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# *INTEGRATED BIO-ECONOMIC LAND USE MODELS: AN ANALYSIS OF THE POSSIBILITIES OF SUSTAINABLE NATURAL FOREST MANAGEMENT IN THE ATLANTIC ZONE OF COSTA RICA*

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CENTRO AGRONOMICO TROPICAL DE
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## THE REPOSA PROJECT

The Research Program on Sustainability in Agriculture (REPOSA) is a cooperation between Wageningen Agricultural University (WAU), the Center for Research and Education in Tropical Agriculture (CATIE), and the Costa Rican Ministry of Agriculture and Livestock (MAG). In addition, REPOSA has signed memoranda of understanding with numerous academic, governmental, international and non-governmental organizations in Costa Rica.
The overall objective of REPOSA is the development of an interdisciplinary methodology for land use evaluation at various levels of aggregation. The methodology, based on a modular approach to the integration of different models and data bases, is denominated *USTED* (*Uso Sostenible de Tierras En el Desarrollo*; Sustainable Land Use in Development).
REPOSA provides research and practical training facilities for students from WAU, as well as from other Dutch and regional educational institutions.
REPOSA's research results are actively disseminated through scientific publications, internal reports, students' thesis, and presentations at national and international conferences and symposia. Demonstrations are conducted regularly to familiarize interested researchers and organizations from both within and outside Costa Rica with the *USTED* methodology.
REPOSA is financed entirely by WAU under its Sustainable Land Use in the Tropics program, sub-program Sustainable Land Use in Central America. It operates mainly out of Guápiles where it is located on the experimental station *Los Diamantes* of MAG.

## EL PROYECTO REPOSA

REPOSA (*Research Program on Sustainability in Agriculture*, o sea Programa de Investigación sobre la Sostenibilidad en la Agricultura) es una cooperación entre la Universidad Agrícola de Wageningen, Holanda (UAW), el Centro Agronómico Trópical de Investigación y Enseñanza (CATIE) y el Ministerio de Agricultura y Ganadería de Costa Rica (MAG). Además REPOSA ha firmado cartas de entendimiento con organizaciones académicas, gubernamentales, internacionales y non-gubernamentales en Costa Rica.
REPOSA ha desarollado una metodología cuantitativa para el análisis del uso sostenible de la tierra para apoyar la toma de decisiones a nivel regional. Esta metodología, llamada USTED (Uso Sostenible de Tierras En el Desarollo) involucra dimensiones económicas y ecológicas, incluyendo aspectos edafológicos y agronómicos.
REPOSA ofrece facilidades para investigaciones y enseñanza para estudiantes tanto de la UAW, como de otras institutiones educacionales holandesas y regionales.
REPOSA publica sus resultados en revistas científicas, tesis de grado, informes informales, y ponencias en conferencias y talleres. REPOSA regularmente organiza demostraciones para investigadores de Costa Rica y de otros países para familiarizarlos con la metodología USTED.
REPOSA es financiado por la UAW bajo su Programa del Uso Sostenible de la Tierra en los Areas Trópicos. La sede de REPOSA está ubicada en la Estación Experimental Los Diamantes del MAG en Guápiles.

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**SUMMARY**

The problem of the definition of sustainable forest management systems is especially felt in developing countries where the increasing population and the urge for economic development lead to an increasing pressure over the existing forest resources and results in high rates of deforestation. Land-use analysis can play an important role in the simulation of the effects of policy changes and in pointing out the conditions that must be met in order to contain the phenomenon of deforestation. This study explore the possibilities of sustainable natural forest management in the Northern Atlantic Zone of Costa Rica (NAZ) with the use of bio-integrated land use models. The NAZ has been object of numerous studies since 1986 by researchers of the Research Program On the Sustainability of Agriculture (REPOSA) of the Wageningen Agricultural University, in collaboration with the Centro Agronómico Tropical de Investigación y Enseñanza in Turrialba, Costa Rica (CATIE) and the Ministerio de Agricultura Y Ganadería de Costa Rica.

The Northern Atlantic zone of Costa rica started to be colonized in the second half of this century and the expansion of agricultural crops (such as banana cultivations) and cattle ranging led to high rates of deforestation causing biodiversity loss, land degradation and increasing emission of greenhouse. Furthermore, the government of Cost Rica, under a structural adjustment program, recently abolished consumer subsidies and producer support prices, thus increasing the pressure on farmers income. These policies favoured the cultivation of non-traditionally export crops (as palmheart and ornamental plants). As a result there is a general concern for the remaining forest and for the environment due to the high use of pesticides.

REPOSA developed a methodology for assessing problems related to income, unemployment and sustainability of agricultural crops, With this study an attempt has been made to introduce forestry issues in the regional framework developed by REPOSA. Theoretical considerations have been carried out in order to adapt the concept of sustainability to forestry issues. Sustainable natural forest management systems have been designed for the area of study and financially evaluated. Finally, several policy scenarios have been explored in order to compare the forestry land use types with other land use options. The results show that sustainable natural forest management can be an attractive land use option in certain conditions. Since the government of Costa Rica is currently promoting sustainable management of natural forests, other scenarios have been explored to see how the subsidies introduced for natural forest can affect actual land use.

## GLOSSARY OF ACRONYMS

| | |
|---|---|
| CATIE | Centro Agronómico Tropical de Investigación y Enseñanza<br>Tropical Agricultural Research and Training Center |
| LUCTOR | Land Use Crop Technical coefficient generatOR |
| LUST | Land Use Systems at a defined Technology |
| MAG | Ministerio de Agricultura Y Ganadería de Costa Rica<br>Ministry of Agriculture |
| NAZ | Northern Atlantic Zone of Costa Rica |
| PASTOR | Pasture and Animal System Technical coefficient generatOR |
| REALM | Regional Economic and Agricultural Land-use Model |
| REPOSA | REsearch Program On Sustainability in Agriculture |
| SFW | Fertile well-drained soils |
| SFP | Fertile poorly-drained soils |
| SIW | Infertile well-drained soils |
| SOLUS | Sustainable Options for Land Use |

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# 1. INTRODUCTION

## 1.1. OBJECTIVES AND RESEARCH QUESTIONS

The problem of the definition of sustainable forest management systems is especially felt in developing countries where the increasing population and the urge for economic development lead to an increasing pressure over the existing forest resources and results in high rates of deforestation. Land-use analysis can play an important role in the simulation of the effects of policy changes and in pointing out the conditions that must be met in order to contain the phenomenon of deforestation.

In Costa Rica deforestation rates have been high during the last 50 years (Current, 1995). The production of tropical timber and the expansion of export crops and animal husbandry are the main causes of deforestation. Other causes are the development of infrastructure and the process of urbanization, the search for land by landless people and the consumption of fuel-wood.

Is natural forest management an attractive land use option for private landowners? How to promote sustainable development of the remaining tropical forest in non-protected areas of Costa Rica? This study explores the possibilities of sustainable natural forest management in the Northern Atlantic Zone of Costa Rica (NAZ) with the use of bio-integrated land use models. Since the government of Costa Rica is currently promoting sustainable management of natural forests, it is interesting to explore how the subsidies introduced for natural forest can affect actual land use.

The NAZ has been object of numerous studies since 1986 by researchers of the Research Program On the Sustainability of Agriculture (REPOSA) of the Wageningen Agricultural University, in collaboration with the Centro Agronómico Tropical de Investigación y Enseñanza in Turrialba, Costa Rica (CATIE) and the Ministerio de Agricultura Y Ganadería de Costa Rica.

This research has been conducted in the attempt to answer three main questions. The first one is related to the concept of sustainable development of tropical forests, issue widely debated at the moment but not yet incorporated adequately in an economic framework:

*1-Is it possible to analyze in quantitative terms the conditions that must be met in order to promote sustainable development of tropical forests in the NAZ?*

Another question is related to the forest land use types to be designed for the Northern Atlantic Zone of Costa Rica and how to link them to the regional model of REPOSA. Since in non-protected areas, private landowners are the relevant decision-makers regarding land use, then another important question is the following:

*2- under which conditions sustainable forest management for timber production is an attractive land use alternative?*

Lastly, in the concluding chapter, some consideration will be made regarding:

*3-Why and how this analysis can be useful for policy makers at the national level?*

## 1.2. PLAN OF THE STUDY

This study can be divided in two parts. The first part introduces the objectives (Chapter 1), methodology (Chapter 2) and assumptions (Chapter 3) of the research. In the second part sustainable management systems for timber production in the area of research are defined, financially evaluated (Chapter 4), and lastly compared to other land use options through an exploration of several forestry-oriented policy scenarios (Chapter 5).

Chapter 2 presents a description of the area of study (Section 2.1) and of the deforestation rates in Costa Rica (Section 2.2). Section 2.3 focuses on the methodology developed by REPOSA, for the valuation of alternative land use scenarios (SOLUS: Sustainable Options for Land USes). The methodology is based on a linear programming model, two technical coefficient generators, respectively for livestock and cropping activities, and a geographic information system (Schipper *et al.*, 1998; Bouman *et al.*, 1998b).

In order to extend the SOLUS methodology for the analysis of the tropical forest three assumptions have been made (Chapter 3). The first assumption states that policy makers aim at increasing social welfare, and that the concept of social welfare is linked with that one of sustainable development (Section 3.2.1). When forestry is concerned, the concept of sustainable development assumes a complex meaning, because of the global public good aspects of natural forest. Furthermore, in forestry there are different levels of decision-makers and thus multiple, often conflicting, objectives (Section 3.2.2). The problem becomes more complex when inter and intra-generational aspects are taken into account. In this context, a social welfare function should integrate the concepts of efficiency, equity and environment. Since such functions are not available in the neoclassical framework (Section 3.3.1) what should be done in order to explore sustainable patterns of development for natural forests? In non-protected areas, private landowners are the relevant decision-makers regarding land use. Therefore, in land use planning for non-protected areas the forestry land use options relevant at the local level (relevant for the decision making of landowners) are related with the production of timber (Sustainable management of tropical forests for timber production). In such case, the neoclassical framework can be still useful in quantifying the conditions that must be met to promote sustainable development of natural forests (see Section 3.3.2).

Several sustainable natural forest management systems for timber production for the Northern Atlantic Zone of Costa Rica (NAZ) have been designed and financially evaluated in chapter 4. Section 4.2 presents an overview of the silvicultural systems that can be adopted in the tropics. In Section 4.3 are presented the assumptions that have been undertaken in this study to design the forest land use systems (LUSTs) for the NAZ. The financial evaluation of the forestry LUSTs, conducted in Section 4.4, show that sustainable management of tropical forests for timber production can be an attractive land use option for landowners under certain conditions. Therefore, non-economical considerations play an important role in explaining deforestation.

The inclusion of the forestry LUSTs in the regional model of REPOSA allows to compare natural forest with other land-use options (agricultural crops and pasture). In Chapter 5, several policy scenarios forestry-oriented are bio-economically evaluated in order to explore under which conditions sustainable forest management for timber production is an attractive land use option for private landowners in non-protected areas. In the concluding chapter some final considerations are presented, which discuss the present state of the art and explore some possible directions for further development of the research on the tropical forests in the NAZ.

## 1.3. LIMITATIONS OF THE STUDY

Regional agricultural planning can be seen as a form of "intermediate level planning of sectors and regions within the national economy. [...] Macro-planning sets, among other things, guidelines for sectoral growth, but usually does not deal with investment projects and their spatial distribution. Project planning goes into great detailed of costs, benefits, organization and financing, but takes as given the broader socio-economic framework in which the project operates" (Fresco *et al.*, 1994, pag.13). It follows from the above definition that in regional modeling the level of specification is an intermediate solution between the level of specification proper of project-level planning and the macro level.

In regional planning one challenge regards how to manage the tension between different levels of aggregation. Fresco (1994b), distinguishes two extreme approaches: on one hand there are the studies of "the explorers" which focus on rapid, explorative methods with a limited number of options; on the other hand, "the holy grail seekers" focus on detailed, farm-level studies with strong participation of social scientists. The challenge for the analyst is to go beyond the explorative method without become lost in too much detail. There are not general formulas for applying this principle and the solutions to this type of problems can be found only case by case and are based on the experience and ability of the researchers. In this study one problem was to define which types of forestry LUSTs should be used for the NAZ region. Another problem was to determine which information should be used in designing each forestry LUSTs. The solutions adopted in this study, discussed in Chapter 4, have been found in collaboration with researchers of CATIE and REPOSA. These solutions have been defined in the effort to maintain into acceptable levels the loss of heterogeneity and detail that inevitably occurs when scaling up from the farm level to the regional level.

In literature it is stressed the importance of keeping modest about the contributions of land use planning since the risk of rising expectations is real (Fresco, 1994b). The analysis of scenarios is not a prediction and it is important to recognize that this type of analysis is not sufficient for the sustainable development of land use (although it is necessary).

## 2. THE RESEARCH AREA AND THE SOLUS METHODOLOGY

### 2.1. THE NORTHERN ATLANTIC ZONE OF COSTA RICA

The Northern Atlantic Zone (NAZ) is located in the northeastern part of Costa Rica, with a total area that covers about 447,000 hectares (Figure 2.1). Of the 334,000 hectares biophysically suitable for agriculture only 279,000 hectares are actually available for agricultural activities since about 55,000 hectares are protected for nature conservation. Two land use types dominate about 87% of the total area: primary and secondary forests (48%) and animal husbandry (39%). The remaining 13% of the soil is used for banana plantations and crops (Bouman *et al.*, 1998b).

The areas of the NAZ have been sub-zoned by researchers of REPOSA and the input-output relations related to different agricultural activities have been geo-referenced according to the types of soil. Originally Nieuwenhuyse (1996: 21) has subdivided the soils of the NAZ into 8 groups:

"1: Old, strongly weathered, well drained clayey soils (about 126.000 ha)
2: Moderately to imperfectly drained clayley soils, developed on sedimentary rock in the Talamanca cordillera (about 19 000 ha)
3: Young soils developed on well drained, sandy sediments derived from the Central cordillera (about 138 000 ha)
4: Young soils developed on poorly to imperfectly drained, sandy sediments derived from the Central Cordillera (about 11 000 ha)
5: Young soils developed on fine textured sediments derived from the Central Cordillera (about 133 000 ha)
6: Soils developed on ash deposit under extremely humid conditions (about 18 000 ha)
7: Soils developed on sediments from the Talamanca Cordillera (about 27 000 ha)
8: Peat soils (about 68 000 ha)"

In order to contain the complexity of the REPOSA model, these 8 groups have been successively re-aggregated in 4 main groups (see Bouman *et al.*, 1998b) according to their features with respect to fertility and drainage (see Figure 2.2):
-SFW- fertile well-drained soils (soils of the 3$^{th}$ group and part of the 7$^{th}$ group in Nieuwenhuyse, 1996)
-SIW- infertile well-drained soils (1$^{th}$ group)
-SFP- fertile poorly-drained soils (groups 4$^{th}$, 5$^{th}$ and most of the 7$^{th}$)
-NS- soils not suited for agriculture (groups 2$^{th}$, 6$^{th}$ and 8$^{h}$).

The first type of soil comprehends, in majority, young soils developed on well drained, sandy sediments derived from the Central Cordillera. These soils account for about 138.000 hectares. Infertile and well-drained soils (SIW) account for about 126.000 hectares of old, strongly weathered, well-drained clayley soils. The group of fertile poorly drained soils (SFP) is the most heterogeneous, because in this type are grouped young soils developed on poorly to imperfectly drained sandy sediments (about 11.000 hectares) as well as fine texture sediments derived from the Central Cordillera (about 133,000 hectares). Also the main part of the soils developed on sediments from the Talamanca Cordillera (about 27,000 hectares) are classified as SFP.

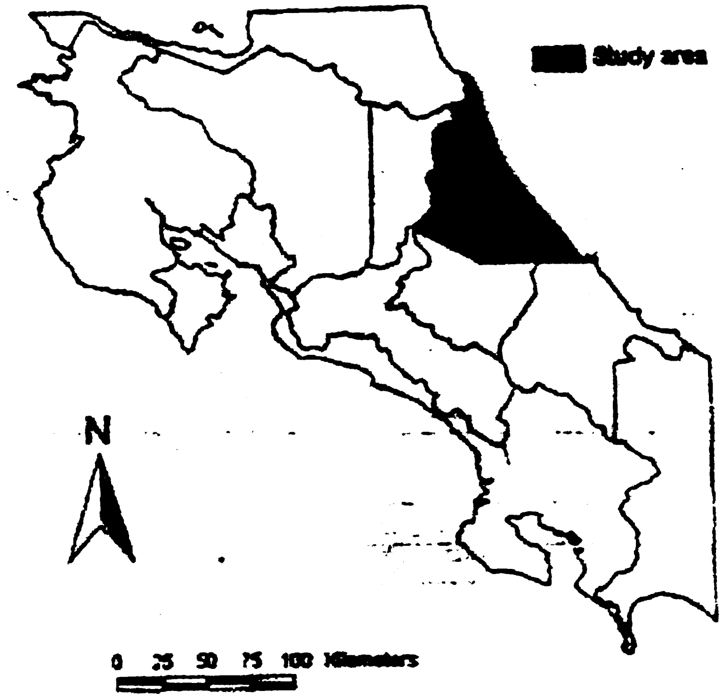
In the last group, non-suitable for agriculture, there are soils moderately to imperfectly drained developed on sedimentary rock in the Talamanca Cordillera (19,000 hectares); soils developed on ash deposit under extremely humid conditions (about 18,000 hectares) and peat soils (about 68,000 hectares). The NS soils have not been included in the model of REPOSA because of their unsuitability for agricultural activities and because the type of forest which occurs mostly in these sites is peat swamp forest not interesting from a commercial point of view (Lamprecht, 1989, Quirós, pers. comm.).

## 2.2. Deforestation rates in the Atlantic Zone of Costa Rica

In Costa Rica the high rates of deforestation of the last 40 years can be related to external factors such as regional development subsidies and macroeconomic policies that favored cattle production. According to FAO (1993a) 1,118,000 hectares of forest have been cleared in the period 1950-1977 (41,000 hectares per year) and 600,000 hectares in the period 1977-1987 (60,000 hectares per year). At present, in Costa Rica should be left approximately 1 million of hectares of moist forest (half of which are protected) and 300,000 hectares of swamp forest, severely degraded forest and mangrove forest. The forest coverage passed from 80% to 25% in the last 50 years (Quesada, 1990) (see Figure 2.3). Repetto and Cruz (1992) states that in the period from 1966 to 1988 deforestation took place in 44.3 % of tropical dry forest, 28.3% of tropical wet forest, 36.5% of tropical moist forest, 43.4% of premontane wet forest and 27.1% of premontane moist forest.

Several causes have been pointed out in order to explain deforestation:
-traditionally the legislation considered forest as a threat to development and as an obstacle to communication, agricultural expansion and trade (Romejin, 1987, Quesada, 1990).
- governmental support of cattle raising through increasing credit availability (Cattle raising used 21% of the total agro-pastoral credits in the year 1958, while in 1974 this had increased to 59% (Romejin, 1987).
- inefficient forest exploitation due to the fact that harvest is limited to few of the commercial species and also to the harvesting process that limit the utilization of the timber exploitable (Quesada, 1990)
-demographic boom which has seen a triplication of the population between the year 1950 and 1985.

In the Atlantic Zone, deforestation trends have been studied by Veldkamp *et al.* (1992). Deforestation took place on a large scale in the period 1960-72, mainly due to the introduction of banana plantations into the study area (15,150 ha of forest were cleared during this period). Accessibility is another important factors in explaining the high deforestation rates. In the NAZ deforestation took place preferentially among the rivers before 1960. With the expansion of infrastructures, access to forest shifted from rivers to roads and the importance of rivers to the process of deforestation decreased. Initially, deforestation took place mainly in fertile soils and only after 1981, when there were was hardly any fertile soil left under forest, relatively infertile soils have been cleared.

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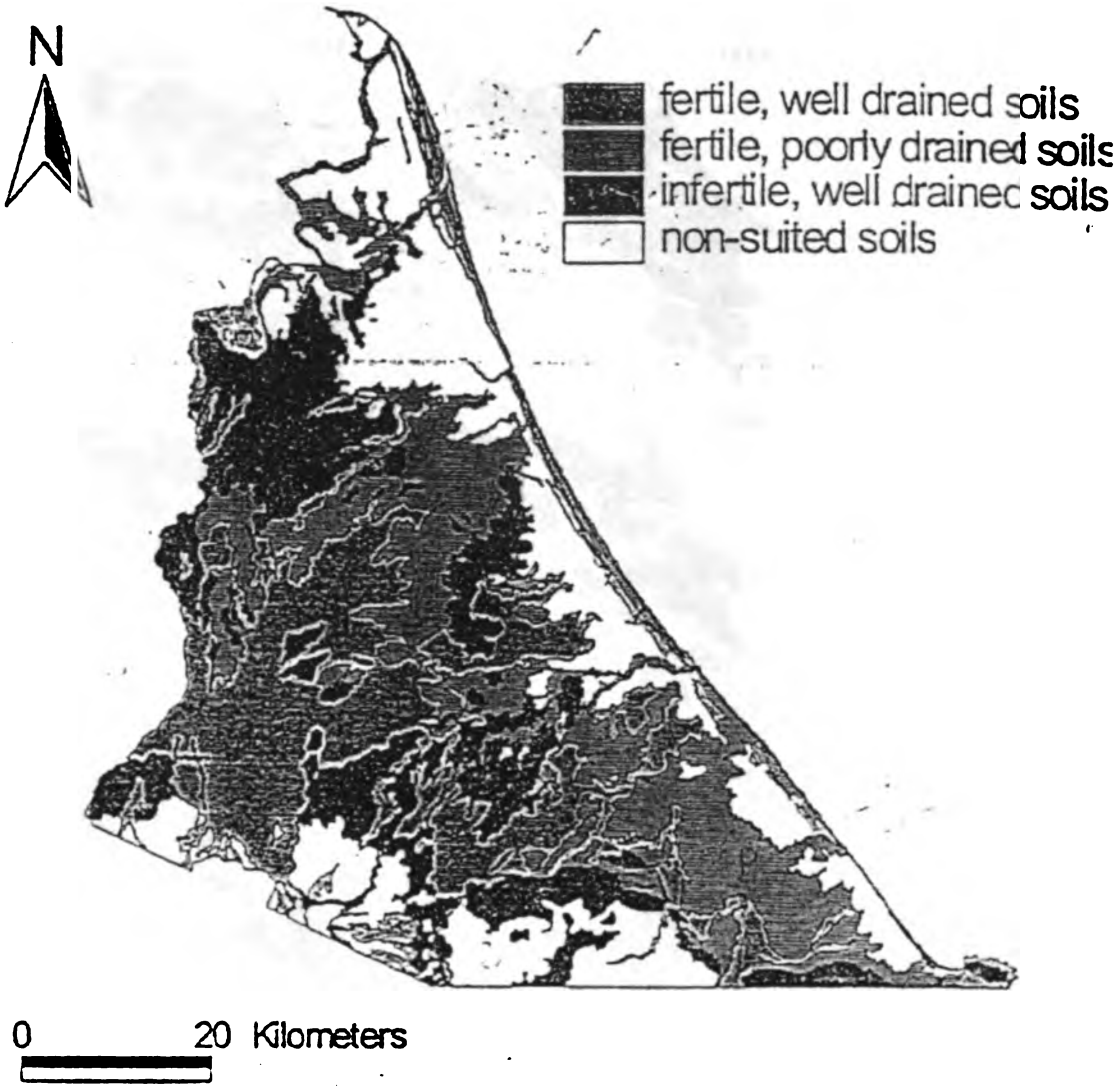
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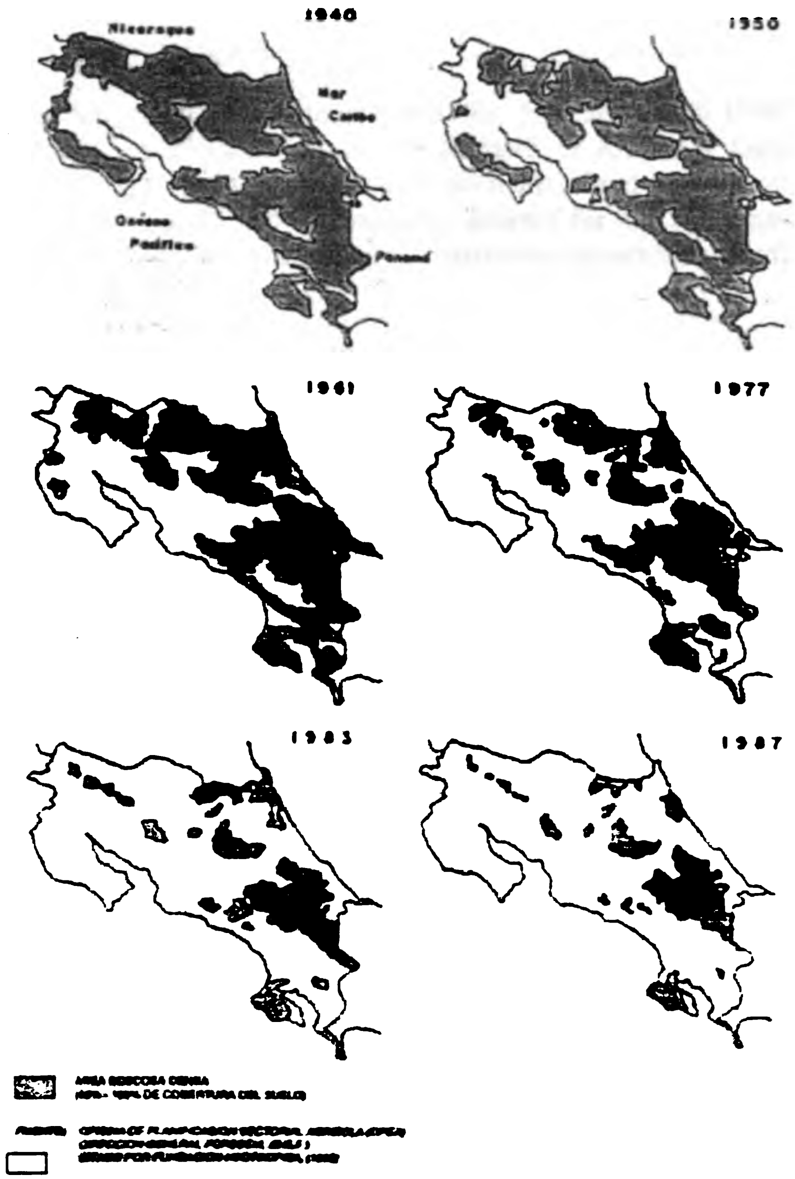


**EVOLUCION DE LA DEFORESTACION EN COSTA RICA ENTRE LOS AÑOS 1940-1987**

## 2.3. THE SOLUS METHODOLOGY

After an initial phase that lasted for 5 years (1986-1990) and in which disciplinary investigation was carried out, the research of REPOSA focused on the development of a methodology for the evaluation of alternative land use scenarios. The SOLUS (Sustainable Options for Land USe) methodology adopted for this study has been developed by REPOSA for the analysis and evaluation of alternative scenarios for profitable and sustainable land use at the regional level.

The SOLUS methodology is defined by a number of sequential steps consisting of data collection, scenario definition, solving the optimization problem, presentation and interpretation of results. The methodology explicitly integrates socio-economic, agronomic and environmental factors. An important objective of this methodology is to show the trade-off that exists between various policy goals and their effect on land use. Variation at the regional level is dealt with by dividing the region into a number of relatively homogeneous sub-regions, each with its own set of data. The NAZ has been zoned in 12 sub-regions on the basis of transportation costs (Bouman *et al.*, 1998b).

The SOLUS methodology consists of *i)* a linear programming model, REALM (Regional Economic and Agricultural Land-use Model), *ii)* two Technical Coefficient Generators, one for crop activities, LUCTOR (Land Use Crop Technical coefficient generatOR, see Hengsdijk *et al.,* 1998), and one for livestock activities, PASTOR (Pasture and Animal System Technical coefficient generatOR, see Bouman *et al.*, 1998a), *iii)* a geographic information system.

The linear programming model maximizes consumer and producer surplus, subject to constraints related to resources and indicators for sustainability and environment. Sustainability is quantified through indicators that measure the depletion of the soil nutrient stock. Soil nutrient depletion is dealt with regard to nitrogen (N), phosphorus (P) and potassium (K), while environmental indicators measure denitrification, N-leaching, N-volatisation, biocide active ingredients, and a biocide index (see Bouman *et al.*, 1998b, Schipper *et al.,* 1998).

The methodology analyses different LUST's (Land Use Systems at a defined Technology), which are a combination of a land unit (the soil type), a land utilization type, and a defined technology. Therefore, a LUST describes a unique quantitative relationship between physical inputs and outputs for a specific crop, given a fixed input-output technology. Research has focused on the analysis of the land units, an inventory of existing LUSTs and the design of alternative LUSTs.

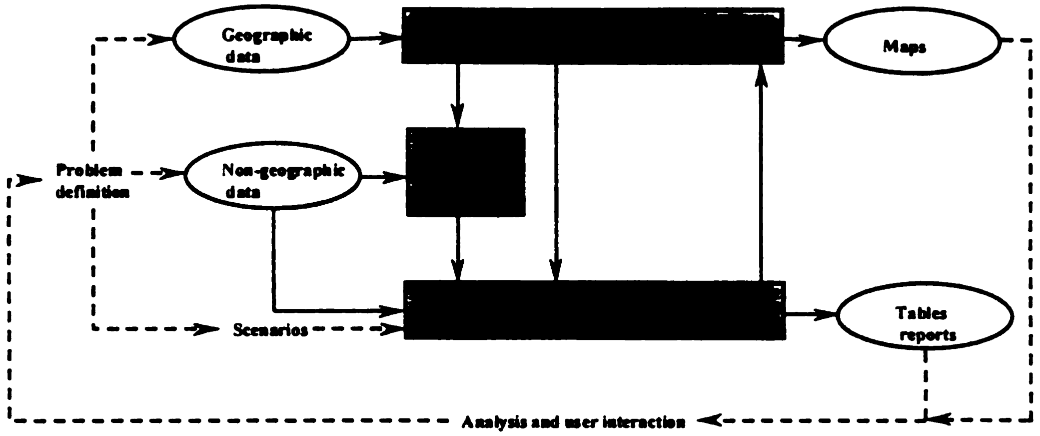


Figure 2.4 Overview of the SOLUS methodology (Schipper *et al.*, 1998)

LUCTOR and PASTOR provide the technical coefficients (inputs and outputs) of the different production systems and the linear programming model select land use options maximizing the regional economic surplus. Technical coefficients include production, costs of production, labor use, sustainability and environmental indicators. Cropping systems include nine products: (black) beans, cassava, maize, palm heart, pineapple, plantain and melina and teak plantations, and natural forests. For each product LUCTOR quantifies actual and alternative cropping systems and the LUSTs are summarized in input-output coefficients. Alternative systems are characterized by optimal combinations of inputs based on knowledge of crop growth (see Hengsdijk *et al.*, 1998). PASTOR generates technical coefficients for pastures, herds and feed supplementing in cattle systems (see Bouman *et al.*, 1998a).

The linear programming model REALM was developed on the basis of the studies conducted previously in two sub-regions: Neguev (Schipper, 1996) and Guacimo (Jansen *et. al.*, 1998). In the model developed for the NAZ region downward-sloping demand functions have been introduced for a number of products for which the share of the NAZ in the national supply and world supply is considerable (Schipper *et al.*, 1998). This has been accomplished by applying a methodology to incorporate variable prices in linear programming models (Hazell and Norton, 1986). In the REALM model for the NAZ, an upward sloping supply function has been introduced for labor. This feature of the model allows to overcome the limitations that result by assuming fixed labor supply and wages (Schipper, 1996; Schipper *et al.*, 1998; Jansen and Stoorvogel, 1998).

# 3. TOWARD THE DEFINITION OF SUSTAINABLE DEVELOPMENT OF TROPICAL FORESTS

## 3.1. THREE ASSUMPTIONS BEFORE PROCEEDING WITH THE ANALYSIS

The crucial role of forestry in sustainable development has been widely recognized after the UNCED Conference of Rio. However, the need to merge conservation and economic development goals for the survival of the forests for future generations is difficult to implement with coherent policies. In this, one of the major difficulties is to harmonize the actions of the different actors involved at the international, national and local levels.

In this chapter three assumptions are discussed in order to use the model developed by REPOSA for the evaluation of scenarios related with forest policies. While in the next Sections the assumptions are discussed more in detail, in this first Section we simply introduce them one by one for the reader that would like to escape theoretical considerations and go directly to the results of the analysis without missing the core of this chapter. The assumptions made in this chapter will be used to make inference on the results of the analysis of Chapters 4 (where a financial analysis of sustainable management of natural forests is conducted) and 5 (where the LUSTs designed for natural forest are compared with land use options related to agriculture and pasture).

The first assumption is connected to the concepts of social welfare and sustainable development. The linear programming model of REPOSA maximizes quasi-social welfare (since income distribution is not taken into account) as regional consumer and producer surplus. Is producer and consumer surplus the goal of the policy maker? And policy makers, in dealing with tropical forestry, are they concerned at the same time with environmental and economic goals? Is it possible, in the context of the research of REPOSA in the NAZ, to associate a practical meaning to the concept of sustainable development of natural forests?

Given the high rates of deforestation in Costa Rica in the last 50 years. the government is looking for strategies that promote sustainable natural forest management in private lands. The first assumption, discussed in Section 3.2, states that that the goal of the policy maker is to promote sustainable development of the natural forests in the NAZ, with a strong interpretation of sustainability, given the high rates of deforestation in the region (see Section 3.2.1). Under this assumption Social Welfare is linked with the concept of sustainable development. However, it will be pointed out that the concept of sustainable development, especially when dealing with forestry issues, is not homogeneous because of the multiple actors with different objective functions (often in conflict with each other) involved in the decision making process (see Section 3.2.2).

Which Social Welfare Function should then be used. given the goal of sustainable development? Once sustainable development has been set as the goal of the policy maker in the NAZ we should choose proper sustainable indicators and a proper social welfare function as objective function to be maximized in order to quantify sustainable development. While for agricultural crops sustainable indicators have been included as constraints that measure the depletion of the soil nutrient stock, with the inclusion of natural forest also the global public good aspects of tropical forests should be included in the analysis. However, it is difficult to establish monetary values given the absence of markets for many non-timber forestry products (i.e. biodiversity, carbon absorption, etc.) (see Section 3.3.1). According to studies that can be found in literature, even when monetary values are assumed for the different functions of the forest, the production of timber results to be the main function of the forest, i.e., other functions play only a small role (the monetary values assumed for them are far lower then the value of timber).

With the second assumption we suppose that, in non-protected areas, the neoclassical framework can be useful in quantifying the conditions that must be met in order to promote the sustainable management of natural forests. This is because it is reasonable to think that private landowners select land use options that maximize their income given market conditions. And since they are not paid for the global public good aspects of tropical forests, these aspects do not influence their decision making regarding land use. Therefore the use of producer surplus as objective function, allows to explore the reaction of private landowners to policy changes. The same reasoning can be applied for consumers, whose behavior can be represented using the concept of consumer surplus. Once compensation for the other functions of the forest is introduced through subsidies for maintaining natural forest, it is interesting to explore how these instruments affect land use by introducing them in the objective function.

Another important issue is concerned with the type of forestry that should be considered in the model or, in technical terms: which forestry land use options should be designed for the non-protected areas of the NAZ? The third assumption, for the same reasons discussed above, states that in land use planning for non-protected areas the forestry functions relevant at the local level (decision making process of landowners) are related with the production of timber (Section 3.3.2).

In summary, we assumed that, given the critical situation of the natural forest in the NAZ, the government seeks solutions that may promote the conservation of natural forest for future generations. This is not a strong assumption, since the government of Costa Rica is currently subsidizing sustainable natural forest management through an annual premium for hectare of land maintained under natural forest. In this way the concept of sustainable development (in its strong interpretation, see Section 3.2.1) and the concept of social welfare are closely related. In this study, however, we use a neoclassical objective function which maximizes producer and consumer surplus in order to explore policy scenarios for non-protected areas, where private landowners are the relevant decision makers regarding land use. The introduction of the three assumptions has been made in order to consider the global public good aspects of tropical forests in the analysis. Using the assumption of rationality of producers and consumers, which are concerned with efficiency (measured through economic surplus), we want to explore the reaction of private landowners when subsidies for natural forest are introduced. In this way the global public good aspects of tropical forests are taken indirectly into account, because subsidies for the preservation of natural forest can be seen as a way to compensate private landowners for the non-timber functions of the forests. This type of analysis can be performed in order to avoid non-sustainable patterns of development. i.e. in order to explore the conditions that must be met (amount of subsidies) for making sustainable natural forest management of natural forest an attractive land use option from the point of view of private landowners (thus avoiding further deforestation).

## 3.2. FORESTRY AND SUSTAINABLE DEVELOPMENT

### 3.2.1. Sustainable development as the goal

The discussion of Section 2.2, showed that no much natural forest is left in Costa Rica, and that the phenomenon of deforestation has reached undoubtedly a critical dimension in the country. In order to contain deforestation the Government of Costa Rica has recently undertaken policies that promote conservation of natural forest in non-protected areas (Quesada, 1990). Yearly subsidies for the conservation of natural forest have been introduced, although they are not sufficient to supply all the landowners that would like to join the conservation program.

Two studies concerned with forestry have been already conducted within REPOSA. The first one, developed by Schipper *et al.* (1998), shows that, without incentives, maintaining natural forest is a choice not economically attractive for landowners that can choose among other land use options related with pasture or agriculture. Another study by Bulte *et al.* (1998) states that the current forest stock of the NAZ is sub-optimally large and that further deforestation increase social welfare.

In this study we assume that the policy makers are concerned with sustainable development rather then with pursuing economic growth only, thus extending the concept of social welfare (see Section 3.3.1). The use of the term sustainability is criticized by some authors for the impossibility to define it properly (Beckerman, 1992), while, others, see the solution in "a more appropriate conceptualization of the interdependency of the economy and the environment" (Victor, 1991: 211). Although in literature the concept of sustainable development has many interpretations, a general definition is the one proposed by the Bruntland Commission (WCED, 1987: 43): "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

"A working definition of sustainable development", proposed by Pearce *et al.* (1990: 24), "might be as follows: it involves maximizing the net benefits of economic development, subject to maintaining the services and quality of natural resources over time". The maintenance of natural resources over time implies *i)* the utilization of renewable resources "at rates less than or equal to the natural rate at which they can regenerate" and *ii)* the optimal use of non-renewable resources "subject to substitutability between resources and technological progress". Behind this definition there is the idea that "*the resource stock should be held constant over time*" (Pearce *et al.*, 1990: 44) although "capital, both natural and manmade, can be maintained at various levels (Daly, 1990: 2). The interpretation of constancy of resource stock depends on "the degree of substitution between renewable and exhaustible resources, and between man-made capital and natural capital (Pearce *et al.*, 1990: 52). Victor (1991) points out the danger in the use of the term "capital" to describe the environment, since "there is an implicit assumption that it can be substituted by other forms of capital, that is reproducible and that it is there to be managed in much the same way as manufactured capital (p.210).

A weak interpretation of sustainable development focuses on the transfer, from one generation to another, of an "aggregate capital stock no less then the one that exists now" under the assumption that there is perfect substitution between different forms of capital (Turner *et. al*, 1994: 56). If this assumption is not taken into account, there are particular assets, the *critical natural capital,* which must be protected since they are not easily substitutable. Given the high rates of deforestation in Costa Rica, the concept of sustainable development has been interpreted in its strong interpretation in this study.

The Thermodynamic school suggests to "approach the question of sustainable development and its indicators through the imposition of a set of biophysical constraints on an economy. These constraints would define the conditions of sustainability in direct biophysical units. The shadow prices of the constraints could be used to indicate the degree to which an economy is not sustainable" (Victor, 1991: 211). The SOLUS methodology, applied in this study, is such an approach, although for the application to forestry issues some other considerations have to be made.

### 3.2.2. Conflicting objectives at the policy levels

An important question that arises when talking about sustainable development of forests is: are conservation and economic development conflicting objectives? The answer seems to be affirmative, and, in this Section, a brief overview based on Sharma (1992) of the different actions needed at the global, national and local levels, will explain why. The issue can be seen over several levels that involve different actors with different objectives that often are in conflict with each other. In most tropical countries there is an increasing demand of land for agriculture and for forestry products from local people that strive to fulfill their basic needs. On the other hand, the international organizations stress the importance of maintaining intact the forests in order to preserve certain important functions for the welfare of future generations (regarding the biodiversity, the need to contain the greenhouse effect, etc.).

At the national level, politicians are confronted with the pressures, from international institutions, which promote conservation of the tropical forests. On the other hand, local people, move toward the more remunerative land use options. From such considerations the difficulties that arise in the effort to harmonize the policy strategies directed at the local, national and global levels, become clear.

The crucial role of forests in sustainable development has been widely recognized at the global level in the past 20 years (Thompson, 1996). International organizations emphasize the importance of maintaining intact the forests in order to preserve the biodiversity and to contain the greenhouse effect. However, as Sharma points out, "there is the need for a major global research effort to address deforestation and associated environmental problems". The issue of sustainable development of forestry has been widely debated at the global level and several initiatives has been undertaken by international organizations. who emphasize the need to consider the welfare of future generations. Examples of these initiatives aiming at the conservation of forests are the Debt-for Nature swaps (DNS) and the Global Environment Facility (GEF). Other important initiatives are the Tropical Forestry Action Plan and the International Tropical Timber Organization. The main issues discussed at the global level are the necessity to develop a global perspective on forest policy and to formulate a common agenda for the sustainable development of forest resources. This is not an easy task, since tropical forest are concentrated in developing countries where often the concern for environmental problems is secondary to the need to promote economic growth. In this sense it is important to develop international legal measures for cost sharing and benefit distribution related to the global benefits derived from tropical forests.

At the local level it is important to promote participation of the local people to ensure the sustainable development of forests, which are unlikely sustainably managed without the direct involvement of people that depends on these resources. Another important topic that must be ensured at the local level is the establishment of clear property rights. The definition of transparent land and tree tenure systems is crucial to promote long term investments. Often wastelands have been treated as open-access resources that have been characterized by multiple use. In such cases common management systems (such as the joint management system) can ensure an utilization of the forest that doesn't affect negatively the environment and that is socially acceptable (Wiersum, 1996).

From the above considerations it is clear that the decision making process related with forest issues is characterized by multiple objectives and multiple actors. The high level of complexity, deriving from the different pressure groups, is particularly evident at the national level, where normative decisions on land use are actually carried out. The national level can be seen as the crucial node where sustainability issues must be actualized. At this level, both the guidelines and criteria designed at the international level and the needs of the local people converge.

At the national level actions are needed to achieve the conditions necessary for transition to conservation and sustainability. These include the need to establish environmentally sound land-use policies that may provide guidance for public investment decisions and to strengthen forestry institutions. Among these policies priority must be given to favor the regulation of the allocation of concessions and forest fees that often are done arbitrarily. Also it is important to promote tree planting through incentives and to formulate plans regarding the forest ecosystem management.

Regarding the necessity to improve agricultural policies, it must be emphasized that policy makers sometimes consider forestry areas as waste area that is subject to improvement when converted to agriculture. This is a perspective probably influenced by the awareness of the needs of local people but, on the other hand, is in contrast with the objectives that have been pointed out at the global level. At the international level is predominant the tendency toward conservation, in order to minimize the negative effects of deforestation on the climate, to contain the greenhouse effect, etc.

Another important aspect to be pointed out is the necessity to promote the development of an efficient forest-based industrial sector, which is often prevented by macroeconomic instability. As an example an import-substitution policy can be the main factor that prevent the growth of an efficient industry. Even if this policy can be justified in the short run with the infant industry argument, in the long term it has been stressed the importance to establish outward looking strategies that can stimulate the growth of a competitive industry sector.

3.3. WHICH SOCIAL WELFARE FUNCTION SHOULD BE USED?

### 3.3.1. A critical review of the neoclassical approach

In the previous Section the fact that in forestry we have multiple actors or decision-makers, and thus, multiple goals, has been discussed. This means that the economic framework of reference is characterized by multiple objective functions to be maximized. Which of these functions are to be maximized? And if the environment has to be taken into account when maximizing social welfare which social welfare function is to be maximized? A brief review of the main characteristics of welfare economics will show how the neoclassical framework is inadequate to address properly sustainability issues.

Welfare Economics, inspired by the philosopher Bentham, became an autonomous field of study with Pigou (1920). Pigou proposed a theoretical framework with cardinal utility, allowing interpersonal comparisons in the hypothesis that utilities of different individuals could be objectively measurable and that therefore it would be possible to come to the utility of the entire society by summing up the utilities of its members.

With the affirmation of the ordinal utility paradigm, proposed by Pareto, the goal of Welfare Economics became the definition of an ordering of social welfare, a complete and coherent classification of the different economic configurations socially admissible. The Paretian ranking, on the basis of the studies of Scitovsky, resulted incomplete and Hick and Kaldor proposed a social rule based on the principle of potential compensation.

The difficulties that arise in applying the compensation principle of Hicks-Kaldor to problems of distributional justice, and the results of the two theorems of welfare economics[1], moved some economist in searching for solutions that would allow the introduction of specific value judgments in welfare economics. Bergson (1938) proposed a Social Welfare Function (SWF) in order to constitute an ordering of the preferences relative to the possible states of an economic system[2]. The main problem that economists face in this analysis lies in the definition of the bergsonian social welfare function. Another crucial issue is linked with the problem of defining social preference from a set of individual preferences. In his Social Choice Theory, Arrow (1963) proposed a rational method for the aggregation of individual

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[1] The two theorems of welfare economics explicited the properties of the competitive equilibrium. Next to that the crucial role of the government was recognized for the redistribution of resources between economic subjects, in order to reach an economic configuration that would also be coherent with the principle of equity. The role of the public authority is also decisive in situations of market failures (Cornes *et al*, 1985, Dick, 1976, Wellisz, 1964).

[2] Following Sen (1986, pp.1975), two independent interpretations of the SWF can be made. The first one is introduced under the hypothesis that, if "the relevant information about the social states in set X can be obtained, then such a social welfare function might as well be thought to be a real-valued function defined on X. If the issue of numerical representation is not emphasized, this really amounts to an ordering R of X".

A second interpretation is to define Social Welfare as a function of the vector of the individual utilities: W= W($\underline{u}$). In this way the preference relation R is not anymore a function of the n-tuple of individual orderings ($R_i$), but of the n-tuple of individual utility functions $\{U_i(.)\}$. Therefore, this approach defines a Social Welfare Functional (SWFL) that specifies a social ordering of the set of social states X, for any given n-tuple $\{U_i(.)\}$ of individual utility functions of the members of a society.

preferences, through social choice functions that specify "one social ordering R for any given n-tuple of individual orderings, $\{R_i\}$ one ordering for each person, $R = f(\{R_i\})$.

Arrow pointed out that, in capitalistic democracies, there are two main methods to formulate social choices: vote (politic choices) and market mechanism (economic choices). These two methods allow an aggregation of individual preferences into a social choice. The challenge was to find out a formal procedure that would allow to arrive to a social choice from given individual preferences. The result of Arrow, known as impossibility theorem, demonstrates the impossibility to define such a social choice function that satisfies the conditions of unrestricted domain, non-dictatorship, independence of irrelevant alternatives, and Pareto principle. Therefore, under the hypothesis of interpersonal incomparability of utility functions the only methods, satisfactory and defined for a wide range of sets of individual orderings, will be imposed or dictatorial, i.e., expression of the preferences of some specific person at the exclusion of others.

The results of Arrow stimulated other researchers toward other possible solutions that could allow an overcoming of the impossibility theorem. In this context the study of Sen followed two main directions: the renunciation of one of the basic hypothesis of Arrow and an enlargement of the information system allowing extra-utilitarian information.

Sen (1977) pointed out that every condition used in the analysis of Social Welfare act as an informational constraint, or, in other words, excludes some information. In this sense the social judgment values will not depend on such information that has been excluded. This informational poverty plays a key role in the impossibility theorem. The main cause of the result of Arrow lies in three points that characterize the Social Choice Theory: Ordinal utilitarianism, welfarism and impossibility of interpersonal comparability. Regarding the first two principles, Sen demonstrates their inadequacy to consider the motivations underlying the relations of individual preference[3]. Therefore, it is impossible to discriminate between different problems of choice.

In order to avoid an excessive generalization in social choice theory, Sen (1986a) distinguishes four general categories of problems of choices:
1-aggregation of individual interests for judgments on social welfare (named problems of the type IW);
2-aggregation of individual interests for social choices, (ID);
3-aggregation of individual judgments for social judgments on welfare (JW);
4- aggregation of individual judgments for social choices (JD).

Sen (1986a) demonstrated that if, on the one hand, the classic scheme of Arrow is adequate in problems of aggregation of individual judgments (problems JW and JD[4]), in case of problems that deal with the aggregation of individual interests the results of impossibility are of little

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[3] With the theorem of the impossibility of the Paretian liberal, Sen demonstrated that to evaluate social states. according to a principle of "minimal liberty", it is necessary to use information underlying individual preferences (Sen, 1986b).

[4] For this second category the validity of the impossibility theorems is more evident. although. as Sen points out. the advantages obtained when going from welfare relations to choice functions have been overvalued (cfr. Sen. 1986a, pag.228)

interest[5]. Furthermore, given the high number of policy problems of the type IW and ID, the necessity of an adequate theoretical framework is evident. Problems of public economic planning generally fell in the categories of aggregation of individual interests for social choices or for judgments about social welfare. These considerations have important implications in approaching problems related with social choice theory, and call for the adoption of a specific framework of reference according to the type of problem we face.

About the interpersonal comparison of welfare levels, the results of Sen extended the framework of traditional Welfare Economics. The author individuates intermediate situations of partial interpersonal comparability that regards either the levels of welfare (according to the maxmin criterion of Rawls and, in general, with the criterion of equity) or the units of welfare (in relation to the utilitarian framework) (Sen, 1986a). In the search for an alternative theoretical paradigm, capable of overcoming the limits of the neoclassical approach, Sen developed the theory of capabilities (Sen, 1987). This theory seems particularly interesting in the analysis of public investments, especially because of its ties with specific disciplines, such as Applied Ecology, that studies the relationships between individuals and the environment.

### 3.3.2. Sustainability and economic value of the functions of the tropical forest

In the previous Section the importance to adopt a specific framework of reference, according to the type of problem we face, has been pointed out. The SOLUS methodology measures social welfare through economic surplus, as an approximation of the equivalent variations (Willig, 1966, Hicks, 1943). Can the introduction of biophysical constraints include properly sustainability issues into a methodology designed for land use planning?

REPOSA researchers, in dealing with agriculture products, addressed sustainability through biophysical constraints related to the balance of nutrients in the soil, and the pollution deriving by the use of biocides. When forestry is concerned, the global public good aspects of forests should also be considered in the analysis. If optimization models are used in order to quantify "optimal forest stocks", the presence of market failures prevents the possibility to reach first best solutions. Which set of prices is to be used for non-timber forest functions such as biodiversity, carbon absorption etc.? Some studies use for the different functions of the forest a set of prices derived through contingency valuation methods. This approach has been seriously criticized in literature (Hanley *et al.*, 1993, Hof, 1993, Wenz, 1988, Westman, 1985) and the adoption of an objective function where the different functions are monetarized gives to the prices a determinant role in the decision making process[6]. In words of Hof (1993:175): "there appears to be growing sentiment that an economic objective function (maximizing net benefits measured with a pecuniary numeraire) is not appropriate for forest management, especially in the public sector. To the degree that this viewpoint should develop into a public mandate, I would like to point out that even if we abandon an economic numeraire – a monetary measure of goods and bads- it does not mean that we should abandon

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[5] SEN, *ibidem* . pag.227.

[6] The neoclassical approach "generally uses "prices" for environmental goods estimated through the concept of willingness to pay, that is, it attributes a value that corresponds to utility derived directly or indirectly (option, existence and bequest value) by the current generation. Whereas now the WTP assessment is generally satisfactory for direct use values, when it comes to other elements comprising the total economic value of resources, the limitations of assessment made by the various approaches of contingent valuation become evident and unfortunately, this latter component of the value of natural resources is usually the most important". (Casini *et. al.*, 1996).

the economic logic of efficiently allocating scarce resources. Perhaps a new "net benefit" objective function will evolve that is more biological then economic; it would then still be very useful to apply the economic logic of using scarce resources only up to the point of equal marginal "benefits" and "costs" defined with the new numeraire such as carbon, or energy, or whatever".

An example of such approach is a methodology developed for the analysis of public investments based on Sen's theory of well being (1985a and 1985b). This theory constitutes an interesting basis for the definition of criteria that could be used for a better evaluation of the environment in social decision processes. In fact using categories as "functionings and capabilities allow the transposition of many principles of applied ecology into terms of social well being. They greatly reduce the imperfections caused by the use of the neoclassical concept of utility on the evaluation of the effects of public projects on the territory and environment" (Casini *et al.*, 1996). Study cases that use a non-neoclassical social choice function have been made within the context of the MCDM methods (Zeleny, 1992). The use of such methodologies allows a multidimensional representation of the decision process because of the possibility to consider multiple objective functions related to the decision-makers (Casini *et al.*, 1996, Bernetti *et al.* 1993, 1995, Marcianò, 1997, Marcianò *et al.*, 1999).

While for the investments of the public sector an estimation of the effects pose the question of how to measure sustainable development, in land-use planning for non-protected areas the private sector is the relevant decision maker. Thus, it can be considered worthwhile to focus only on the reaction of the private sector to market or institutional changes, and on exploring how land use is affected by such changes. In this way the neoclassical framework can be very useful in quantifying the conditions that must be met in order to promote sustainable development of forests. It is possible, for example, to explore scenarios in order to measure the levels of subsidies that must be granted to the private sector in order to make sustainable forest management competitive with more remunerative land use types. The subsidies can be interpreted as a way to compensate the private sector for the global public good aspects of tropical forests. In this way a neoclassical objective function measuring economic surplus can describe the effects on land use caused by policy changes. However, since the choices of the private landowner regarding land use will affect the society as a whole, it must be remembered that this kind of objective function does not consider properly intra-generational or inter-generational problems and it can be used mainly in order to avoid non-sustainable patterns of development (see Section 3.2.1). For private landowners it is important that natural forest management is financially attractive when compared with other land use types. When considering the land-use option of natural forest, timber is one of the main forest-product that can constitute a source of income for the private sector. Therefore, in the next chapter of the study the focus will be on the design of sustainable natural forest management systems for timber production.

# 4. SUSTAINABLE FOREST MANAGEMENT SYSTEMS FOR TIMBER PRODUCTION IN THE NAZ

## 4.1. INTRODUCTION

The crucial role that sustainable forest management systems play in tropical America has already been pointed out (see FAO, 1993a), and shifting cultivation, the expansion of export agricultural crops and animal husbandry have been identified as the main causes that results in high rates of deforestation. This is particularly evident in Costa Rica, where FAO (1993a) estimated a decrease of about 2 million hectares of forest in the last 50 years (see Section 2.2).

Even if in literature much emphasis is given to the role of sustainable management of natural forest, it seems still to be an open question if, for private landowners, the financial results of natural forest are attractive compared to others types of land use. The fact that deforestation is a phenomenon that is going on in Costa Rica can be an indication of the low confidence private farmers have on natural forest. Forest mining is a major factor in explaining deforestation, since there are few possibilities to reestablish reasonable yields from forests once they are strongly compromised by non-sustainable harvesting. Lack of information is another important factor that prevents the adoption of sustainable natural forest management at large scale; in the diffusion of such knowledge the extension services play a key role.

Another important issue is related to the discount factor to be applied for the financial analysis of forests. However, it could be argued that the possibility of a first harvest in the second year (for forests in good conditions) can make sustainable forest management very attractive from a financial point of view even using high discount rates (Quirós & Finegan, 1994a, Quirós & Gómez, 1999). In this sense deforestation can be seen as a spiral phenomenon: the more a forest is degraded through forest mining, the less possibility there is to make financially attractive management plans. On the contrary, in reasonable fertile soils, the less a forest degraded by non-sustainable practices, the more likely it will be that it is financially attractive to introduce it into sustained natural forest management by planning a first harvest in the beginning of the management plan (an evidence of this statement can be found in Section 4.4.3, see also Section 5.2 on good and bad forests).

Another controversial issue is related to the land use types to be promoted in infertile soils. FAO (1993a) states that "there are 2 strong arguments in support of management for the production of timber in natural tropical forests. The first is that no ecologically satisfactory alternative land uses to natural forests are to be found for many tropical sites because they are too infertile for agriculture. Secondly, wood having the qualities found in many types of tropical forests cannot be produced as cheaply, in large dimensions or in the quantities required to meet present and future industrial requirements from intensively managed plantations on the same infertile sites. Maintaining the land under a permanent forest cover. and adopting a planned basis of sustained yield management within an overall, sustainable forest management plan, is usually the most appropriate long-term development strategy."
The FAO's statements clearly point out that natural forest management would be the most suitable land use in infertile tropical soils. However, in this study we address the possibility that in the infertile soils the conversion to cattle ranching is more convenient than natural

forest management and that the latter is particularly attractive in fertile but poorly drained soils (see Section 4.4.3.).

The purpose of Chapter 4 is to specify detailed natural forest LUSTs for the NAZ. In Section 4.2 are introduced the main characteristics of the tropical silvicultural systems. These features constitute the theoretical base of reference for the proposed enlargement of the information system contained in the model developed by REPOSA. It follows the design of sustainable management systems for the NAZ (Section 4.3). These LUSTs are evaluated financially in this Section 4.4 and successively incorporated in the regional model developed by REPOSA (Chapter 5).

## 4.2. OBJECTIVES OF TROPICAL SILVICULTURAL SYSTEMS

Given the different and heterogeneous nature of the outputs that derive from a forest, the adoption of a silvicultural system for the management of a forest is function of the objectives of the relevant decision-makers[7]. Although there are several possibilities of choice among alternative management systems, in this report the focus is on designing sustainable management systems for timber production. This assumption gives the possibility to focus primarily on designing alternative forest LUSTs with the objective of maximizing the function of profit related to the production of commercial timber. This will make the forest LUSTs comparable with the other agricultural LUSTs designed for the NAZ and to explore the conditions under which the forest LUSTs become attractive at the regional level.

In a natural tropical forest the choice of silvicultural systems is linked to the initial conditions of the forest[8]. If the conditions of the forest make it suitable for the direct introduction into sustained yield management, the silvicultural systems to be adopted are those which are also used for the temperate forests (see Figures 4.1 and 4.2). These conditions are hardly met in tropical forests, and, therefore, in order to ensure the forest into sustained yield management it is often necessary to restructure the original stock through one of the methods which are currently classified as domestication measures (Lamprecht, 1989). These methods can be classified according to the objectives of the decision-maker. The sub-objectives[9] of domestication measures can be identified in reaching either a Selection forest or an Uniform High forest.

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[7] In this chapter we assume that there is homogeneity of objectives among the relevant decision makers. The multiple dimensions involved in forest decision making are linked to the multiple functions of the forest and to the conflicting objectives of the several groups of decision makers. In this chapter, however, these multiple dimensions will be not considered for the economic considerations discussed in chapter 3.3. This does not mean, hovewer, that the necessary conditions that must be met in order to promote sustainability of the tropical forests in the NAZ will not be addressed (see chapter 5).

[8] In this context we focus mainly on natural primary forest, but not excluding mature secondary forest considering that "as a rule one can hardly distinguish between old secondary stands and original climax forest" (Lamprecht, 1989, p.106). The distinction between the two types of forest has been also considered in footnote 11.

[9] Given the general main objective of every silvicultural system to secure sustained silvicultural yield management (see Lamprecht, 1993).

In a Selection forest the goal of sustained silvicultural yield management is accomplished only by homogenization of the stocking stand through one of the different alternative methods present in the literature (see Figure 4.3).

In case of an Uniform High Forest, the sustained silvicultural yield management can be reached through the homogenization of the stocking stand and structure (transformation) or through conversion, replacing the natural forest by pure stands or plantations with fast growing species (see Figure 4.4). Some cases of Uniform High Forest have been already considered in REPOSA. LUSTs for tropical forest plantations (Teak and Melina) have been designed (see Floors, 1997) and incorporated in the models developed in REPOSA (see Nieuwenhuyse *et al.*, in press). They can be seen as cases of conversion since tropical plantations have replaced the natural forest. In the REALM model of REPOSA the allocation of land among alternative uses is dealt through linear programming. At the moment, the case of Uniform High Forest is limited in the model to the mentioned tropical forest plantation LUSTs although, for further development of the research, it could be interesting to enlarge the information system designing new LUSTs either for different species suitable for tropical plantations and/or for some transformation system present in Costa Rica.

The objectives of domestication, as described by Lamprecth, comprise all the actions to be taken in order to improve the economic performance of the forest until the classic silvicultural systems designed for preservation of natural forest productivity can be adopted[10] (see Figure 4.1). In this context, domestication could be seen as an intermediate stage that precedes the undertaking of a classical silvicultural system for sustained yield management. Domestication, interpreted as an "intermediate way of achieving a tropical production forest" (Lamprecht, 1989 p.108), should not be incorporated as an alternative land use type in a regional model designed for long-run simulations for the following economic considerations. The main question could be formulated as follow: Is it useful to include in a regional model domestication measures that can be interpreted as "temporary" LUSTs? The answer is negative if the domestication process is seen as a sort of intermediary step, as discussed above. In the other hand, the nature of the regional model of REPOSA, being a linear programming model, is especially suited for short and medium run simulations. Once the goal of domestication is reached, it could be useful to extend the classical silvicultural system, designed for other forest types of the NAZ, to the forest types originally addressed for domestication measures. This seems a realistic solution, since domestication techniques are actually adopted in the NAZ[11]. Also, domestication measures can be adopted for several rotations, i.e. as long as an economic assessment of the stand determines that it is convenient to improve the structure and the species composition of the forest.

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[10] It should be remembered that with "economic performance of the stand" we are addressing only the function of timber production of the forest. This is because the focus of this chapter is on sustainable forest management system for wood production. The other functions of the forest are secondary in this context. It is useful to do so because it will be possible to simulate the optimal allocation of land among competitive land-use alternatives. This will result in pointing out the conditions that have to be met in order to make sustainable forest management systems an attractive alternative for farmers (see Section 4.3.1.).

[11] As Lamprecht points out "moist tropical primary forests are as a rule either not capable, or insufficiently capable, of meeting the economic demands that have to be made on commercial forests" and also "[...] secondary forests are as a rule insufficiently or not at all suitable for sustained forestry. However, secondary forests should be possibly be given a much more positive assessment where there is a market for pulpwood and other industrial woods. [...] Production can be stabilized by arresting development at the economically desirable stage by means of suitable silvicultural operations"(Lamprecht, 1989, p.106).

In summary, since in many cases a tropical forest cannot be introduced directly into sustained yield management, domestication measures are a common practice in the tropics. Moreover, domestication measures can be implemented for several rotations. In this sense, thinking of domestication measures within a limited temporal horizon, domestication can be seen as "the silvicultural goal" (Lamprecht, 1989, pag.107) and included in a regional model, such as the one developed by REPOSA, for short and medium run simulations in land use planning. Therefore, domestication has been implemented as a definite forest LUST in REPOSA model, suitable for those sites where the conditions of the forests do not permit a consistent sustained yield management without silvicultural treatments.

In the rest of the study the focus will be on, either, selection forest systems or simple sustained yield production through one of the classical silvicultural systems. Therefore, for simplicity, the term domestication will be used to address further only silvicultural systems that aim at the homogenization of the stocking stand mainly only by tree species[12].

[12] This is, obviously, a restriction because domestication includes several types of silvicultural measures designed either for Selection or Uniform High forest, as commented earlier and described in Figure 4.1. However, given the choice to exclude from this study the Uniform High Forest LUSTs (already considered in REPOSA through studies about teak and melina forest plantations), it seems reasonable to use the term domestication in the context of the silvicultural measures considered in the study which aim at a Selection forest.

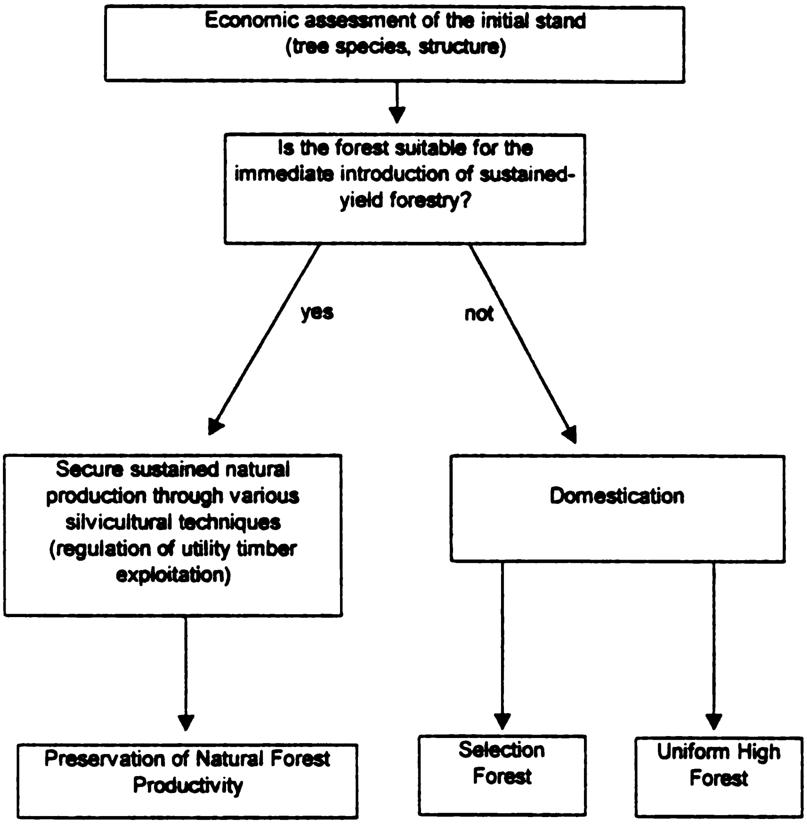


Figure 4.1- The decision making process in selecting a silvicultural system (from Lamprecht, 1986, adapted)

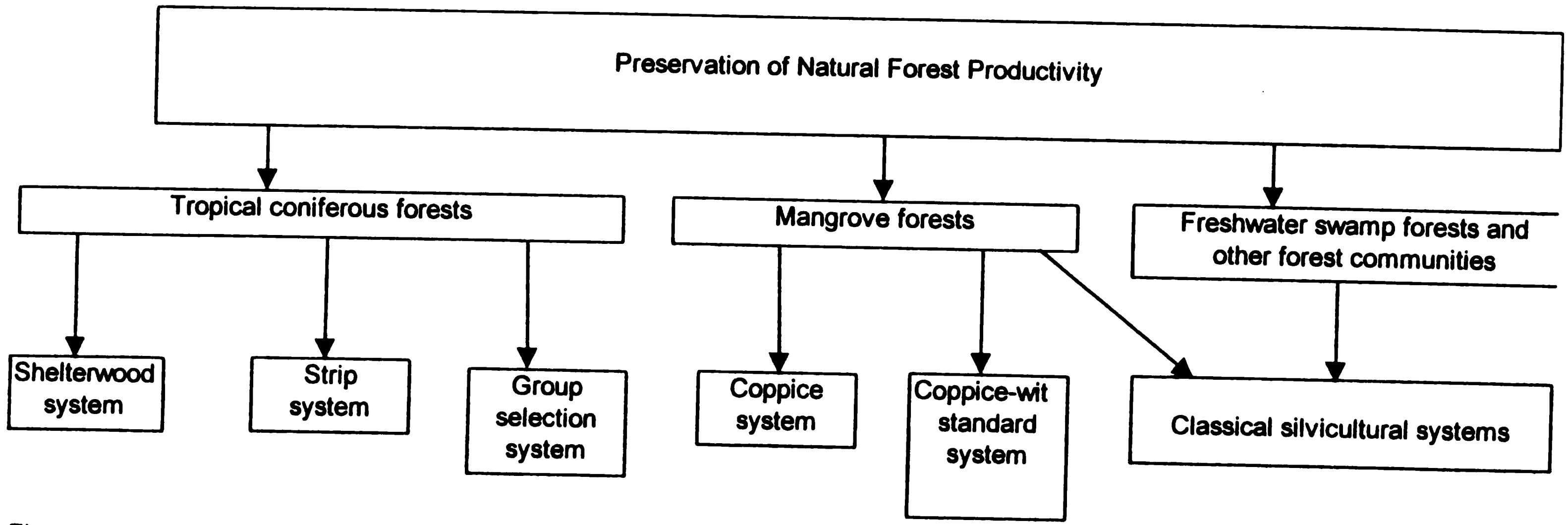


Figure 4.2 -Alternative silvicultural systems for the preservation of natural forest productivity

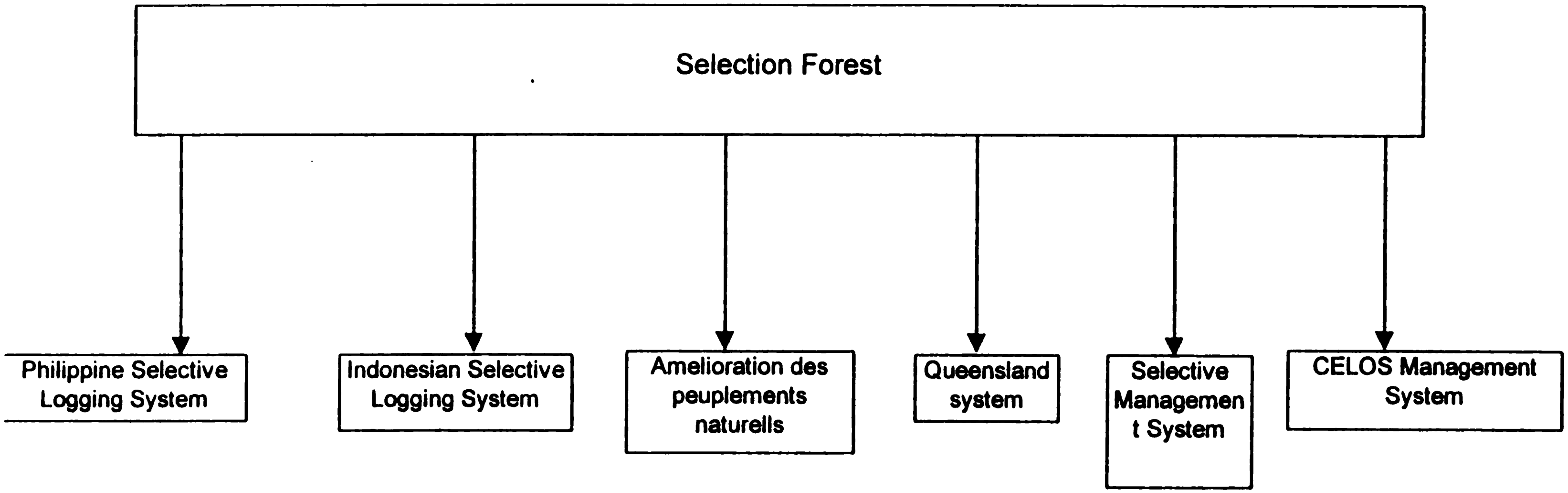


Figure 4.3 - Alternative silvicultural systems for Selection Forests

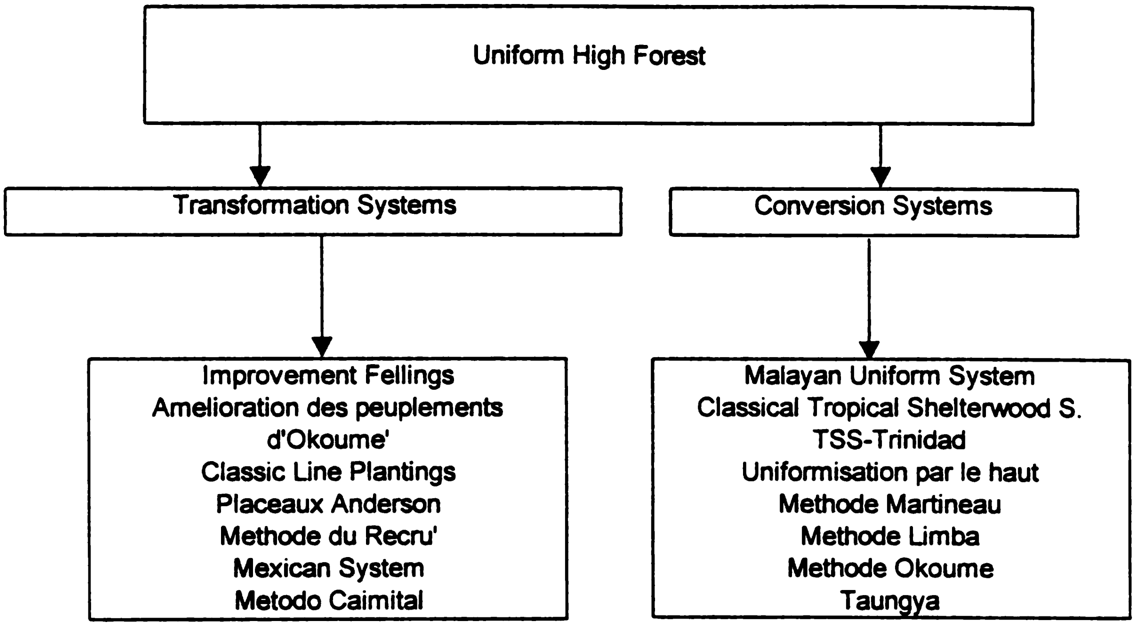


Figure 4.4 - Alternative silvicultural systems for Uniform High Forests

## 4.3. The definition of forestry LUSTs for the NAZ

### 4.3.1. How many LUSTs for the NAZ?

Regional agricultural planning has been defined in the introductory chapter as a form of intermediate level planning between Macro-planning and Project planning. In Costa Rica, REPOSA developed since 1986 several studies on the biophysical characteristics of the NAZ. These studies permitted to build a geographical information system and to geo-reference the input-output relations linked with agricultural crops.

In this type of analysis a decisive factor is related with the ability of the analyst to wisely choose the level of specification and aggregation of data. The main struggle in this phase is in finding out a reasonable solution between the two extremes of including as possible detailed information, present in institutions that focus on project-level studies, and in yielding too much generalization.

In order to achieve a specification of the tropical forest LUSTs types presented in the NAZ it was primarily necessary to define the types of forest to include in the model. The forest land use types designed for the NAZ are those for natural tropical forests. Lamprecht criticizes the common view that address secondary forest as less natural then original climax forests (see footnote 8). The author attributes the specification of "natural forest "to the original climax forest as well to the secondary (natural) forests "arisen without the intervention of man and [where] the succession stages have not been disturbed" (Lamprecht, 1989 p.106).

Three types of natural forest LUSTs have been designed for the NAZ:
-Natural forest in well-drained infertile soil (SIW);
-Natural forest in well-drained fertile soil (SFW), and
-Natural forest in poorly drained fertile soil (SFP).

Since the price landowners get for timber is different if they sell standing wood or if they process it by themselves and then transport the round wood at the sawmill, another distinction has been made according to the way farmers sell timber. By selling standing wood landowners get lower prices, but in the other hand they do not care at about the harvest plan and harvest operations or transportation. Therefore, the management plans will be developed not only according to the types of forests, but also considering the way landowners can sell timber. Three optional management plans have been chosen for each type of forest, because the landowner can sell:

-Standing wood,
-Round wood at the roadside,
-Round wood at the sawmill.

From the above considerations it results that 3 types of forest have been considered for the NAZ, and for each type of forest 3 different management plans have been designed according to the way landowners will sell timber, as this determine how many operations will be organized directly by the landowners. Therefore 9 natural forestry LUSTs have been designed:

-3 LUSTs for natural forest in well-drained infertile soil (SIW) where timber can be sold either as standing wood, round wood at the roadside or round wood at the sawmill.

-3 LUSTs for natural forest in well-drained fertile soil (SFW), where timber can be sold either as standing wood, round wood at the roadside or round wood at the sawmill.

-3 LUSTs for natural forest in poorly-drained fertile soil (SFP) where timber can be sold either as standing wood, round wood at the roadside or round wood at the sawmill.

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The choice of representing the forest types present in the NAZ through 9 different forest LUSTs has been made in collaboration with the group of researchers involved in the project of "Unidad Manejo de Bosques Naturales" of CATIE. The assumption was that, with respect to the levels of detail of the models developed by REPOSA, with this number of different LUSTs the complexity of the forest-types present in the NAZ could be reasonably simplified without incurring in too many details or loosing too much of the available information. Moreover, in this way it was possible to relate the soil types developed in REPOSA with the forest types studied in CATIE.

#### 4.3.2. The management plans

The crucial role of the forest management plan as an operational program that reflects national or regional policies has been pointed out by FAO (1998, pag.22). In Costa Rica, the concern for deforestation and for uncontrolled logging, has led to the definition of policies that established a harvest cycle of at least 15 years, limited to 60% of the commercial trees (with a DBH > 60 cm) (see Maginnis *et al.* 1998; FAO, 1993a).

The features and operations of a forest management plan are to be tailored according to the objectives, which we want to pursue managing the forest. These objectives can be multiple, for many are the functions that are carried out within a forest. The functions of the forest are also dependent on different factors, social, economic, and biological. Therefore, forest management can be seen as the discipline that integrates the different factors that influence a decision for the accomplishment of one or more objectives.

In this report, as pointed out in chapter 3, the focus is on sustainable management of natural tropical forests for timber production. In this context, the guidelines for the definition of sustainable management forest have been defined, at the international level, by the International Tropical Timber Organization. On the basis of the research carried out in CATIE in the last decade, it possible to design specific management systems for the main different types of forests that can be representative of the entire NAZ region as it has been defined in chapter 2.1. A first management model was designed for forests situated on infertile soils, where the initial presence of commercial timber volumes doesn't allow a harvest in the first years. In these forests an initial investment in the form of silvicultural treatments aimed at liberation may consistently improve the composition of the forest. Quirós and Finegan (1994a) developed a management plan for a case study that has been adapted for the forest types of this study. A list of the operations of the management plan for natural forests in well-drained infertile soils is the following:

**Management model A**

| *Year* | *Operations* |
|---|---|
| 0 | Forest Inventory and management plan |
| 2 | Diagnostic sampling |
| 3 | Silvicultural treatments |
| 12 | Evaluation and management plan modifications |
| 22 | Control Inventory |
| 23 | Planning Inventory |
| 23 | Harvest Plan |
| 24 | First Harvest |

In forests where the initial composition of commercial species make it profitable to plan a first harvest in the first years of the management, the plan could be modified as follows:

**Management model B**

| *Year* | *Operations* |
|---|---|
| 0 | Forest Inventory and management plan |
| | Planning Inventory |
| | Harvest Plan |
| 1 | First harvest |
| 2 | Diagnostic sampling |
| | Treatment design |
| 3 | Application of silvicultural treatments |
| 12 | Diagnostic sampling |

Evaluation and management plan modifications
22 Control Inventory
23 Planning Inventory

These 3 management plans are related to the three different types of forests where the landowners sell round wood at the sawmill. Management plans for landowners that sell round-wood at the road-side can be derived from the plans described above simply deleting the costs related to transport (which are included in the first harvest), while for the option of selling standing wood, only the following operations are organized by the landowners:

-Forest Inventory and management plan
-Planning Inventory
-Harvest Plan

Detailed descriptions of each of the mentioned operations can be found in literature (Carrera *et al.*, 1998; FAO, 1993a, 1996, 1998; Finegan *et al.*, 1993; Gamboa, 1996; Maginnis *et al.*,1998; Quirós 1996, 1998a and 1998b; Quirós *et al.*, 1994a and 1994b; Sabogal *et al.*, 1993). Further we describe some features of those operations that are particularly interesting for the development of the financial analysis carried out in the following Sections.

*-Forest Inventory and management plan*
There are several types of inventories that may be grouped in two main classes: planning inventories and operational inventories[13]. FAO (1993a) indicates 3 guidelines in the determination of forest inventories: to distinguish the various objectives in concert with all the persons who will make use of the results; to determine priorities among the objectives, and to consider in detail the activities necessary in order to implement the inventory.

The sample areas have been examined in the context of the Project "Silvicultura de Bosques Naturales" of CATIE. The information gathered for the forest inventory has been used for the management plan (Quirós *et al.* 1994q). The management plan describes all the activities to be implemented in at least one rotation and should be enough flexible to be adjusted if necessary (Carrera *et al.*, in press)[14].

*-Diagnostic sampling*
A practical field sampling is conducted in order to provide information on the conditions of the forest, the forest management interventions and the useful silvicultural operations to be adopted, to improve the forest. The main characteristic of diagnostic sampling lies in the identification of a tree called *Leading Desiderable* within each sample area, or the best tree present in the sample area with respect to specific criteria that should be determined before field sampling.

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[13] FAO (1998 p. 58) mentions 8 types of forest inventories each one with its own objectives. They are organized in to groups: Harvesting (Pre-concession (for bidding), Logging planning, Management planning) and Management (Growth studies, Biodiversity surveys, Social surveys, Post harvest and Diagnostic sampling).
[14] Carrera et. Al (in press) indicates the following elements as necessary for the preparation of a management plan: executive summary, objectives, duration and review of the plan, basic information on property, results of the forest inventory, limits and possible solutions for forest management, management activities, administrative activities, protecting activities, calendar of the activities, maps and annexes.

A practical methodology for Diagnostic sampling is described in FAO (1998 pp. 83-84). In the Northern Zone of Costa Rica this sampling is used to collect information on the commercial and non commercial species, on the DBHs, on illumination and the presence of lianas (see Quirós, 1996 and 1998)[15].

*-Silvicultural treatments*

The purpose to apply silvicultural treatments are related to the necessity to improve the conditions of the desirable species, whether this means to induce natural regeneration, to increase the rate of growth, to decrease mortality, to increase the number of desirable species or to improve the shape of trees (see Quirós 1998[16]).

In this study only refinements have been considered, applied in order to eliminate the not desirable species. In the area of Tirimbina, in the Northern Atlantic Zone of Costa Rica, the operation of refinement has been conducted with the elimination of the trees with DBH > 40 cm (Quirós *et al.* 1994a). In the context of the Project Silvicultura de Bosques Naturales a software (SIRENA) has been developed in order to estimate the effects of the application of refining treatments. The application of silvicultural treatments should be planned only in case of necessity. In this study we assumed that silvicultural treatments were necessary only in forests situated in unfertile well drained soils[17].

*-Planning Inventory, Harvest Plan and Harvest*

The objective of the planning inventory is to provide basic information for the first harvest, and it consists in an inventory of the trees that can be commercialized. A detailed metodology followed to prepare the planning inventory in the sample area of Tirimbina is described in Quirós and Finegan (1994a). The operations related to harvest comprise road construction, extraction, preparation in place and transport operations. A detailed descriptions of the technical aspects of the harvest plan and harvest operations can be found in Carrera *et al.* (1998) and Quirós and Finegan (1994a). Studies on harvest costs in the NAZ have been carried out by Méndez Gamboa (1996), Quirós and Gómez (1998 and 1999).

## 4.4. A FINANCIAL EVALUATION OF THE FORESTRY LUSTs

### 4.4.1. Analysis of the costs

The different types of costs have been grouped for type of activity (Quirós and Gómez, 1999, Reiche, 1989, FAO, 1978, 1979a, b and c, 1992) according to the management plan

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[15] A detailed practical description of the phases followed in Costa Rica for diagnostic sampling are contained in Quiros (1998). For Costa Rica, Quiros recommends an intensity of sampling of 5% in areas large up to 100 ha and of 3,5% or 4% in larger areas. In areas much larger it should be enough to limit the sample to 500 units of register for each stratification.

[16] Quirós specify 10 different main types of silvicultural treatments relevant for tropical forests: soil treatments, cleaning of the **sotobosque**, **corta del dosel medio**, harvest, **liberacion**, **refining**, **saneamiento**, **raleo**, cutting lianas and **enriching planting**.

[17] There are several studies carried out in CATIE about the of the effects of silvicultural treatments. the estimation of the costs involved with these operations has been conducted according to Quiros et al. (1994), Vàsquez Mejia (1996).

presented in the previous Section. The mentioned management plan can be represented more in detail including a detailed list of activities and costs related to each phase:

**Detailed Management model A**

| *Year* | *Operations* |
|---|---|
| 0 | Forest Inventory and management plan |
| 2 | Diagnostic sampling |
| 3 | Silvicultural treatments |
| 12 | Evaluation and management plan modifications |
| 22 | Control Inventory |
| 23 | Planning Inventory |
| 23 | Harvest Plan |
| 24 | First Harvest |
| 24 | Taxes |
| 24 | Road Construction |
| 24 | Extraction |
| 24 | Preparation in place |
| 24 | Transport operations |

The above management plan is related to the case of selling round wood at the sawmill. For the case of round-wood at the road side only transport operations should be deducted, while for the case of selling standing wood remain only the operations of management plan and inventory, planning inventory and harvest plan.

Three categories of costs were distinguished:

-*Labor*, quantified with the method of efficiency for operations, and measured in days for man (8 hour for day). Three sub-categories have been defined:
-Operator, who handles utilized machinery;
-Assistant, who realizes auxiliary work;
-Technician, who is responsible for planning and monitoring the sequence of the activities.

-*Machinery*, for which the use was quantified recording the time needed for each operation. The machinery utilized were tractor, skidder and chainsaw.

-*Materials and taxes,* quantified with the direct cost of the materials utilized, and with the amount of taxes to be paid (see Quiròs and Gomez, 1999).

Given the high level of detailed data available in CATIE, it was possible to perform a detailed calculation of the costs involved in each operation. In order to calculate the unitary costs (for $m^3$ or for hectare), the total cost was divided by the production. The total costs have been calculated considering the materials required daily (market costs), the costs of labor according to the number of days, the cost of assistants according to the effective time of each operation[18], and machinery costs. For the estimation of annual machinery costs, the charges of contract work (typical for the NAZ region) for each type of machinery have been

[18] For laborer, technician and operator have been considered salaries of 1792 Col./day (7.5 US$/day), 4770Col./day (20 US$/day) and 5351 Col./day respectively (22,5 US$/day).

estimated[19]. The estimated values have been multiplied for the time required for each operation in the different areas.

The costs for hectare of the three type of forest for round wood transported at the sawmill are summarized in the tables 4.1, 4.2 and 4.3. Since two types of forests (forests in well-drained fertile soil and poorly-drained fertile soil) are directly introduced into sustained yield management, silvicultural treatments have been considered only for forest in well-drained infertile soil. The costs for harvest operations are related to the increments set for the different types of forest of the NAZ (see next Section).

### 4.4.2. Estimation of the benefits

The benefits have been calculated through the values of round wood for cubic meter[20] and *pulgadas ticas*[21] (pmt), according to the type of selling (standing wood, round wood in the forest, round wood transported at the sawmill).

The increments of wood for forests in poorly-drained fertile soil (SFP) and well drained fertile soils (SFW) were set respectively at 3 and 2,5 $m^3$ $ha^{-1}$ $yr^{-1}$. In poor sites, forests in well-drained infertile soils (SIW), the production was set at 1 $m^3$ $ha^{-1}$ $yr^{-1}$. For the production of round wood logs, only 60% of these values have been considered (respectively 1,8 $m^3$ $ha^{-1}$ $yr^{-1}$ for SFP, 1,5 $m^3$ $ha^{-1}$ $yr^{-1}$ for SFW and 0,6 $m^3$ $ha^{-1}$ $yr^{-1}$ for SIW)

The prices for the commercial species found in the NAZ have been derived from the Camera Costaricense Forestal (stumpage price and price of round wood at the sawmill, CCF, 1995) and from local investigation (prices for round wood at the roadside).

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[19] Estimated in 3000 Col./hour (12,6 US$/hour) for tractor and skidder and 422/Col./hour for chainsaw (1,8 US$/hour) (values adapted from the local investigations made by Quiros and Gomez, in press).

[20] The calculation of the volume has been executed through the method of Smalian : $V= ((D+d)/2)^2 \times 0{,}07854 \times L$; where V= Volume in cubic meters, D= Diameter of the wood log in the major extreme, d= Diameter of the wood log in the minor extreme and L= Longitude of the wood log in meters.

[21] The pmt unit is used to measure wooden blocks, and it is determined by measuring, in inches and through a cord, a wood log in its thinnest part. The value of the circumference, C, is used in the following formula in order to arrive at the PMT value: $PMT= (C/4)^2 * L/4$, where L is the width of the wooden block in *varas* (1 vara = 0,84 m) (see Quiros, Gomez, in press).

Table 4.1- Costs for hectare of the operations of management plan A: forests in well-drained infertile soil (SIW) (harvesting 15 $m^3$/ha of round wood)

| Operations | Labor | | Technician | | Operator | | Machinery | | Other costs | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | day/ha | Col/ha | day/ha | Col/ha | day/ha | Col/ha | hr./ha | Col/ha | Col/ha | Col/ha | US$/ha |
| 1 Forest Inventory and management plan | 0.18 | 315.95 | 0.31 | 1473.06 | - | - | - | - | 132.27 | 1921.29 | 9.28 |
| 2 Diagnostic sampling | 0.44 | 789.81 | 0.22 | 1052.19 | - | - | - | - | 132.27 | 1974.27 | 9.54 |
| 3 Silvicultural operations | 4.01 | 7187.34 | 0.10 | 491.06 | - | - | - | - | 2314.82 | 9993.21 | 48.28 |
| 4 Evaluation and management plan modifications | 0.09 | 157.94 | 0.31 | 1473.08 | - | - | - | - | 403.44 | 2034.47 | 9.83 |
| 5 Control Inventory | 0.09 | 157.94 | 0.18 | 841.74 | - | - | - | - | 132.27 | 1131.95 | 5.47 |
| 6 Planning Inventory | | | | | | | | | | | |
| -Opening and setting up | 0.44 | 789.81 | 0.22 | 1052.19 | - | - | - | - | 66.14 | 1908.14 | 9.22 |
| -Sampling | 0.79 | 1421.70 | 0.26 | 1262.63 | - | - | - | - | 992.07 | 3676.40 | 17.76 |
| 7 Harvest Plan | | | | | | | | | | | |
| -Office | - | - | 0.22 | 1052.19 | - | - | - | - | 304.23 | 1356.42 | 6.55 |
| -Field | 0.09 | 157.94 | 0.09 | 420.90 | - | - | - | - | 99.21 | 678.05 | 3.28 |
| 8 First Harvest | 0.98 | 1759.48 | | | 0.98 | 4297.79 | 1.56 | 656.93 | | 6714.20 | 32.44 |
| 9 Taxes | - | - | - | - | - | - | - | - | 4722.77 | 4722.77 | 22.82 |
| 10 Road Construction | | | | | | | | | | | |
| -Clearing (chainsaw) | 0.09 | 157.94 | - | - | 0.09 | 385.85 | 0.55 | 232.34 | - | 776.13 | 3.75 |
| -Cleaning (chainsaw) | 0.13 | 236.97 | - | - | 0.13 | 578.78 | 0.53 | 223.02 | - | 1038.75 | 5.02 |
| -Cleaning (tractor) | - | - | | | 0.13 | 744.05 | 0.53 | 1587.30 | - | 2331.35 | 11.26 |
| -Opening (chainsaw) | 0.09 | 157.94 | - | - | 0.09 | 385.85 | 0.46 | 195.11 | - | 738.89 | 3.57 |
| -Opening (tractor) | 0.09 | 157.94 | - | - | 0.09 | 496.04 | 0.46 | 1388.90 | - | 2042.85 | 9.87 |
| 11 Extraction | | | | | | | | | | | |
| -Extraction (tractor) | 1.83 | 3284.31 | - | - | 0.92 | 5156.75 | 2.76 | 8282.25 | - | 16723.34 | 80.79 |
| -Extraction (Skidder) | 1.44 | 2580.55 | - | - | 1.44 | 8103.50 | 6.33 | 18976.90 | - | 29660.93 | 143.29 |
| 12 Preparation in place | | | | | | | | | | | |
| -preparation of wooden blocks | - | - | - | - | 0.13 | 573.04 | 0.25 | 108.45 | - | 681.48 | 3.29 |
| 13 Transport operations | - | - | - | - | - | - | - | - | 22500.00 | 15049.51 | 72.70 |
| Total | 10.78 | 19313.52 | 1.91 | 9119.04 | 4.01 | 20721.62 | 13.43 | 31651.18 | 31799.48 | 105154.37 | 507.99 |

-all costs are actualized at 1996 (1 US$= 207 Col.)

Table 4.2- Costs for hectare of the operations of management plan A: forests in well-drained fertile soil (SFW) (harvesting 37.5 $m^3$/ha of round wood)

| Operations | Labor | | Technician | | Operator | | Machinery | | Other costs | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | day/ha | Col/ha | day/ha | Col/ha | day/ha | Col/ha | hr./ha | Col/ha | Col/ha | Col/ha | US$/ha |
| 1 Forest Inventory and management plan | 0.18 | 315.95 | 0.31 | 1473.08 | - | - | - | - | 132.27 | 1921.29 | 9.28 |
| 2 Evaluation and management plan modifications | 0.09 | 157.94 | 0.31 | 1473.08 | - | - | - | - | 403.44 | 2034.47 | 9.83 |
| 3 Control Inventory | 0.09 | 157.94 | 0.18 | 841.74 | - | - | - | - | 132.27 | 1131.95 | 5.47 |
| 4 Planning Inventory | | | | | | | | | | | |
| -Opening and setting up | 0.44 | 789.81 | 0.22 | 1052.19 | - | - | - | - | 66.14 | 1908.14 | 9.22 |
| -Sampling | 0.79 | 1421.70 | 0.26 | 1262.63 | - | - | - | - | 992.07 | 3676.40 | 17.76 |
| 5 Harvest Plan | | | | | | | | | | | |
| -Office | - | - | 0.22 | 1052.19 | - | - | - | - | 304.23 | 1356.42 | 6.55 |
| -Field | 0.09 | 157.94 | 0.09 | 420.90 | - | - | - | - | 99.21 | 678.05 | 3.28 |
| 6 First Harvest | 2.45 | 4398.69 | | | 2.45 | 10744.47 | 3.90 | 1642.33 | | 16785.50 | 81.09 |
| 7 Taxes | - | - | - | - | - | - | - | - | 11806.93 | 11806.93 | 57.04 |
| 8 Road Construction | | | | | | | | | | | |
| -Clearing (chainsaw) | 0.09 | 157.94 | - | - | 0.09 | 385.85 | 0.55 | 232.34 | - | 776.13 | 3.75 |
| -Cleaning (chainsaw) | 0.13 | 236.97 | - | - | 0.13 | 578.78 | 0.53 | 223.02 | - | 1038.75 | 5.02 |
| -Cleaning (tractor) | - | - | | | 0.13 | 744.05 | 0.53 | 1587.30 | - | 2331.35 | 11.26 |
| -Opening (chainsaw) | 0.09 | 157.94 | - | - | 0.09 | 385.85 | 0.46 | 195.11 | - | 738.89 | 3.57 |
| -Opening (tractor) | 0.09 | 157.94 | - | - | 0.09 | 496.04 | 0.46 | 1388.90 | - | 2042.85 | 9.87 |
| 9 Extraction | | | | | | | | | | | |
| -Extraction (tractor) | 4.57 | 8210.77 | - | - | 2.30 | 12891.89 | 6.91 | 20705.63 | - | 41808.34 | 201.97 |
| -Extraction (Skidder) | 3.60 | 6451.37 | - | - | 3.60 | 20258.74 | 15.82 | 47442.25 | - | 74152.31 | 358.22 |
| 10 Preparation in place | | | | | | | | | | | |
| -preparation of wooden blocks | - | - | - | - | 0.33 | 1432.59 | 0.63 | 271.11 | - | 1703.71 | 8.23 |
| 11 Transport operations | - | - | - | - | - | - | - | - | 0.00 | 37623.79 | 181.76 |
| Total | 12.70 | 22772.88 | 1.59 | 7575.80 | 9.22 | 47918.24 | 29.78 | 73687.98 | 13936.56 | 203515.24 | 983.17 |

-all costs are actualized at 1996 (1 US$= 207 Col.)

Table 4.3- Costs for hectare of the operations of management plan A: forests in poorly-drained fertile soil (SFW) (harvesting 45 $m^3$/ha of round wood)

| Operations | Labor | | Technician | | Operator | | Machinery | | Other costs | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | day/ha | Col/ha | day/ha | Col/ha | day/ha | Col/ha | hr./ha | Col/ha | Col/ha | Col/ha |
| 1 Forest Inventory and management plan | 0.18 | 315.95 | 0.31 | 1473.08 | - | - | - | - | 132.27 | 1921.29 |
| 2 Evaluation and management plan modifications | 0.09 | 157.94 | 0.31 | 1473.08 | - | - | - | - | 403.44 | 2034.47 |
| 3 Control Inventory | 0.09 | 157.94 | 0.18 | 841.74 | - | - | - | - | 132.27 | 1131.95 |
| 4 Planning Inventory | | | | | | | | | | |
| -Opening and setting up | 0.44 | 789.81 | 0.22 | 1052.19 | - | - | - | - | 66.14 | 1908.14 |
| -Sampling | 0.79 | 1421.70 | 0.26 | 1262.63 | - | - | - | - | 992.07 | 3676.40 |
| 5 Harvest Plan | | | | | | | | | | |
| -Office | - | - | 0.22 | 1052.19 | - | - | - | - | 304.23 | 1356.42 |
| -Field | 0.09 | 157.94 | 0.09 | 420.90 | - | - | - | - | 99.21 | 678.05 |
| 6 First Harvest | 2.94 | 5278.43 | | | 2.94 | 12893.37 | 4.68 | 1970.80 | | 20142.60 |
| 7 Taxes | - | - | - | - | - | - | - | - | 14168.32 | 14168.32 |
| 8 Road Construction | | | | | | | | | | |
| -Clearing (chainsaw) | 0.09 | 157.94 | - | - | 0.09 | 385.85 | 0.55 | 232.34 | - | 776.13 |
| -Cleaning (chainsaw) | 0.13 | 236.97 | - | - | 0.13 | 578.78 | 0.53 | 223.02 | - | 1038.75 |
| -Cleaning (tractor) | - | - | | | 0.13 | 744.05 | 0.53 | 1587.30 | - | 2331.35 |
| -Opening (chainsaw) | 0.09 | 157.94 | - | - | 0.09 | 385.85 | 0.46 | 195.11 | - | 738.89 |
| -Opening (tractor) | 0.09 | 157.94 | - | - | 0.09 | 496.04 | 0.46 | 1388.90 | - | 2042.85 |
| 9 Extraction | | | | | | | | | | |
| -Extraction (tractor) | 5.48 | 9852.93 | - | - | 2.76 | 15470.26 | 8.29 | 24846.75 | - | 50170.01 |
| -Extraction (Skidder) | 4.32 | 7741.65 | - | - | 4.32 | 24310.49 | 18.98 | 56930.70 | - | 88982.78 |
| 10 Preparation in place | | | | | | | | | | |
| -preparation of wooden blocks | - | - | - | - | 0.40 | 1719.11 | 0.76 | 325.34 | - | 2044.45 |
| 11 Transport operations | - | - | - | - | - | - | - | - | 67500.00 | 45148.54 |
| Total | 14.82 | 26585.04 | 1.59 | 7575.80 | 10.96 | 56983.78 | 35.23 | 87700.24 | 83797.94 | 240291.35 |

-all costs are actualized at 1996 (1 US$= 207 Col.)

According to the forest LUST's types of the NAZ designed in Section 4.3, silvicultural treatments have been applied only in forest situated in well-drained infertile soils. The effect of domestication measures in terms of increased yield has not been considered in the financial analysis. The consideration was that in many cases without silvicultural treatments these types of forest are characterized by very low productivity and that with silvicultural treatments they are going to produce still little, given the low fertility of the soil. Given the long time between treatments and harvest, it would have been possible to make significant errors simulating the effect of silvicultural treatments. However, this may well result in underestimation of the effects of domestication measures for forests situated in infertile soils.

### 4.4.3. Financial results

The financial analysis provides, from the point of view of private farmers, an overview of the results that it is possible to expect from sustainable management of natural forest. In the context of this study it will give also useful indications on the more remunerative type of selling (standing wood, round wood at the roadside, round wood at the sawmill). The data elaborated in this Section will be further developed in Chapter 5, in order to compare the returns from sustainable forest management with those ones of other land use types and see if natural forest is an attractive land use option.

The main indicator used in the financial analysis has been the Net Present Value (NPV), calculated as follow:

$$NPV = \sum_{t=1}^{T} \frac{B_t - C_t}{(1+i)^t}$$

where: $B_t$= benefit in each year,
$C_t$ =cost in each year,
i = discount rate,
t=1,2,3...n and
n= number of years.

Other indicators used in the financial analysis have been the equivalent annual value ($V_a$) and the value of the base basket (CnB, *canasta bàsica*). The base basket is a monetary amount that gives the possibility to acquire the basic products for a family of 4,5 persons). The relation CnB/ $V_a$ gives the number of hectares of forests that it is necessary to manage in order to obtain an annual income equivalent to the base basket.
The equivalent annual value was calculated as follow:

$$V_a = NPV \cdot i \Big/ 1 - \frac{1}{(1+i)^n}$$

where $V_a$ = equivalent annuity.

The results of natural forest management for the different forest types are presented in table 4.4, discount rates ranging from 10 to 0%. The financial results are obviously very sensitive to the discount rates, being the benefits (timber production) in this analysis situated in the 25th year.

The advantage of selling round wood directly at the sawmill is evident in all types of forests (see also Figure 4.5). But this is true only when the transport is included in the operations organized by the landowner. If transport is left out, then it is more convenient to sell directly standing wood instead of including the operations related to the harvest.

Only in the case of well-drained forest situated in infertile soil (Figure 4.6) the economic performance of forest management appear similar both for selling standing wood or including all the other operations up to the sawmill. In this case, the high costs due to the inclusion of silvicultural treatments and the low yields allow only modest financial returns. It is interesting to see in this types of soils which land use options is more attractive for the private farmers (see Chapter 5).

Although the economic performances of both types of forests situated in fertile soils (well-drained and poorly-drained, see Figures 4.7 and 4.8) appear particularly promising when harvest operations and transport are organized by the private farmers, such operations are generally not adopted in the region and often the farmer prefers to sell directly standing wood. This can be due to high transaction costs related with the organization of the operations of harvesting and transport. Since this is a fact we face in reality, high transaction costs will be considered when comparing natural forest management with other land use options (see Section 5.5).

One disadvantage related with selling standing wood is that the buyer usually fixes the price. Commercializing wood directly at the sawmill, in the other hand, requires much more knowledge on forestry operations and on the market of timber (Quirós and Gòmez, in press).

In table 4.4 the results of natural forest management are expressed in Colones as well as in US$. In the last column of each type of forest it is possible to see the numbers of hectares of natural forest to be managed in order to have an income equivalent to the base basket (in 1997 equal to 639,769 Col. equivalent to 2699 US$).

The financial results are similar to other studies found in literature, and relatively good performances have been estimated for forests in fertile soils. With respect to forests in infertile soils, the results are quite poor, due also to the underestimation of the effects of silvicultural treatments, as discussed in the previous Section. Several empirical studies in Costa Rica estimated low financial returns from the management of natural forest. Sánchez et al. (1996) evaluated the financial returns of the management of broad-leaved forests with and without silvicultural treatments and government incentives. With a cutting cycle of 20 years and without silvicultural treatments and government subsidies, the estimated NPV was 136 US$/ha, equivalent to 7 US$/ha/year. By including in the management plan silvicultural treatments the NPV decreases to 95 US$/ha, equivalent to 5 US$/ha/year. Only with the incorporation of government subsidies natural forest becomes financially attractive, the NPV reaching, with and without silvicultural treatments, 400 and 440 US$/ha respectively.

Méndez (1996) furthermore concluded that sustainable forest management is attractive only in the presence of government incentives. His results, in tropical moist lowland forests of the

Northern Atlantic Zone of Costa Rica, give an interesting insight into the possibility of transporting the round wood directly in the sawmill instead of selling standing wood. The added value occurring from such practice would increase NPV from 2 to 3 times with respect to that obtainable by selling standing wood. Of the farmers interviewed in his study, only 35.5% use to transport the round wood at the sawmill while 61.5% sell standing wood.

On the other hand there are studies which estimate a higher NPV from natural forest management. Rodriguez (1997) concludes that an NPV of 800 US$/ha can be obtained from sustainable forest management with silvicultural treatments (harvesting only 10% of the biomass and using a discount rate of 8%).

Howard *et al.* (1996) compared potential returns from 3 different land use options: cattle ranching, forest management and crop production (corn and bean). Their conclusion was that under some conditions financial returns from natural forest management are higher then those of the competitive agricultural uses analyzed. They proceeded explaining deforestation as a phenomenon deriving from some factors that influence the decision process of the landowners, factors as aversion to the periodic nature of the cash flow associated with natural forest management and the lack of basic information on the potential returns of it.

Several limitations related to the financial analysis we made should be mentioned concluding this chapter. A first limitation regards the fact that only timber products has been included in this study, since timber is the only forestry product that can be valued consistently using market prices. However, the application of Contingency Valuation Methods in order to attribute monetary values for the other forestry functions, in the majority of the cases do not provide effective incomes to the farmer and may therefore play a marginal role in the decision making process of the landowner (see Chapter 3).

Another limitation is that we considered in table 4.4 the benefits derived from the timber only in the 25th year, according to the management model A. It could be possible that in a forest in initial good conditions a first harvest could be planned in the first years of the management plan. The financial results of this second management plan (management model B) are completely different from the ones discussed in this chapter. Since financial considerations play a key role in forest management, it seems also very important to distinguish, for natural tropical forests, the two possible types of management plans. Of course such distinction, which may be related to the initial condition of the forest in terms of commercial species, makes forests in good initial conditions particularly attractive financially. The fact that there is another period of at least 15-20 years before a second harvest can be taken into account only designing management plan for more then one rotation. Since in REPOSA it is available a GIS of the NAZ region, a practical way to incorporate these considerations in the model could be to assimilate in the existing GIS a satellite map of the land cover, trying to make a distinction between forests in bad or good initial conditions. This would allow to use the data of both management plans, geo-referencing them according to the initial conditions of the forests (it could be enough to distinguish between forests in good or bad initial conditions)[22].

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[22] However it is not easy to distinguish the condition of a forest only through a satellite image. Another possibility would be to combine the satellite image on forest cover with the map of soils developed in REPOSA. In this way, it could be possible to see in which type of soil the existing forests of the NAZ are situated and make further investigation on the initial conditions of it in order to see where it would be possible to apply the management plan with the harvest in the first years and where this is not possible.

The results of plan management B are shown in table 4.5. The financial results of this management plan are much better compared with the management plan A (see Figure 4.9 to 4.12).

In the next chapter, the data on sustainable management of natural forest of the two management plans will be used in order to see if natural forest is competitive with other land use options in the NAZ. The consistent difference in land use scenarios that results when considering the two different types of management models is described in Section 5.2. on good an bad forests. The results of this type of scenarios call for further deepening of the analysis in the NAZ region, since the introduction of forest as a new land use option can be modeled effectively only when the initial condition of the types of forests are taken into account.

Tab. 4.4 - Financial returns of sustainable natural forest management in the Northern Atlantic Zone of Costa Rica (management plan A)

| | *Forest in well drained infertile soil (SIW)* | | | | | *Forest in well-drained fertile soil (SFW)* | | | | | *Forest in poorly drained fertile soil (SFP)* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NPV (Col) | NPV(US$) | Annuity(Col) | Ann.($) | CnB/An (Ha) | NPV (Col) | NPV(US$) | Annuity(Col) | Ann.($) | CnB/An (Ha) | NPV (Col) | NPV(US$) | Annuity(Col) | Ann.($) | CnB/An (Ha) |
| **d.r. = 0%** | | | | | | | | | | | | | | | |
| Standing wood | 89,157 | 376 | 3,566 | 15 | 179 | 230,523 | 973 | 9,221 | 39 | 69 | 277,645 | 1171.498 | 11,106 | 47 | 58 |
| Round wood (roadside) | 62,052 | 262 | 2,482 | 10 | 258 | 212,530 | 897 | 8,501 | 36 | 75 | 258,963 | 1092.673 | 10,359 | 44 | 62 |
| Round wood (sawmill) | 124,238 | 524 | 4,970 | 21 | 129 | 367,997 | 1,553 | 14,720 | 62 | 43 | 445,523 | 1879.843 | 17,821 | 75 | 36 |
| **d.r. = 2%** | | | | | | | | | | | | | | | |
| Standing wood | 54,336 | 229 | 2,783 | 12 | 230 | 142,227 | 600 | 7,285 | 31 | 88 | 171,523 | 723.7276 | 8,786 | 37 | 73 |
| Round wood (roadside) | 33,783 | 143 | 1,730 | 7 | 370 | 130,945 | 553 | 6,707 | 28 | 95 | 159,814 | 674.3202 | 8,186 | 35 | 78 |
| Round wood (sawmill) | 72,446 | 306 | 3,711 | 16 | 172 | 227,602 | 960 | 11,658 | 49 | 55 | 275,802 | 1163.721 | 14,127 | 60 | 45 |
| **d.r. = 3.5%** | | | | | | | | | | | | | | | |
| Standing wood | 37,476 | 158 | 2,274 | 10 | 281 | 99,389 | 419 | 6,030 | 25 | 106 | 120,026 | 506.4394 | 7,282 | 31 | 88 |
| Round wood (roadside) | 20,264 | 86 | 1,230 | 5 | 520 | 91,392 | 386 | 5,545 | 23 | 115 | 111,728 | 471.4244 | 6,779 | 29 | 94 |
| Round wood (sawmill) | 47,499 | 200 | 2,882 | 12 | 222 | 159,479 | 673 | 9,676 | 41 | 66 | 193,433 | 816.1714 | 11,736 | 50 | 55 |
| **d.r. = 5%** | | | | | | | | | | | | | | | |
| Standing wood | 25,781 | 109 | 1,829 | 8 | 350 | 69,614 | 294 | 4,939 | 21 | 130 | 84,225 | 355.3809 | 5,976 | 25 | 107 |
| Round wood (roadside) | 11,017 | 46 | 782 | 3 | 818 | 63,917 | 270 | 4,535 | 19 | 141 | 78,315 | 330.4412 | 5,557 | 23 | 115 |
| Round wood (sawmill) | 30,299 | 128 | 2,150 | 9 | 298 | 112,122 | 473 | 7,955 | 34 | 80 | 136,161 | 574.5175 | 9,661 | 41 | 66 |
| **d.r. = 7%** | | | | | | | | | | | | | | | |
| Standing wood | 15,500 | 65 | 1,330 | 6 | 481 | 43,370 | 183 | 3,722 | 16 | 172 | 52,660 | 222.1929 | 4,519 | 19 | 142 |
| Round wood (roadside) | 3,062 | 13 | 263 | 1 | 2435 | 39,717 | 168 | 3,408 | 14 | 188 | 48,872 | 206.209 | 4,194 | 18 | 153 |
| Round wood (sawmill) | 15,321 | 65 | 1,315 | 6 | 487 | 70,367 | 297 | 6,038 | 25 | 106 | 85,651 | 361.3971 | 7,350 | 31 | 87 |
| **d.r. = 10%** | | | | | | | | | | | | | | | |
| Standing wood | 6,860 | 29 | 756 | 3 | 847 | 21,212 | 90 | 2,337 | 10 | 274 | 25,996 | 109.6879 | 2,864 | 12 | 223 |
| Round wood (roadside) | -3,323 | -14 | -366 | -2 | | 19,308 | 81 | 2,127 | 9 | 301 | 24,022 | 101.3587 | 2,646 | 11 | 242 |
| Round wood (sawmill) | 2,991 | 13 | 329 | 1 | 1942 | 35,092 | 148 | 3,866 | 16 | 165 | 42,963 | 181.2767 | 4,733 | 20 | 135 |

*Cnb= Base basket (canasta basica) : US$ 2699 = Colones 639,769*

**Figure 4.5: NPV for the different types of forest (dr=5%)- Management plan A**

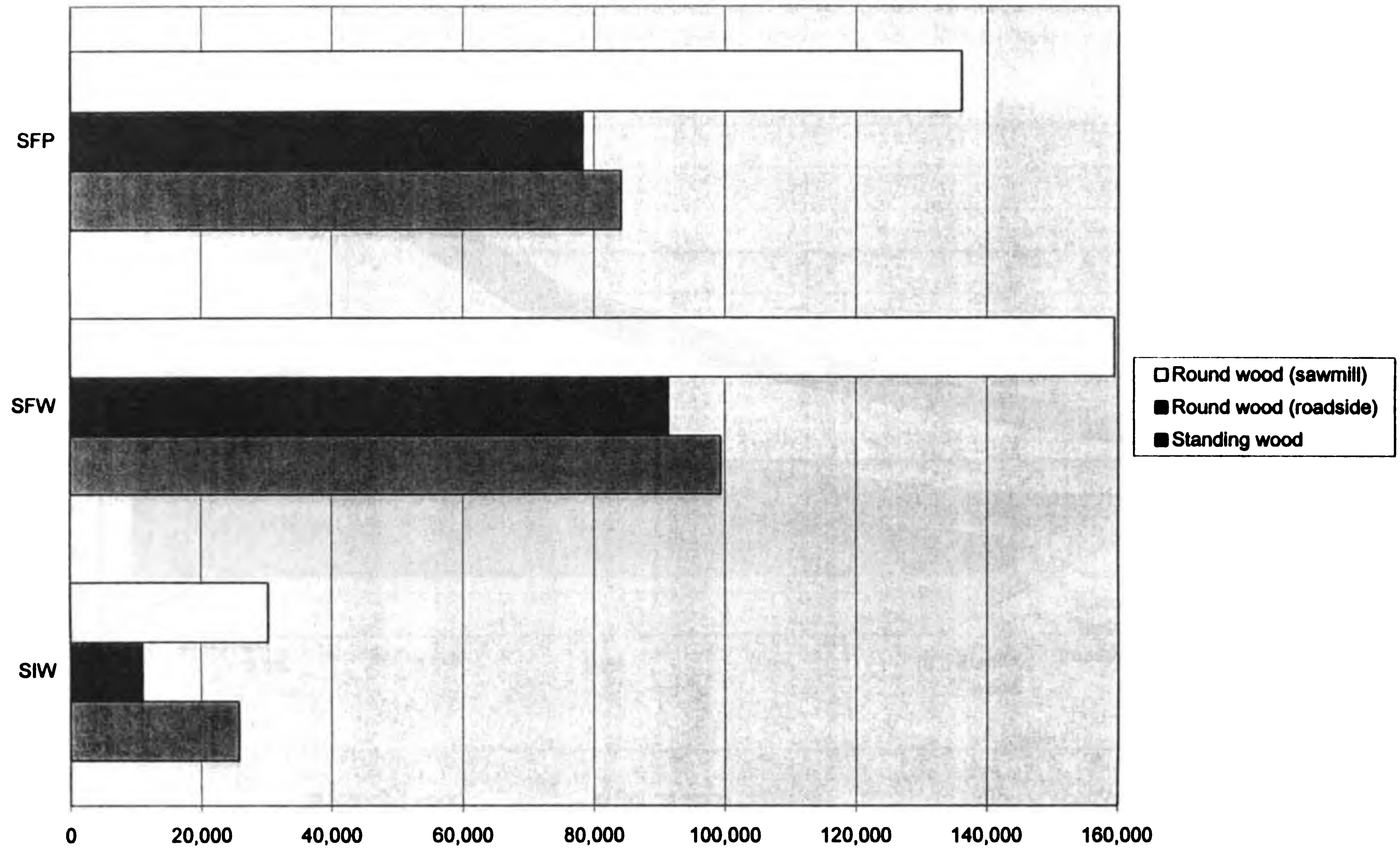


Figure 4.6: NPV of forest in well drained infertile soil (SIW) - Plan A

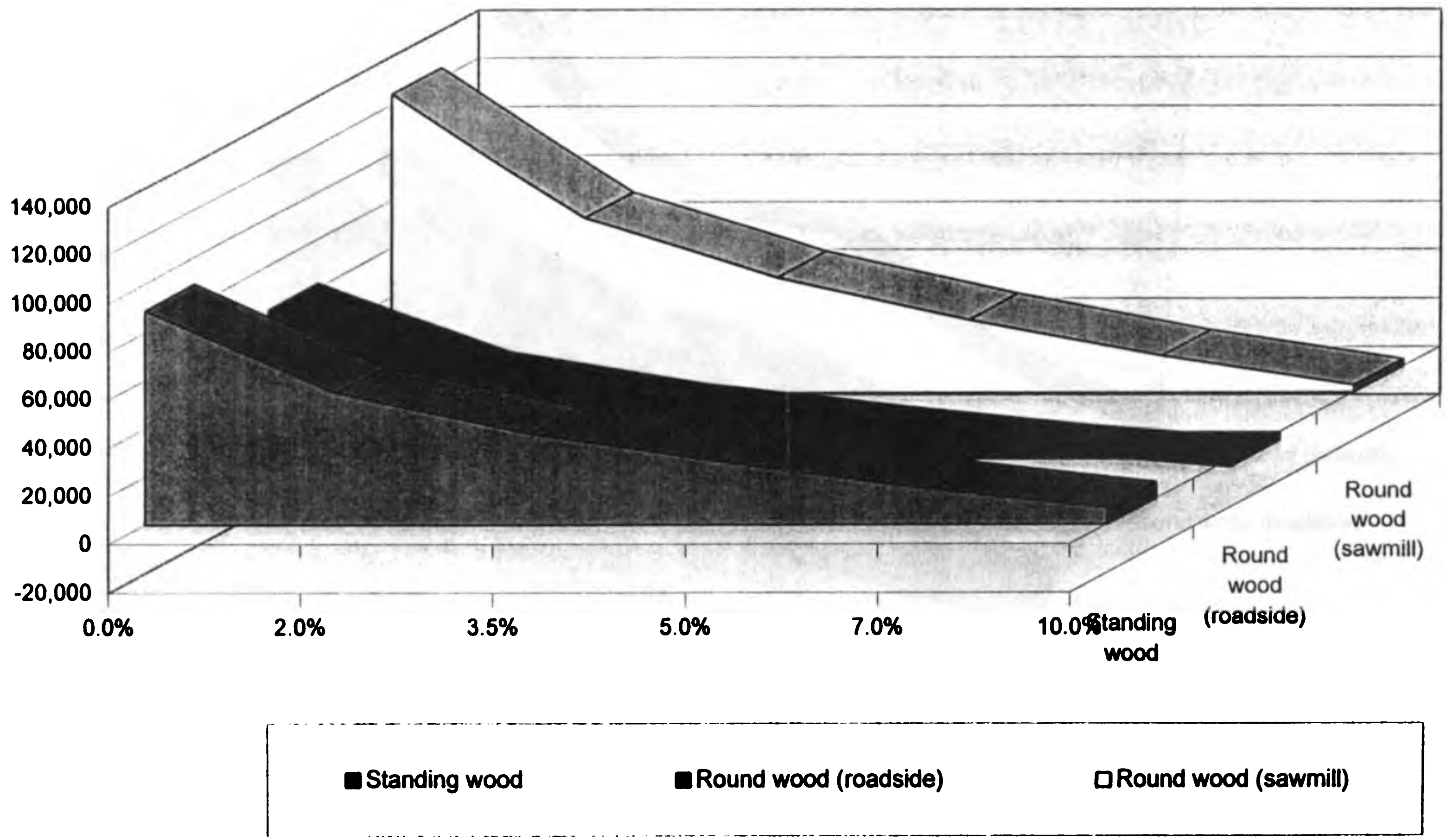


**Figure 4.7: NPV of forest in well drained fertile soil (SFW) - Plan A**

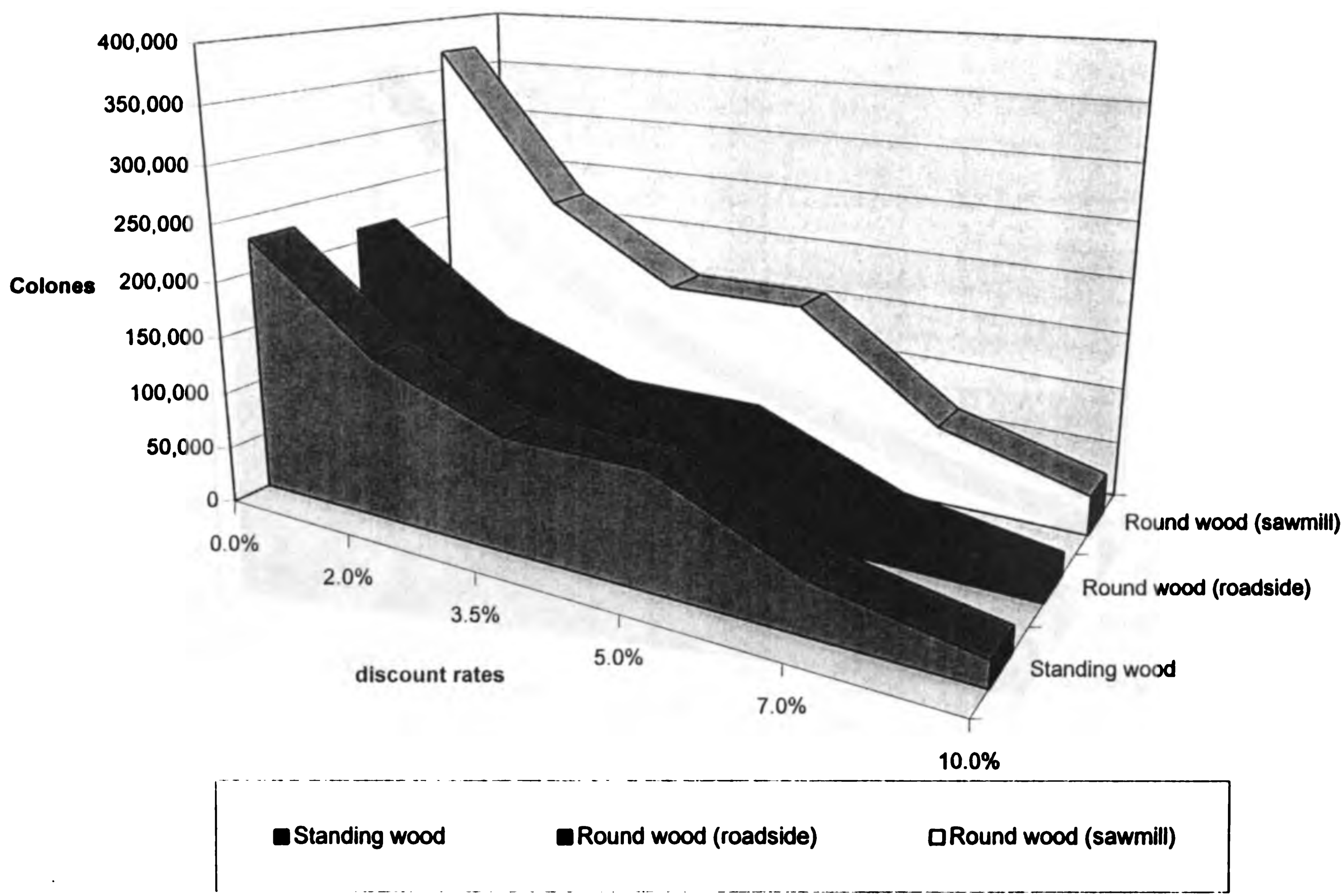
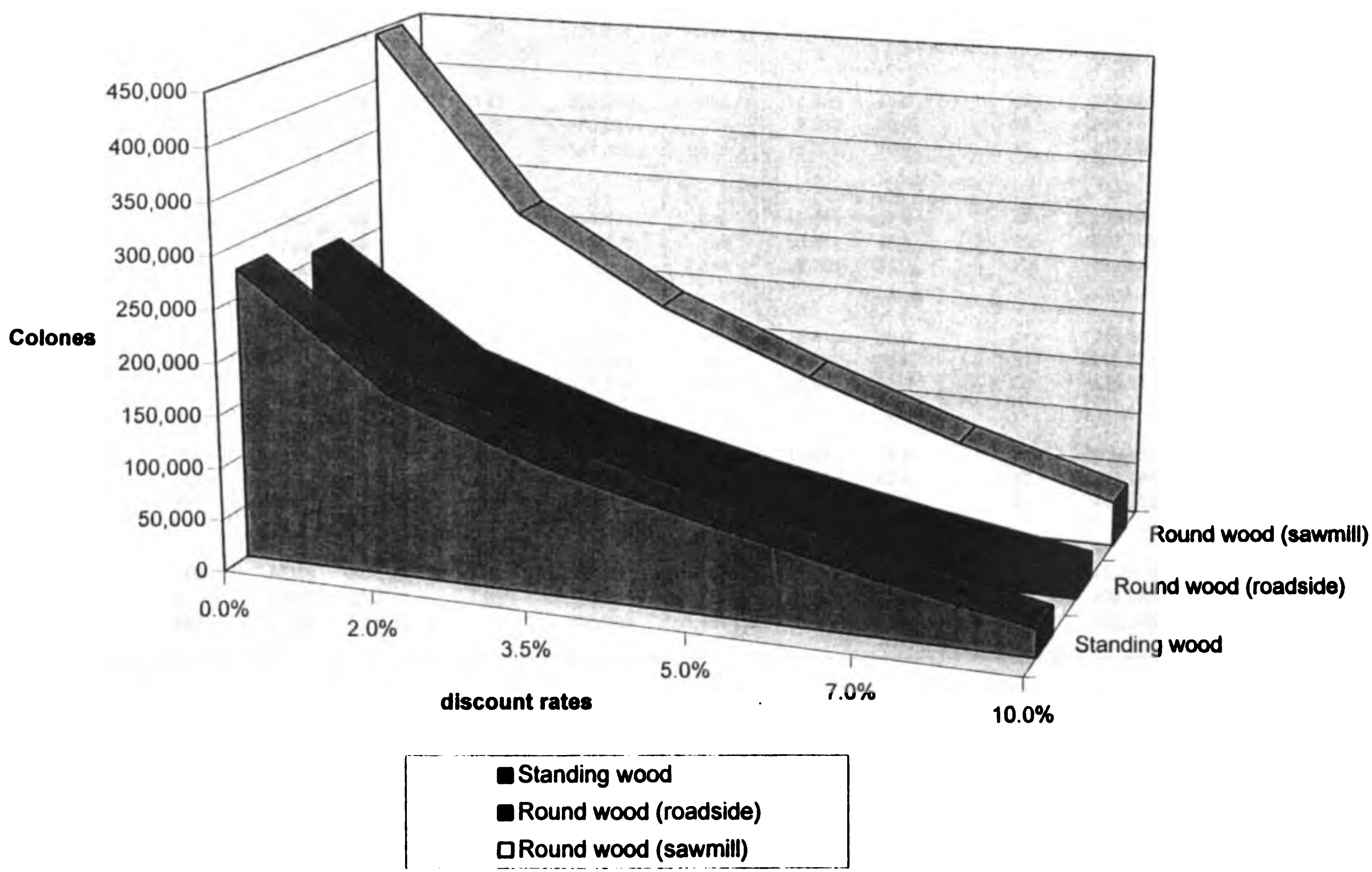


**Figure 4.8: NPV of forest in poorly-drained fertile soil (SFP) - Plan A**



Tab. 4.5 - Financial returns of sustainable natural forest management in the Northern Atlantic Zone of Costa Rica (management plan B)

| | *Forest in well drained infertile soil (SIW)* | | | | | *Forest in well-drained fertile soil (SFW)* | | | | | *Forest in poorly drained fertile soil (SFP)* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NPV (Col) | NPV(US$) | Annuity(Col) | Ann.($) | CnB/An (Ha) | NPV (Col) | NPV(US$) | Annuity(Col) | Ann.($) | CnB/An (Ha) | NPV (Col) | NPV(US$) | Annuity(Col) | Ann.($) | CnB/An (Ha) |
| **d.r. = 0%** | | | | | | | | | | | | | | | |
| Standing wood | 89,157 | 376 | 3,566 | 15.0 | 179 | 230,523 | 973 | 9,221 | 38.9 | 69 | 277,645 | 1171 | 11,106 | 46.9 | 58 |
| Round wood (road | 63,868 | 269 | 2,555 | 10.8 | 250 | 212,530 | 897 | 8,501 | 35.9 | 75 | 258,963 | 1093 | 10,359 | 43.7 | 62 |
| Round wood (saw | 124,238 | 524 | 4,970 | 21.0 | 129 | 367,997 | 1,553 | 14,720 | 62.1 | 43 | 445,523 | 1880 | 17,821 | 75.2 | 36 |
| **d.r. = 2%** | | | | | | | | | | | | | | | |
| Standing wood | 87,665 | 370 | 4,490 | 18.9 | 142 | 226,260 | 955 | 11,589 | 48.9 | 55 | 272,458 | 1150 | 13,955 | 58.9 | 46 |
| Round wood (road | 63,600 | 268 | 3,258 | 13.7 | 196 | 180,266 | 761 | 9,233 | 39.0 | 69 | 254,467 | 1074 | 13,034 | 55.0 | 49 |
| Round wood (saw | 122,787 | 518 | 6,289 | 26.5 | 102 | 361,362 | 1,525 | 18,509 | 78.1 | 35 | 437,368 | 1845 | 22,402 | 94.5 | 29 |
| **d.r. = 3.5%** | | | | | | | | | | | | | | | |
| Standing wood | 86,922 | 367 | 5,274 | 22.3 | 121 | 224,171 | 946 | 13,601 | 57.4 | 47 | 269,921 | 1139 | 16,377 | 69.1 | 39 |
| Round wood (road | 63,377 | 267 | 3,845 | 16.2 | 166 | 178,719 | 754 | 10,844 | 45.8 | 59 | 252,199 | 1064 | 15,302 | 64.6 | 42 |
| Round wood (saw | 121,989 | 515 | 7,402 | 31.2 | 86 | 358,057 | 1,511 | 21,725 | 91.7 | 29 | 433,325 | 1828 | 26,292 | 110.9 | 24 |
| **d.r. = 5%** | | | | | | | | | | | | | | | |
| Standing wood | 85,447 | 361 | 6,063 | 25.6 | 106 | 220,082 | 929 | 15,615 | 65.9 | 41 | 264,960 | 1118 | 18,800 | 79.3 | 34 |
| Round wood (road | 62,807 | 265 | 4,456 | 18.8 | 144 | 175,593 | 741 | 12,459 | 52.6 | 51 | 247,673 | 1045 | 17,573 | 74.1 | 36 |
| Round wood (saw | 120,302 | 508 | 8,536 | 36.0 | 75 | 351,514 | 1,483 | 24,941 | 105.2 | 26 | 425,349 | 1795 | 30,180 | 127.3 | 21 |
| **d.r. = 7%** | | | | | | | | | | | | | | | |
| Standing wood | 83,994 | 354 | 7,208 | 30.4 | 89 | 216,112 | 912 | 18,545 | 78.2 | 34 | 260,152 | 1098 | 22,324 | 94.2 | 29 |
| Round wood (road | 62,121 | 262 | 5,331 | 22.5 | 120 | 172,465 | 728 | 14,799 | 62.4 | 43 | 243,198 | 1026 | 20,869 | 88.1 | 31 |
| Round wood (saw | 118,542 | 500 | 10,172 | 42.9 | 63 | 345,098 | 1,456 | 29,613 | 124.9 | 22 | 417,553 | 1762 | 35,830 | 151.2 | 18 |
| **d.r. = 10%** | | | | | | | | | | | | | | | |
| Standing wood | 81866 | 345 | 9,019 | 38.1 | 71 | 210,381 | 888 | 23,177 | 97.8 | 28 | 253,219 | 1068 | 27,897 | 117.7 | 23 |
| Round wood (road | 60961 | 257 | 6,716 | 28.3 | 95 | 167,841 | 708 | 18,491 | 78.0 | 35 | 236,645 | 999 | 26,071 | 110.0 | 25 |
| Round wood (saw | 115843 | 489 | 12,762 | 53.8 | 50 | 335,766 | 1,417 | 36,991 | 156.1 | 17 | 406,245 | 1714 | 44,755 | 188.8 | 14 |

*Cnb= Base basket (canasta basica) : US$ 2699 = Colones 639,769*

**Figure 4.9: NPV for the different types of forest (dr=5%)- Management plan B**

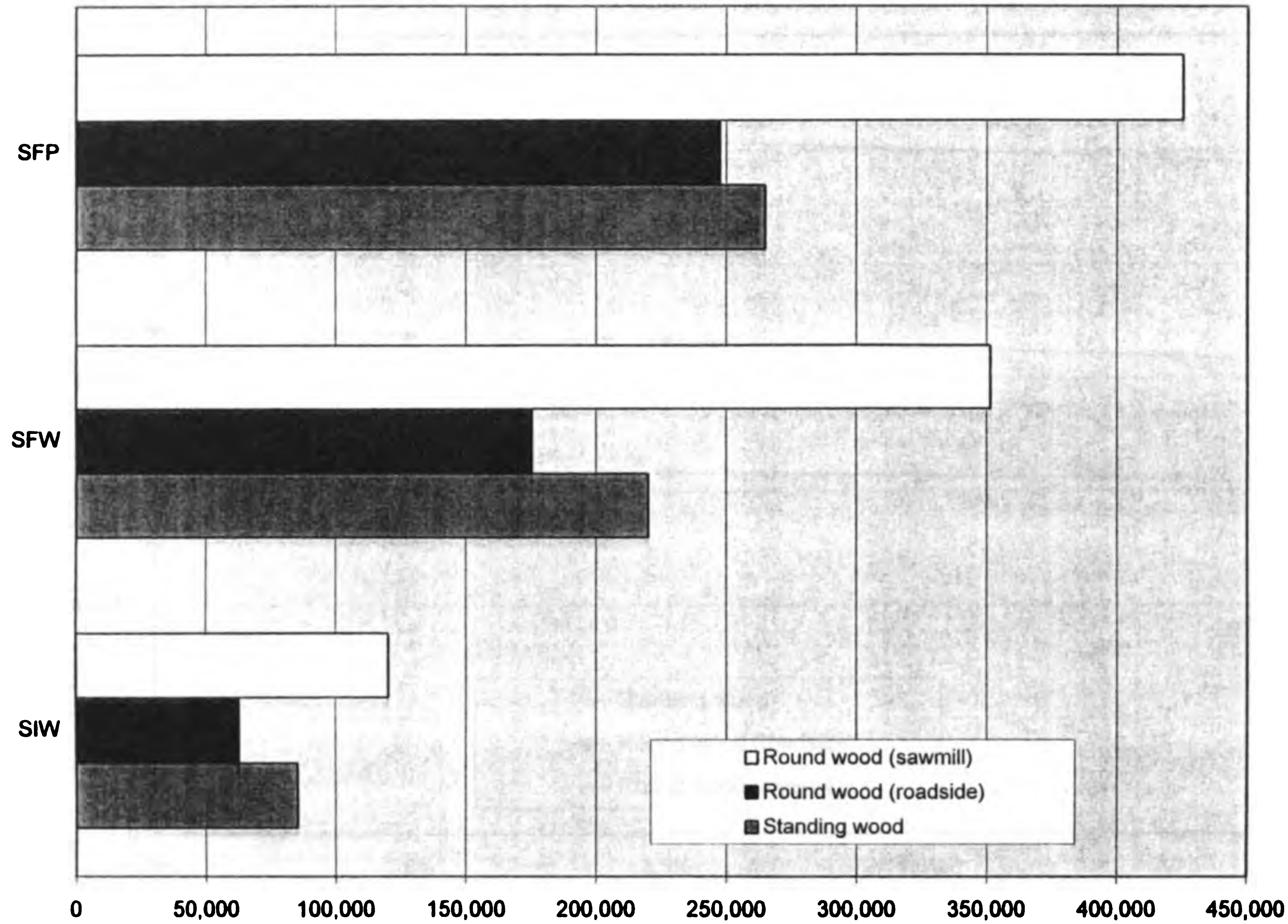


Figure 4.9: NPV for the different types of forest (dr=5%)- Management plan B

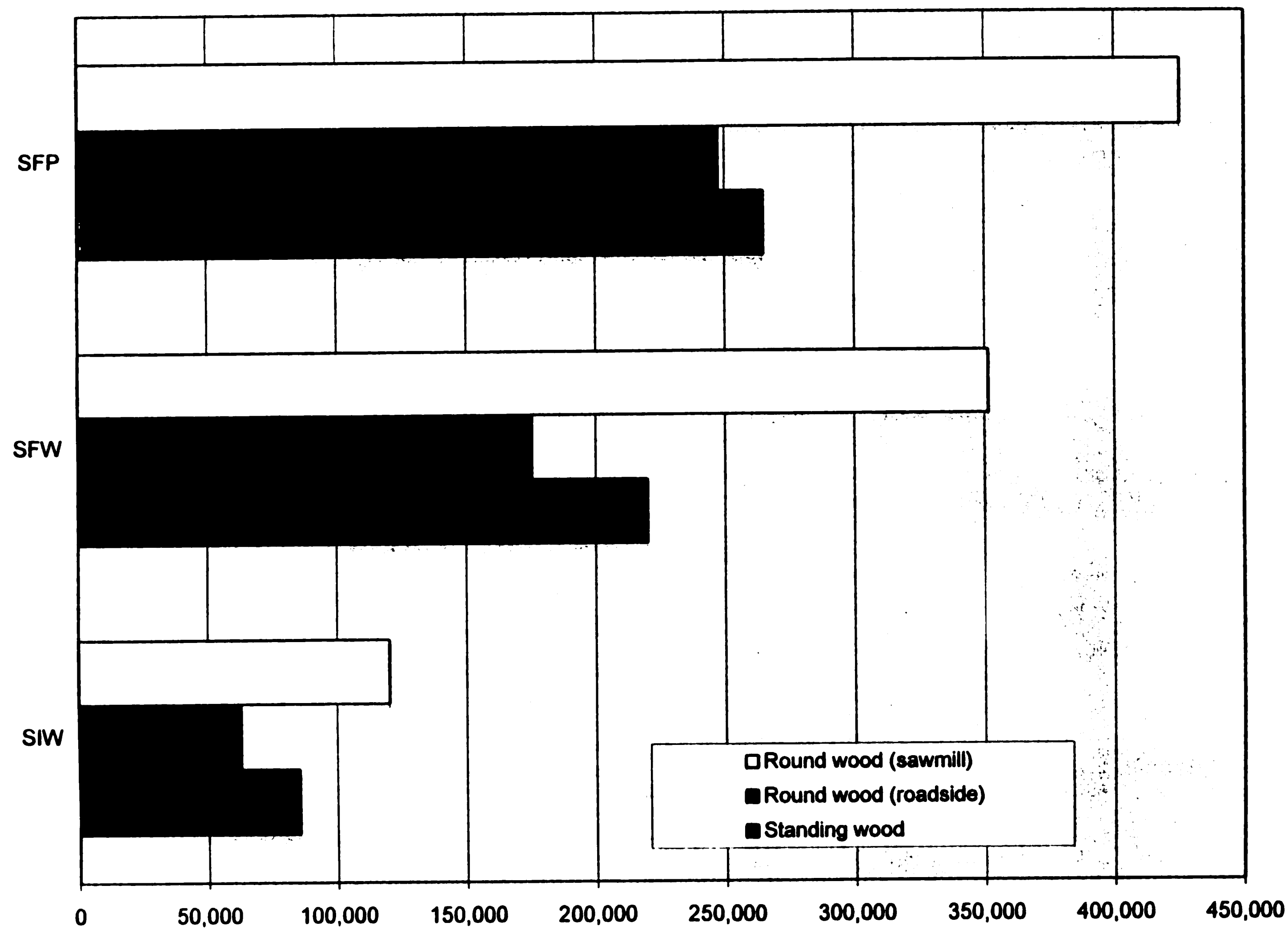


**Figure 4.10: NPV of forest in well drained infertile soil (SIW) - Plan B**

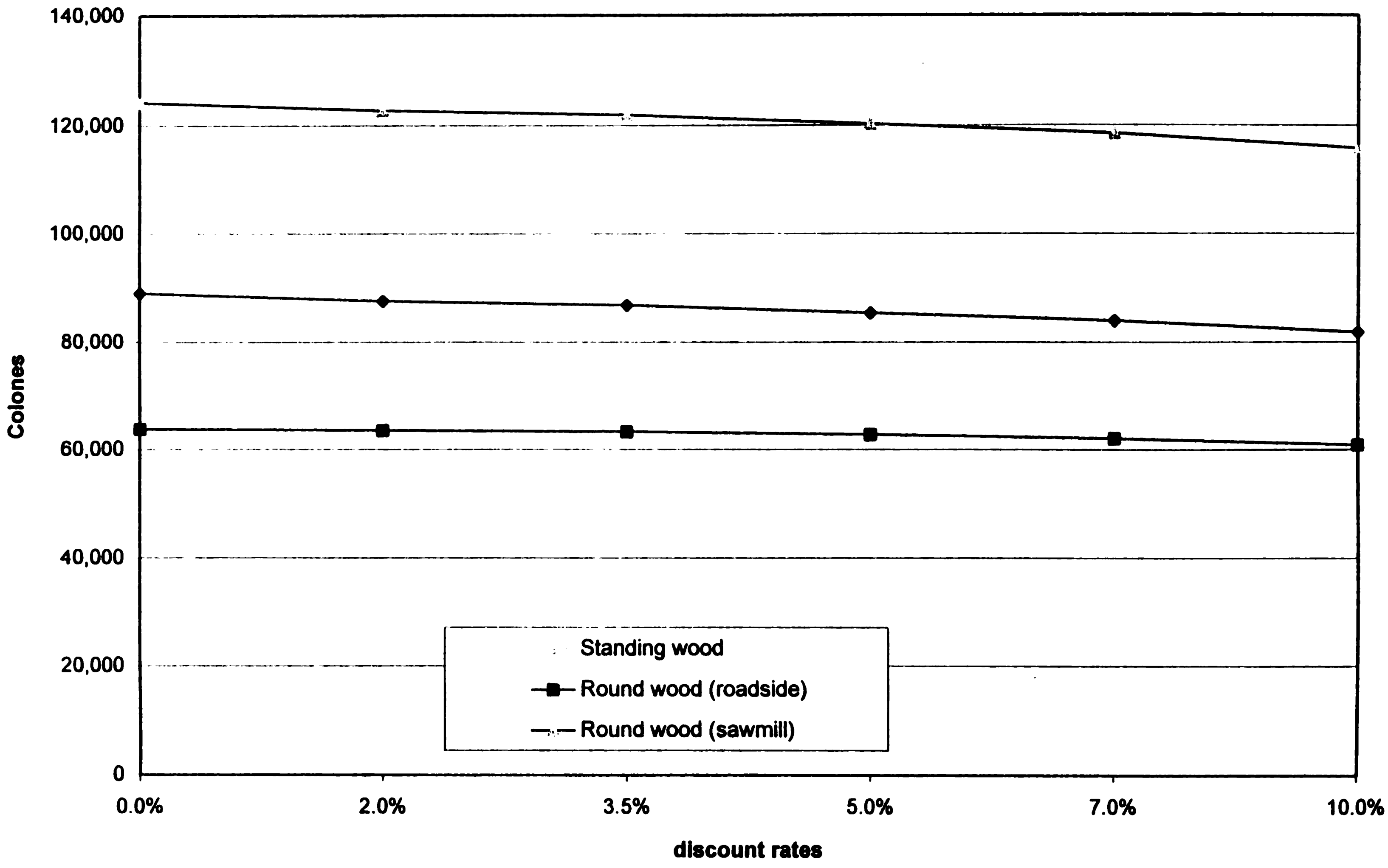


Figure 4.11: NPV of forest in well drained fertile soil (SFW) - Plan B

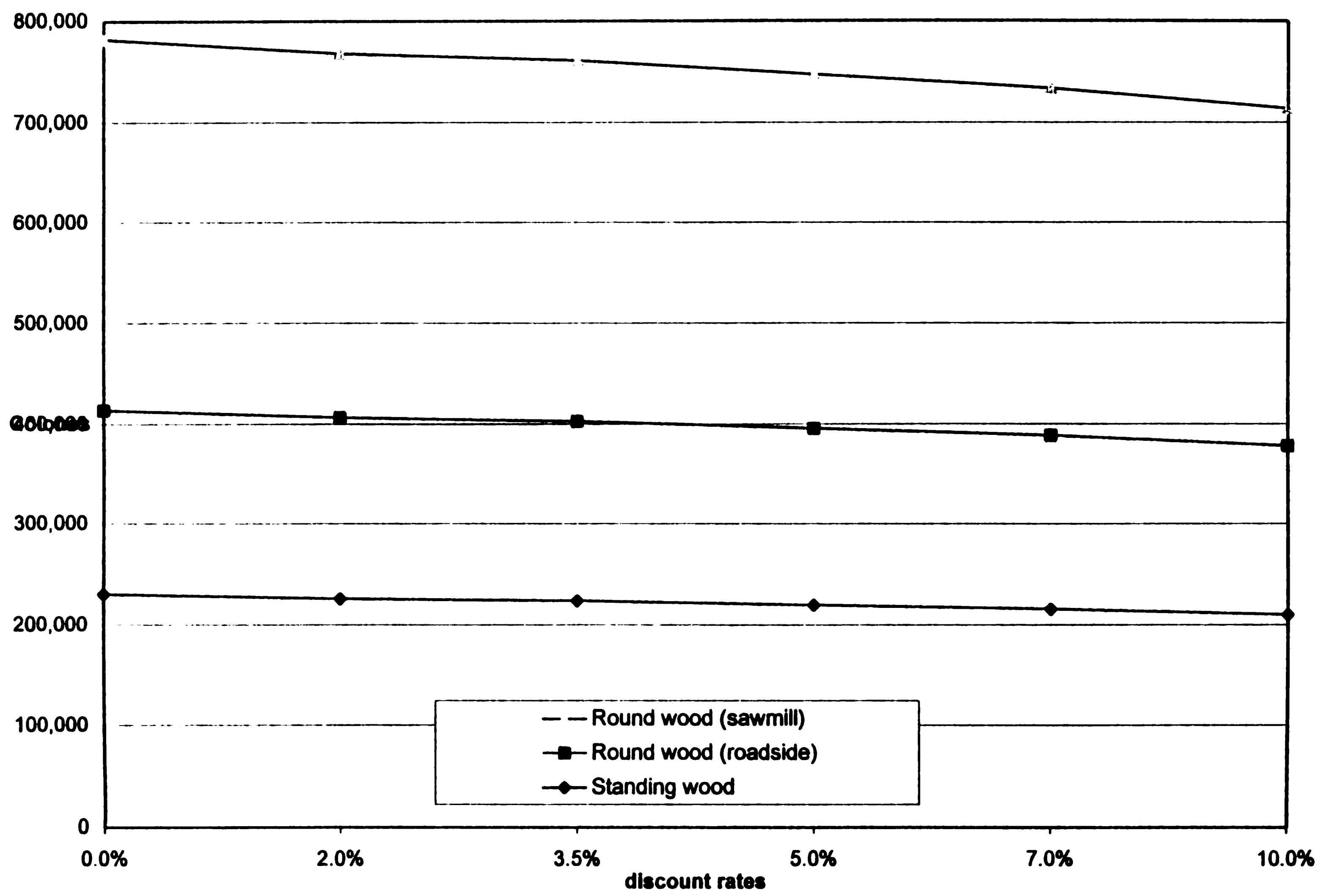
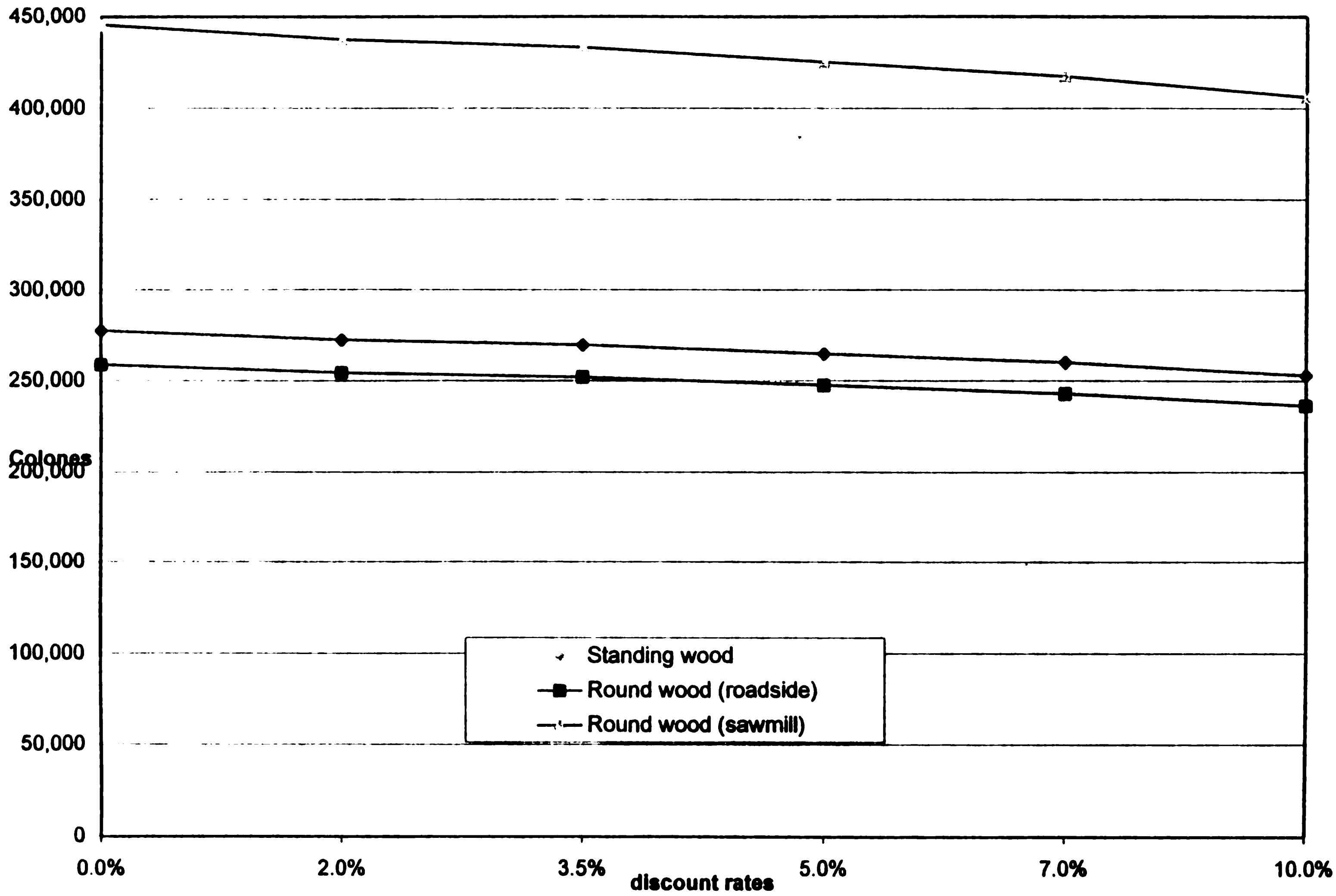


**Figure 4.12: NPV of forest in poorly-drained fertile soil (SFP) - Plan B**



## 5. ECONOMIC EVALUATION OF POLICY SCENARIOS

### 5.1. INTRODUCTION

The scenarios explored in this chapter are particularly linked with policies that aim at the protection of natural forests. The forest LUSTs have been built considering timber as the only forest products. One research question introduced in Section 1.1 was: Under which conditions sustainable natural forest management for wood production is an efficient land use option? The results of the first group of scenarios (Section 5.2) show that natural forest management can be an attractive land use option if the initial conditions of the forest are good enough to allow a first harvest in the first years of the management plan. If a first harvest can be planned only after several years other land use options become more attractive from the view of the private sector. In this case becomes crucial to give an answer to another research question: Is it possible to analyze in quantitative terms the conditions that must be met in order to promote sustainable development of tropical forests in the NAZ? This question has been investigated analyzing scenarios where it has been assumed that compensation for the global public good aspects of natural forests plays an important role for the preservation of tropical forests (Sections 5.3, 5.4, 5.5, 5.6 and 5.7). With the introduction of Government subsidies for the preservation of natural forest it is possible to influence the decision making process of farmers in such a way that, even if indirectly, other forest functions then timber are taken into account. If the government has the goal of promoting natural forest in non-protected lands, since market failures prevent the individuation of optimal prices for NT functions (which are a form of public goods), then it seems worthwhile to explore the effects of different subsidies (compensation values) that can make natural forest an attractive land use option.

Given the current deficit in the balance of trade of Costa Rica regarding timber products, it seems worthwhile to explore scenarios with the inclusion of tropical forest plantations. In Section 5.4 forestry LUSTs developed in REPOSA for tropical forest plantations are introduced in order to see how they compete with natural forest. It should be remembered that, even if plantations show higher financial returns, they do not have the same ecological role of natural forest.

Since it is a common practice in the NAZ to sell standing wood instead of transporting the round wood at the sawmill, despite the potential added value shown in the previous chapter, the hypothesis of high transaction costs was considered in Section 5.5.

Costa Rica is currently undertaking policies that aim at the reduction of the Government deficit, which most likely will results in lower public demand for capital and thus reduction of the real interest rate. In order to explore scenarios related with lower interest rates, the model was run with a lower discount rate (3%) and the results are discussed in Section 5.6. Finally, a sensitivity analysis on timber prices has been conducted in Section 5.7.

Scenarios that simulate the effects of different policies, such as the potential impact of real wage increase on land use or the effects of taxes on biocides in order to reduce environmental contamination, have been explored by Schipper *et al.* (1998). Another feature of the present simulations are connected with transport costs, that have been excluded in the forest LUSTs, since it is a common practice in the NAZ to fix the cost for transportation of the round wood to the sawmill relatively independent from the distance to the sawmill (for distance that may vary between 30 and 80 Km). However, simulations done by Schipper *et al.* (1998) show that a reduction of transportation costs has modest effects on land use in the NAZ.

## 5.2. Good and bad forests

Two different management plans have been designed in Chapter 4. The first one, management plan A, was designed for forests situated on infertile soils, where the initial composition of commercial species do not allow an harvest in the first years and silvicultural treatments of refinement are necessary to improve the composition of the forest. The first harvest for this management plan was set at year 25. In forests where the initial composition of commercial species make it profitable to plan a first harvest in the first years of the management, the first harvest has been set at year 2 (see Section 4.3).

From a financial point of view, it is very important to distinguish the two cases, and an ideal solution would be to assign each type of management plan according to the initial condition of the forest in terms of commercial species. Since in the GIS of REPOSA it has not been incorporated the map of the forest cover, it is not possible to make a distinction between forests in bad or good initial conditions. For this reason the model was run twice, considering for the forests of the NAZ either management plan A or B.

The results are shown in table 5.1 and Figures 5.1 and 5.2. The model allocates no area under natural forest when we consider the management plan A, designed for the forests in precarious initial conditions. All area of the NAZ is found to be either on agricultural crops (19%) or pasture (81%).

On the contrary, when considering the other management plan, with the first harvest in the second year, 56% of the area of the NAZ is allocated under natural forest, and pasture is limited to 25%. With respect to the soil types, natural forest is particularly attractive on poorly-drained fertile soil, and secondarily on well-drained fertile soil. No shift occurs in infertile soils, where all area remains under pasture. Two considerations can be made to explain this phenomenon. First, although the harvest was planned in the 25$^{th}$ year for all types of forests, silvicultural treatments of refinement have been introduced only in forests situated in infertile soils, which make the management of these types of forests relatively more costly (see tables 4.1, 4.2 and 4.3 for details). Secondarily, as pointed out in chapter 4, the effects of silvicultural treatments on the composition of the forest may well be underestimated, and we preferred to maintain rather a low estimation of growth instead of assuming an optimistic one difficult to justify and to generalize for the whole region.

Another run of the model was done planning the first harvest in year 12$^{th}$ (see Figure 5.3). This corresponds to assume a third management plan, for forest with average initial conditions. Again the silvicultural treatments have been planned only for forests situated in infertile soils. This management plan has been used for the exploration of scenarios of the following chapters. Using this intermediate position for the first harvest, we tried to mitigate the financial effects that are linked with the initial condition of the forests. This has been done bearing in mind that it is crucial, in order to estimate effectively the effects of alternative policies on land use planning, to consider the initial conditions of the forests. The results of this chapter strongly call for further development of the research. A possibility could be to geo-referentiate the two different management plans according to the real conditions of the forests in the NAZ. This fact, which may well be underestimated in other studies, can be the key factor in demonstrating that, under certain conditions, sustainable natural forest management for timber production can be an attractive land use option in the NAZ.

Table 5.1- Scenarios considering the initial conditions of the forests

| | | GROUP 1 Good and bad forests | | |
|---|---|---|---|---|
| | Units | Harvest in year 2 | Harvest in year 25 | Harvest in year 12 |
| Objective function | Col * $10^6$ | 50,416 | 47,761 | 47,765 |
| | US $ * $10^6$ | 279 | 264 | 264 |
| Labor | Days * $10^3$ | 8,364 | 8,984 | 8,907 |
| **Land use** | total for agr. | 294,852 | 294,852 | 294,852 |
| Forest | ha | 166,329 | 0 | 22,815 |
| Pasture | ha | 72,517 | 238,372 | 215,558 |
| Crops | ha | 56,006 | 56,480 | 56,479 |
| *of which* | | | | |
| Pineapple | ha | 3,071 | 3,116 | 3,115 |
| Palm heart | ha | 8,059 | 8,366 | 8,367 |
| Banana | ha | 33,456 | 33,456 | 33,456 |
| Plantain | ha | 2,926 | 2,933 | 2,933 |
| Cassava | ha | 8,391 | 8,500 | 8,500 |
| Beans | ha | 0 | 0 | 0 |
| Maize | ha | 104 | 109 | 109 |
| **Number of animals** | | | | |
| Fattening system | | 44,912 | 156,038 | 141,909 |
| Breeding system | | 81,991 | 284,859 | 259,065 |
| **Lust type distribution over soil types** | | | | |
| *SFP - TOTAL* | ha | *118,363* | *118,363* | *118,363* |
| Forest | ha | 118,363 | 0 | 22,815 |
| Crops | ha | 0 | 0 | 0 |
| Pasture | ha | 0 | 118,363 | 95,548 |
| *SFW - TOTAL* | ha | *103,973* | *103,973* | *103,973* |
| Forest | ha | 47,966 | 0 | 0 |
| Crops | ha | 56,007 | 56,481 | 56,479 |
| Pasture | ha | 0 | 47,492 | 47,494 |
| *SIW - TOTAL* | ha | *72,517* | *72,517* | *72,517* |
| Forest | ha | 0 | 0 | 0 |
| Crops | ha | 0 | 0 | 0 |
| Pasture | ha | 72,517 | 72,517 | 72,517 |
| **Sustainability indicators** | | | | |
| NBAL | Kg * $ha^{-1}$ | 10 | 37 | 33 |
| PBAL | Kg * $ha^{-1}$ | 0 | -1 | -1 |
| KBAL | Kg * $ha^{-1}$ | 6 | 8 | 8 |
| **Environmental indicators** | | | | |
| BIOA | Kg * $10^3$ | 85 | 240 | 219 |
| BIOI | $10^3$ | 70,432 | 73,101 | 72,836 |

Figure 5.1 - Harvest in year 2

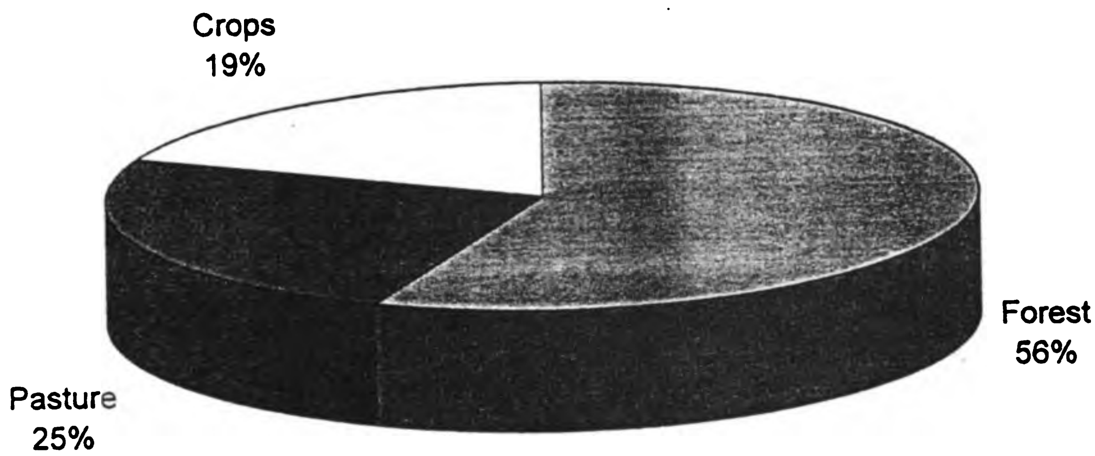



Figure 5.2 - Harvest in year 25

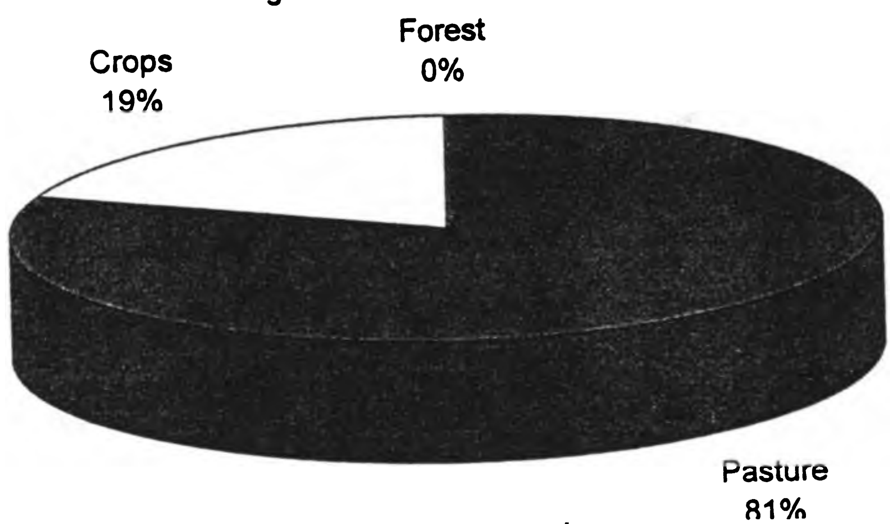
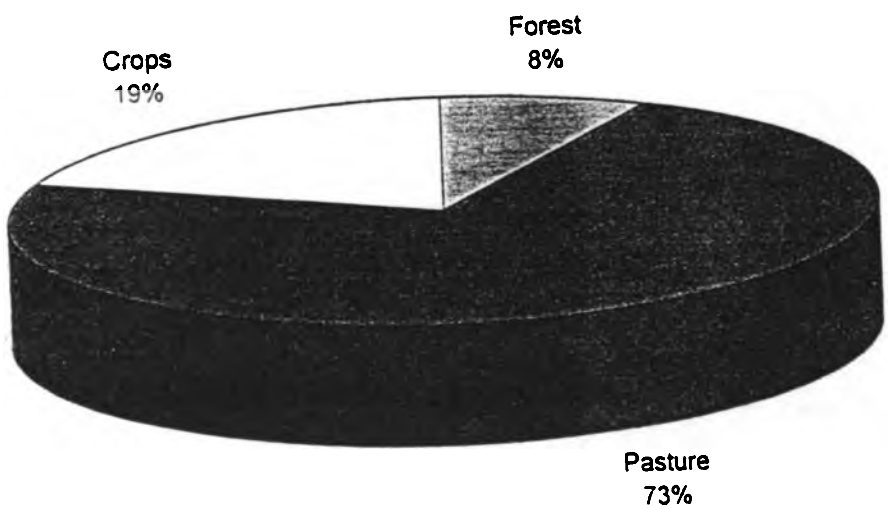



Figure 5.3 - Harvest in year 12



## 5.3. Forest subsidies

The government of Costa Rica has recently adopted a policy to promote conservation of natural forest. Landowners can obtain a yearly subsidy of 10,000 Col./ha of forest if they will not harvest for a period of 5 years. The budget has not been sufficient to cover the demand for subsidies in 1997.

The linear programming model was run as the subsidies were available for the entire NAZ region, and a sensitivity analysis was conducted to explore the effect of different subsidies on land use. The area under forest cover increased from almost 22 thousands hectares to 118 thousands hectares when the subsidy was introduced, mainly at the expenses of pasture in poorly-drained fertile soil (see Table 5.2). The model was not sensitive to a decrease of the subsidy to 50% of the current one, while an increase to 15,000 Col/ha per year caused a shift of 38 thousands of hectares from pasture to forest in well drained fertile soil. Agricultural crops do not compete with forest but there is a trade-off between pasture and forest (see Figure 5.4). A shift in the allocation of infertile soils from pasture to forest occurs only when the subsidy is set at 20,000 Col/ha per year.

In order to see the effects of planning the first harvest only in the 25$^{th}$ year, instead of using the intermediate solution of the 12$^{th}$ year, the model was run again and the results showed that in such case it is not convenient to maintain natural forest for the landowners. This fact again points out the importance to upgrade the research trying to include a differentiation between the different types of forests.

With the introduction of subsidies natural forest becomes attractive first only on poorly-drained fertile soils (Figure 5.5). Only with subsidies larger then the current ones natural forest becomes an attractive land use option first in well-drained fertile soils and lastly on infertile soils. These results show that, at least for the NAZ of Costa Rica, pasture is more attractive then natural forest on infertile soils.

A positive externality induced by the conservation of natural forest is related to the reduction that occurs in the quantities of biocides applied. The positive environmental effect of maintaining natural forest is shown in Figure 5.6 by the decrease in the levels of the sustainable indicators.

Table 5.2- Scenarios considering yearly subsidies for natural forest

| | | GROUP 2 | On forest subsidies | | | | |
|---|---|---|---|---|---|---|---|
| | Units | | ***Harvest year 12*** | | | | ***Harvest year 25*** |
| | | no subsidy | 5,000 $Col*yr^{-1}*ha^{-1}$ | 10,000 $Col*yr^{-1}*ha^{-1}$ | 15,000 $ol*yr^{-1}*ha^{-}$ | 20,000 $ol*yr^{-1}*ha^{-}$ | 10,000 $Col*yr^{-1}*ha^{-1}$ |
| Objective function | $Col * 10^{6}$ | 47765 | 48216 | 48808 | 49499 | 50421 | 47761 |
| | $US\ \$ * 10^{6}$ | 264 | 266 | 270 | 274 | 279 | 264 |
| Labor | $Days * 10^{3}$ | 8907 | 8581 | 8576 | 8375 | 8267 | 8984 |
| **Land use** | total for agr. | 294852 | 294852 | 294852 | 294852 | 294852 | 294852 |
| Forest | ha | 22815 | 118362 | 118363 | 164489 | 211717 | 0 |
| Pasture | ha | 215558 | 120011 | 120055 | 74345 | 27129 | 238372 |
| Crops | ha | *56479* | *56479* | *56434* | *56018* | *56006* | *56480* |
| *of which* | | | | | | | |
| Pineapple | ha | 3115 | 3115 | 3072 | 3072 | 3072 | 3116 |
| Palm heart | ha | 8367 | 8367 | 8367 | 8059 | 8059 | 8366 |
| Banana | ha | 33456 | 33456 | 33456 | 33456 | 33456 | 33456 |
| Plantain | ha | 2933 | 2933 | 2933 | 2933 | 2926 | 2933 |
| Cassava | ha | 8500 | 8500 | 8500 | 8391 | 8391 | 8500 |
| Beans | ha | 0 | 0 | 0 | 0 | 0 | 0 |
| Maize | ha | 109 | 109 | 109 | 109 | 104 | 109 |
| **Number of animals** | | | | | | | |
| Fattening system | | 141909 | 82732 | 82767 | 47791 | 27454 | 156038 |
| Breeding system | | 259065 | 151034 | 151098 | 87245 | 50120 | 284859 |
| **Lust type distribution over soil types** | | | | | | | |
| ***SFP - TOTAL*** | ha | *118363* | *118363* | *118363* | *118363* | *118363* | *118363* |
| Forest | ha | 22815 | 118363 | 118363 | 118363 | 118363 | |
| Crops | ha | 0 | 0 | 0 | 0 | 0 | 0 |
| Pasture | ha | 95548 | 0 | 0 | 0 | 0 | 118363 |
| ***SFW - TOTAL*** | ha | *103973* | *103973* | *103973* | *103973* | *103973* | *103973* |
| Forest | ha | 0 | 0 | 0 | 38114 | 20838 | 0 |
| Crops | ha | 56479 | 56479 | 56435 | 56018 | 56006 | 56481 |
| Pasture | ha | 47494 | 47494 | 47538 | 9841 | 27129 | 47492 |
| ***SIW - TOTAL*** | ha | *72517* | *72517* | *72517* | *72517* | *72517* | *72517* |
| Forest | ha | 0 | 0 | 0 | 8013 | 72517 | 0 |
| Crops | ha | 0 | 0 | 0 | 0 | 0 | 0 |
| Pasture | ha | 72517 | 72517 | 72517 | 64504 | 0 | 72517 |
| **Sustainability indicators** | | | | | | | |
| NBAL | $Kg * ha^{-1}$ | 33 | 19 | 18 | 11 | 2 | 37 |
| PBAL | $Kg * ha^{-1}$ | -1 | -1 | -1 | 0 | 0 | -1 |
| KBAL | $Kg * ha^{-1}$ | 8 | 8 | 8 | 6 | 9 | 8.4 |
| **Environmental indicators** | | | | | | | |
| BIOA | $Kg * 10^{3}$ | 219 | 129 | 130 | 85 | 12 | 240 |
| BIOI | $10^{3}$ | 72836 | 71733 | 71686 | 70453 | 69518 | 73101 |

**Figure 5.4 - Effect of yearly forest subsidies in land use**

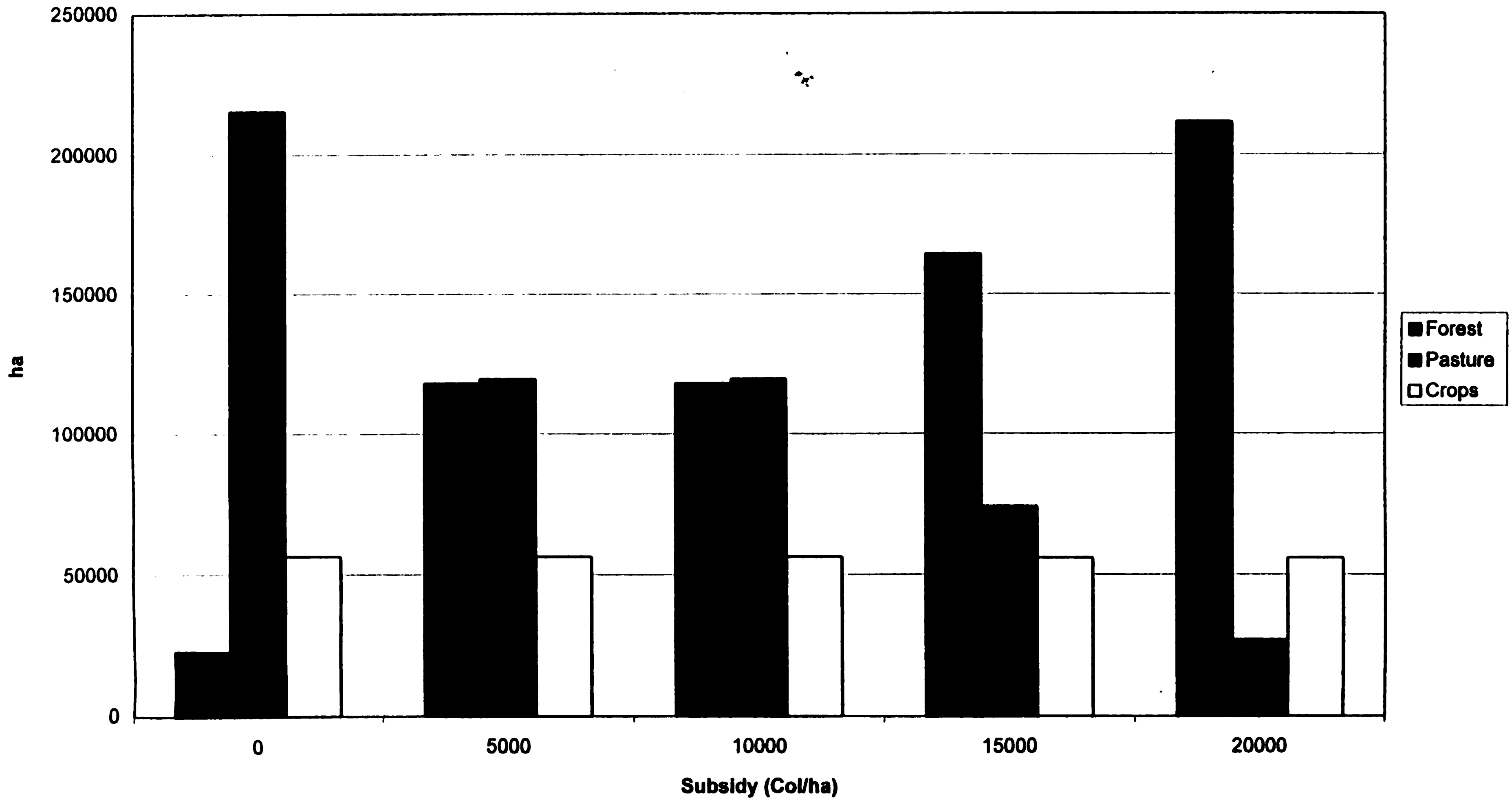


**Figure 5.5 - Soil types and forest land-use for increasing forest subsidies**

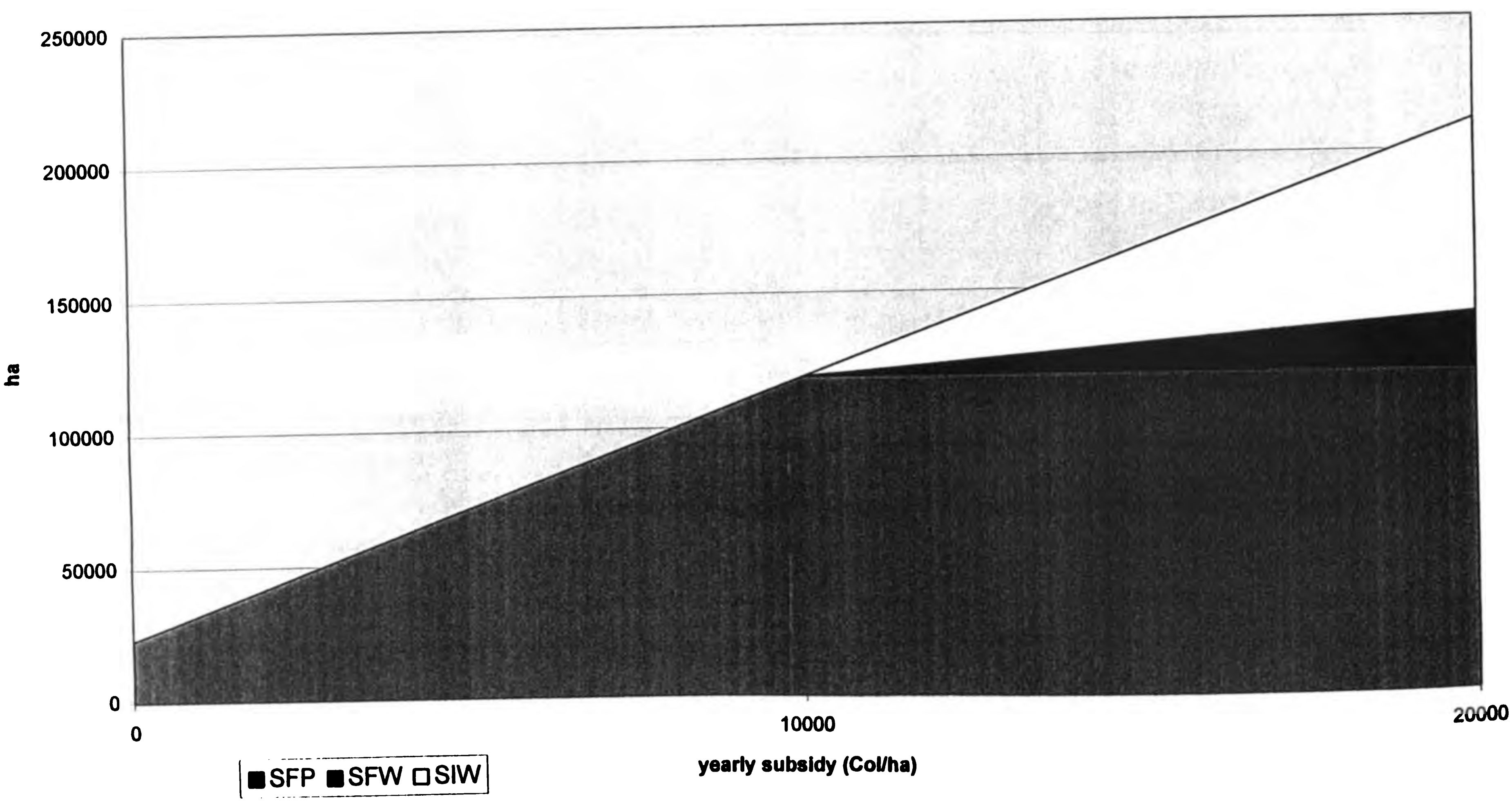
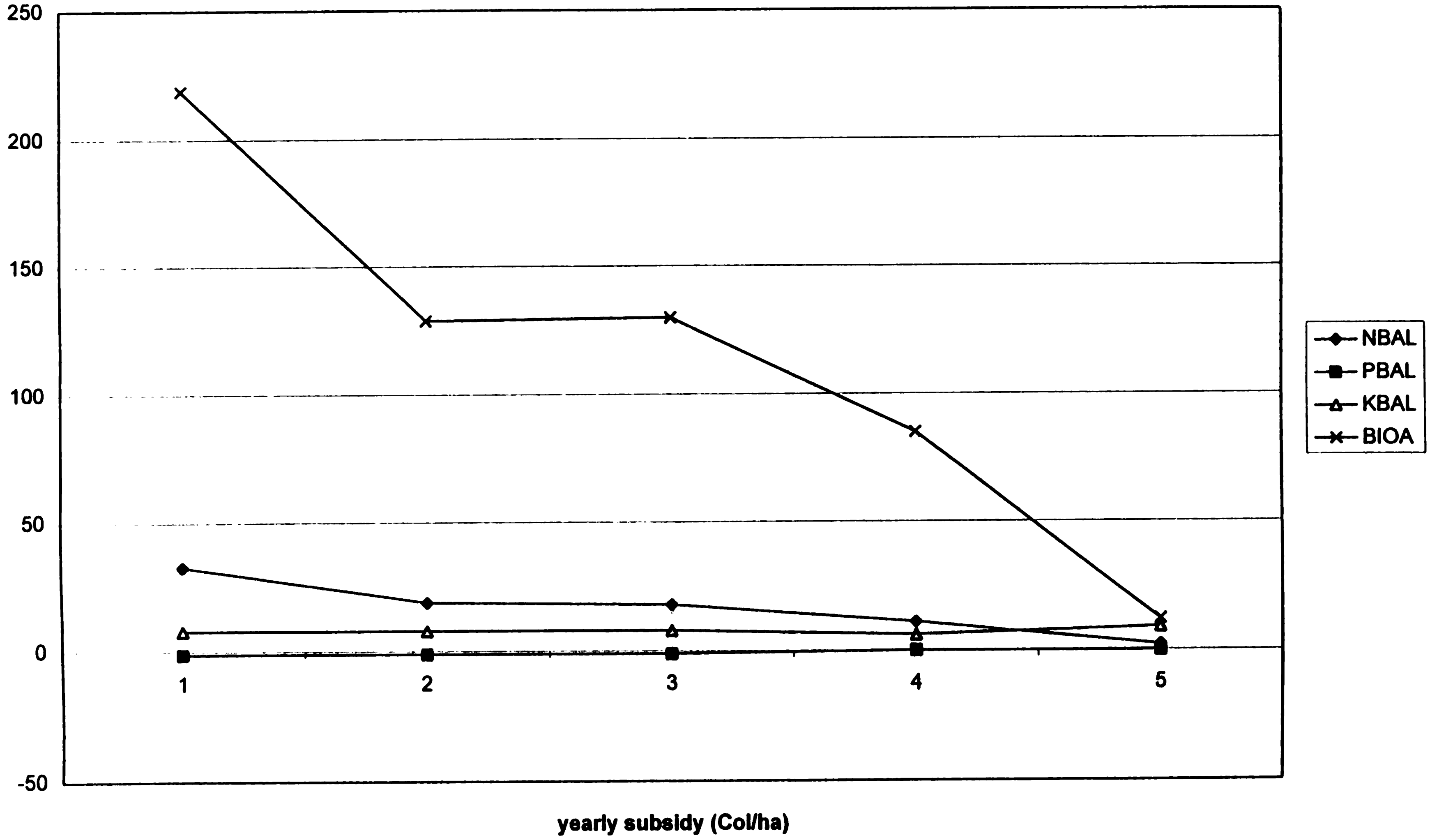


Figure 5.6 - Levels of the environmental indicators for different yearly subsidy for natural forest



## 5.4. Natural forests and tropical forest plantations

Studies on tropical forest plantations have been conducted in REPOSA (Floors, 1997, Brouwershaven, 1993, De Vriend, 1998). Nieuwenhuyse *et al.* (1998) explored scenarios related with forestry options and the results show that natural forest is not attractive when compared with tropical forest plantations, especially teak. He pointed out that only when natural forest revenues increases by at least a factor 4.4 natural forest becomes an attractive land use option. Since the evaluation of timber products was done through stumpage prices it is interesting to see how land use in the NAZ is affected by the introduction of different natural forest LUSTs that include the possibility to process the wood in the farm itself and to transport it to the sawmill.

The model was run assuming market constraints that reflect domestic demand and export possibilities (Nieuwenhuyse *et al.* 1998). Without the inclusion of subsidies for natural forest the model allocate land resources only between pasture, agriculture and tropical forest plantations. It should be remembered, however, that for natural forest the first harvest has been planned only in the 12$^{th}$ year, given the impossibility to distinguish between forest in good and bad initial conditions (see 5.2). If this distinction could be effectively implemented including in the GIS the map of the forest cover and thus allowing a first harvest in the second year of the management plan where it is possible, then natural forest would compete with tropical plantations even in absence of subsidies.

The inclusion of yearly natural forest subsidies of 10,000 Col/ha makes natural forest competitive with forest plantations (26% and 30% of the land resources are allocated respectively for natural forest and tropical forest plantations, see Figure 5.8). It is interesting to notice that tropical forest plantation compete with pasture on infertile soil as well as on well-drained fertile soil, while natural forest is an attractive land use option only on poorly drained fertile soils. The inclusion of a yearly subsidy for natural forest of 20,000 Col/ha causes an increase of the area under forest in fertile well-drained soils and infertile soils, at the expenses of pasture (Figure 5.9). Tropical forest plantations are a less attractive land use option in poorly-drained soil types because of the inclusion of costs related to the construction of drainage systems.

Among the two options of tropical forest plantations included in the model it is teak that is particularly attractive, since the selected area under teak does not change even with large changes in prices (Nieuwenhuyse *et al.* 1998). Running the model with melina as the only option for tropical forest plantation, the area selected for plantations is limited to ca. 23,000 hectares in well-drained fertile soils and for only 560 hectares in swamp fertile soils. Natural forest becomes again the main land use option chosen for poorly drained fertile soils, while in infertile soils only pasture is selected.

Table 5.3- Scenarios including tropical forest plantations and yearly subsidies for natural forest

| | Units | Forest planta + n.f.subsidy 10000 Col*yr | Forest plantati + n.f.subsidy 20000 Col*yr$^{-1}$ | Melina + n.f.subsidy 10000 Col*yr$^{-1}$*ha$^{-1}$ |
|---|---|---|---|---|
| *GROUP 3* | | ***Including tropical forest plantations*** | | |
| Objective function | Col * $10^6$ | 69321 | 70241 | 50213 |
| | US $ * $10^6$ | 383 | 388 | 277 |
| Labor | Days * $10^3$ | 9172 | 8786 | 8641 |
| **Land use** | total for agr. | 294852 | 294852 | 294852 |
| Natural Forest | ha | 76522 | 120326 | 117800 |
| Tropical forest planta | ha | 88570 | 88570 | 23855 |
| Pasture | ha | 76522 | 31701 | 97511 |
| Crops | ha | 53238 | 54255 | 55686 |
| *of which* | | | | |
| Pineapple | ha | 3071 | 3027 | 3027 |
| Palm heart | ha | 8059 | 8059 | 8059 |
| Banana | ha | 33456 | 32175 | 33456 |
| Plantain | ha | 2836 | 2828 | 2836 |
| Cassava | ha | 8172 | 8062 | 8171 |
| Beans | ha | 0 | 0 | 0 |
| Maize | ha | 106 | 102 | 106 |
| **Number of animals** | | | | |
| Fattening system | | 50292 | 25421 | 64816 |
| Breeding system | | 91811 | 46407 | 118326 |
| **Lust type distribution over soil types** | | | | |
| *SFP - TOTAL* | ha | *118363* | *118363* | *118363* |
| Forest | ha | 76523 | 77967 | 117800 |
| Crops | ha | 0 | 0 | 0 |
| Pasture | ha | 0 | 0 | 0 |
| Tropical forest planta | ha | 41840 | 40396 | 563 |
| *SFW - TOTAL* | ha | *103973* | *103973* | *103973* |
| Forest | ha | 0 | 14090 | 0 |
| Crops | ha | 55699 | 38584 | 55655 |
| Pasture | ha | 24995 | 10904 | 24995 |
| Tropical forest planta | ha | 23279 | 24726 | 23323 |
| *SIW - TOTAL* | ha | *72517* | *72517* | *72517* |
| Forest | ha | 0 | 28269 | 0 |
| Crops | ha | 0 | 0 | 0 |
| Pasture | ha | 49066 | 20797 | 72517 |
| Tropical forest planta | ha | 23451 | 23451 | 0 |
| **Sustainability indicators** | | | | |
| NBAL | Kg * ha$^{-1}$ | 19 | 11 | 19 |
| PBAL | Kg * ha$^{-1}$ | 0 | 0 | 0 |
| KBAL | Kg * ha$^{-1}$ | 16 | 17 | 14 |
| **Environmental indicators** | | | | |
| BIOA | Kg * $10^3$ | 81 | 25 | 108 |
| BIOI | $10^3$ | 162051 | 160207 | 10213 |

**Figure 5.7 - The Inclusion of tropical forest plantations and yearly subsidies for natural forest**

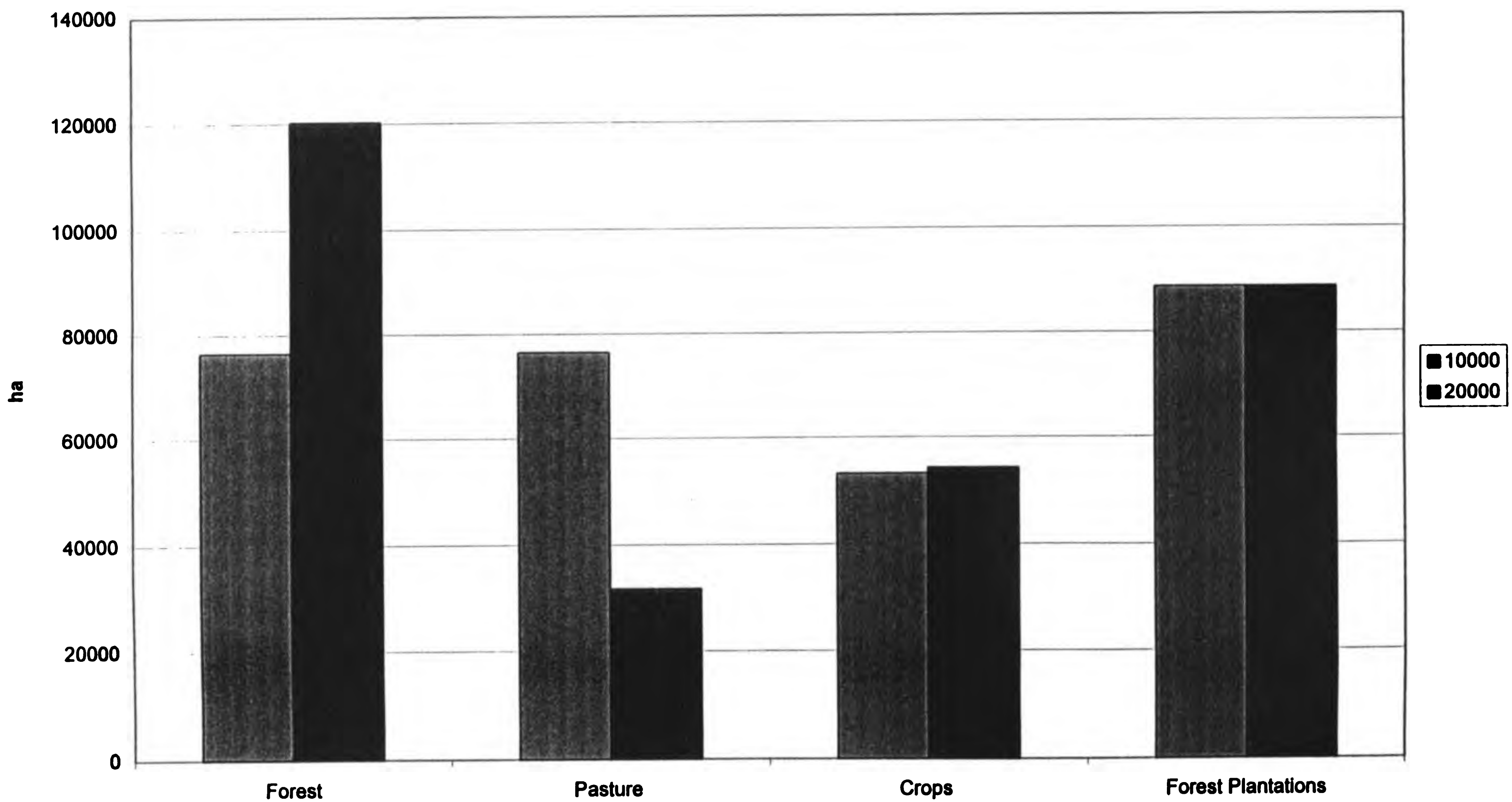
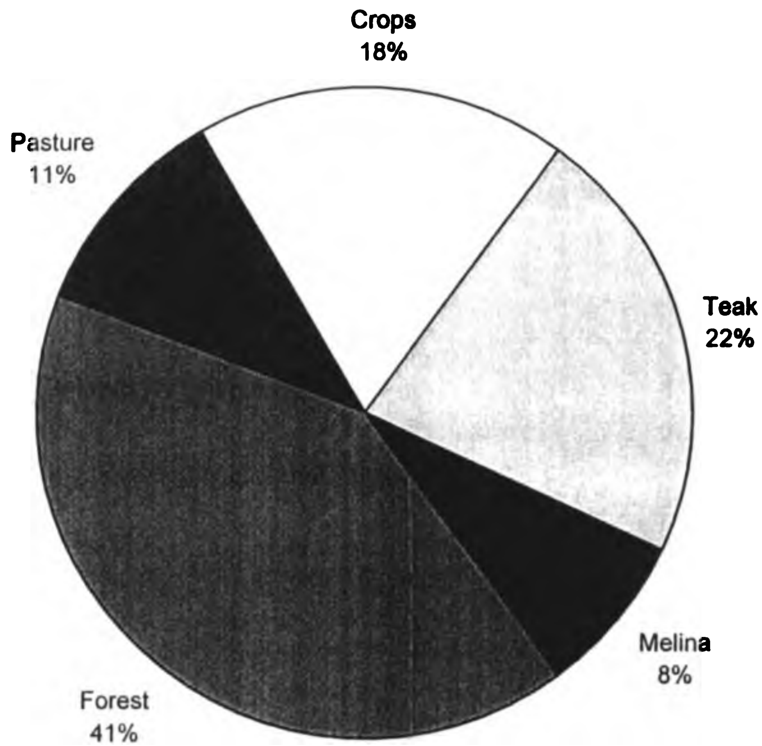


Figure 5.9 - Land use with the inclusion of tropical forest plantations and a yearly subsidy of 20000 Col/ha for natural forest



## 5.5. High transaction costs

Since it is a common practice in the NAZ to sell standing wood instead of transporting round wood directly at the sawmill, despite the greater profitability of the latter practice, in this Section we undertake the hypothesis that high transaction costs occur when organizing harvesting and transport operations. This has been done indirectly, i.e. excluding the possibility of transporting round wood to the sawmill or to produce round wood on the road and leaving only the possibility to sell standing wood.

This simulation is interesting because it is comparable with previous studies conducted in REPOSA, where timber was valued at stumpage prices although the LUSTs for sustainable management of natural forest have been completely redefined. The results are very similar to the ones of Schipper *et al.* (1998), and natural forest becomes a poor option when the possibility to include harvest and transport operations is excluded. These activities, as pointed out in chapter 4, can consistently increase the profitability of sustainable forest management (Table 5.4). The model allocates the whole land of the NAZ between pasture and agricultural crops. The area under pasture concerns the whole poorly-drained fertile soils and infertile soils plus a part of the well-drained fertile soils. Agricultural crops are found only in well-drained fertile soils.

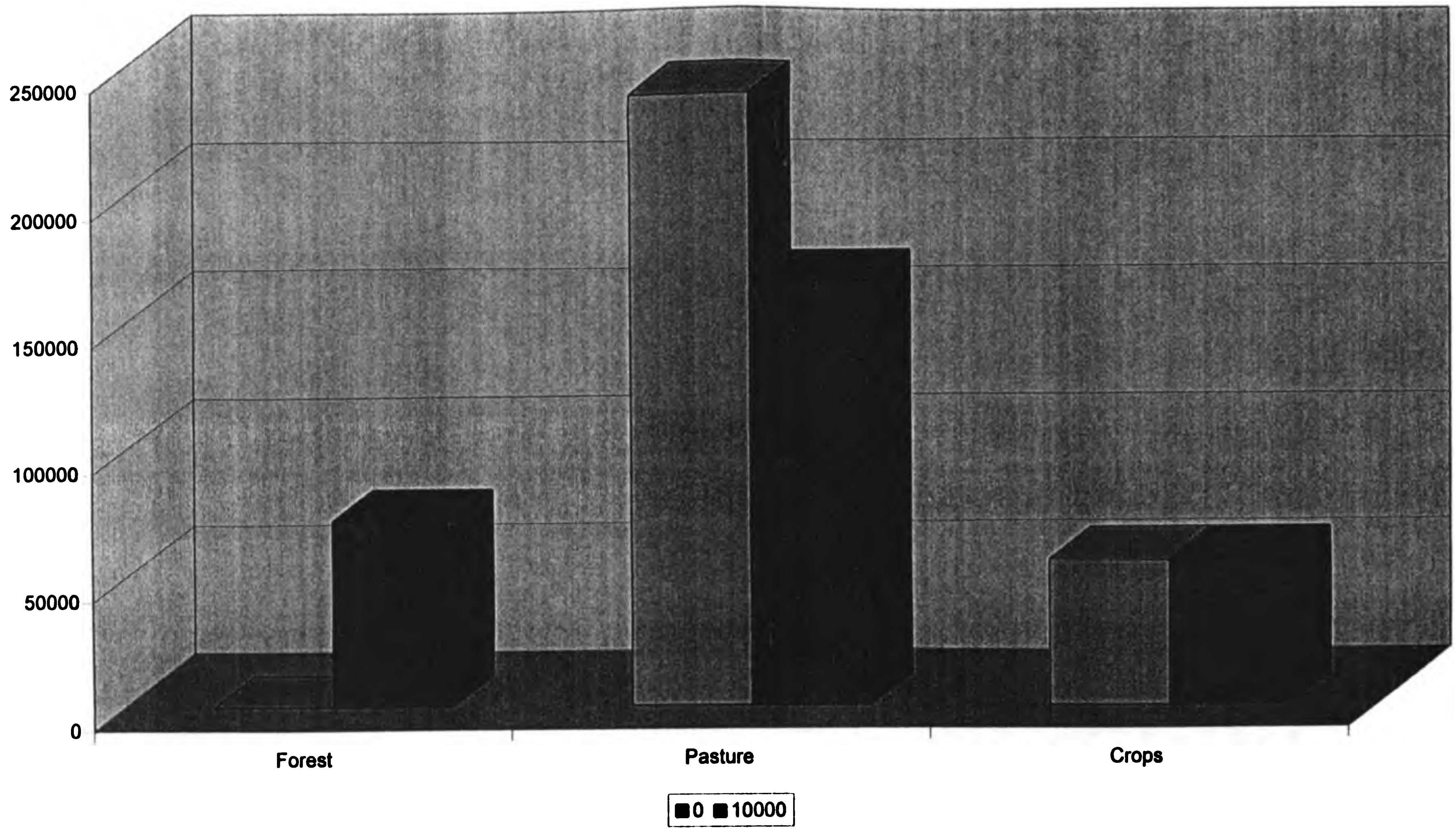
Another run of the model was done by including a yearly subsidy of 10,000 Col/ha for natural forest. This results in a shift away from pasture to natural forest (see Figure 5.10). This shift occurs only in poorly-drained fertile soils and therefore only swamp forests are considered in the solution.

These results show the importance of processing the wood directly in the farm by the landowners, condition that must be met in order to make sustainable natural forest management a competitive land use option in the NAZ.

Table 5.4- Scenarios that include high transaction costs

| | GROUP 4 | *High Transaction costs* | |
|---|---|---|---|
| | Units | High transac costs | High transaction costs and yearly subsidy for natural forest 10000 $Col*yr^{-1}*ha^{-1}$ |
| Objective function | $Col * 10^6$ | 47761 | 47838 |
| | $US \$ * 10^6$ | 264 | 264 |
| Labor | $Days * 10^3$ | 8985 | 8738 |
| **Land use** | total for agr. | 294852 | 294852 |
| Forest | ha | 0 | 72421 |
| Pasture | ha | 238373 | 165952 |
| Crops | ha | 56479 | 56479 |
| *of which* | | | |
| Pineapple | ha | 3115 | 3115 |
| Palm heart | ha | 8367 | 8367 |
| Banana | ha | 33456 | 33456 |
| Plantain | ha | 2933 | 2933 |
| Cassava | ha | 8500 | 8500 |
| Beans | ha | 0 | 0 |
| Maize | ha | 109 | 109 |
| **Number of animals** | | | |
| Fattening system | | 156039 | 11185 |
| Breeding system | | 284861 | 202978 |
| **Lust type distribution over soil types** | | | |
| ***SFP - TOTAL*** | ha | ***118363*** | ***118363*** |
| Forest | ha | 0 | 72421 |
| Crops | ha | 0 | 0 |
| Pasture | ha | 118363 | 45942 |
| ***SFW - TOTAL*** | ha | ***103973*** | ***103973*** |
| Forest | ha | 0 | 0 |
| Crops | ha | 56478 | 56479 |
| Pasture | ha | 47495 | 47494 |
| | | 0 | |
| ***SIW - TOTAL*** | ha | ***72517*** | ***72517*** |
| Forest | ha | 0 | 0 |
| Crops | ha | 0 | 0 |
| Pasture | ha | 72517 | 72517 |
| **Sustainability indicators** | | | |
| NBAL | $Kg * ha^{-1}$ | 37 | 26 |
| PBAL | $Kg * ha^{-1}$ | -1 | -1 |
| KBAL | $Kg * ha^{-1}$ | 8 | 8 |
| **Environmental indicators** | | | |
| BIOA | $Kg * 10^3$ | 241 | 173 |
| BIOI | $10^3$ | 73100 | 72263 |

**Figure 5.10 - Hypothesis of high transaction costs**



## 5.6. Deforestation and interest rate

The scenarios explored in the previous Sections were characterized by a discount rate of 7%. Since Costa Rica is undertaking policies to reduce the public sector deficit, it is possible that in future the demand for capital by the Government will decrease, resulting in lower interest rates (Schipper *et al.* 1998). In order to simulate the effect of a reduction in the interest rate, the model was run with a discount rate of 3%. The results show (Table 5.5) a consistent decrease of the area under pasture. Confronting Figure 5.3 with Figure 5.11, the area under forest goes from 8% to 64%, while pasture decreases from 73% to 17%. It is interesting to notice that the area under forest increases consistently both in well and poorly-drained fertile soils, and only slightly in the infertile soils which remain mainly under pasture. Regarding agricultural crops, although the total number of hectares is almost the same in both runs, there is a shift away from fertile soils towards infertile soils. Since most benefits take place later then costs, the value of the objective function increases when considering a lower discount rate. Running the model with the inclusion of the subsidy for natural forest causes a drastic reduction in the area under pasture since natural forest becomes a competitive land use option even in infertile soils.

These results are quite different from the simulations done by Schipper *et al.* (1998) and natural forest seems to be an attractive land use option in the context of this study. The reason for these changes is related to the natural forest LUSTs that have been completely redefined with the data presented in Chapter 4. The natural forest LUSTs chosen by the model in the present study are different from the ones considered in Schipper *et al.* (1998), where timber production was valued at stumpage prices. The introduction of the possibility to transport round wood directly to the sawmill, which is much more profitable then selling standing wood, explains the main differences discussed in this Section.

Table 5.5- Land use and discount rate

| | Units | 3% interest r | 3% interest rat and yearly nat forest subsidy 10000 Col*yr$^{-1}$ | 3% interest r plantations a natural fores 10000 Col*yr | 3% interest rate plantations and yearly natural forest subsidy 20000 Col*yr$^{-1}$*ha$^{-1}$ |
|---|---|---|---|---|---|
| ***GROUP 5*** | | ***A change in the interest rate*** | | | |
| Objective function | Col * $10^6$ | 57258 | 59481 | 135328 | 77897 |
| | US $ * $10^6$ | 316 | 329 | 748 | 430 |
| Labor | Days * $10^3$ | 8190 | 7965 | 8621 | 8594 |
| **Land use** | total for agr. | 294852 | 294852 | 294852 | 294852 |
| Forest | ha | 187625 | 239173 | 9476 | 163494 |
| Pasture | ha | 50885 | 0 | 0 | 0 |
| Crops | ha | 56342 | 55679 | 49536 | 55679 |
| *of which* | | | | | |
| Pineapple | ha | 3026 | 3026 | 8246 | 3026 |
| Palm heart | ha | 9541 | 9187 | 8119 | 9187 |
| Banana | ha | 33184 | 33184 | 28272 | 33184 |
| Plantain | ha | 2779 | 2697 | 841 | 2687 |
| Cassava | ha | 7734 | 7516 | 10154 | 7515 |
| Beans | ha | 0 | 0 | 0 | 0 |
| Maize | ha | 78 | 72 | 0 | 72 |
| **Number of animals** | | | | | |
| Fattening system | | 31521 | 0 | 0 | 0 |
| Breeding system | | 57545 | 0 | 0 | 0 |
| **Lust type distribution over soil types** | | | | | |
| ***SFP - TOTAL*** | | ***118363*** | ***118363*** | ***118363*** | ***118363*** |
| Forest | | 118363 | 118363 | 0 | 90762 |
| Crops | | 0 | 0 | 1706 | 0 |
| Pasture | | 0 | 0 | 0 | 0 |
| Tropical forest plantations | | 0 | 0 | 116657 | 27601 |
| ***SFW - TOTAL*** | | ***103973*** | ***103973*** | ***103973*** | ***103973*** |
| Forest | | 57172 | 57480 | 604 | 33507 |
| Crops | | 46801 | 46493 | 29400 | 46493 |
| Pasture | | 0 | 0 | 0 | 0 |
| Tropical forest plantations | | 0 | 0 | 73969 | 23973 |
| ***SIW - TOTAL*** | | ***72517*** | ***72517*** | ***72517*** | ***72517*** |
| Forest | | 12090 | 63330 | 0 | 39225 |
| Crops | | 9541 | 9187 | 27273 | 9187 |
| Pasture | | 50886 | 0 | 0 | 0 |
| Tropical forest plantations | | 0 | 0 | 0 | 0 |
| **Sustainability indicators** | | | | | |
| NBAL | | 8 | 0 | 16 | 9 |
| PBAL | | 0 | 0 | -3 | 0 |
| KBAL | | 5 | 3 | 17 | 14 |
| **Environmental indicators** | | | | | |
| BIOA | | 60 | 0 | 0 | 0 |
| BIOI | | 68220 | 66074 | 221663 | 126522 |

**Figure 5.11 - Land use and discount rate at 3%**

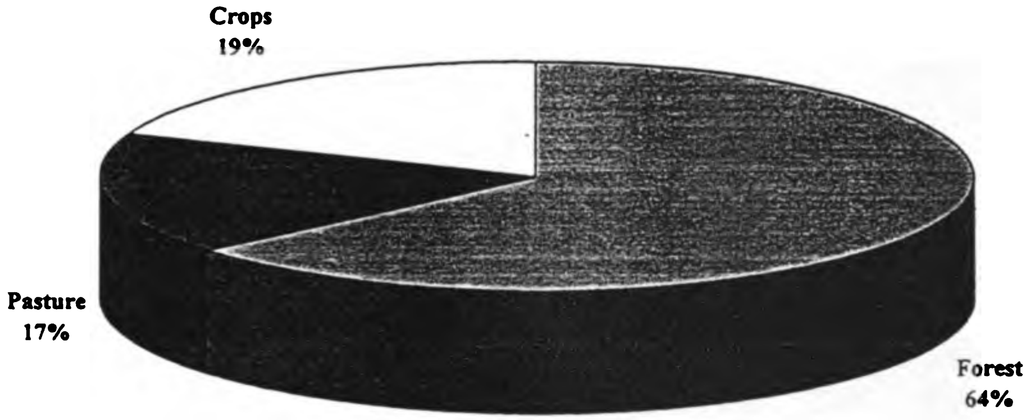



**Figure 5.12 - Land use and 3% discount rate with a yearly subsidy of 10.000 Col/ha**

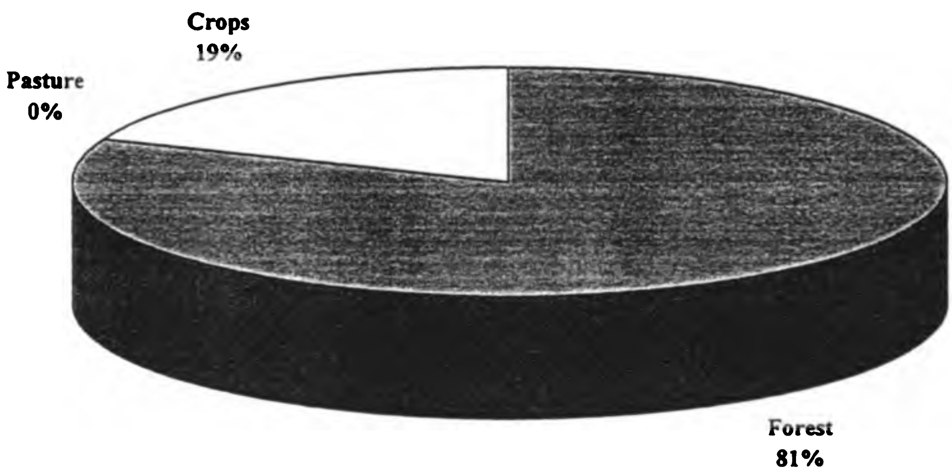
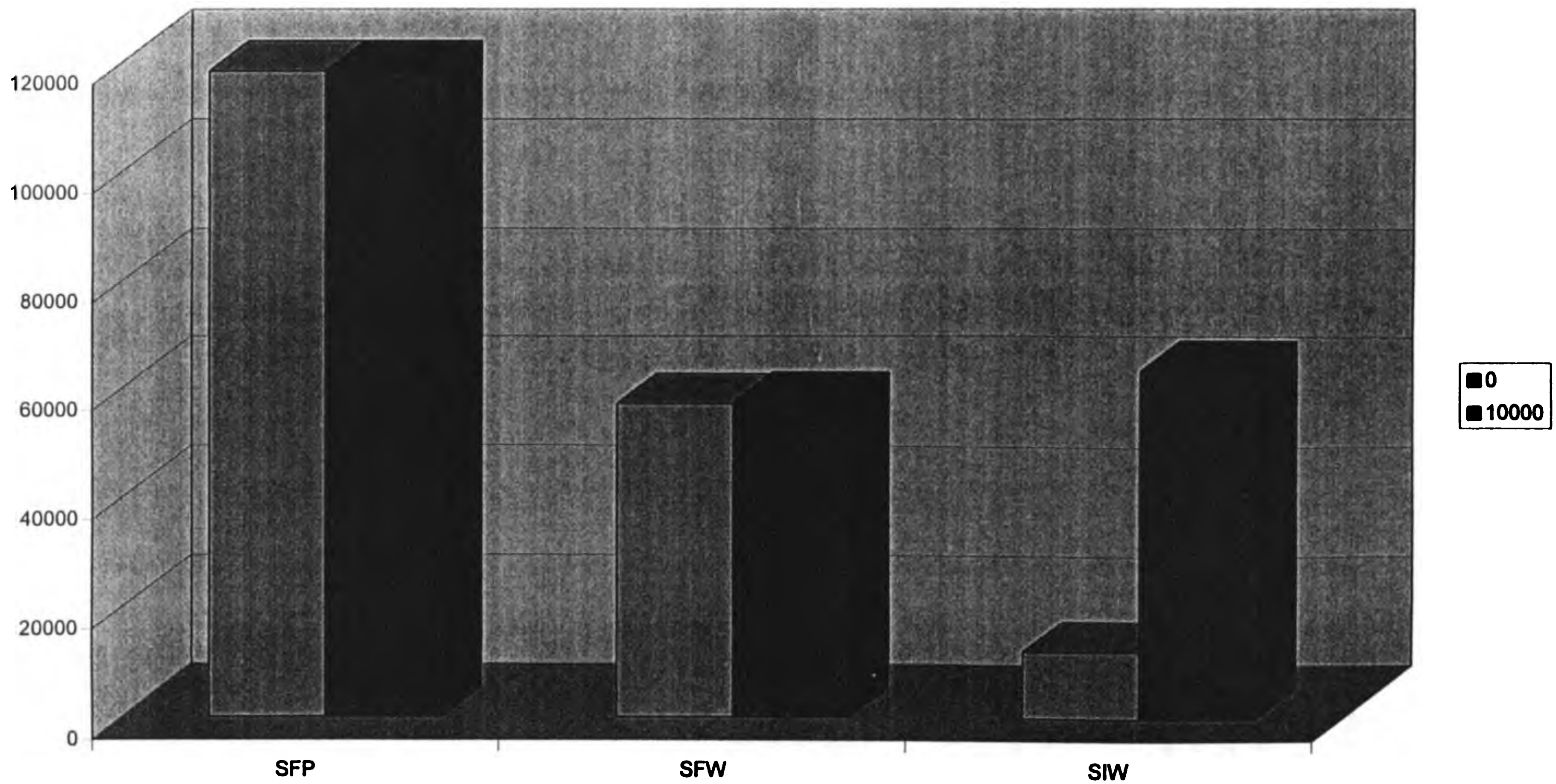


Figure 5.13 - Forest land-use for soil types with and without forest subsidy
(d.r.= 3%)



## 5.7. Sensitivity analysis on timber prices

Fluctuation of timber prices are likely to occur in Costa Rica and several run have been made in order to estimate the effects timber price changes on land use.

Von Platen and Lujàn found that average real prices for round wood timber at the sawmill increased between 6,4% and 7,6% per year in the period 1976-1993. These increments, however, were not uniform in time and the authors concluded that the market is too complex to make forecasts. Howard (1995) points out that real stumpage prices have increased by almost 11% per year in the period 1983-1993.

In absence of subsidies, natural forest wood variations have been set at 30% and 50% of the base prices (see table 5.7 and Figure 5.14). The results obtained including negative variations of wood prices excluded natural forest, and only with a positive variation of 30% of the base prices there is a shift in favor of natural forest from pasture which interests the whole poorly-drained soils (see Figure 5.15). Further changes in the area under natural forest do not occur including a 50% variation of the base price.

The model was run including a yearly subsidy of 10,000 Col/ha per year, and positive and negative variations of prices of 10% and 30% of the base run. The trade-off between pasture and natural forest that occurs when analyzing the combined effect of subsidy and price variation is shown in Figure 5.16. It is interesting to notice that natural forest becomes competitive first on poorly-drained soils and then in well-drained fertile soils, infertile soils remaining under pasture with a variation of up to 30% of the base prices (Figures 5.17).

Table 5.7- Sensitivity analysis on tropical timber prices considering a yearly subsidy for natural forest of 10000 Co

| ***GROUP 7*** | ***Sensitivity analysis on tropical timber prices*** | | | | | |
|---|---|---|---|---|---|---|
| | Units | | | **Initial price** | | |
| | | ***-30%*** | ***-10%*** | ***0%*** | ***+10%*** | ***+30%*** |
| Objective function | Col * $10^6$ | 47788 | 48454 | 48808 | 49176 | 50057 |
| | US $ * $10^6$ | 264 | 267 | 270 | 272 | 277 |
| Labor | Days * $10^3$ | 89066 | 8581 | 8576 | 8520 | 8364 |
| **Land use** | total for agr. | 294852 | 294852 | 294852 | 294852 | 294852 |
| Forest | ha | 22922 | 118363 | 118363 | 132444 | 166306 |
| Pasture | ha | 215451 | 120011 | 120055 | 105973 | 72537 |
| Crops | ha | *56479* | *56478* | *56434* | *56435* | *56009* |
| **Lust type distribution over soil types** | | | | | | |
| ***SFP - TOTAL*** | ha | ***118363*** | ***118363*** | ***118363*** | ***118363*** | ***118363*** |
| Forest | ha | 22922 | 118363 | 118363 | 118363 | 118363 |
| Crops | ha | 0 | 0 | 0 | 0 | 0 |
| Pasture | ha | 95441 | 0 | 0 | 0 | 0 |
| ***SFW - TOTAL*** | ha | ***103973*** | ***103973*** | ***103973*** | ***103973*** | ***103973*** |
| Forest | ha | 0 | 0 | 0 | 14081 | 47944 |
| Crops | ha | 56479 | 56479 | 56435 | 56437 | 56009 |
| Pasture | ha | 47494 | 47494 | 47538 | 33455 | 20 |
| ***SIW - TOTAL*** | ha | ***72517*** | ***72517*** | ***72517*** | ***72517*** | ***72517*** |
| Forest | ha | 0 | 0 | 0 | 0 | 0 |
| Crops | ha | 0 | 0 | 0 | 0 | 0 |
| Pasture | ha | 72517 | 72517 | 72517 | 72517 | 72517 |
| **Sustainability indicators** | | | | | | |
| NBAL | Kg * $ha^{-1}$ | 33 | 18 | 18 | 16 | 10 |
| PBAL | Kg * $ha^{-1}$ | -1 | -1 | -1 | -1 | 0 |
| KBAL | Kg * $ha^{-1}$ | 8 | 8 | 8 | 8 | 6 |
| **Environmental indicators** | | | | | | |
| BIOA | Kg * $10^3$ | 219 | 129 | 130 | 116 | 85 |
| BIOI | $10^3$ | 72835 | 71733 | 71686 | 71524 | 70432 |

**Figure 5.16 - Sensitivity analysis on tropical timber prices with a yearly subsidy of 10,000 Col/ha for natural forest**

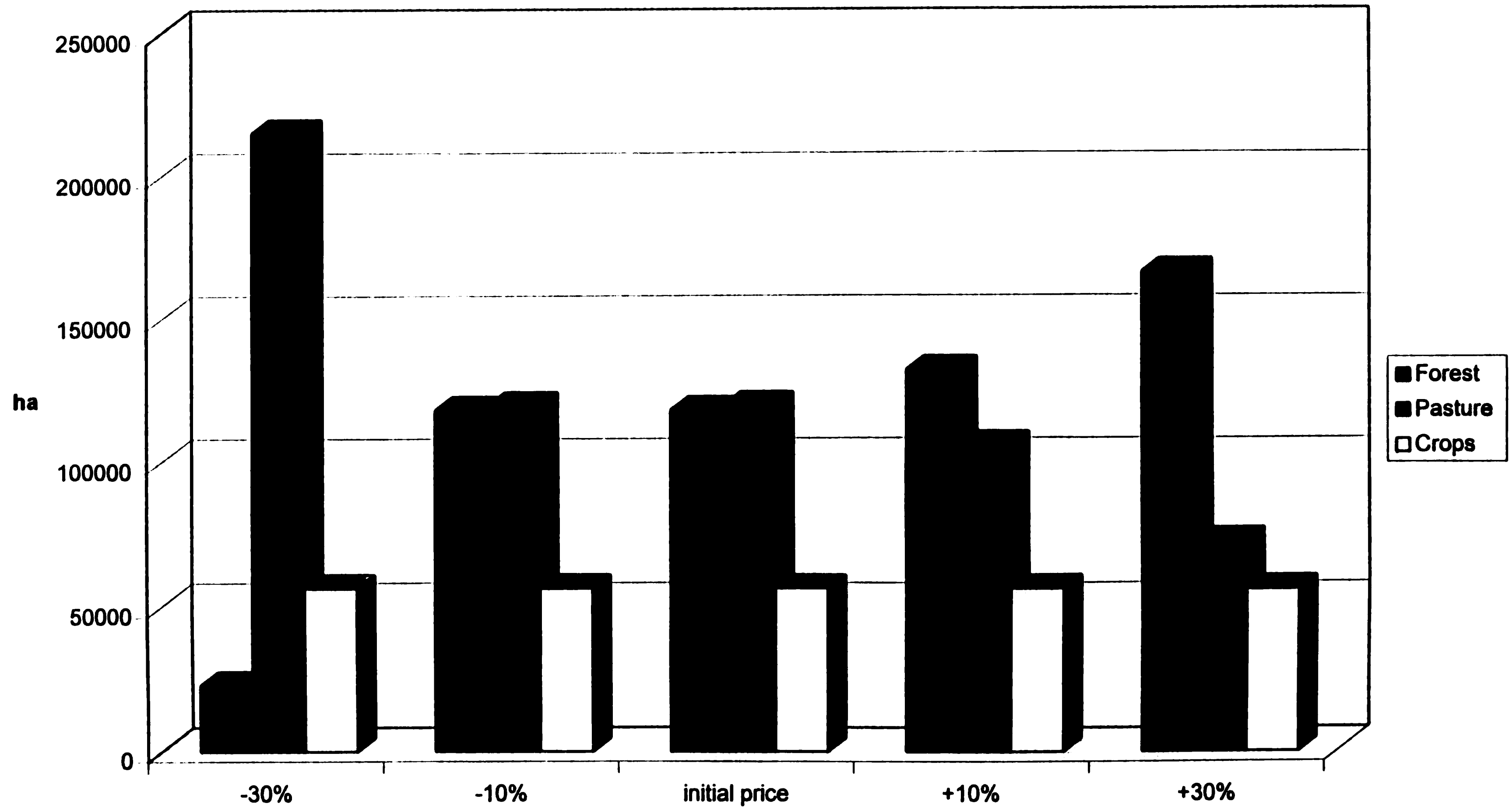
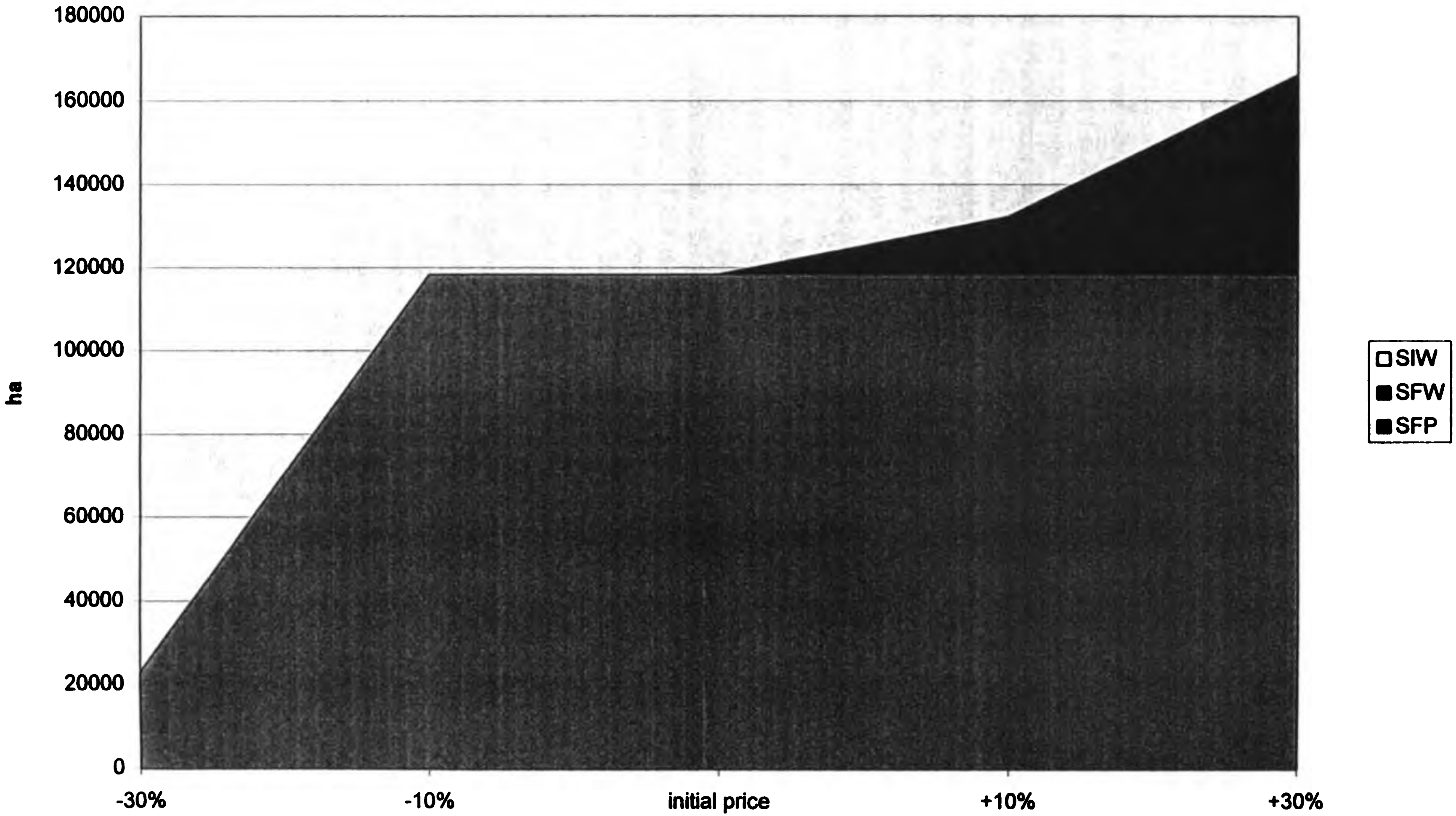


**Figure 5.17 - Forest land use for soil types at different timber prices**



## 6. CONCLUDING OBSERVATIONS

It is a research question if land use analysis can be *useful* for policy makers at the national level. The literature suggests to keep modest about the contributions since in land use planning the risk of rising expectations is real (Fresco, 1994). It is important to remember that this type of analysis is not meant to make forecasts but to explore scenarios based on explicit assumptions and given set of goals. It should be also considered that, although new goals as sustainable development and the need to preserve natural resources are receiving increasing attention at the international level, there is large uncertainty for the definition of ecological parameters that could make sustainability objectively "measurable". International initiatives have led to the definition of criteria in order to evaluate forestry projects on a sustainable base. However, a more appropriate conceptualization of the interdependency of the economy and the environment is needed before the concept of sustainable development can find its place in an economic framework. Given these assumptions, the philosophy of this study has been to explore scenarios in order to avoid non-sustainable patterns of development that could lead to the disappearance of the remaining natural forest in Costa Rica.

The aim of this study was to explore under which conditions sustainable natural forest management for wood production is an efficient land use option in the Northern Atlantiz Zone of Costa Rica. The results of the scenarios explored show that natural forest management can be an attractive land use option if the initial conditions of the forest are good enough to allow an harvest in the first years of the management plan. If a first harvest can be planned only after several years other land use options happen to be more attractive from the view of the private sector. In this case becomes important to analyze in quantitative terms the conditions that must be met in order to promote sustainable development of the remaining tropical forests in the NAZ. In adopting the methodology developed in REPOSA for the analysis of forestry issues, it has been assumed that market imperfections, related to the global public good aspects of tropical natural forests, act as a constraint to reach first best solutions and, therefore, the focus was placed in exploring scenarios in order to select an optimal second best policy. In case of land use planning for non-protected areas, the global public good aspects of tropical forests could be taken indirectly into account, considering the introduction of subsidies for the sustainable management of natural forests. These types of subsidies have been introduced recently in Costa Rica, where farmers can receive a yearly subsidy for natural forest under the presentation of a management plan for the forest and the commitment that no harvest will occur for several years. These subsidies can be seen as a way to compensate private landowners for the global public good aspects of tropical forests. This type of analysis has been performed in order to avoid non-sustainable patterns of development, i.e. in order to explore the conditions that must be met (amount of subsidies) for making sustainable natural forest management of natural forests an attractive land use option from the point of view of private landowners (thus avoiding further deforestation).

In literature, the phenomenon of deforestation in the Northern Atlantic Zone of Costa Rica has been explained as result of major attractiveness of other land use types (Schipper *et al.*, 1998; Bouman *et al.*, 1998b). The conditions of the natural forest in Costa Rica are not ideal, and natural forests are rapidly disappearing in non-protected areas. In this study it has been shown that sustainable forest management can be an attractive land use option for private landowners under certain conditions. The key factor lies in the initial conditions of the forest or, in other words, in the possibility to make an harvest in the first years of the management plan. However, other factors are important in explaining deforestation. First of all the farmer's aversion to risk and the type of cash flow related to natural forest management. There is also little knowledge among farmers on the technical aspects of sustainable forest management. The expansion of infrastructures, is also one important factor in explaining the high deforestation rates in the NAZ. If the deforestation keeps at the present rates in 25 years the only natural forests left in Costa Rica will be in protected areas. Moreover, by the year 2010 Costa Rica could be in in severe shortage of wood (Wendland *et al.*, 1996). In order to meet future demand for timber in the country, it seems that tropical forest plantations will play an important role, because it has been shown that they are financially very attractive for the private sector. However it should be remembered that they do not have the same ecological role of the natural forest.

A possible direction for further development of the research that would allow to consider properly the initial condition of the natural forests could be to geo-reference the different forest types present in the NAZ. This could be done overlaying the forest cover map with the soil type map of the GIS of REPOSA. Although it is rather complex to distinguish the different types of forests with a satellite image, This further development of the research would allow to use different sets of technical coefficients according to the conditions of the forests and would give a deeper insight into the real possibilities of the forests left in non-protected areas.

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## APPENDIX - MATHEMATICAL FORMULATION OF REALM
(adapted from Schipper *et al.*, 1998)

Table 1 Relevant part of - simplified - NAZ model

Objective function: benefits less costs: area below domestic demand functions plus value of exports, plus value of subsidies, less product market transaction costs, less value of current input and labor costs (wage sum, transaction costs and area below labor supply function)' (¢ year$^{-1}$)

$$\text{Max } Z = \sum_{j \in J1} p_{j \in J1}\, D_{j \in J1} + \sum_{j \in J2} p_{j \in J2}\, E_{j \in J2} + \sum_{j \in J3}\sum_{d} \omega^{d}_{j \in J3,d}\, D^{s}_{j \in J3,d} + \sum_{j \in J4}\sum_{d} \rho^{x}_{j \in J4,d}\, E^{s}_{j \in J4,d}$$
$$+ \sum_{z}\sum_{s}\sum_{l}\sum_{t} \phi_l X_{zslt} - \sum_{z}\sum_{j} t^{p}_{jz} S_{jz} - p\, C - \sum_{z}\sum_{\zeta} t^{l}_{\zeta z} L_{\zeta z} - \sum_{z} t^{o}_{z} O_{z} - \sum_{o} \varpi^{o}_{o} O_{o} \qquad (1)$$

Subject to:

* balances of product annuity per product per sub-region (ton year$^{-1}$)

$$\sum_{s}\sum_{l}\sum_{t} - y_{jslt} X_{zslt} + \sum_{h} - y_{jh} A_{zh} + S_{jz} \leq 0 \quad \text{all } j, z \qquad (2)$$

* balances of product annuity per product for whole NAZ (ton year$^{-1}$)

$$S_j - \sum_{z} S_{jz} \leq 0 \quad \text{all } j \qquad (3)$$

* balance per product: domestic demand + export < production (ton year$^{-1}$)(excluding imports as not relevant for the products concerned)

$$D_j + E_j - S_j \leq 0 \quad \text{all } j \qquad (4)$$

* segmentation of domestic demand per product (ton year$^{-1}$)

$$- D_j + \sum_{d} q^{d}_{jd}\, D^{s}_{jd} \leq 0 \quad \text{all } j \in J3 \qquad (5)$$

* convex combination constraint for domestic demand segment-limits variables

$$\sum_{d} D^{s}_{jd} \leq 1 \quad \text{all } j \in J3 \qquad (6)$$

* segmentation of export demand per product (ton year$^{-1}$)

$$- E_j + \sum_{d} q^{x}_{jd}\, E^{s}_{jd} \leq 0 \quad \text{all } j \in J4 \qquad (7)$$

* convex combination constraint for export demand segment-limits variables

$$\sum_{d} E^{s}_{jd} \leq 1 \quad \text{all } j \in J4 \qquad (8)$$

Table 1 Relevant part of - simplified - NAZ model, continuation

* annuity of inputs (sum of current inputs costs) balances per sub-region (¢* 1000 year$^{-1}$)

$$\sum_{s}\sum_{l}\sum_{t} c_{slt}\ X_{zslt} + \sum_{h} c_{h}\ A_{zh} + \sum_{s}\sum_{p}\sum_{r} c_{spr}\ P_{zspr} + \sum_{f} c_{f}\ F_{zfm} - C_{z} \leq 0 \qquad \text{all } z \qquad (9)$$

* annuity of inputs (sum of current inputs costs) balances for whole NAZ (¢* 1000 year$^{-1}$)

$$-C + \sum_{z} C_{z} \leq 0 \qquad (10)$$

* feed balance per nutrition type, per period per sub-region (Mcal year$^{-1}$; kg year$^{-1}$)

$$\sum_{p}\sum_{s}\sum_{r} n_{sprmn}\ P_{zspr} + \sum_{f} n_{fn}\ F_{zfm} - \sum_{h} n_{hnm}\ A_{zh} \geq 0 \qquad \text{all } z, n, m \qquad (11)$$

* animal stock balance for pastures and herds per sub-region (animal units year$^{-1}$)

$$\sum_{p}\sum_{s}\sum_{r} s_{spr}\ P_{zspr} - \sum_{h} h_{h}\ A_{zh} = 0 \qquad \text{all } z \qquad (12)$$

* balance of calves (ton year$^{-1}$)

$$\sum_{z} y_{j=calves,h=breeding}\ A_{z,h=breeding} - \sum_{z}\sum_{h} v_{h=fattening,double\ purpose}\ A_{z,h=fattening,double\ purpose} \geq 0 \qquad (13)$$

* use of land units per sub-region per farm type by LUSTs (ha year$^{-1}$)

$$\sum_{l}\sum_{t} X_{zfslt} + \sum_{p}\sum_{r} P_{zspr} \leq b_{zs} \qquad \text{all } z, s \qquad (14)$$

* annuity of labor use balanced by labor supply per sub-region (days year$^{-1}$)

$$\sum_{s}\sum_{l}\sum_{t} l_{slt}\ X_{zslt} + \sum_{h} l_{h}\ A_{zh} + \sum_{s}\sum_{p}\sum_{r} l_{spr}\ P_{zspr} + \sum_{f} l_{f}\ F_{zfm} - \sum_{\varsigma} L_{z\varsigma} - O_{z} \leq 0 \qquad \text{all } z\ (15)$$

* agricultural labor force availability per sub-region (days year$^{-1}$)

$$\sum_{z} L_{z\varsigma} \leq a_{\varsigma} \qquad \text{all } \varsigma \qquad (16)$$

Table 1 Relevant part of - simplified - NAZ model, continuation

* calculation of use of agricultural labor force for whole NAZ (days year$^{-1}$)

$$\sum_{z}\sum_{\zeta} L_{z\zeta} - L \leq 0 \qquad (17)$$

* segmentation of labor supply function (days year$^{-1}$)

$$L + \sum_{z} O_z - \sum_{o} o_o\, O_o \leq 0 \qquad (18)$$

* convex combination constraint for labor

$$\sum_{o} O_o \leq 1 \qquad (19)$$

* calculation of environmental indicators per soil type per sub-region per indicator (kg year$^{-1}$; index year$^{-1}$)

$$\sum_{l}\sum_{t} \delta_{slte}\, X_{zslt} + \sum_{p}\sum_{r} \delta_{spre}\, P_{zspr} - A_{sze} = 0 \qquad \text{all } s, z, e \qquad (20)$$

* limit to environmental indicator per sub-region per soil type per indicator (kg year$^{-1}$; index year$^{-1}$)

$$A_{sze} \leq d_{sze} \qquad \text{all } s, z, e \qquad (21)$$

* limit to environmental indicator per sub-region per indicator (kg year$^{-1}$; index year$^{-1}$)

$$\sum_{s} A_{sze} \leq d_{ze} \qquad \text{all } z, e \qquad (22)$$

* limit to environmental indicator per soil type per indicator (kg year$^{-1}$; index year$^{-1}$)

$$\sum_{z} A_{sze} \leq d_{se} \qquad \text{all } s, e \qquad (23)$$

* limit to environmental indicator per indicator for whole NAZ (kg year$^{-1}$; index year$^{-1}$)

$$\sum_{s}\sum_{z} A_{sze} \leq d_{e} \qquad \text{all } e \qquad (24)$$

Table 1 Part of indices in NAZ model



| Indices | Description | Elements |
|---|---|---|
| *J* | Products | depends on selection of LUSTs; the set *J* with elements *j* has four sub-sets: *J1*, products for domestic market without a market limitation; *J2*, products for export market without a market limitation; *J3*, products for domestic market with a downward-sloping demand function; and *J4*, products for export market with a downward-sloping demand function In the GAMS formulation this index is a combination between index C(PA) for crops (land use types) and index Q (product type/quality), or index HP(PA) for livestock product and the same index Q |
| *D* | segment-limits | 1 to 100 in case of demand for products |
| *z* | sub-region | 1 to 12, for sub-regions Rxxx; there is also index $\zeta$ as an alias for *z* |
| *s* | soil types | SFP, SFW, SIW |
| *L* | land use types | depends on selection of LUSTs, at present: pineapple, palm heart, melina, banana, plantain, cassava, (black) beans, teak, maize (corn), maize (cobs), natural forest (selling standing wood), natural forest (selling round wood at the roadside), natural forest (selling round wood at the sawmill) |
| *t* | Technology | depends on level (high/low) of fertilizer, biocides, herbicides and mechanization and on length of crop cycle (01, 02, 03, 10 or 15 years) |
| *H* | herd type | herds of 50 animals, either breeding, fattening or double purpose |
| *P* | Pasture | depends on pasture (Brachiaria, Estrella, Natural, Brachiaria/Aracis pintoi, Tanner), weeding type (only herbicides, manual/herbicides, only manual) and fertilization level (low to high) |
| *R* | stocking rate | low to high, at present: 1 to 5 animal units per ha |
| *F* | feed types | Molasse of sugar cane, rejected bananas, *galinaz engorde*, $P_2O$ phosphorus |
| *N* | nutrition types | Metabolizable energy, crude protein, phosphorus |
| *M* | Period | season 1 (dryer): January to March, season 2 (wetter): April to December |
| *O* | segment limit | 1 to 100 in case of labor supply |
| *E* | Environmental indicator | N balance, P balance, K balance, N denitrification, N leaching, N valorization, biocide active ingredient, biocide indicator |

Table 2 Part of variables in NAZ model

| Variables[1] | Description | unit of measurement |
|---|---|---|
| $Z$ | value of objective function | ¢ $year^{-1}$ |
| $S_j$ | annuity production per product | ton $year^{-1}$ |
| $S_{jz}$ | annuity production per product per sub-region | do |
| $D_j$ | domestic demand per product | do |
| $D_{jd}^d$ | domestic demand segment limit variable per product | |
| $E_j$ | export demand per product | ton $year^{-1}$ |
| $E_{jd}^x$ | export demand segment limit variable per product | |
| $C$ | annuity of current input use (materials and services) | ¢ * 1000 $year^{-1}$ |
| $C_z$ | annuity current input use per sub-region | do |
| $X_{zslt}$ | LUSTs (Land Use System & Technology) per sub-region per soil per land use type per technology | ha $year^{-1}$ |
| $P_{zspr}$ | PASTs (PASTure activity) per sub-region per soil type per pasture type per stocking rate | ha $year^{-1}$ |
| $F_{zfm}$ | FASTs (Feed Acquisition System & Technology) per sub-region per supplementary feed type per period | Mcal $year^{-1}$; kg $year^{-1}$ |
| $A_{zh}$ | APSTs (Animal Production System & Technology) per sub-region per herd type | herds $year^{-1}$ |
| $L_{z\zeta}$ | annuity of use of labor from the 'agricultural labor force' per sub-region $z$, originating from sub-region $\zeta$ | days $year^{-1}$ |
| $L$ | annuity of use of labor from the 'agricultural labor force' for whole NAZ | do |
| $O_z$ | annuity of use of labor not belonging to the 'agricultural labor force' per sub-region | do |
| $O_o$ | segment limit variable for total labor supply | |
| $A_{sze}$ | Environmental indicator variable per soil type per sub-region per indicator type | kg $year^{-1}$; index $year^{-1}$ |

All variables in the model are continuous and larger than, or equal to, zero, except for $Z$ and $A_{sze}$ which are 'free' variables (larger than minus infinity). Furthermore, ¢ = *Colón*, the currency unit of Costa Rica.

Table 3 Part of coefficients in NAZ model

| Coefficients | Description | units of measurement |
|---|---|---|
| $P_j$ | product price per product (OBJ)[1] | ¢ ton$^{-1}$ |
| $\phi_l$ | Subsidy per land use type | ¢ ha$^{-1}$ |
| $P$ | price of current inputs and (reservation) wage (OBJ) | ¢¢$^{-1}$1000$^{-1}$ |
| $T_{jz}$ | product market transaction costs per product per sub-region (OBJ) | ¢ ton$^{-1}$ |
| $\omega_{jd}^{d}$ | areas below domestic demand function related to each segment limit of domestic demand functions (OBJ) | ¢ year$^{-1}$ |
| $\rho_{jd}^{x}$ | producer revenue related to each segment limit of export demand functions (OBJ) | ¢ year$^{-1}$ |
| $q_{jd}^{d}$ | quantity of domestic demand related to each segment limit of domestic demand functions | ton year$^{-1}$ |
| $q_{jd}^{x}$ | quantity of export demand related to each segment limit of export demand functions | ton year$^{-1}$ |
| $T_{\zeta z}^{l}$ | agricultural labor force transaction cost from sub-region $\zeta$ to sub-region $z$ (OBJ) | ¢ day$^{-1}$ |
| $W$ | wage of agricultural labor force (OBJ) | ¢ day$^{-1}$ |
| $T_z^{o}$ | transaction costs for labor from outside the agricultural sector (OBJ) | ¢ day$^{-1}$ |
| $\varpi_o^{o}$ | area under total labor supply function sector (OBJ) | ¢ day$^{-1}$ |
| $Y_{jslt}$ | annuity yield of a LUST[2] per product | ton ha$^{-1}$ |
| $y_{jh}$ | annuity yield of an APST[3] per product | ton herd$^{-1}$ |
| $c_{slt}$ | annuity use of current inputs by a LUST | ¢ * 1000 ha$^{-1}$ |
| $C_h$ | annuity use of current inputs by an APST | ¢ * 1000 herd$^{-1}$ |
| $c_{spr}$ | annuity use of current inputs by a PAST[4] | ¢ * 1000 ha$^{-1}$ |
| $V_h$ | calves as input for APST in case of fattening or double purpose | ton herd$^{-1}$ |
| $C_f$ | annuity use of current inputs by a FAST[5] | ¢ * 1000 kg$^{-1}$ |
| $N_{sprmn}$ | feed elements yielded by a PAST per soil type per pasture type per stocking rate per period per nutrition type | Mcal year$^{-1}$; kg year$^{-1}$ |
| $n_{fn}$ | feed elements yielded by a FAST per supplementary feed type per nutrition type | do |
| $n_{hnm}$ | feed elements required by an APST per herd type per nutrition type per period | do |
| $s_{spr}$ | stocking rate per soil type per pasture type per stocking rate | animal units ha$^{-1}$ |
| $h_h$ | herd size per herd type | animal units herd$^{-1}$ |
| $b_{zs}$ | land availability per farm type per land unit (RHS)[6] | ha year$^{-1}$ |

[1] OBJ: objective function coefficient

[2] LUST: variable $X_{zslt}$, see Table 3

[3] APST: variable $A_{zh}$, see Table 3

[4] PAST: variable $P_{zspr}$, see Table 3

[5] FAST: variable $F_{zfm}$, see Table 3

[6] RHS: right hand side coefficient

Table 3 Part of coefficients in NAZ model, continuation

| Coefficients | Description | units of measurement |
|---|---|---|
| $l_{slt}$ | annuity use of labor by a LUST[1] | days $ha^{-1}$ |
| $l_h$ | annuity use of labor by an APST[2] | Do |
| $l_{spr}$ | annuity use of labor by a PAST[3] | Do |
| $l_f$ | annuity use of labor by a FAST[4] | Do |
| $o_o$ | annuity use of labor related to each segment limit of the total labor supply function | days $year^{-1}$ |
| $a_\varsigma$ | (annuity of) agricultural labor force availability (RHS)[5] | days $year^{-1}$ |
| $\delta_{slte}$ | sustainability indicator of LUSTs per indicator type | kg $ha^{-1}$; index $ha^{-1}$ |
| $\delta_{spre}$ | sustainability indicator of PASTs per indicator type | kg $ha^{-1}$; index $ha^{-1}$ |
| $d_{zse}$ | limit to sustainability indicator per sub-region per soil type per indicator type (RHS) | kg $year^{-1}$; index $year^{-1}$ |
| $d_{ze}$ | limit to sustainability indicator per sub-region per indicator type (RHS) | kg $year^{-1}$; index $year^{-1}$ |
| $d_{se}$ | limit to sustainability indicator per soil type per indicator type (RHS) | kg $year^{-1}$; index $year^{-1}$ |
| $d_e$ | limit to sustainability indicator per indicator type for whole NAZ (RHS) | kg $year^{-1}$; index $year^{-1}$ |

[1] LUST: variable $X_{zslt}$, see Table 3
[2] APST: variable $A_{zh}$, see Table 3
[3] PAST: variable $P_{zspr}$, see Table 3
[4] FAST: variable $F_{zfm}$, see Table 3
[5] RHS: right hand side coefficient 3