the first runs that the optimal farm plan did not adequately portray the farm decision environment when, for instance, no constraints on land per crop were included. That is, land was allocated to the crop that produced the highest total farm gross margin. However, the behaviour of subsistence farms was distinct from this plan, because other than maximising income, their prime objective is to achieve food security and for that they allocate specific proportion of their cropping land to each of the major components of their diet.

Therefore, the two predominant constraints on the maximisation problem were land allocation per crop and diet composition. The specific proportion of land allocated to either cereals or tubers was determined by the agricultural potential of the ecozone in terms of soils and availability of water, potential to grow crops in both the dry and wet seasons. According to expert opinion based on field observations generally, maize occupied large proportions of land, at least 50%, in virtually all ecozones followed by either cassava or sweet potato, then beans and peanuts.

Nutrition constraints were introduced with the general assumption that about three quarters of the dietary requirement was met with maize, cassava and/or sweet potato, and thus provided the staple diet in rural Maputo and other Southern African countries (nutritionist observation). Other crops and by-products supply the remaining one third of diet requirement.

Constraints on land and nutrition were essential since food security was the immediate concern in the ecozones, so it was fundamental that the Reforestation

Strategy was not looked at in isolation of farmers' issues and the overall socio-economic environment.

Another hypothesis looked at in this research was that participatory reforestation will not bring negative disruption of the traditional socio-economic environment. The results of the modelling framework at the farm level showed a reduction on unused labour and increase on the farmers' welfare. Nevertheless, the size of the positive outcome was highly influenced by the average land available for each representative farm to plant with trees. In general, traditional activities both farming and non-farming were not affected negatively, that is, the same level of performance was maintained with and without tree plantation. This was illustrated when the solutions did not exclude activities associated with harvesting the natural forest for commercial purposes, for instance, hence the need to introduce administrative measures in order to ensure a more rational use of the resources while still providing alternatives for generation of income.

7.3 Data issues

It is common in many rural land use studies to limit the planning framework to examine only one specific activity; either cropping, livestock, tree planting or management. One of the philosophies of this study was that the impact of the implementation of the Reforestation Strategy which envisaged community participation, had to be analysed in more holistic and integrated context. For that, farming and non-farming activities were incorporated, and particular consideration was given to labour competition between these activities as a key causal factor as to whether farmer response towards this strategy would be positive or negative.

It was conceived in the earlier stages of this research that agricultural, forestry, and wildlife activities would be integrated in the structure of the model. However, limitations in data availability and time to investigate adequate proxies for derivation, resulted in exclusion of some of the components of the model (wildlife).

An attempt was made to obtain information regarding species indicators and inventories. In fact, through expert knowledge provided by Provincial Officers, a map of wildlife species distribution was drawn, yet insufficient detail could be provided to use this in the planning framework. Moreover, despite that it is a fact that some sources of protein and income in the rural areas come from wildlife, particularly the wild goat which is predominant in the Maputo province, because of the illegality of hunting, farmers were understandably reluctant to provide information regarding this activity.

One of the problems in building models is that data are often non existent, or it is not reliable and frequently mutually inconsistent (Hazel and Norton, 1986). Maputo province proved to be no exception to this due particularly to political instability preventing government institutions from gathering data and disruption of the farm environment, which meant that primary data sets were also poor or incomplete.

Therefore, in order to mitigate this data scarcity, various alternative sources were used: farmers, officers at local, district, province and national level; both primary data and secondary data were used from Governmental and Non Governmental Institutions. Thus the applicability of the planning framework should be looked at in the context of difficulties in data gathering and the main purpose of this study is to provide a framework: it is demonstrated that it is possible to combine various sources of information that can be used in analysing the impact of macro policy at the micro planning level.

7.4 Reforestation in practice versus the model output

As mentioned in the introductory chapters, the government has made attempts to implement a large scale Reforestation Plan since 1978, which envisaged to satisfy the demand for firewood and poles for three of the major cities in Mozambique. This program of reforestation was, according to Burley (1989), financed by external organisations such as MONAP and FAO with government participation only accounting for about 19 per cent of total funding. The project did not meet the targets due to a termination of external funding and lack of enough qualified staff to carry on with management activities and thus make the plantations profitable as well as representing a reinvestment in reforestation.

In 1987, deforestation around Maputo was estimated to be occurring at a rate of approximately 20 ha per day and one of the concerns was that in the short term an alternative source of energy could not be identified. The National Plan of Reforestation (PNR, 1987) already recognised the incapacity of the government to guarantee the supply of wood products to urban areas given the projected increases in population which would continue to require forest products as a source of energy and of construction material for years to come. Also the PNR highlighted the need for prioritisation of zones with more severe problems of deforestation around the major cities. The planning framework detailed in this study addresses this question. For example, the results clearly show the ecozones with low forest productivity rely on forest resources for generation of income, such as the Grassland, Dryland and Open Forest ecozones, whereas the impact on other, more productive, ecozones is not as significant.

An alternative was then to involve the community in reforestation which was introduced as one of the strategies to meet reforestation policy goals. However, the policy approach initially adopted was to distribute tree seedlings as an incentive for adoption, with particular emphasis on alley cropping and taungya systems. It was reported by Getahun (1991) that technical problems regarding selection of species, periods of plantation and competition between trees and crops, led farmers to increase spacing between trees to reduce the shading effect which resulted in a failure to achieve the participatory reforestation objectives.

Also, an important aspect which was not dealt with by the Forestry authorities prior to persuasion of farmers to plant trees, was the question of land tenure. Many farmers think they own the land because they have been farming it for generations. However, recent developments in land allocation to private entrepreneurs by the government have illustrated the vulnerability of the farmers in ensuring that 'their land' is not sold. In fact, concern over the prospect that the farm land once 'owned', may be taken away is increasing. In 1994/95, during the survey farmers were unanimous in considering that one of the government incentives for them to plant trees would be to guarantee a plot of land separate from the current cropping plots. According to Cuco (1993) an *ad hoc* land committee was given the responsibility to regulate land occupation, use and tenure besides analysing ways of incorporating traditional customary land rules to the official law. However, to date, it is reported that land conflicts are increasing, especially in the South, because the government conceded land to agriculture and animal rearing projects in areas occupied by farmers (NotMoc:102, 1997 quoting the Rural Association of 'Mutual Assistance'). Furthermore, the delay in passing the Land bill by the parliament is taken by some Mozambican entities as an intention to perpetuate the confusion over the interpretation of the 1979 Land law. This issue also concerns some entities of IMF and BIRD when considering the allocation of funds to the country.

This situation clearly shows that despite farmers' willingness to plant trees, either only one hectare or large areas like in the Grassland ecozone and despite availability of family labour to undertake such activities as illustrated by the model solutions, the real implementation is still bound by the clarity on the land tenure issues, i.e., the right to own and use the land. This also illustrates that policies and strategies can cross boundaries of a sector, i.e., implementation of the Reforestation Strategy is influenced by limitations not necessarily technical.

In the farm model framework land sizes varying between 2 and 30 ha were used as upper bounds that each representative farm could potentially plant with trees. This gives a total of 842,568 ha of land that the strategy could accomplish in Maputo province with existing labour in the family sector. This land covers only about 24 per cent of the land with potential for reforestation in Maputo according to the National Plan of Reforestation (DNFFB, 1987). Despite that almost 10 years have passed since this figure was published, it is clear that neither government nor community projects have been successful enough to have reduced substantially the area to be reforested. Therefore, the area proposed can actually be realised if farmers are willing to do so and if government provides incentives.

7.5 The proposed methodology within the policy framework

The increased concern on reforestation led Burley (1989) to identify 'Agroforestry studies to integrate tree planting into rural production systems' as one of the research priority areas. Moreover, the government document named 'Bases for an Agrarian Policy'(1992) also stresses the need for the government to encourage agri-silvilcultural practices in order to deal with the problem of rural employment and also emphasise the need to link production and research in development of extension services.

Cuco (1993) points out that the 1991 Strategy for Forest Development introduced a new point of convergence which emphasised an integrated approach to contribute to a wider range of socio-economic development issues, instead of concerns towards the exploration of resources for commercial purposes. However, the lack of skilled personnel and institutional weakness with scarce human resources for planning, supervision and control of both private and public forest projects limits the possibilities for the sector to adequately address development issues. The author further states that Agenda 21 also brought an impetus to the need for minimisation of deforestation as a major challenge for conservation and sustainable utilisation of forests and the involvement of the community as well as need for clear legislation on land tenure as a means to achieve it.

The proposed planning framework in this research is interdisciplinary and needs an intersectorial approach for its successful application. One of the major changes that may have to be introduced is the creation of only one Department of Extension Services instead of the Agrarian Extension Services under the National Directorate of Rural Development and the National Forestry Extension Service under the National Directorate of Forestry and Wildlife and even the separate National

Program of Animal Restocking. This study has shown that farmers concerns are associated with development of agriculture and livestock production as well as the availability of wood products. Therefore, targeting these activities individually fails to address the primary problem of the rural community. The unification or better co-ordination of the extensions services would perhaps even minimise the lack of human resources that all of them are concerned with. It would also increase reliability on the information provided by the farms since if all problems were addressed simultaneously it would avoid the lack of credibility farmers are developing towards the various surveys carried out for rural development purposes.

7.6 Conclusion and future research

The general objective stated for this research was the need to carry out an *ex-ante* analysis of community involvement in reforestation for fuelwood and poles production in order to reduce pressure in the natural woodland while providing food security. That meant assisting planners with mechanisms by which reforestation should take place. For that, representative farm models were constructed in order to analyse the current situation and changes brought by the Reforestation Strategy looking at the farm as self-contained planning unit, i.e., which produce and sell or buy to offset the deficit without considering possible interaction with other producers and consumers. The regional model then looks at an integrated picture in which constraints are maintained to secure the satisfaction of the farm household demand while creating opportunity for interecozone trade and limits on the target urban market for the various food and wood products.

The results of the farm and regional models have shown that reforestation does not automatically lead to conservation of the natural forest, that is, it uses the resources available, particularly labour to enhance the total farm gross margin. In order to achieve conservation and sustainable use of the natural forest it seems pertinent to associate the extension of forest resources to an administrative measure which ensures rational use of resources.

The first specific objective was the identification and analysis of social forestry alternatives suitable for each of the ecozones based on socio-economic data. This was achieved through elicitation of information from the farmers themselves who identified woodlots as the preferred option to intercropping. As a result, the model evaluates the impact of farm forestry on farm household welfare. Therefore, there is emphasis placed upon a bottom-up planning approach represented by this methodological approach where farmers views are elicited and included in the planning framework.

The second objective was evaluation of social forestry alternatives identified through farmers expressed preferences with an application of mathematical programming. It was also envisaged to integrate in the model framework cropping, forestry, wildlife and marketing activities and constraints. The farm models were structured to include cropping activities, animal rearing activities, activities related to use of the natural forest, tree plantation activities and selling and buying activities. These were constrained by the availability of land, labour and demand for various products for family consumption and generation of income. It was mentioned earlier that difficulties in data acquisition meant exclusion of the wildlife component of the model. However, it can be argued that the major issues in planning the implementation of the Reforestation Strategy have been considered and that the model output shows what the implications are in terms of use of the available resources and change in farmers welfare. This was illustrated through the change in labour surplus and on the TFGM. Postoptimality analysis showed that food security and the reduced cost was either nil or very high for selling and buying activities according to farm output and the capacity to meet the household demand. Moreover, increases in production costs showed that such increases could not influence the marginal value product of scarce resources such as land. Also, sensitivity analysis permitted a further examination of how the base solution may change given the fact that the data used for this research were collected in a particularly unstable environment.

One particular aspect of the regional model was the creation of the common pool from which supplies go either to the deficit ecozones or to the urban market. This allowed a more realistic consideration of the trading activities in the region and the extent to which the demand can be met. As to the regional food goal however, one aspect that needs attention is diet habits and consumer preferences which were not incorporated in the model. This would have needed stratification of the consumers into perhaps low, medium and high income groups and survey details of the major diet composition of each in order to more objectively give an account of the contribution of the ecozones towards food security in the urban areas. However, this was out of scope of this research due to financial cost and the time that would have been required to gather such information.

The third objective regarded the identification of data needs and gaps for future model application in rural land use planning. This issue is also associated with the hypothesis regarding the use of a sophisticated planning methodology in a data scarce environment. Various sources of information were used to gather information that allowed the modelling to take place. However, there is a need for extension services to encourage record keeping in terms of labour use, yield per crop or output, allocation of the produce to family consumption and trading activities, amount of farm inputs like hired labour, the participation of each of the family members in various activities, income generated and its application. This information could have eased model construction and provided a more reliable database for validation. The major information gap though, concerns the wildlife data for which only a simple inventory and farmer information (biased to hunting activities) were available.

It can be recalled that GIS was used to overlay land use from the 1994 Forestry Inventory and soil maps which above all highlighted the alluvial land having major limitations due to salinity and seasonal floods. This ecozone was taken as the spatial planning unit with a representative farm being modelled. This meant that for designing the regional model and accounting for the total demand (purchases) and supply (surplus) an aggregation would have to be made to the level of the number of farms in each ecozone. This was necessary in order to evaluate the aggregated impact of the Reforestation Strategy, considering the current farm socio-economic environment. Conversely, population census data is given for administrative units (provinces, districts and localities). This meant that a proxy to derive this information had to be used. Studies done before have indicated that land use or existent forest types are associated with density of population. Therefore, the agricultural land comprising both the Dryland and Alluvial ecozones were associated with a bigger percentage of human population density. Furthermore, Thicket offers opportunities for farming and harvesting forest products, therefore it was considered natural that the population would also concentrate in this area. The opposite was assumed for the Grassland ecozone where there are few opportunities and farming is not as productive. Furthermore, despite potential for cattle rearing in the Open Forest ecozone, drought conditions and war meant that few people could inhabit this zone. In short, the proposed planning framework analysed resource availability and the impact that may result from tree planting being introduced. However, from an aggregation point of view, perhaps it is necessary to use more recent population data with spatial distribution using GIS which will make it possible to associate more closely land use or ecozone size with the number of households using the resources.

The final objective is the analysis of the usefulness of the methodology as a tool for policy analysis. Running the farm model for scenarios with and without trees, and with and without animal rearing activities, allowed the evaluation of changes that might result from incorporating new activities in the current farming system. Also, running the model with different amortisation factors for the tree components, gave the regional decision maker information to evaluate the level of gains and losses (trade-offs) that the farmers can accrue depending on how they may have to repay the government. Alternatively, it shows an assessment of how much budget the government would have to allocate to encourage reforestation.

The regional model framework illustrates the impact of macro policy using micro constraints. The government aims to produce wood products to supply the urban consumers. Moreover, conservation or sustainable use of the natural forest resources is envisaged without depriving completely the rural population from their source of income. The Weighted Goal Programming model used at the regional level allowed different goals to be weighted according to the importance attached by the decision makers and provided the advantage of being able to simultaneously, consider all goals in a composite objective function. Changing priorities from wood production to food or conservation showed the opportunity cost that would be associated with modification in priorities. This is an important instrument for the planners to decide on the best option. In general, Run D, which minimises the budget in the first place seems to result in better land allocation in each representative farm, provides the widest range of food surplus to Maputo-city market, produces wood for meeting the demand and, more importantly, meets the conservation goal with the stock of wood in the field. Hence, this information appears to provide decision makers at regional levels with some measure of the potential farm response to change in policy environment.

In short, the model can be used for *ex-ante* policy analysis regarding the potential impact of implementation of the participatory Reforestation in Maputo province and possibly in other provinces of Mozambique where the strategy has particular relevance (Nhantumbo *et al*, 1997). The model output delivers information concerning the opportunity cost resulting from shifts in the definition of the importance of goals and the resulting impact at a micro level. The final confidence in the model, however, can only grow, as Beck *et al* (1995) underlines, with its successful application. This, of course, implies operational validation or validation of the model as it is used (McCarl, 1984). Nevertheless, the basis for planning and analysing the potential impact of a Reforestation Strategy has been built and provides a framework for similar analyses in data scarce environments.

REFERENCES

Adejuwon, J. O. and Adesina, F. A. (1990). Organic matter and nutrient status of soils undercultivated fallows: an experiment of *Gliricidia sepium* fallows from the Southern West of Nigeria. *Agroforestry Systems,* **10**, 23-32.

Aiyelaagbe, I. O. O. (1992). Fruit crops: are they relevant for agroforestry? *Agroforestry Today*, **4:1**, 12-13.

Allen, J. A. (1990). Homestead tree planting in two rural Swazi communities. *Agroforestry Systems*, **11**, 11-22.

Anaman, K. A. (1993). Risk analysis in the economic appraisal of a smallholder aricultural development project in Papua New Guinea. *Agricultural Systems*, **43**, 1-15.

Anderson, T. R. (1991). *Computer modelling of agroforestry systems*. PhD Thesis. The University of Edinburgh. UK.

Atta-Krah, A. N. and Francis, P. A. (1989). The role of on-farm trials in the evaluation of alley farming. In: *Alley cropping in the humid and suhhumid tropics: Proceedings of an International Worksop in Ibadan, Nigeria*, 92-106

Babu, S. C. and Rajasekaran, B. (1991). Agroforestry, attitude towards risk and nutrient availability: a case study of south Indian farming systems. *Agroforestry Systems,* **15**, 1-15.

Bare, B. B. and G., Mendoza (1988). Multiple objective forest land management planning: an illustration. *European Journal of Operations Research*. 34, 44-51.

Barlett, B. (1976). *Goal Range Science Series no 21*. College of Natural Resources. Colorado University.

Barry, P. J. (1984). *Risk management in agriculture*. Iowa State University. Iowa.

Barrow, E. G. C. (1991). Building on local knowledge: the challenge of agroforestry for pastoral areas. *Agroforestry Today*, **3:4**, 4-7.

Baumer, M. (1990). *Agroforestry and Desertification*. TCTA. The Netherlands.

Bayer, W. (1990). Use of native browse by Fulani cattle in Central Nigeria. *Agroforestry Systems*, **12**, 217-228.

Beck, M. B., Jakeman, A. J. and McAller, M. J. (1995). Construction and evaluation of models of environmental systems. In: *Modelling Change in Environmental Systems*. Jakeman, A. J., Beck, M. B., and McAleer, M. J. (ed.). John Wiley and Sons. Chichester.

Beldt, R. J. V. D. (1990) Agroforestry systems in semiarid tropics. In: *Agroforestry Classification and Management*. John Wiley and Sons. New York.

Benayoun, R., Montgolfier, J. De, Tergny, J. and Laritchev, O. (1971). Linear Programming with multiple objectives: Step Method (STEM). *Mathematical Programming*, **1**, 366-375.

Bene, J. G., Beall, H. W. and Cote, A. (1977). Trees, food and people: land management in the tropics. IDRC. Ohawa.

Berbel, J. (1992). Land use planning and multicriteria mathematical programming. *Revista de Estudios Agro Sociales*, **40**, 171-188.

Berbel, J., Zamora, R. and Loseby, M. (1992). Natural resource management: an intearctive multiple criteria decision making approach. *The environment and the management of agricultural resources. Proceedings of the 24th Seminar of the EAAE*. Viterto. 265-273.

Bila, A. (1992). *Trees for sustainable fuelwood production in rural subsistence farming at Boane, Maputo*. Dissertation. College of North Wales.UK

Bjerke, J. O. (1990). *Woodfuel consumption and transport in Maputo, Mozambique*. Msc Thesis. Agricultural University of Norway. Norway

Brenner, A. J. (1992). *Tree crop interaction within a Sahelian windbreak system*. PhD Thesis. University of Edinburgh. UK.

Bruce, J. W. (1990). Community forestry: rapid appraisal of tree and land tenure. *FAO-Community Forestry Note*, **5**.

Budellman, A. (1989). Nutrient composition of the leaf biomass of three selected woody leguminous species. *Agroforestry Systems*, **8**, 39-51.

Budelman, A. (1989a). The performance of selected leaf mulches in temperature reduction and moisture conservation in the upper soil stratum. *Agroforestry Systems*, **8**, 53-66.

Burley, C. F. (1989). *Country profile: Mozambique*. DNFFB. Maputo.

Calkins, H. W. (1991). GIS and public policy. In: *GIS: Principles and Applications*. Maguire, D. J., Goodchild, M. F. and Rhind, D. W. (ed.), **1**, 233-246. Longman Scientific and Technical. UK.

Cameron, D. M., Rance, S. J., Jones, R. M. and Charles-Edwards, D. A. (1991). Trees and pasture: a study on the effects of spacing. *Agroforestry Today*, **3:1**, 8-9.

Campbell, B. M., Clarke, J. M. and Gumbo, D. J. (1991). Traditional practices in Zimbabwe. *Agroforestry Siystems*, **14**, 99-111.

Carilho J. (1992). O debate actual sobre a questão das terras rurais em Moçambique. In: *EXTRA* especial. CFA-MA. Maputo.

Carolyne, R. (1993). *The World Handbook*. Philips. UK.

Catterson T., Kir, A., Rossi, M. and Dutton, P. (1991). *A provisional programme for the Forestry and Wildlife Sector*. FAO/DNFFB. Mozambique.

Chamshama, S. A. O., Monela, G. C., Sekiete, K. E. A. and Persson, A. (1992). Suitability of the taungya system at North Kilimanjaro forest plantations. *Agroforestry systems,* **17**, 1-11.

Chuvieco, E. (1993). Integration of linear programming and GIS for land-use modelling. *Int. J. Geographical Information Systems*, **7:1**, 71-83.

Cloke, P. (1989). *Rural land use planning in developed nations*. Unwin Hyman. London.

Cohon, J. L. (1978). *Multiobjective programming and planning*. Mathematics in Science and Engineering, **140**. Academinc Press. New York.

Combe, J. (1983). Agroforestry techniques in tropical countries: potential and limitations. *Agroforestry Systems,* **1**, 13-27.

Cowen, D. J. and Shirley, W. L. (1991). Integrated planning information system. In: *GIS: Principles and Applications*. Maguire, D. J, Goodchild, M. F. and Rhind, D. W. (ed.), 1. Longman Scientific and Technical. UK.

Cuco, A. (1993). *Some aspects on forestry policy in Mozambique*. FAO. Maputo.

Dalland, A., Vaje, P. I., Mathews, R. B. and Singh, B. R. (1993). The potential of alley cropping in improvement of cultivation systems in the high rainfall areas of Zambia. III. Effects on Soil Chemical and Physical Properties. *Agroforestry Systems*, **21**,117-132.

Danso, A. A. and Morgan, P. (1993). Alley cropping rice (*Orysa sativa* var. *Barafita*) with cassia (*Cassia siamea*): soil fertility and crop production. *Agroforestry Systems*, **21**, 147-158.

Danso, A. A. and Morgan, P. (1993a). Alley cropping maize (*Zea mays)* with cassia (*Cassia siamea*) in The Gambia: crop production and soil fertility. *Agroforestry Systems*. Vol.21,133-145.

Day, R. H. (1963). On aggregating linear programming models of production. *Journal of Farm Economics*, **45**, 767-813.

DEA (1993). *Inquérito Agrícola ao sector familiar*. MAP. Maputo.

Dent, J. B. and Blackie, M. J. (1979). *Systems simulation in Agriculture.* Applied Science Publications. London.

Dent, J. B., Harrison, S. R. and Woodford, K. B. (1986). *Farm planning with Linear Programming: concept and practice.* Butterworths. Sydney.

Dent, J. B. and Jones, J. W. (1993). Multiple Criteria Analysis in agricultural systems - editorial. *Agricultural Systems*, **41:3**, 235-237.

Dionísio, A. C. (1985). *Evolution of livestock production in Mozambique with special emphasis on beef cattle.* Livestock Production Seminar. MA-FAO. Maputo. 1-61.

DNE (1992). População, posse de terra e agricultura em Boane. *CNP-População e Desenvolvimento*, **6**.

DNFFB (1987). *Legislação do Uso e Aproveitamento da Terra.* Imprensa Nacional de Moçambique. Maputo.

DNFFB (1991). *Estratégia de Desenvolvimento Florestal.* DNFFB-MA. Maputo.

Drecshel, B., Glaser, B. and Zech, W. (1991). Effect of multipurpose tree species on soil amelioration during tree fallow in central Togo. *Agroforestry Systems*, **16**, 193-201.

Evans, J. (1992). *Plantation forestry in the tropics.* Clarendon Press. Oxford.

Evans, P. T. and J. S., Rombold (1984). Paraiso (*Melia azedarch* var. gigant) woodlots: an agroforestry alternative for the smallholder farmer in Paraguay. *Agroforestry Systems*, **2**, 199-214.

FAO (1989). *Forestry and Food Security*, **90**. Rome.

FAO (1993). *Tables of food requirement in Mozambique.* Rome.

FAO/WFB (1995). *Crop and food supply assessment mission to Mozambique and assessment of crop and food supply in Southern Africa.* FAO Sepecial Reports. Rome.

Fernades, E. C. M. (1989). The Chagga homegardens a multistoreyed agroforestry cropping system in Mount Kilimanjaro (N Tanzania). In: Agroforestry Systems in the Tropics. Nair, P. K. R. (ed.). *Forestry Sciences*, **31**, 309-332.

Fleisher, B. (1990). *Agriculture risk management.* Lynne Rienner. Colorado.

Fleming, E. M. (1990). Proposal for a marketing systems research approach in agricultural development planning. *Agroforestry Systems*, **32**, 219-231.

Fodden, M. (1986). *Forest farm husbandry*. Technological Consultancy Centre. Kumasi.

Foley, G. and Barnard, G. (1984). *Farm and community forestry*. Earthscan. London.

Fonweban, J. N., Mayaka, T. B. and Sewkep, J. B. (1995). Construction and validation of tree volume for *Eucalyptus saligna* in Cameroon. *Commonwealth Forestry Review*, **74:4**, 355-360.

Fortman, L. (1984). The tree tenure factor in agroforestry with particular reference to Africa. *Agroforestry Systems*, **2**, 229-251.

Fortman, L. and Rocheleau, D. (1984). Women and agroforestry: four myths and three case studies. *Agroforestry Systems*, **2**, 253-272.

Fraser, A. and KarKari, E. (1987). *Forestry sub-sector study: Mozambique*. FAO. Maputo.

Gastellu, E. J. P. and Sinulingga, A. B. (1988). Designing a GIS for the study of forest evolution in central Java. *Tijdschrift voor Economische en Sociale Geographie*, **79:2**, 93-103.

Getahun, A. (1991). *Forestry extension in Mozambique*. FAO Moz/86/003. Maputo.

Ghosh, S. P., Kuma, B.M., Kabeerathumma, S. and Nair, G. M. (1989). Productivity, soil fertility and soil erosion under cassava based agroforestry. *Agroforestry Systems*, **8**, 67-82.

Ghuman, B. S. and Lal, R. (1990). Nutrient addition into soil by leaves of *Cassia siamea* and *Gliricidia sepium* grown on an Ultisol in Southern Nigeria. *Agroforestry Systems*, **10**, 131-133.

Gittinger, P. (1982). *Economic analysis of agricultural projects*. The John Hopkins. Baltimore. Colorado. 2nd edition.

Goodman, A. S. (1984). *Principles of water resources planning*. Prentice-Hall. New Jersey.

Grove, A. T. (1990). *The changing geography of Africa*. Oxford University Press. Oxford.

Haggar, J. P. and Beer, J. W. (1993). Effect on maize growth of the interaction between increased nitrogen available and competion with trees in alley cropping. *Agroforestry Systems*, **21**, 239-249.

Hastings, D. A. and Clark, D. M. (1991). GIS in Africa: problems, challenges and opportunities for co-operation. *Int. J. Geographical Information Systems*, **5:1**, 29-39.

Hazell, P. B. R. and Norton, R. D. (1986). *Mathematical programming for Economic analysis in Agriculture*. Macmillan. London.

Heathcote, R. L. (1983). *The arid lands: their use and abuse.* Longman. London.

Hocking, D. and Rao, D. G. (1990). Canopy management possibilities for *Arborela Leucaena* in mixed sorghum and livestock small farm production in South India. *Agroforestry Systems*, **10**, 135-152.

Hoekstra, D. A.(1990). Economics of agroforestry. In: *Agroforestry Classification and Managemnt*. John Wiley and Sons. New York.

Holden, S. T. (1993). Peasant household modelling: farming systems evolution and sustainbility in northern Zambia. *Agricultural Economics*, **9:3**, 241-267.

Howard, A. F. (1991). A critical look at multiple criteria decision making techniques with reference to forestry applications. *Canadian Journal of Forest Research*, **21:11**, 1649-1659.

Hudson, N. W. (1987). Soil and water conservation in semiarid areas. FAO *Soils Bulletin*, 57.

Hutachareon, M. (1987). *Application of geographic information systems technology to the analysis of deforestation and associated environmental hazards in Thailand.* Annual International Conference, Exbits and Workshops on Geographical Information Systems, **2**, 509-518. San Francisco.

Huxley, P. A. (1989). Hedgerow intercropping: some ecological and physiological issues. *Alley Cropping in the Humid and Suhhumid Tropics: Proceedings of an International Worksop in Ibadan, Nigeria.* 208-219.

Informação Estatística (IE), (1991). *Anuário Estatístico*. CNP. Maputo.

Informação Estatística (IE), (1994). *Anuário Estatístico*. MPF. Maputo.

Instituto Nacional de Investigação Agronómica (INIA), (1991). *Provincias do Maputo e Gaza: Carta de Solos*. DTA. Maputo.

Information System Ltd and Dept. of Geography at the University of Leicester (ISLtd and DGUL) (1996). *Fuelwood assessment and management in Chad: planning for a sustainable woodland resource.* University of Leicester. UK.

Jama, B. and Getahun, A. (1991). Intercropping *Acacia albida* with maize (*Zea mays*) and green gram (*Phaseolus aureus*) at Mtwapa, Coast Province, Kenya. *Agroforestry Systems*, **14**, 193-205.

Janssen, W. G. (1995). Aggregating economic knowledge for use at national, regional, sector and farm level. In: Eco-regional approaches for sustainable land Use and food production. Bouma, J., A. Kuyvenhoven, B. A. M., Bouman, J. C., Luyten and H. G., Zandstra (ed.). *Systems Approach for Sustainable Agricultural Development*, **4.**

Karim, A. B. and Savill, P. S. (1991). Effect of spacing on growth and bioamss production of *Gliricidia Sepium* (Jacq) Walp in an alley cropping system in Sierra Leone. *Agroforestry Systems*, **16**, 213-222.

Karim, A. B., Rhodes, E. R. and Savil, P. S. (1991). Effect of cutting interval on dry matter yield of *Leucaena leucocephala* (Lan) De Wit. *Agroforestry Systems*, **16**, 129-137.

Karlberg, A. (1985). Comparação de Inventários em Moçambique. DNFFB. Maputo.

Katawatin, R., Crown, P. H. and Grant, R. F. (1996). Simulation modelling of land suitability evaluation for dry season peanut cropping based on water availability in Northern Thailand: evaluation of MACROS crop model. *Soil Use and Management*, **12:1**, 25-32.

Kazana, V. (1988). Optimisation techniques for agroforestry production systems. In: *Economic Evaluation and Management of Agroforestry: a novel problem? Proceedings of a workshop.* Sinclair, F. L., Kazana, V. and Shrimpton, N. H. (ed.), Depart. of Forestry and Natural Resources, The University of Edinburgh, 42-51.

Kerkhof, P. (1990). *Agroforestry in Africa - a survey of project experience.* Panos. UK.

Krawiec, B., Bernetti, I., Casini, L., Romano, D. and Loseby, M. (1992). Application of MCDM techniques to forestry management. *The environment and the management of agricultural resources*. Proceedings of the 24th Seminar of EAAE. Viterto. 273-288.

Langton, S. (1990). Avoiding edge effects in agroforestry experiments: the use of neighbour-balanced designs and guard areas. *Agroforestry Systems*, **12**, 173-185.

Lexa, J. P. (1985). Some aspects of the mixed farming systems in the family sector of Mozambique. *Livestock Production Seminar.* MA-FAO. Maputo.

Lilieholm, R. J. and Reeves, L. H. (1991). Integrating Economic risk aversion in agroforestry planning. *Agroforestry Systems*, **13:1**, 63-67.

Lundgren, B. O. (1991). Agroforestry Research for Development: comentary. *Agroforestry Today*, **3:3**, 6-7.

Macdicken, K. and Vergara, N. P. (1990) *Agroforestry Classification and Management.* John Wiley and Sons. New York.

McMeekin, T.A. and Ross, T. (1996). Modelling applications. *Journal of Food Protection.* **Supplement**, 37-42.

Macucule, A. and Bila, A. (1991). *Práticas agroflorestais tradicionais nos círculos de Zintava e Faftine- Distrito de Marracuene.* Eduardo Mondlane University. Maputo.

Maguire, D. J., Goodchild, M. F. and Rhind, D. W. (1991). *GIS: principles and applications*, **1**. Longman Scientific and Technical. UK.

Makeham, J. P. and Malcom, L. R. (1986). *The economics of tropical farm management.* Cambridge University Press. UK.

Malik, R. S. and Sharma, S. K. (1990). Moisture extraction and crop yield as a function of distance from a row of *Eucalyptus tereticornis*. *Agroforestry Systems,* **12**, 187-195.

Mallawaarachchi, T., Walker, P. A., Young, M. D., Smyth, R. E., Lynch, H. S. and G. Dudgeon (1995). GIS-based integrated modelling systems for natural resource management. *Agricultural Systems*, **50:2**, 169-189.

Mansur, E. (1986). *Levantmento do abastecimento de lenha e carvão na Cidade de Maputo*. Ministério da Agricultura. Maputo.

Marshal, F. and Ong, C. and Black, C. (1992). Tree arrangement effect on competition with crops. *Agroforestry Today*, **4:4**, 9-10.

McCarl, B. A. and Nuthall, P. (1982). Linear Programming for repeated use in the agricultural systems. *Agricultural Systems*, **8**, 17-39.

McCarl, B. A. (1984). Model Validation: an overview with some emphasis on risk models. *Review of Marketing and Agricultural Economics*, **52:3**, 153-173.

McCarl, B. A. (1992). *Mathematical programming for resource appraisal under multiple objectives*. EPAT/NUCIA Working paper No 6.

McGregor, M. J., Dent, J. B. and Cropper, M. (1996). *The role of multi-criteria decision making methods in guiding grazing systems development.* Conference paper. Aberdeen.

McGregor, M. J. (1986). *A multiobjective framework for the analysis of water and soil resource conflict in New Zealand.* PhD Thesis. Lincoln college, University College of Agriculture. New Zealand.

Mendoza, G. A. and Sprouse, W. (1989). Forest planning and decision making under fuzzy environments: an overview and illustration. *Forest Science*, **35:2**, 481-502.

Mendoza, G. A, Campbell, G. E. and Rolfe, G. L. (1986). Multiple objective programming: an approach to planning and evaluation of agroforestry systems-part 1: model description and development. *Agricultural Systems*, **22**, 243-253.

Mieche, S. (1989). *Acacia albida* and other multipurpose trees on Fur farmlands in the Jebel Marra Highlands Western Darfur, Sudan. In: Agroforestry Systems in the Tropics. *Forestry Sciences*, **31**, 353-384.

MINED (1986). *Atlas Geográfico*. MINED. Maputo.

Moench, M. (1991). Soil erosion under a sucessional agroforestry sequence: a case study from Idukki district, Kerala, India. *Agroforestry Systems*, **15**,31-50.

Moxey, A. P., White, B. and O'Callagham, J. R. (1995). The economic component of NELUP. *Journal of Environmental Planning and Management*, **38:1**, 21-33.

Mucavele, F. (1994). *A mathematical programming for farm household evaluation: economic efficiency analysis of farms under uncertainty in Mozambique.* PhD Thesis. University of Florida. USA.

Myers, G. W. (1992). Land tenure and resettlement in post war Mozambique: capacity and individual choice.

Myre, M. (1971). *As pastagens da região do Maputo*. IIAM. Maputo.

Nair, P. K. R. (1989). *Agroforestry Systems in the Tropics*. Kluwer and ICRAF. Nairobi.

Nair, P. K. R. (1989a). Food producing trees in agroforestry. In: Agroforestry Systems in the Tropics. *Forestry Siences*, **31**, 541-551.

Nair, P. K. R. (1989b). Role of trees in soil productivity and protection. In: Agroforestry Systems in the Tropics. *Forestry Siences*, **31**, 576-589.

Nair, P. K. R (1993). *An introduction to agroforestry*. Klumer Academic Publishers. ICRAF. Nairobi.

Negrão, J. (1997). *Que politica de terras para Moçambique*? NotMoc,101:3. Maputo.

Nhantumbo, I., Dent, J. B., Kowero, G. S. and Oglethorpe, D. (1997). *Regional model for rural land use planning: an application of Goal Programming.* Paper presented at the Seventh Symposium on Systems Analysis in Forestry Resources. May. Michigan.

Nhantumbo, I., Dent, J. B., Kowero, G. S. and McGregor, M. J. (1996). *Non-market benefits of forests: a modelling approach for policy intervention in Mozambique.* Paper presented at the International Symposium of Non-market Benefits of Forestry. June. Edinburgh.

Nhantumbo, I and Soto, S. (1994). *Mercado de productos madeireiros e não madeireiros.* FAO/MA. Maputo.

Nijkamp, P. and Spronk, J. (1980). Interactive multiple goal programming: an evaluation and some results. In: *Multiple Criteria Decision Making Theory and Application.* Fandel, G. (ed.). 278-293. Springer Verlag.

Njiti, C. F. and Sharpe, D. M. (1994). A Goal-Programming approach to the management of competition and conflict among land uses in the tropics: the Cameroon example. *Ambio*, **23:2**, 112-119.

Nkambwe, M. (1991). Resource utilization and regional planning information systems (RURPIS) in Botswana. *Int. J. Geographical Information Systems*, **5:1**, 111-122.

Nkowani, K. (1996). *Modelling land/resource-use options open to smallholder farmers in the Northern Region of Zambia: a multiple objective programming approach.* PhD Thesis. University of Edinburgh. UK.

Norton, R. D. and Schiefer, G. W. (1980). Agricultural sector programming models: a review. *Euro. R. agr. Eco.*, **7**, 229-264.

Norton, R. D. (1995). Response to section C. In: Eco-regional Approaches for Sustainable Land Use and Food Production. *Systems Approach for Sustainable Agricultural Development*, **4**, 237-247.

NotMoc (1996/1997). Mozambique electronic news.

Nygren, P. and Jimenez, J. M. (1993). Radiation regime and nitrogen supply in modelled alley cropping systems of *Erythrina poeppigiana* with sequential maize-bean cultivation. *Agroforestry Systems*, **21**, 271-285.

Oboho, E. G. and Nowoboshi, L. C. (1991). Windbreaks: how well do they really work? *Agroforestry Today*, **3:1**, 15-16.

ODA (1988). *Appraisal of projects in developing countries: a guide for economists.* Crown. London.

Oduol, P. A.(1989). The shamba system: an indigenous system of food production from forest areas in Kenya. In: Agroforestry systems in the tropics. Narir, P. K. R. (ed.). *Forestry Sciences*, **31,** 401-410.

Oglethorpe, D. R. (1996). *Farm level land use and environmental management decisions: a modelling approach to the analysis of policy change*. PhD Thesis. Univerity of Newcastle-Upon-Tyne. UK.

Ong, C. K., Rao, M. R. and Mathuva, M. (1992). Trees and crops: competition for resources above and below the ground. *Agroforestry Today*, **4:2**, 4-5.

Onim, J. F. M., Mathuva, M., Otieno, K. and Fitzhugh, H. A. (1990). Soil fertility changes and response of maize and beans to green manures of *Leucaena*, *Sesbania* and pigeonpea. *Agroforestry Systems*, **12**, 197-215.

Owusu, D. Y. (1993). Farm-based agroforestry: four years of experience in Ghana. *Agroforestry Today*, **5:1**, 8-10.

Palada, M. C. (1989). On farm research methods for alley cropping. In: *Alley cropping in the humid and sub-humid tropics.* Preceedings of an International Workshop at Ibadan, Nigeria. 84-91.

Pereira, C. R. (1990). *National survey of biomass/woodfuel activities in Mozambique*. SADCC. Maputo.

Piech, B. and Rehman, T. (1993). Application of multiple criteria decision making methods to farm planning: a case study. *Agricultural Systems*, **41:3**, 305-319.

PNR (1987). *Plano Nacional de Reflorestamento*. DNFFB-MA. Maputo.

Poschen, P. (1989). An evaluation of the *Acacia albida* based agroforestry practices in the Harghe Highlands of Eastern Ethiopia. I:n Agroforestry systems in the tropics. *Forestry Sciences*, **31**, 385-400.

Price, C. (1989). *The theory and application of forest economics*. Basil Blackwell. Oxford.

Rae, A. N. (1994). *Agricultural management economics: activity analysis and decision making.*University Press. Cambridge.

Rao, M. R., Sharma, M. M. and Ong, C. K. (1991). A tree/crop interface design and its use for evaluating the potential of hedgerow intercropping. *Agroforestry Systems,* **13**, 143-158.

Rehman, T. and Romero, C. (1993). The application of the MCDM paradigm to the management of agricultural systems: some basic considerations. *Agricultural Systems,* **41**, 239-255.

Robinson, P. J. (1985). *The role of forestry in farming systems with particular reference to forest-grazing interactions*. PhD Thesis. University of Edinburgh. UK.

Rocheleau, D., Weber, F. and Feld-Juma, A. (1988). Agroforestry in Dryland Africa. *Science and Practice of Agroforestry*, **3**.

Romero, C. (1991). *Handbook of critical issues in Goal Programming*. Pergamon. Oxford.

Romero, C. and Rehman, T. (1984). Goal programming and multiple criteria decision making in farm planning: an expository analysis. *Journal of Agricultural Economics,* **36:2**, 177-190.

Romero, C. and Rehman, T. (1989). *Multiple criteria analysis for agricultural decisions*. Development in Agricultural Economics, **5**.

Rosato, P. and Stellin, G. (1993). A multi-criteria approach to the territorial management: the case of the Caorle and Bibione laggon natural park. *Agricultural Systems*, **41:3**, 399-417.

Roughley, R. J. (1986). Australian acacias in developing countries. *ACIAR Proceedings,* **16**, 45-49.

SADCC (1988). *Desenvolvimento de energia madeira-lenha: relatório de Moçambique*. ETCF. Maputo.

Saket, M. (1994). *Report on the updating of the exploratory national forest inventory*. FAO. Maputo.

Schaefer, K. C. (1992). A portfolio model for evaluating risk in economic development projects, with an application to agriculture in Niger. *Journal of Agriculture Economics*, **43:3**, 412-423.

Scherr, S. J. (1991). On-farm Research: the challenges of agroforestry. *Agroforestry Systems*, **15**, 95-110.

Selley, R. (1984). Decision rules in risk analysis. In: *Risk management in agriculture*. Barry, P. J. (ed.). Iowa State University. Iowa.

Sharma, R. (1990). *Socio-economic planning in social forestry with particular reference to Orissa, India*. PhD Thesis. The University of Edinburgh. UK.

Siaw, D. E. K. A., Kang, B. T. and Okali, D. U. U. (1991). Alley cropping with *Leucaena leucocephala* (lam.) De Wit and *Acioa barteri* (Hook.f.) Engl. *Agroforestry Systems*, **14**, 219-231.

Sidney, B. W. and Kawdia, A. (1991). For a determined farmer agroforestry brings an unexpected reward. *Agroforestry Today*, **3:3**, 4-5.

Simonet, O., Turyatunga, F. And Witt, R. (1987). *Environmental database development for assessment of deforestation, soil erosion hazards and crop suitability: a joint Uganda-UNEP/GRID case study.* Annual International Conference Exhibits and Workshops on Geographic Information Systems. San Francisco, **2**, 544-553.

Sinclair, F. L. (1995). Agroforestry: science, policy and practice. *Forestry Science,* **47**.

Snijders, F. L. (1985). *Land Use Inventory of Mozambique.* INIA. Maputo.

Somarriba, E. and Lega, F. (1991). Cattle grazing under *Pinus Caribae*: evaluation of farm historical data on stand age and animal stocking. *Agroforestry Systems,* **13**,177-185.

Soto, S. and Sitoe, A. (1994). *Análise de sistemas de receitas fiscais dos recursos naturais.* FAO/MA. Maputo.

Stoorvogel, J. J. (1995). Integration of computer-based models and tools to evaluate alternative land-use scenarios as part of an agricultural systems analysis. *Agricultural Systems,* **49**, 353-367.

Taylor, D. R. (1991). GIS and developing countries. In: *GIS: principles and applications.* Maguire, D. J, Goodchild, M. F. and Rhind, D.W. (ed.), **1**. Longman Scientific and Technical. UK.

Teklehaimanot, Z. (1990). *Rainfall interception loss as a function of tree spacing.* PhD Thesis. The University of Edinburgh. UK.

Timberlake, J. R. (1985). *Natural pastures in Mozambique. Livestock Production Seminar.* MA-FAO. Maputo.

Tiwari, K. M. (1986). Is social forestry the same as agroforestry? In: *Agroforestry systems: a new challenge.* ISTS. India.

Torres, F. (1989). Tree fodder and silvopastoral systems. In :Agroforestry Systems in the Tropics. *Forestry Sciences,* **31**,553-556.

Torres, F. (1983). Role of wood perennials in animal agroforestry. *Agroforestry Systems,* **1**, 131-163.

UDA (1982). *Normas Técnicas Agrícolas.* Imprensa Nacional de Mocambique. Maputo.

UNIDO (1972). *Guidelines for social benefit-cost analysis.* World Bank. New York.

Veloso, R. (1990). *Crop farm development in the Brazilian 'Cerrado' region: an ex-ante evaluation.* PhD Thesis. The University of Edinburgh. UK.

Verinumbe, I. (1993). Soil and *Leucaena leucocephala* L. growth variability under *Faidherbia albida* Del and *Ziziphus spina-christi* L. Desf. *Agroforestry Systems*, **21**, 287-292.

Warkentin, M. E., Nair, P. K. R., Ruth, S. R. and Sprague, K. (1990). A knowledge-based expert system for planning and design of agroforestry systems. *Agroforestry Systems*, **11**, 71-83.

Warner, A. J. (1983). *A Review of operations research in forestry and application in wood flow resource analysis*. MSc Dissertation. Australian National University. Australia.

Weldu, G. (1992). *An application of multiple objective goal programming to integrated land use planning in semi-tropical environment.* MSc Thesis. The University of Edinburgh. UK.

West, C. E., Pepping, F. And Tamaliwa, C. R. (1988). *The composition of foods eaten in East africa*. CTA/ESCA.

Willan, R. L. (1981). Zonas de reflorestatmento e escolha de espécies. MA-PNUD. Maputo.

Williamson, G. and Payne, W. J. A. (1978). An introduction to animal husbandry in the tropics. Longman. London. (3rd edit.).

Winston, W. L. (1995). *Introduction to mathematical programming: applications and algorithms*. Duxbury Press. California.

Wood, P. (1990). Principles of species selection for agroforestry. In: *Agroforestry Classification and Management*. John Wiley and Sons. New York.

Yaakup, A. B. (1991). *The application of Geographical Information System for urban planning and management: a case study of squatter settlement planning in Kwala Lummpu, Malaysia*. PhD Thesis. The University of Edinburgh. UK.

Yoon, K. P. and Hwang, C. (1995). *Multiple attribute decision making: an introduction*. Sage Publications. London.

Young, D. L. (1984). Risk concepts and measures for decision analysis. In: *Risk management in agriculture*. Barry, P.J. (ed.). Iowa State University. Iowa. 31-42.

Young, A. (1989). *Agroforestry for soil conservation.* ICRAF. Nairobi.

Zekri, S. And Romero, C. (1992). A methodology to assess the current situation in irrigated agriculture: an application to the village of Tauste (Spain). *Oxford Agrarian Studies*, **20:2**, 75-88.

Appendix 1

A.1 Potential species for social forestry in Maputo

1.*Anacardium occidentalis* (cashew nut tree)
It is one of the predominant cash crops in the coastal provinces and particularly in Maputo. It produces highly priced kernels used in confection of desserts, shell oil with several industrial uses, therefore important source foreign currency for the country. The nuts are also important for local consumption. The cashew apple is juicy and edible and it is used to produce traditional beer and brandy. Its role extends to supply shade, firewood and medicine. This tree can be found scattered in the cropland or as a sole crop depending on the farmland size and farmer's priorities.

Seed or vegetative propagation, with around 10 m2 spacing, little after care and it bears fruit from the age of 7-10 to 50 years. It is important in social forestry where cattle can grazer under cashew plantations, tree gardens in small holdings, in homegardems and as windbreak or shelterbelts.

The specie is drought resistant, the only problems are non synchronised flowering and difficulties in collecting the nuts.

2.*Mangifera indica* (mango tree)
This tree species is largely used in landscape of East Africa. It produces a delicious fruit, when immature is used in chutneys and pickles and when ripe has to be preserved since it is quickly perishable and it demands a ready access to market. The branches of the tree are used for farm construction and firewood.

It is propagated by seed, layering or grafting, pruning for shape and inducement of flowering branches, full bearing at age of 8 up to 50 or more years. the tree grows in association with other fruit trees in the backyard, good as shelterbelt, animal fee and cattle penning in the shade and a multipurpose tree on farmland.

3. *Sclerocarea birrea* and *Trichlia emetica*

These two native species, supply fruit and shade; one particular consideration is that the first is associated with taboo. For instance, the sale of fruit juice fermented or not is forbidden, and it is drunk by the villagers. What is more, people believe that if it is given to the Gods(ceremony done by the elderly), it brings rain(!?). It also has nuts are eaten as snack. The second is also a cash crop; the fruit is consumed and the seed produce high quality oil and soap (locally processed). This economic strength has, for instance, been recognised by the government of Tanzania resulting in promoting its plantation (FAO, 1983).

4. *Casuarina equisetifolia* L.

Produces firewood known as the best in the world (4950 Kcal/kg) for domestic and industrial use. The timber is used for house posts, rafters, electric poles, mine props, tools handles and the wood is also used for pulp. The specie is best known for its ability to control erosion in the coastlines of Mozambique and as windbreaks. It is adaptable to moderately poor soils, salt tolerant, it fixes nitrogen.

The seedlings are raised in nursery, transplanting onset of the rainy season, it requires irrigation for about three years. When planted in exotic places requires inoculation of the soil with crushed nodules from natural stands, initial poor competition with weeds but later the trees can exhaust moisture in the soil, lower the water table and suppress growth understorey. It is particularly useful for windbreaks or shelterbelts and for soil improvement hedges. It is vulnerable to attack of ants, and it is sensitive to fire.

5. *Leucaena leucocephala* (Lam.) De Wit

This species has been widely used as a multipurpose tree in agroforestry systems and it has been given particular attention in investigation of tree-crop interactions by institutions like ICRAF and IITA in the different ecological zones.

The tree produces firewood, poles, nutritious fodder for cattle and goats. However, it may contain mimosine which is toxic to ruminants if excessively consumed. The wood has potential to be used for pulp. It is a rich organic fertiliser, fixes nitrogen and its aggressive roots can break up impervious subsoil layers improving water penetration and reducing runoff.

Propagation by hand or machine planted seeds, survival increase when seed is tested with hot water and it needs weeding for control of establishment. It is a drought tolerant specie, it growths in marginal land, steep slopes, highly resistant to pests and diseases. However, it may become a weed.

The specie is used in alley cropping, multipurpose shrub or cropland, shelterbelts, windbreaks, woody hedgerow for browse, green manure and soil conservation.

6. *Eucalyptus* spp.

The specie has been planted by the state to supply fuelwood and poles for construction for the main urban areas. It is also used as electric poles besides the potential for its use for pulp. Fruits and leaves are also used as fodder and from the nectar and pollen, honey is produced.

It can be propagated by seed or vegetatively, being tolerant to poor soils and drought. Moreover, it is suitable as windbreak, for land reclamation or simply as ornament.

Appendix 2

A.2.1 Questionnaires to Policy Makers

General Background:
Issue: Multiobjective Rural land Use Planning with emphasis on the Potential for social Forestry in the Maputo Province

The answer to this question is deemed important for future development of planning rural development programs. Furthermore, it is necessary for analysis of the implications of the implementation of policy strategies and achievement of the stated goals. Reforestation Strategy is the planning problem under consideration.

The research focus is the development of a planning methodology which will encompass the multiple objectives associated with both micro (farm) and meso/macro decisions (province/nation) levels.

It is an empirical fact that programs and projects envisaging the involvement of the community in their implementation in Mozambique, have failed either due to administrative, technical and financial problems or simply because socio-economic aspects of the target group (potential participant and beneficiary) have not been considered. Another cause of that failure may be the top-down planning approach where policies and programs are decided at a national or regional level, and the micro level have only the task of implementation. Therefore, this approach suggests the lack of a priori analysis of potential conflict between objectives and priorities of the different planning or decision levels. What is more, any compromise solution or opportunity cost associated with decision at the micro and meso/macro are not taken into account.

This questionnaire intends to elicit information from staff direct or indirectly involved in policy and strategy development in the Agrarian and Forestry sector.

Question:
The Reforestation Strategy which states the involvement of the rural community in the replacement of the forestry resources exploited suggests a need for an integrated land use, i.e., combination of agriculture and forestry activities.

a) List at least five goals that justify the implementation of reforestation strategy and their respective priorities.

b) Set the targets as far as possible and indicate whether you would like a positive or negative deviation from the target.

Your collaboration is appreciated.

A.2.2 Preliminary questionnaire to administrative and agricultural officers at the district and locality levels

I. Information from the District Administration

1. Population distribution in the district

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2. Distribution of labour by sector of activity

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3. Main problems of the district

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4. What are the goals that an integrated land use should seek to achieve.

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In case were it was difficult to elicit the goals from the administrator, then the following list of goals was provided asking for prioritisation.

Food supply
Cost of production
Income generation
Firewood and poles production
Employment generation
Conservation of soil and or forest resources

II. Information from the District Directorate of Agriculture

1. Agricultural land distribution per sector (private, subsistence farmers and others)

2. Calendar of agricultural activities

3. Crop yield

Crop	Yield in private sector	Yield in the subsistence farms

4. Production per locality

5. Local producer and consumer prices

Crop	Producer price	Producer price

6. Predominant types of food surplus, preferred market and cost of transportation

7. Labour sale

8. Who explores and sales wood products and who benefits

9. Goals of the integrated land use

10. Non-farming activities and other issues

A.2.3 Forms for registration of the wood flow to Maputo-City markets

Check Point:						
Date	Lorry capacity	Firewood m^3	Charcoal bags	Poles m^3	Source[1]	Market

[1] Locality where the wood products were harvested from.

A.2.4a Preliminary Farm interview

1. Household composition

2. Decision making

3. Land size

4. Main crops and land allocation

5. Labour allocation

6. Calendar of activities

7. Agricultural production, how long in the year is the family self-sufficient on food.

8. Utilisation of wood products

9. Animal rearing information

10. Income generation and application

11. Use of wood products

12. Problems

A.2.4b Questionnaire for typical farm information

1. General information
1.1 Family size and composition

1..2 Main activities on farm and off-farm, who practice them and decision making (land allocation to crops, income allocation,..)

2. Information on agricultural activities
2.1 Land size, tenure, location and implication on cropping pattern

2.2 Crops grown, season and relative proportion of land allocation

2.3 Crop production per season or year and use

2.4 Staple food, and source

2.5 Hired labour and machinery (quantity, season, price)

2.6 Main agricultural tools and inputs (seed and fertilisers, quantity and price, irrigation facilities)

2.7 Time allocated to farming and domestic activities by each family member

2.8 Livestock information: type and herders

2.9 Willingness to plant trees (pure forest stands or intercropping) and reason

2.10 Farm goals

3. Information on non-farming activities

3.1 Wood harvesting activities

3.1.1 Charcoal

Kiln capacity, frequency of production per season

Duration of wood harvesting

Duration of kiln preparation

Tools used

Combustion period, what activities are performed during this period

Unloading of the kiln

Where the product is sold, price and how long it takes to sale a kiln

Family labour allocation per season

Hired labour (when, how much and compensation method)

3.2 Poles

Quantity, type and duration of harvesting

Market place, transportation mean and cost, producer price

Frequency of harvesting

Family labour

Hired labour

Harvesting tools

3.3 Other Non-farming activities:
What kind of activities

Family labour allocation, hired labour

Duration of the activities

Quantity of produce

Tools or ingredients used, source and price

Market place, producer prices

Frequency of production

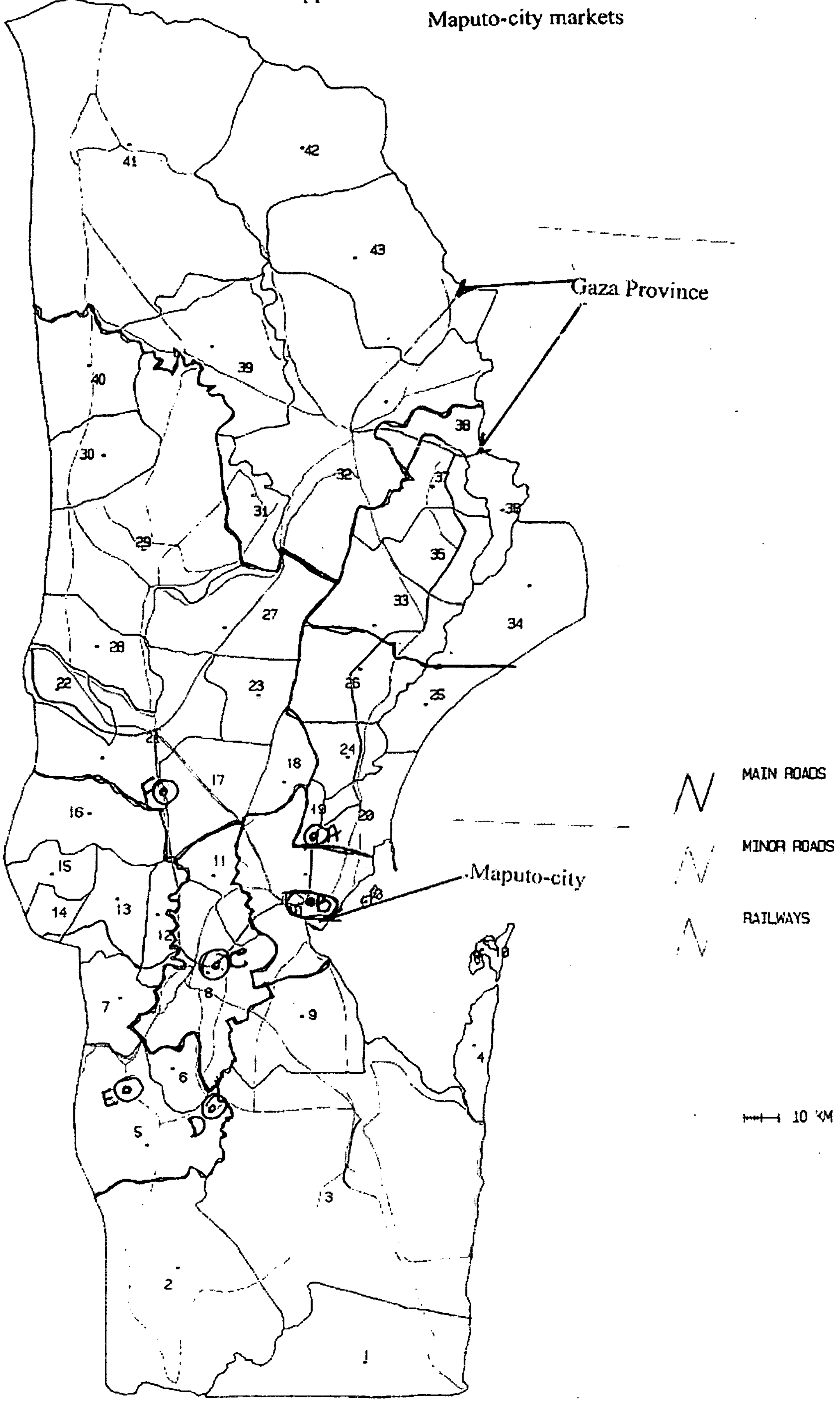
A.2.5 Nutrient content of food crops as harvested

Crops	Energy (Kcal/gram)	Protein (g/kg)
Maize	3550	100
Beans	3200	220
Sweet potato	1100	16
Cassava	3200	16
Peanuts	5700	230
Vegetables	130	10
Pumpkin	5410	245
Bean leaves	580	45
Sweet potato leaves	490	46
Cassava leaves	280	20
Pumpkin leaves	250	40
Fish	3000	527

Source: West, *at al* (1988)

A. 2.6 Location of check points for wood flow to Maputo-city markets

Appendix 2.6 Location of Check points for wood flow to Maputo-city markets



Appendix 3

A.3.1 Prices of crops per season

Ecozone	Crops	Selling Price Dry season ($/ha)
Dryland	Maize	0.1
	Beans	0.25
	Peanuts	0.9
	Cassava	0.1
	Pumpkin	0.09
	Bean leaves	0.11
	Cassava leaves	0.09
	Pumpkin leaves	0.09
	Charcoal	1.21/bag
Alluvial	Maize	0.1
	Beans	0.3
	Peanuts	0.9
	Cassava	0.1
	Sweet potato	0.09
	Green beans	0.24
	Pumpkin	0.09
	Bean leaves	0.1
	Cassava leaves	0.09
	Sweet potato leaves	0.1
	Pumpkin leaves	0.08
	Charcoal	1.37/bag
	Fish	1.53/0.81/l
	Halves	0.2/unit
	Reeds	0.36/bundle
	Beer (maize meal)	0.07/l
Thicket	Maize	0.15
	Beans	0.24
	Peanuts	0.19
	Cassava	0.9
	Sweet potato	0.09
	Bean leaves	0.1
	Cassava leaves	0.11
	Sweet potato leaves	0.09
	Pumpkin leaves	0.09
	Charcoal	1.42
	Small poles	
	Medium poles	
	Beer (Sugar cane)	0.36/l

Open Forest	Maize	o.16
	Beans	0.19
	Peanuts	1.4
	Cassava	0.21
	Sweet potato	0.16
	Bean leaves	0.1
	Cassava leaves	0.09
	Sweet potato leaves	0.1
	Charcoal	1.38
	Beer (Pumpkin)	0.04/l
	Bricks	0.08/unit
Grassland	Maize	0.1
	Beans	0.27
	Peanuts	0.9
	Cassava	0.1
	Sweet potato	0.09
	Bean leaves	0.11
	Cassava leaves	0.09
	Sweet potato leaves	0.09
	Beer (Palm)	0.18/l

NB. All units are $/kg unless otherwise states

Buying prices are about 20% higher than the selling. Price of cereals is lower durin the harvesting season (dry) whereas the contrary holds for the by-products, i.e., cheaper during the wet season.

A.3.2 Formulas for derivation of coefficients for goal constraints - normalisation by percentage

While coefficients of food (equation 5.1), fuelwood (equation 5.2) and poles (equation 5.3) are placed in the Maputo-city market activities, conservation and budget coefficients are associated with each of the tree species in each ecozone within the regional matrix framework. The derivation of the coefficients were based on the following formulas:

Food

$C_f = (En)*100/T_f$

Where

En= Energy supply per crop (kcal)

T_f= Target value of food (Kcal)

$100/T_f$ = normalisation factor

Fuelwood

$C_{fw} = C_h *100/Tch$

where,

C_h = Charcoal (1000 bags)

T_{fw} = Target value for firewood (bags of charcoal)

100/Tch = normalisation factor

Poles

$C_p = P*100/T_p$

where,

P = poles (1000 m^3)

T_p = Target value for poles (m^3)

$100/T_p$ = normalisation factor

Conservation

$C_c = (A_s * F_i) * 100 / T_c$

(5.4)

where,

s= tree species 1,..3

I = ecozone 1,....,5

A= 1/2 ha or 1/5 (ha) depending on whether it is *Leucaena* spp. or *Eucalyptus* spp. and *Melia* spp.

F = number of farms in each ecozone

T_c = target value for conservation in the region (ha)

T_c = normalisation factor

Budget

$(C_s * F_i)100/T$

where,

C= Cost of plantation ($/ha)

T= target value of the budget cost in the region ($)

other variables as defined in (5.1)

The RHS of all the goal constraints is 100 and all equations are expressed in terms of percentage. This allowed to avoid the scaling problem and artificial extra weights associated with different goal units and considerable difference in range of numerical values.

Appendix 4

A.4.1 Crop yield as given by the Agricultural norms for stable climatic and political conditions in Maputo

Crop	Dryland kg/ha	Irrigated kg/ha
Maize	4500	3500-2500
Peanuts	680	1200
Green beans		4000
Pumpkin	12000	

A.4.2 Change in yield parameters for sensitivity analysis of the typical farm model in the Alluvial ecozone

Land class	-25%	25%	50%	75%
Saline land				
Maize	-	+	+	+
Beans		+	+	+
Cassava	-	+		
Sweet potato	-	+	+	
Irrigated land				
Maize	-	+	+	+
Beans	-	+	+	+
Alluvial				
Maize	-	+	+	+
Peanuts	-	+	+	+
Beans	-	+	+	+
Cassava	-			
Sweet potato	-			

- = allowed decrease, + allowed increase, blank means no change from the current

A.4.3 Change in yield parameters for sensitivity analysis of the typical farm model in the Thicket ecozone

	-25%	+25%	+50%	+75%
Low Thicket				
Maize	-	+	+	+
Beans	-	+	+	+
Cassava	-	+		
Sweet potato	-			
Medium Thicket				
Maize	-	+	+	+
Beans	-	+	+	+
Cassava		+	+	+
Sweet potato		+	+	+
High Thicket				
Maize	-	+	+	+
Peanuts		+	+	+
Beans		+	+	+
Cassava	-			
Sweet potato	-			

A.4.4 Change in yield parameters for sensitivity analysis of the typical farm model in the Open Forest ecozone

	-25%	+25%	+50%	+75%
Wooded Grassland				
Maize		+	+	+
Beans		+	+	+
Cassava	-	+	+	+
Open forest				
Maize		+	+	+
Beans	-	+	+	+
Cassava	-	+	+	+
Sweet potato	-	+		

Appendix 5
Conference papers

REGIONAL MODEL FOR RURAL LAND USE PLANNING: AN APPLICATION OF GOAL PROGRAMMING

By Nhantumbo, I.[1]; Dent, J.B.[1]; Kowero, G.S.[2] and Oglethorpe, D. R.[3]

ABSTRACT. Strong demand for firewood and construction material in the urban areas of Mozambique, especially Maputo-city, coupled with slash and burn agriculture, has led to an increase in deforestation. As a measure to mitigate this and other problems facing the forestry sector, the government designed what is known as Strategies for Forestry Development (1991) which includes a reforestation strategy. This contemplates the involvement of the community as a way forward for afforestation since the government has limited funds to embark in large scale reforestation programs. This paper reports the results of a study which explored the potential for using Weighted Goal Programming (WGP), in assessing the impact of integrating trees into the farming systems in the province of Maputo. Models of typical farms from five ecozones were constructed and aggregated in an effort to assess the impact of the reforestation strategy, at provincial (macro) level, while focusing on the use of resources at the household (micro) level. Despite the scarcity of data and political and climatic instability which influenced the quantity and quality of data, the planning framework results show that all regional goals can at least be achieved. Land use is predicted to change in all ecozones with regard the land allocation to individual crops. Furthermore, allowing each typical farm to be able to plant at least one hectare with trees was found to be possible, but with some changes in the level of performance of the current farm activities. In addition to income generation, the reforestation strategy was found to reduce adult underemployment, especially in the grassland ecozone, however, in some ecozones it implied the use of more child labour. There is potential for applying mathematical programming in land use conflict resolution in a data scarce environment.

1. INTRODUCTION

In many developing countries, clearance of forestry resources for construction and energy supply in urban areas accompanied by slash and burn agricultural practice, has resulted in deforestation. In Mozambique, and particularly the Maputo province, (the capital city of which is home to a large proportion of the national population), such a situation led the government to design what is known as the Strategies for Forestry Development (1991) which includes a Reforestation strategy. This states that the community should participate in the replacement of the forest resources extracted in order to guarantee their sustainable use. In some zones, such a strategy has been implemented without previous appraisal of the relevant technical and socio-economic issues involved. The result was a significant underachievement of the projects' aims in terms of tree survival rate and management of plantations, either in woodlots or in intercropping systems. Therefore, it can be argued that such situations arise as a direct result of introducing a tree component into existing agricultural systems without considering the potential conflicts such as labour availability and its allocation to the different farm activities.

This research attempts to use a relatively sophisticated *ex-ante* planning approach, in a data scarce environment, to explore the mechanisms by which reforestation should take place. A modelling framework is constructed where both technical and socio-economic goals are incorporated to deal with the assessment of reforestation strategy under an integrated land use context. In this way, the study analyses the impact of tree plantation in conjunction with already competing farm activities as well as conflicting household and regional goals.

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The reforestation strategy is therefore a two level decision problem involving the farm and the regional levels. Although the subject of this paper is focused on the latter, it incorporates constraints reflecting the activity of the former. The paper presents preliminary results of a regional model which aims to analyse the trade-offs amongst regional goals and their impact at the farm level in terms of land use, dietary issues, tree plantation, conservation and income levels.

2. MULTIPLE CRITERIA DECISION MAKING (MCDM)

Advances in science and computer technology questions the validity of the traditional single objective planning approach (Dent and Jones, 1993) due to inadequacy of such criterion to represent satisfactory the multiple objectives decision problems related with land use planning (Spronk and Matazarro, 1992). The decision maker (DM), at micro or macro level, generally looks for a compromise result, i.e., trade-offs amongst goals. Multiple criteria decision making methods (MCDM) take into account the various objectives of the DM and start with the definition of 'best' which differs for each individual in the society. This, according to Kazana (1988), is the basic distinction between MCDM and linear programming (LP). Cohon (1978) also considers that multiobjective approaches assign adequate roles for both the analyst and the DM. In other words, the analyst generates alternatives and objective trade-offs while the DM makes value judgement about the relative significance of those alternatives.

With regard to Reforestation strategy, implementation implies adoption of agroforestry systems by rural farmers in Mozambique. A survey conducted for this study showed that, in the case of the Maputo province, farmers have preference for village woodlots over intercropping. Kazana (1988) states that agroforestry systems in small farming systems in developing countries is mainly a decision making problem at a micro-economic level, because (also according to Janssen (1995)) farmers control the use and management of the natural resources.

Therefore, a bottom-up planning approach appeared the appropriate procedure for this research. In order to do this, rural Maputo was classified into five ecozones based on existing land use, described by Saket (1994). A survey was conducted in each of these ecozones in order to elicit information regarding farm household objectives and constraints concerning food security, availability of fuelwood and wood for construction and income generation activities. Also, a survey of Maputo planning authorities was conducted to elicit the regional goals associated with the implementation of the reforestation strategy.

Goal programming (GP), one of the MCDM based on the geometric definition of 'best' is regarded as a model which operationalizes the Simonian approach of 'satisfaction' to the fulfilment of the DM's objectives (Rehman and Romero, 1993 quoting Simon 1955, 1957). GP has two variants: Lexicographic Goal Programming (LGP) which is based on pre-emptive ordering of goals and priorities by the DM, and Weighted Goal Programming (WGP), based on a simultaneous consideration of goals and minimisation of the sum of relative weighted undesired deviations from the targets. WGP was applied in the regional model which is discussed further in the section 3.

A criticism of the limited application of GP is the large amount of data required from the DM (including objectives, targets, weights and priorities) and for estimation of the technical coefficients of the decision variables. This is a particularly important limitation in developing countries were planning in subsistence farming is made difficult due to a lack of record keeping of farm performance and where lack of co-ordination between agricultural and forestry extension services is likely to reduce the reliability of information provided by the DM. However, Rehman and Romero (1993) defend the application stating that sensitivity analysis can be used to generate information and reduce the amount of data needed from the DM.

3. METHODOLOGY

3.1 Introduction

In Maputo province there is a recognised energy problem due to high surplus demand of fuelwood. This is partly caused by the growing market in the urban areas. However, recent socio-economic, political and drought conditions led to the situation where the main source of survival for farmers was through exploitation of the natural forest, which provided a ready source of income. This is despite the fact that, according to existing forest legislation (MA-DNFFB, 1987) the rural population can only exploit, for their consumption, third and fourth class species for poles and firewood without licensing. In the event of infringement, i.e., clear felling of trees with diameters greater than 30 cm for commercial purposes, fines ranging from US$52 to 155 can be charged. However, perhaps due to the recognition of the fact that forest products were the only source of farm livelihood during the civil war and drought periods, the government was passive in enforcing this legislation. The coexistence of these two issues (demand for income in the rural areas and demand for wood products in Maputo-city) led to deforestation which resulted in some zones having fuelwood shortages even for local consumption.

Previous studies by Getahun (1991) and Bila (1992) and results of the survey for this study, have showed that farmers recognise deforestation as a problem and tree plantation as a possible solution, as did the policy makers when they designed the 1991 Reforestation strategy. Therefore, this suggests that the apparent disparity in the definition of the problem facing the macro and the micro level of policy making, in other words, what Janssen (1995) calls aggregation of private and public rationale, may not be important. Consequently, it is hypothesised that solving farm level problems may simultaneously solve higher hierarchical level policy problems.

In this modelling approach typical farm models are used as the basic building blocks of the regional model and are aggregated for Maputo province. These individual farm models allow us to understand how farmers' interact with the environment and thus what their likely voluntary response to policy will be, in order to meet their own goals, given land and labour resource limitations. The aggregation of the farm models is designed to model the overall farmer response to regional plans for meeting food and wood demands, as well as conservation policies for the natural forest within a regional budget constraint.

3.2 The Framework of the Regional Model

3.2.1 The Farm Models

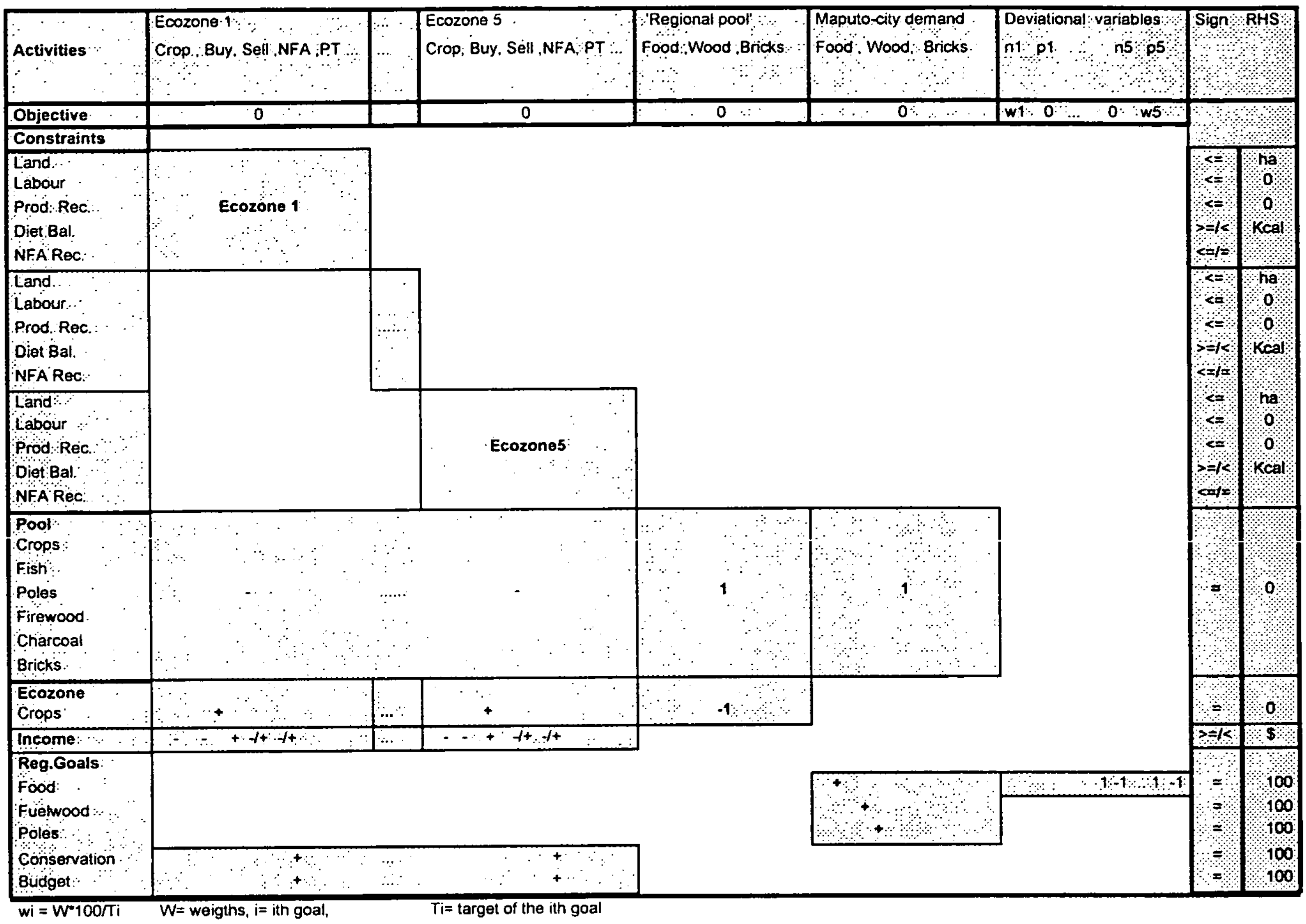
The farm models representative of each ecozone comprise five main groups of decision variables: growing crops, selling surplus produce, purchasing food to offset deficits, non farming activities (NFA) (harvesting natural forest, carving, brewing, brick making) and tree plantation activities (PT) as shown in the Figure 1. In addition, the main constraints on these farm activities include land, seasonal labour, production reconciliation, diet balance and NFA reconciliation.

Representative farms were selected from each ecozone classified in terms of similar cropping patterns and yields, same limitations in terms of inputs and technologies such as access to irrigation or not and alternative rural employment opportunities. Hazell and Norton (1986) state that simple rules like similar yields and similar technologies as well as similar land to labour ratios reduce aggregation bias and maintain a certain degree of conformity to Day's (1963) aggregation conditions. These include technological homogeneity, pecunious proportionality and institutional proportionality regarding respectively, the same production possibilities, proportional returns and proportional constraint vectors (in this case, land).

3.2.2 The 'Regional Pool' Activities and Constraints

The aggregated surplus from each ecozone creates a common pool of activities at the regional scale. This permits interecozone trade, particularly of food products, to satisfy deficits in production of crops essential to the diet (Figure 1). The constraints and activities of this common pool comprise the total number of assumed homogeneous farms in each ecozone supplying the surplus of food, wood products and construction materials to the 'regional pool' (Fig.1) from which Maputo-city requirement is supplied (once aggregated interecozone trade is satisfied). This illustrates a realistic exchange of food products amongst ecozones, because there are markets in the rural areas which enable farmers from deficit zones (like dryland, grassland and open forest) to purchase from surplus zones without having to travel to Maputo-city.

Fig. 1 Structure of the regional model



wi = W*100/Ti W= weigths, i= ith goal, Ti= target of the ith goal

3.2.3 Regional Goals

A survey of staff at the Eduardo Mondlane University in Maputo, the Ministry of Agriculture and Fisheries and provincial and district agricultural officers, was conducted to elicit the goals of the reforestation strategy as viewed by these different planning entities. A summary of the ranked goals as perceived by these policy makers (PMs) is shown in Table 1.

Table 1 Summary of the goals and the desired achievement function

Goals	Targets	Deviational variables
Fuelwood (bags)	3,743 ,249	Minimise under-achievement
Poles (m3)	44,146	Minimise under-achievement
Food (Kcal)	11,214,310,020	Minimise under-achievement
Conservation (ha)	97,735	Minimise under-achievement
Budget ($)	2,765,900	Minimise over-achievement

Although policy makers provided the goal typology, values for respective targets were estimated from previous studies. The values of the targets regarding consumption of fuelwood and poles were based on a study by

Nhantumbo and Soto (1994). However, these target values also take into account the demand for energy from the food processing industry (Perreira, 1990).

The food target is based on population information (DNE, 1994) and daily energy requirements, aggregated to reflect annual demand and consumption. Unlike the farm models, no dietary constraints were included in the regional model due to the complexities associated with the heterogeneity of the population in terms of their origin and dietary habits and disparity of income levels between urban and suburban dwellers in Maputo-city.

With regard to the conservation target, it was assumed that each household would plant at least one hectare of trees. The budget constraint reflects, in turn, the cost of planting that area with any of the tree species included in the farm model (*Leucaena* spp., *Eucalyptus* spp, *Melia* spp.).

3.2.4 Weights and Deviational Variables

As indicated above there are various key decision makers at the regional level. It therefore appears more appropriate to rank the several goals of the DM/PMs and derive weights which encapsulate not only their preferences, but also reflect the relative importance attached to the goals as well as the relative significance of positive or negative deviations (Cohon, 1978).

The weights for each goal were determined using the procedure described by Yoon and Huang (1995) for derivation of weights from ranks. These were determined by the frequency at which each goal was placed at a certain rank by the various policy makers. Exchanges in the position of ranks allowed the evaluation of the trade-offs amongst the objectives according to associated weights (see results).

Weighted Goal Programming (WGP) simultaneously considers all goals in a composite objective function minimising the deviations between goals and aspiration levels (Romero and Rehman, 1989; Romero 1991). The objective function of a WGP model is meaningless when it aggregates incommensurable deviational variables (Romero, 1991). Therefore, a normalisation method which scales the deviational variables using relative percentages was used. Besides reducing significantly the range of units which can affect results of models run in the simplex algorithm, it provides meaningful results because the objective function is a sum of percentages, which are adimensional, and the new sets of weights (w_i/b_i) represent the preference of the DM.

4. RESULTS OF THE REGIONAL MODEL

4.1 The Scenarios

The regional model was run four times each time changing the weights or the relative importance of goals as defined by planners or policy makers (Table 2). This was done to assess how farm activities might change and thus how the regional situation might benefit from changing priorities.

Table 2 Weights associated to the goals in each scenario

Scenarios	Run A (survey)	Run B	Run C	Run D
Fuelwood	Highest	2nd Highest	2nd Highest	3rd Highest
Poles	Highest	2nd Highest	2nd Highest	3rd Highest
Food	2nd Highest	Highest	3rd Highest	Lowest
Conservation	3rd Highest	3rd Highest	Highest	2nd Highest
Budget	Lowest	Lowest	Lowest	Highest

These changes of preferences may be dictated by change in the economic situation resulting from political stability and better climatic conditions, change in policy makers, and hence their perception of the problems and priorities.

4.2 The Achievement Function

The representative farm models for each of the ecozones were run first as LP and Lexicographic Goal Programming (LGP) models in which the efficiency determined the maximum use of all resources available in the first case and, trade-offs between farm goals were provided in the second case. However, alternatives generated by the WGP aiming for the 'satisfaction' of the regional goals resulted in a large proportion of unused resources, such as labour and land.

Table 3 presents the achievement of the various goals, with the target multiples (the number of times the target is exceeded) given for each scenario. All multiples are positive since all goals were at least achieved.

Table 3 Targets multiples resulting from change in priorities of PMs

	Run A	Run B	Run C	Run D
P1 (Fuelwood)	2.17	1	1	1
P2 (Poles)	111.53	69.8	69.62	38.93
P3 (Food)	1.06	1	1.10	1.33
P4 (Conservation)	1.42	1.33	1.32	1.56
P5 (Budget)	1.33	1.24	1.23	1.49

In Run A when wood for energy supply to Maputo city is the most important for the policy makers, then three of the four ecozones producing charcoal, produce at their full capacity. This results in more than twice as much fuelwood being produced over that required by the target. The result is validated by experience in the Maputo-city market where shortages of firewood are uncommon, despite difficulties of access to the production zones experienced by timber merchants in the wet season. Increased production and transportation costs generally reflect higher fuelwood prices, rather than less supply.

Only one ecozone currently produces poles from the natural forest. However, with tree plantation the supply of volume required for building houses in the Maputo-city suburbs is substantially surpassed (P_2) in all runs. It should be stressed, however, in a similar fashion to fuelwood and food goals, wood demand for construction in the rural areas is endogenous to the representative farm model and the target of the region refers only to the Maputo-city consumers demand. The achievement of this goal is directly associated with the conservation goal which is also overachieved (P_4).

The Grassland ecozone has the highest area of land allocated to trees at 21 ha, 17 ha, 16 ha and 27 ha, per household, respectively, in Run A, Run B, Run C and Run D, and this is the main reason for such an excess over the target level. In all the other ecozones, the representative farm only plants one hectare. This result seems to correspond to the fact that the Grassland ecozone is the poorest ecozone in terms of agricultural performance and in terms of opportunities for income generation. Therefore, it is reasonable that the reforestation strategy offers an alternative both in terms of employment and income from wood sales. This also conforms with the reasoning that farmers in the most productive ecozones have no preference for planting large areas with trees, but would rather plant enough to hinder the expansion of the saline land, for instance. Conversely, the Thicket ecozone, still has a significant natural tree cover and it would not be rational, in terms of sustainable use of the natural forest, to substitute it with plantation of *Eucalyptus* spp., for instance. Therefore, a one hectare plantation as shown by the model output may not be a pessimistic target.

In the Dryland ecozone, the rationale for planting only one hectare of trees may be associated with the fact that farmers may be willing to expand their agricultural land in order to meet consumption requirements rather than transforming the ecozone into a forest area. The particular benefit that this ecozone can get is from the improvement of soil fertility through incorporation of leaf biomass if the selected tree specie was *Leucaena* spp. instead of *Eucalyptus* spp. Finally, in the Open Forest ecozone, the plantation of one hectare can be justified as protection of the crops from the reported damage of strong winds.

The food goal is expressed in terms of dietary energy (Kcal) and the solutions of all but one scenario (Run B) show an overachievement of this goal. In the first three scenarios such satisfaction is derived mainly from sweet potato and fish. However, Run D, appears more realistic due to a wider range of crops supplying a significant amount of maize and cassava which together with sweet potato and by-products form the major contributions to the diet of Maputo-city consumers from the ecozones.

It also is worth mentioning that diet constraints (Figure 1) have been included as endogenous constraints to each of the farm models. These may be interpreted as all ecozones satisfying the 'domestic' demand for food. Consequently, it may also suggest that in Maputo province everyone has access to food to meet at least the minimum energy requirement. Nevertheless, the purpose of including such constraints is to simply evaluate the level of food self-reliance of the farm. The interecozone trade serves to show the potential capacity of the ecozones generating surplus to supply the deficient ones.

Finally, it is obvious that planting more area than the conservation target stipulates will need more investment, hence the overachievement of the budget target.

4.3 Farmers Response in terms of Land Use and Income

The change in the relative importance of the goals also results in a modification of farmers response in terms of land allocation to individual crops and the total area farmed by each typical farm. Although there is only a slight change (perhaps negligible) in the total farmed area particularly in the less productive areas (Dryland, Open forest and Grassland), land allocation per crop changes significantly in all ecozones illustrated by the changes which occurred within the food goal as shown in Table 2.

As regards income generation constraints, because the multiobjective regional model seeks a compromise solution then the income generated by the five representative farms only covers the minimum bound ($10 000). Despite that, it is important to retain this constraint because even though it was difficult to derive the income distribution envisaged by the policy makers, the reforestation strategy can only succeed if its implementation does not mean that farmers would have to forego too much in terms of food security, for instance, which can come from their own production or from purchases if cash is available.

5. DISCUSSION AND CONCLUSIONS

Clearly for such a planning tool to be successfully operational, validation of the farm-level component of the model becomes an issue. McCarl (1984) defines a model as an 'adequate' abstraction of reality for its anticipated use. Validation is a process of evaluation of the usefulness of such model. Therefore, to comply with this basic requirement of modelling, the farm models which form the main building blocks of the regional model, were validated via expert opinion, an acceptable and widely used method (McCarl, 1984, Hazel and Norton, 1986). Furthermore, due to the difficulties of data availability and its reliability for construction of models for policy analysis in Mozambique, as in many developing countries, particular emphasis was given to the logic structure of the model. This, according to Hazel and Norton (1986), is better than compounding the data problems with poor logic. Therefore, subjective judgement of the output assuming a broad comprehension of the system represented by the model (Dent and Blackie, 1979) was used under the concept that the model should be judged relevant for its task (Beck *et. al.*, 1995). Consequently, having judged the basic structures to be valid, the link between the various parts of the model, the 'regional pool' and the Maputo-city demand activities set the trade relations between ecozones and with Maputo-city market. Hence, it can reasonably be concluded that the regional model structure adequately represents the problem.

One important aspect that is also worth mentioning concerns the assumptions made to reduce aggregation bias. A basic assumption of the model implies that farmers within each ecozone have similar production possibilities and despite the relatively free access to land, traditional explicit and implicit rules create uniformity of land tenure conditions. This guarantees the proportionality of resource endowments, which according to Norton (1995), are probably the most relevant of Day's criteria for unbiased aggregation.
Moreover, the survey data for this research and previous observations by Getahun (1991) and Bila (1992) showed that farmers are aware of environmental and fuelwood shortage problems created by deforestation and, similarly to the policy makers, see reforestation as the likely solution. Therefore, this reduces what Jansen (1995) considers a shift in the rationale (private and public) due to aggregation of farm to regional level.

In short, this model is a proposed for *ex-ante* policy analysis regarding the potential impact of implementation of the participatory reforestation strategy in Maputo province and possibly in other provinces of Mozambique where the reforestation strategy has particular relevance. The model output delivers information regarding the opportunity cost resulting from shifts in the definition of the importance of goals and the resulting impact at a micro level. The final confidence in the model can only grow, as Beck *et al* (1995) underlines, with its successful application. This, of course, implies operational validation or validation of the model as it is used (McCarl, 1984). Nevertheless, the basis for planning and analysing the potential impact of a reforestation strategy has been built and provides a framework for similar analyses in data scarce environments.

6. REFERENCES

Beck, M.B., A.J. Jakeman and M.J. McAller (1995). Construction and evaluation of Models of Environmental Systems. In: *Modelling Change in Environmental Systems* edited by Jakeman, A.J., M.B., Beck and M.J. McAleer. John Wiley & Sons. Chichester. 3-35

Bila, A.T. (1992). *Trees for sustainable fuelwood production in rural subsistence farming at Boane, Maputo.* Bsc Honours in Agroforestry Dissertation. University of Wales. UK.

Cohon, J. (1978). Multiobjective programming and Planning. *Mathematics in science and Engineering.* Vol. 140. Academic Press.

Day, R. H. (1963). On aggregating linear programming models of production. *Journal of Farm Economics.* 45:767-813.

Dent, J.B. and M.J. Blackie (1979). *Systems simulation in Agriculture.* Applied Science Publications. London.

Dent, J.B. and J.W. Jones (1993). Multiple Criteria Analysis in agricultural Systems - editorial. *Agricultural Systems.* 41:3, 235-237

DNE (1994). *Anuario Estatistico.* DNE-MPF. Maputo.

Getahun, A. (1991). *Forestry Extension in Mozambique.* FAO. Maputo.

Hazell, P.B.R. and R.D. Norton (1986). *Mathematical Programming for Economic Analysis in Agriculture.* Macmillan Publishing Company. New York.

Janssen, W.G. (1995). Aggregating economic knowledge for use at national, regional, sector and farm level. In Eco-regional Approaches for Sustainable Land Use and Food Production edited by Bouma, J., A. Kuyvenhoven, B.A.M., Bouman, J.C., Luyten and H.G. Zandstra. *Systems Approach for Sustainable Agricultural Development*, 4

Kazana, V. (1988). Optimisation techniques for Agroforestry Production Systems. In: *Economic Evaluation and Management of Agroforestry: a novel problem?* Proceedings of a workshop, Depart. of Forestry and Natural Resources, The University of Edinburgh, edited by Sinclair, F.L., Kazana, V. and Shrimpton, N.H., 42-51

McCarl, B.A. (1984). Model validation: An Overview with some Emphasis on Risk Models. *Review of Marketing and Agricultural Economics*, 52:3, 153-173

McCarl, B.A. (1984). Model Validation: An overview with some Emphasis on Risk Models. *Review of Marketing and Agricultural Economics.* Vol. 52:3, 153-173.

MA-DNFFB (1987). *Manual de Legislaçao Florestal.* DNFFB. Maputo.

Nhantumbo, I and S. Soto (1994). *Mercado de produtos madeireiros e nao madeireiros.* FAO. Maputo.

Norton, R.D. (1995). Response to section C. In Eco-regional Approaches for Sustainable Land Use and Food Production. *Systems Approach for Sustainable Agricultural Development*, 4, 237-247.

Pereira, C.R. (1990). *National Survey of Biomass/woodfuel activities in Mozambique.* SADCC. Maputo

Rehman, T. and C. Romero (1993). The application of the MCDM paradigm to the management of agricultural systems: some basic considerations. *Agricultural Systems.* 41:3, 239-255.

Romero, C. and T. Rehman (1989). Multiple Criteria Analysis for agricultural decisions. *Developments in Agricultural Economics.* Vol. 5. Elsevier.

Romero, C.(1991). *Handbook of critical issues in Goal Programming.* Pergamon. Oxford.

Saket, M. (1994). *Report on the Updating of the Exploratory National Forest Inventory.* FAO. Maputo

Spronk, J. and B. Matarazzo (1992). Interactive multifactorial planning: state of the art. *Rivista di Economia Agraria.* 47:4, 531-543

Tabucanon, M.T., P. Berck and D. Bigman (1993). Applications of multiple criteria decision-making methodology in food policy analysis. In *Food Security and Food Interventions in Developing Countries* edited by Berck, P. and. CAB International, UK. 151-174

Yoon, K.P. and C. Hwang (1995). *Multiple Attribute Decision Making: an introduction.* Sage Publications. London.

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NON-MARKET BENEFITS OF FORESTS: A MODELLING APPROACH FOR POLICY INTERVENTION IN MOZAMBIQUE

Paper presented at the International Symposium of Non-Market Benefits of Forestry

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Abstract

Tradable forest products are normally the focus of attention in forest management as opposed to non tradable products and non marketable benefits such as erosion control, aesthetic and traditional ceremonies values, biodiversity maintenance, wildlife conservation and other intangible benefits. This situation results from the fact that tradable goods are included in the national accounts in terms of their contribution to the GDP. Potential and still controversial proxies for analysis of the macroeconomic impacts of environmental variables include the creation of the Resource Environmental Accounts (REA) and the Environmental Adjusted Net Domestic Product (EDP) and other approaches such as change of macroeconomic policies and linear programming.

Planning sustainable forest management demands an integration of all resources including potential uses by different social groups at the national and international level over medium or long term. The commitment of both the formal and informal sectors in the planning and implementation of measures to protect the environment at national level depends on the perceived value that each associate with the resources. However, the most applied method of valuation of environment, Contingent Valuation (CV), is still facing a great deal of scepticism concerning the reliability of its results. Therefore, methodological problems rise further when attempting to analyse the likely impact of alternative future environmental policy /strategies at macro level in a data scarce situation, where target groups have minimum or no information about environmental goods. Other difficulties include derivation of coefficients and selection of the appropriate aggregation level.

In this research, a multiobjevtive mathematical programming model framework incorporating farmers' preferences, regional and national environmental goals and priorities is developed to determine the impact of utilisation of marketable forest products on the non-market benefits of forests. The incorporation of the latter in the model provides the basis of a powerful decision support system for policy interventions.

Keywords: non market benefits of forests, valuation methods, mathematical programming, farm preferences, regional and national goals and priorities

1. Introduction

Despite providing a myriad of products and services, the economic importance of the forestry sector in many developing countries continues to be evaluated in terms of the marketable goods. Ignoring outputs which have no established markets leads to an underestimation of the role of the sector to the welfare of the people in these countries. The contribution of forests to soil conservation, stabilisation of water flows and regulation of regional and global climate are some of the services often taken for granted.

This study attempts to bring into focus the benefits of forests to some local communities in the province of Maputo in Mozambique. While the undervaluation of the forestry sector in the Mozambican economy has been noted by Kowero & Nhantumbo (1992), Soto & Sitoe (1994), and Nhantumbo & Soto (1994), Cuco (1993), states that the role of non tradable products and services from the forests is increasingly becoming prominent in national policies and plans.

Human activity influences the spatial and temporal distribution of natural resources and the quantity and quality of benefits derived from them. Research is therefore a potential and powerful tool which can increase our understanding of how man relates to natural resources. Such information can assist in the formulation of policies and strategies which can reconcile the dynamic nature of the environment with human demands.

The objective of this paper is to explore the potential for applying a multiobjective mathematical modelling framework which integrates productive and conservation activities within a given socio-economic context. It hypothesises that this fairly sophisticated approach can serve as a decision support tool even in data scarce environments.

2. Concept

Tradable or marketable goods are divided into two categories: firstly,. goods for export valued in terms of the marginal export revenue at border prices (free on board). These include wood products from valuable indigenous tree species and wildlife products, especially trophies. Secondly, goods for local consumption valued at market prices including wood products mainly from the less precious tree species and the so-called secondary species. Included in this category are non wood products such as medicinal plants, wild fruits, plant leaves and roots, honey, wax and wildlife products; all of which are traded in local markets.

The level of exploitation of the marketable products, estimated at over 18 million m3/yr in Mozambique, influences the availability of non marketable forestry goods and services. For example, relatively closed forests or thickets not exploited but preserved as sacred areas for local communities are generally richer in species diversity.

Non market benefits include environmental services important for soil protection, regulation of river flows, maintenance of diversity and aesthetic values. However, there is no widespread tradition in Mozambique of recreation activities like walking in the woods or simply enjoying the aesthetic value of natural vista. On the other hand, local recreation and tourism in the study area is confined mainly to the coast where the natural vegetation, particularly mangroves, has been cleared for fuel as well as planted trees, mainly *Casuarina* sp., whose role is to protect the coastal belt from erosion.

There is a wide range of non market benefits of forestry in the country. Nevertheless, lack of awareness may inhibit the full exploitation of the potential offered. Conservation may only be achieved when people associate long term values with the resources, such as those ascribed by rural people with regard to their beliefs and customs. As Panayotou & Ashton (1992) stress, timber and non timber goods and services(NTGS) increase the value of forest resources, but these are undervalued due to lack of information on NTGS. Therefore, the major research challenge is the development of a methodology for valuation which incorporates the complete range of forest goods and services in a planning framework for sustainable management. Such a framework must explicitly permit trade offs between conflicting objectives to be maximised.

3. Environmental goods and services in decision support system framework

3.1 Methods of valuation of non-market benefits of forests

There are several methods of economic valuation of environmental goods and services or non marketable benefits of forests. These methods are either based on conventional markets, implicit markets or artificial markets (Angelsen et al 1994). The first category includes the effect on production (EOP), human capital (HC), preventive expenditure (PE) and replacement costs (RC). Travel costs (TC) and hedonic prices such as property value (PV) and wage differentials are examples of the second category, whereas contingent valuation methods (CVM) represent the last category. Another categorisation by Dixon et al (1994) include macroeconomic models such as linear programming in the approaches with potential for valuing environmental impacts. Each of these approaches have clear limitations either due to the irrelevance of the measure, the difficulties of perception of the local people, or the problems of application.

Mozambique is in its initial stages of developing an environmental policy in which non market benefits of forests are expected to be incorporated. Therefore, policy makers may benefit from a decision support framework which gives an overview of the resource base, and how it can be managed and used without adverse ecological or environmental effects. These cannot be accomplished with methods measuring microeconomic variables. Therefore, one possible framework is the multicriteria decision making approach which combines ecological or environmental and economic data within a socio-cultural setting in order to satisfy the demands of a specific community. The approach uses mathematical programming to facilitate the harmonisation of various societal demands and limited resources.

3.2 Macroeconomic model: Goal Programming

The management of natural resource involves many uses and users. Each user may desire satisfaction of a range of objectives such as economic, and socio-cultural, as well as ecological or conservation of the resource.

Planning the use of resources involving multiple and conflicting objectives, demands a technique which permits the various trade-offs to be assessed. This is particularly important when incorporating non market benefits of forests into a modelling framework and when there is need to take intergenerational issues into account. The technique must also be capable of analysing a wide range of alternatives, making the analyst's perception of the problem more realistic.

The application and limitations of multiple criteria decision making (MCDM) approaches in forestry and rural land use planning have been reviewed (Jordi &, Peddie 1988; Bare and Mendonza 1988; Romero and Rehman 1989).

Goal Programming (GP) principle is that the decision maker (DM) sets targets aiming for minimisation of deviations from the goal levels (Rehman & Romero 1993). It is applicable for multiple goals problems even when they are incompatible or incommensurable (Barlett et al 1976). In general GP requires a large amount of information from the DM. However, sensitivity analysis reduces the analyst-DM interaction while ensuring that reliable information on opportunity cost of alternative courses of action allows the DM to make rationale decisions (Rehman & Romero 1993). In contrast, opportunity costs information, is not offered by multiple attribute utility methods (Sharma 1990).

Interactive methods such as multiple objective linear programming (MOLP) can deal with the size of problems in planning forest land management, but require large amount of DM's input information. Even though, Romero & Rehman (1989) consider such information as modest, they also recognise that the mathematical sophistication of the models limit their application.

Multiple objective programming (MOP) identifies mutually exclusive solutions expressed in a production possibility frontier and identifies trade offs of a maximum of 3 objectives (Rehman and Romero, 1993). This contradicts the fact the analyst uses MCDM to assist in resolving problems involving relatively large number of conflicting goals. One example is the list of farm and regional goals in the next section. Therefore, GP appears to be appropriate to the study area in permitting the integration of farm production and environmental requirements while addressing multiple conflicting goals presented by DM.

3.3 General planning Framework

As mentioned before, planning the use of renewable natural resources, needs an integration of local and regional planning levels. This ensures that policy formulation concerning environmental and natural resources are relevant for both the farmer and the policy maker (McCarl 1992). Administrative policies imposing measures for resource conservation are not likely to succeed unless the farmers and other users understand the importance of conservation and alternatives are created either to reduce the use of the resources or to improve efficiency in its use. It may also be necessary to guarantee a fair public return and reinvestment.

Figure 1 presents the general planning framework proposed and illustrates the linkage between farm and regional models so that trade offs can be explored between objective sets at each of the levels.

Geographical Information Systems (GIS) are the basic building block of this approach. GIS provides a visual display of natural and human resources and infrastructure distribution. This facilitates the differentiation of homogeneous zones in terms of forest type or potential land use and opportunities concerning non agricultural activities. Farm models were built for each of these zones. GIS was also used to generate some model coefficients, such as wood available/person in each district.

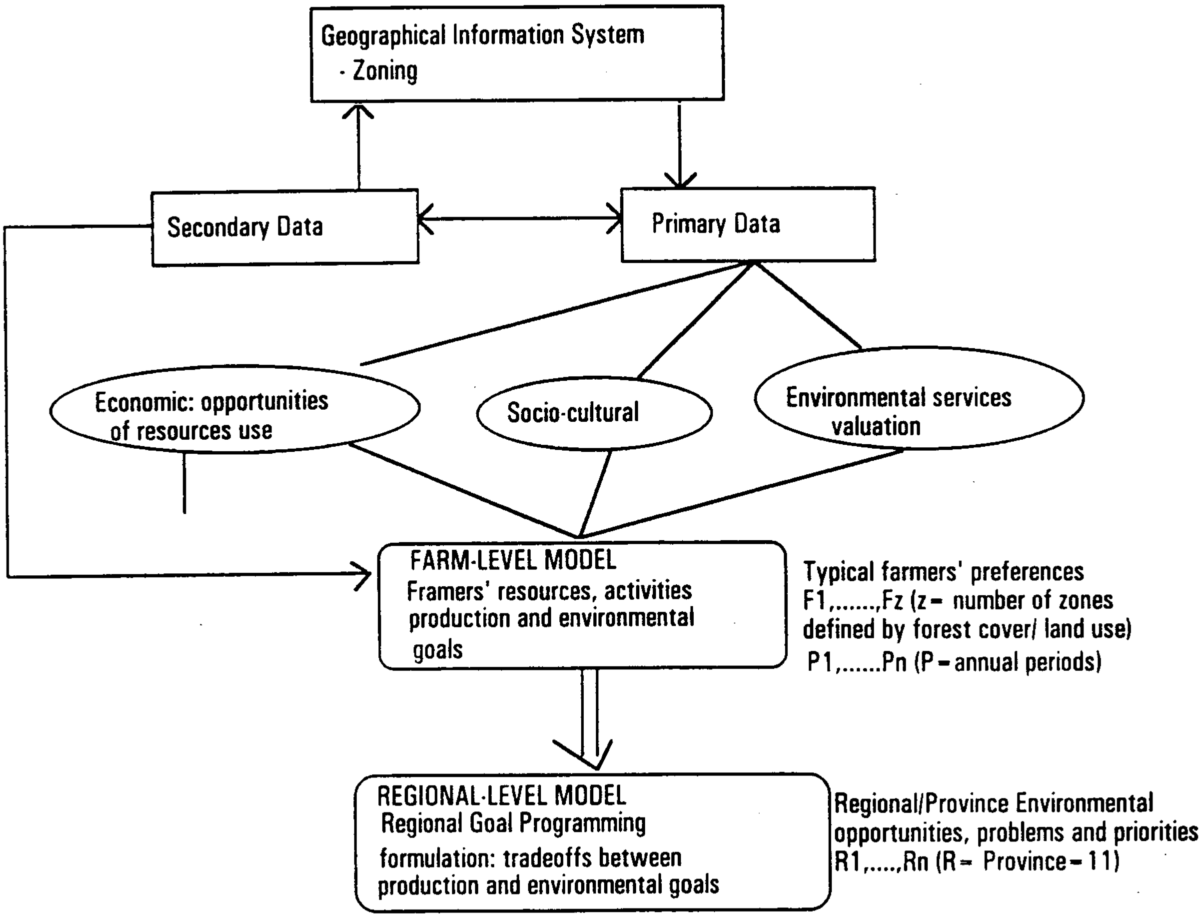

Fig.1 General planning framework for environmental policy/strategy analysis: integration of farm and regional planning levels

Data collection was an important phase in developing this framework. Secondary data were collected on major agricultural or industrial activities being carried out, the extent of forest exploitation for local use and supply to the markets, cropping patterns and resource availability. Secondary data sources were extremely limited because of the breakdown of the infrastructure during the war, and in this case were supplemented by information provided by key individuals such as agricultural officers and administrators. The primary data were based on surveys in each ecozone on the social, cultural and economic aspects of farm households including their attitudes/perceptions towards environmental conservation.

A major consideration in collecting primary data was to elicit the farmers' willingness to plant trees (WTPt)in areas under their control. These data were necessary to include coefficients which linked farmers' intentions with the increasing demand for wood products in the suburbs of the capital city, Maputo. WTPt in monetary terms is out of context for the rural farmers because of their low income and poverty. However, their expressed WTPt where the deforestation consequences are obvious, gives an indication of the cost of restoration (labour and land, for instance) they are prepared to incur as well as their implicit willingness to pay (WTP) for preserving the remaining forest.

3.4 Farm-level model framework

Activities and Constraints

The farm-level model provides the most appropriate mix of farm activities mix given the resource constraints and the objectives they envisage.

The farm-level model in Figure 2 is in generic terms applied for each defined ecozone. It includes as major activities, all alternative farm enterprises such as crops (C1,...Cn) including cereals, tubers and vegetables grown on dryland or alluvial land during the dry (D) and/or wet (W) season. These activities demand land, labour and cash for purchasing seed, hired labour, tractor or draft power, and produce an output.

Animal activities include cattle (C) and goats (G). These activities demand pasture and labour.

Food supply, including wild fruits and nuts, roots, plant leaves and wildlife is matched with food demand for three groupings: males, females and children. Any excess is available for sale to provide income for other family needs.

Non agricultural activities such as collection of reeds, artisan work, harvesting of poles and firewood for sale, brick and domestic instruments production compete in terms of labour with agricultural activities. However, they are also important as they supply income to supplement food during periods of shortage, especially the wet season as well as for purchasing farm inputs.

Other potential activities include agroforestry, wood requirement, hire or sale of labour and income generation.

The forest growth restriction ensures that the rate of annual exploitation of forest resources is sustainable.

Most of the survey data obtained from farmers is qualitative in nature and later transformed into numerical form to include it in the mathematical model.

Figure 2: Summary of farm model highlighting major activities, restraints and goals

Typical Farm model															
Act / Const		Cropping C1...Cn D, W	Animal C, G	Sales C1,..Cn D, W	Purchases p1....pn D,W	Nutrient C1,....Cn D, W	Provision ;S1...Sn	Non Agric. Activ.	Seed	Wood F, P, C	Agrofor.	Househ equival. M F C	Hire Lab. M F	Income On	Off
Land	s >=	1	1								1				
Crops	0 >=	s		1	-1	1	1		d		s				
Fam. Labour	0 >=	d	d	d	d			d			d	s			
Hir. Labour	0 >=	d											s		
Energy	0 >=					s	s					d			
Protein	0 >=					s	s					d			
Wood	s >=									d d					
For. Growth	s >=						d								
Fruits/nuts	s >=														
Pasture	s >=		d								s	1			
Fam. Size	s =														
Hire tract/ draft	0 >=	d												s	
Income	0 =	d		s	d			s	d		d			1	
....															
Goals															
Food	Max.	1	1								1				
Wood	Max.										1 1				
Income	Max.													1	
Cost	Min.													-1	
Loss fert.	Min.	1									1				
Intergen. transfer	Max.										1 1				

Farm-level goals

Farmers perform the activities mentioned in the last section under resource limitations and they seek to achieve several and conflicting goals. These include:

1. Maximum self-reliance on food
2. Maximum self-reliance on wood products
3. Maximum generation of income from non farm activities
4. Minimum loss in soil fertility and salinisation
5. Prevention of floods
6. Intergenerational transference

The last goal was not explicitly stated by farmers, but it is included to account for the expressed willingness to plant trees to ensure medium and long term wood and non wood products in the different homogeneous zones. Despite the low priority, its choice indicates the farmers' awareness of environmental damage caused by continuous harvesting.

Presently, farmers give more weight to self-reliance on food production and this is implicitly linked with minimum costs which may include rotation of crops such as leguminous and cereals.

3.5 Regional level model framework

Regional activities and constraints

The regional level model selects the best farm organisation and mix of regional land use activities to provide a regional land use plan that clearly matches regional goals.

The model includes activities such as the output of farm models which provide a range of potential farm organisations (Fa...Fc) for each homogeneous zone representing specific farm preferences and responses to policies such as prices, subsidies in form of land and seedlings. It also incorporates activities concerning wood supply to Maputo city markets including the industry, recreation and conservation or restoration needs as well as generation of income and employment.

The activities are performed under resource constraints such as farm and communal land, demand for food and wood, capacity of the forest to satisfy the demand and restriction ensuring prevention of resource depletion.

Figure 3: Regional model including farm output with regional activities and resource constraints

act. / const.		Ecozone1			Ecozone2			Wood Ind.	Wood Loc.	Wood Exp.	Nonwd prod.	Recr.	Conservation				Farm Inc.	Region. Inc.	Empl.
		Fa	Fb	Fc	Fa	Fb	Fc						For.	Wildl.	Water	Soil			
			1 ha			1 ha			1 ha					1 ha					
Farm land	s > -	1	1	1	1	1	1												
Crops	d >	s/d	s/d	s/d	s/d	s/d	s/d												
Animals	d >	s/d	s/d	s/d	s/d	s/d	s/d												
Wood Exp	0 >							s		s								d	
Construct.	0 >							s	s									d	
Furniture	0 >							s										d	
Conserv.	s >											d	1 -1	1 -1	1 -1	1 -1		d	
Recreation	0 -																		
Nonwd Prod.	d <										s	1							
Charcoal	d <	s	s	s	s	s	s										1		
Firewood	d <	s	s	s	s	s	s										1		
For. growth	s > -							1	1	1									
Crafting	0 >	s	s	s	s	s	s										1		
Farmer Inc.	0 -	d/s	d/s	d/s	d/s	d/s	d/s										1		
Reg. Inc.	0 -	d	d	d	d	d	d											1	
Farm pref.		1	2	3	1	2	3												
Goals																			
Wood Prov.	Max.							1	1	1									
Food	Max.	1	1	1	1	1	1												
Conservat.																			
Forest	Max.												1						
Wildlife	Max.													1					
Water	Max.														1				
Soil	Max.															1			
Income	Max.	1	1	1	1	1	1	1	1	1		1						1	
Employment	Max.	1	1	1	1	1	1	1	1	1		1	1	1	1	1			1

Regional goals

An open ended questionnaire was carried out to elicit regional objectives and goals of implementing the participatory reforestation strategy in Maputo. The survey included university staff, directorates of agriculture and forestry, and some provincial and district agricultural officers.

The goals stated in order of priority were as follows:
1. Maximum regional wood provision
2. Maximum regional food production
3. Maximum conservation of forest, wildlife, water and soil in the region
4. Maximum Income generation for the region
5. Maximum employment generation in the region

Other regional goals in the study area could include:
1. Minimisation of flooding and salinisation effects by planting appropriate tree species
2. Promotion of eco-tourism
3. Reduction of risk of soil acidification resulting from the excessive use of fertilisers in intensive production This goal could be obtained through plantation of nitrogen fixing species and incorporation of their organic matter into the soil. The effectiveness of such organic farming

would depend on the farm size, but it would reduce the damage to the environment.

Many agricultural experts did not state goals and priorities because they saw no association between the implementation of a participatory reforestation strategy and agricultural activities. Also experts responsible for co-ordination of environmental activities at national level could not express goals and priorities, because they claimed that this was a forestry issue which needed only forest expertise. Although may seem trivial, it is very important in that the use of goal programming demands that policy or decision makers provide guides on goals, targets, priorities in addition to weights for their rankings. It also shows that sensitivity analysis have to be used to overcome the limitation concerning the amount of information required from the DM.

4. Policy Implications for Mozambique

The protection of the environment or forest areas demands both bottom up planning to deal with decision making situations in which farmers can participate, and top down planning for large scale interventions necessitating the involvement of the regional and national government institutions. Under such circumstances an integrated planning framework which incorporates farm level as well as higher level objectives to guide decision making is a necessity.

It is possible to generate data in Mozambique for use in fairly sophisticated planning approaches like goal programming. Therefore, there is potential transferability of the methodology to serve as a decision support tool for policies and strategies analysis in Mozambique.

5. Literature cited

Angelsen, A., O.Fjeldstad and U.R. Sumaila (1994). Project Appraisal and Sustainability in Less Developed Countries. Chr. Micvhelsen Institute. Norway.

Bare, B.B. and G. Mendonza (1988). Multiple Objective Forest Land Management: An Illustration. *Eur. J. Opl. Res.*, 34, 44-54.

Barlett, E.T., K.E. Bottows and R.P. Pope (1976).Goal: Multiple Objective Programming. Goal range Series no 21. College of Natural Resources. Colorado University.

Cuco,A.(1993). Some Aspects on Forestry Policy in Mozambique. FAO-UNDP/MA. Maputo.

Dixon, J.A., L.F. Scura, R.A. Carpenter and P.P. Sherman (1994). Economic Analysis of Environmental Impacts. Earthscan. London. 2nd Edition.210 pp.

Jordi, K.C. and D. Peddie (1988). A Wildlife Management Problem: A case Study in Multiple-Objective Linear Programming. *J. Opl. Res.*, 39 1011-1020.

Kowero, G.S. and Nhantumbo, I.(1992) O Sector Florestal e o Desenvolvimento de Mocambique (The Forestry Sector and Development of Mozambique). UEM. Maputo.8 pp.

Nhantumbo, I. and Soto, S.J. (1994). Mercado de Produtos Madeireiros e Nao Madeireiros (Marketing of wood and Non Wood Products - pre-program for Institutional Support of Sustainable Management of Forests and Wildlife). FAO-UNDP. Maputo. 44 pp.

McCarl, B.A. (1992). Mathematical programming for resource policy appraisal under multiple objectives. EPAT/NUCIA Working paper no 6.18 pp.

Panayotou, T. and P.S. Ashton (1992). Not By Timber Alone: Economics and Ecology for Sustainable Tropical Forests. Island Press. Washington.282 pp.

Rehman, T and C. Romero (1993). The Application of the MCDM Paradigm to the Management of Agricultural Systems: some basic considerations. *Agric. Syst.*, 41, 239-255

Romero, C. and T. Rehman (1989). Multiple criteria analysis for agricultural decisions. Development in Agricultural Economics, no 5.257 pp.

Sharma, R. (1990). Socio-economic Planning in Social forestry with Particular Reference to Orissa, India. PhD Thesis. The University of Edinburgh, UK.

Soto, S.J. and A. Sitoe (1994). Analise do Sistema de Receitas de Recursos Naturais. (Analysis of Revenue System of Natural Resources - pre-program for Institutional Support of Sustainable Management of Forests and Wildlife)FAO-UNDP. Maputo. 40 pp.