# Economic Analysis of Tree-Based Intercropping in Southern Ontario, Canada

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# ABSTRACT

Tree Based Intercropping (TBI) integrates the use of crops and trees on the same land unit. Such systems can provide a variety of economic, environmental and social benefits in comparison with mono-cropping agriculture system. The specific objectives of this thesis were to determine the productivity, profitability, and practicality of TBI systems relative to mono-cropping system in Canada. Predicting the productivity, profitability and practicality consisted of several steps. First of all, a comprehensive process-based mathematical model called Ecosys© were used to estimate the trees growth. Secondly, a economic analysis model (Farm-SAFE) was used to determine the profitability and feasibility of TBI system relative to mono-cropping system.

The evaluation of mono-cropping and TBI systems was undertaken for selected tree and crop species. Selected tree species were hybrid poplar, Norway spruce and red oak and crops species were wheat, corn, soybean and barley. The results of this study suggested that TBI systems can under certain circumstances provide a productive, profitable and feasible alternative to mono-cropping system. Tree and crop production was invariably more efficient in the use of land when combined in TBI systems hybrid poplar than when separated in mono-cropping system. Farmers can use a combination of fast-growing specie (hybrid poplar) and slow-growing specie (red oak) simultaneously to increase their profit by using TBI agriculture system.

# RÉSUMÉ

Sur la base des arbres Intercropping (TBI) intègre l'utilisation des cultures et des arbres sur l'unité même terre. Ces systèmes peuvent fournir une variété d'avantages économiques, environnementaux et sociaux en comparaison avec des mono-système de culture agricole. Les objectifs spécifiques de cette thèse étaient de déterminer la productivité, la rentabilité et l'applicabilité des systèmes TCC par rapport à la monoculture système au Canada. Prédiction de la productivité, la rentabilité et le caractère pratique consistait en plusieurs étapes. Tout d'abord, un processus exhaustif basé sur le modèle mathématique appelé Ecosys © ont été utilisées pour estimer la croissance des arbres. Deuxièmement, un modèle d'analyse économique (Farm-SAFE) a été utilisée pour déterminer la rentabilité et la faisabilité du système de TBI par rapport à la monoculture du système.

L'évaluation de la monoculture et des systèmes de TBI a été entrepris pour l'arbre choisi et les espèces cultivées. Espèces d'arbres sélectionnés ont été le peuplier hybride, l'épicéa et le chêne rouge et des espèces de cultures étaient le blé, le maïs, le soja et l'orge. Les résultats de cette étude suggère que les systèmes de TBI peuvent dans certaines circonstances, constituer une alternative productive, rentable et faisable de monoculture système. Arbre et la production des cultures a été invariablement plus efficace dans l'utilisation des terres lorsqu'elles sont combinées dans les systèmes de TBI (peuplier hybride et l'épinette de Norvège) que quand ils sont séparés en mono-système de culture. Les agriculteurs peuvent utiliser une combinaison d'espèces à court terme (peupliers hybrides) et espèces à long terme (chêne rouge) simultanément pour augmenter leur profit en utilisant TBI système agricole.

# DEDICATION

I dedicate my work to my Father and Mother who always accepted my decisions in life, allowing my wings to flow and taste different kinds of “*weather*”.

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Although the sins of omission and commission are solely mine, this research is a collaborative effort of many individuals. Some individuals who helped me immensely wish to remain anonymous and I respect their wishes and thank them for all they did for me.

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## List of Abbreviations

| | | |
|---|---|---|
| *A* | $ $ha^{-1}$ | Assignable fixed costs |
| *A* | - | First constant for phased *kt* |
| *Aa* | ha | Area of arable system |
| *Aarable* | ha | Arable area |
| *Alu* | ha | Area of land unit |
| *as* | ha | Area of silvoarable system |
| DBH | - | Diameter at breast height (dbh) -tree diameter measured at 4.5 feet above ground level. |
| *EAV* | $ $ha^{-1}$ $a^{-1}$ | Equivalent annual value |
| *F* | $ $farm^{-1}$ | Other fixed costs |
| Farm-SAFE | | Farm And Resource-use Model for Silvoarable Agroforestry for Europe |
| *i* | - | Discount rate |
| *iNPVfarm* | $$farm^{-1}$ | Infinite net present value of farm |
| *LER* | - | Land equivalent ratio |
| *N* | - | Number of cases |
| *NPV* | $ $ha^{-1}$ | Net present value |
| *NPVm* | $$ha^{-1}$ | Net present value of mono-cropping system |
| *NPVc* | $$ha^{-1}$ | Net present value of crop in mono-cropping or agroforestry system |
| *NPVInfinite* | $ $ha^{-1}$ | Infinite net present value |
| Stumpage price | - | The price paid for standing forest trees. |

# Chapter 1

## GENERAL INTRODUCTION

### 1.0 Introduction

Agroforestry is a traditional system of growing trees and crops together in an integrated system dating back to Roman times [Lelle and Gold 1994]. This system provided a sustainable supply of tree products, which would otherwise be harvested from the forest, and a supply of food grains. Agroforestry has the potential to improve agricultural sustainability and productivity. Agroforestry systems also diversify income, and when managed as low-input systems require few off-farm purchases [Mathews et al. 1993]. The major advantage of agroforestry is that both wood and agricultural products come from the same land base, making it an efficient production system especially in areas where farmers have small holdings.

Degradation of agricultural lands, environmental pollution from excess nutrients and pesticide residues, and loss of forested lands due to the economically driven expansion of intensive agricultural production systems has led to some undesirable environmental and ecological consequences in the temperate regions of North America. Public demand for more sustainable and ecologically friendly agricultural practices has led to the promotion of agroforestry as a practice to improve the environment in industrialized nations (America, Canada, European Countries) [Nair 2007]. There has already been a moderate level of adoption of agroforestry in many European countries [Graves et al. 2005]. Research over the past 20 years provides strong evidence that temperate agroforestry can be more biologically productive, more profitable, and thus more sustainable than monoculture forestry or agriculture systems [Gordon et al. 1997].

Much of the North American research into temperate agroforestry systems has focused on the ecosystem services provided, including water quality, biodiversity conservation, carbon sequestration, good land stewardship and aesthetics [Gordon et al. 1997; Nair 2007]. These ecological changes may yield economic benefits, in addition to the revenues obtained from tree and crop production, which could put temperate agroforestry ahead of conventional agriculture in terms of long-term productivity [Thevathasan and Gordon 2004].

While temperate agroforestry tends to emphasize environmental benefits in addition to crop revenue, it is important to consider how growing trees and crops together on the same land base will affect the financial outlook of farms. Diversifying the potential sources of income by including trees in the production system could be a risk-reducing strategy because incorporating new activities that are less dependent on, independent of, or negatively correlated with the outcome of on-going activities reduces the risk of the portfolio [Knutson et al. 1998; Reardon et al. 1992]. Diversification is a strategy that maximizes use of all available resources [Ellis 1998; Scherr 1995]. It has been shown that income from non-traditional farm products helped reduce the variability in total farm income [Mishra and Sandretto 2002]. However, there are few studies on the economic consequences of adopting agroforestry as a means of stabilizing farm income in the temperate regions of Canada.

## 1.1 Background and rationale

Agroforestry is an integrated production scheme that includes trees or shrubs in the same field where crops are grown. The trees are grown in rows with the between row area seeded to an annual crop. Although modern agroforestry has proven its value in temperate America, and seems promising in temperate Europe as well, only few investigations have been undertaken on this subject Canada. It is only recently that modern agroforestry has received attention in Canada and researchers and other stakeholders with interest and knowledge of agroforestry are interchanging their experiences and views. Adoption of agroforestry systems has been studied in the tropics [Pattanayak et al. 2003], but less in the temperate regions like Canada. Farmers will not be motivated to establish an agroforestry system on their farm without better knowledge of the economic benefits of this system. Trees planted with annual crops can help to increase economic benefits, as cash income is generated from the sale of tree products. However, with trees there is a long time lag between planting and harvesting. Farmers have many questions about agroforestry systems, such as: (i) which tree species by annual crop combination works best for their area? (ii) what is the optimal row width and time period for optimizing resource production in an agroforestry system? and (iii) what is the optimal tree rotation time? To answer these questions, an economic model will be used to evaluate the Net Present Value (NPV) of returns considering annual crop yields and revenues, establishment and production costs, and wood yield and prices. The study will utilize productivity data from a 22-year temperate agroforestry study site and supplement these data with other studies of longer duration required for many hardwood tree species (maple, black walnut and oak).

## 1.2 Objectives

The aim of this research is to improve understanding of the perception, productivity, profitability and practicality (feasibility) of temperate agroforestry systems in eastern Canada. It is necessary to undertake an economic analysis of an agroforestry system that includes system comparisons, and an assessment of feasibility. For this purpose, there are two major objectives of the thesis:

1. To adopt an agroforestry model that can be used to estimate the productivity, profitability and practicality of agroforestry and mono-cropping systems.
2. To determine the productivity, profitability and practicality of selected agroforestry systems (tree-based intercropping), compared to mono-cropping systems.

The first objective is to select and test a model that could be adopted to evaluate the productivity, profitability and practicality of agroforestry. The selected model will need to be modified, parameterised, calibrated and validated for plot- and farm-scale bio-economic models of agroforestry and mono-cropping systems for eastern Canadian conditions. The second objective is to evaluate tree-based intercropping (TBI) systems and factors that impact profitability of TBI systems (i.e., price, costs, etc). This will facilitate identification of the most profitable combination of tree-crop systems for eastern Canadian farmers.

## 1.3 Hypotheses

This study is based on the overall hypothesis that agroforestry, specifically TBI, can provide economic and environmental benefits. Tree-based intercropping could be more resilient to market price fluctuations, provide intangible benefits to the farmer in addition to the financial benefits, and allow the farmer to obtain a satisfactory level of financial profit and cash flow.

## 1.4 Organization

This thesis is organized as follows: the first chapter provides a general introduction and overview of the objectives. The second chapter reviews the relevant scientific literature on agroforestry systems (definitions and classifications) and the current state of knowledge regarding the economic feasibility of agroforestry systems. Chapter 3 will present the methodological approach and model used for the analysis. The data sources selected for this study include data collected from peer-reviewed literature, technical reports, government agencies and private industry, as well as data obtained from a 22-year TBI research site at the University of Guelph, Ontario, Canada. Chapter 4 will describe and interpret results of the economic model. Chapter 5 consists of the conclusions, recommendations and future research prospects on this issue relevant to the adoption of agroforestry systems in temperate regions of Canada.

# Chapter 2

## LITERATURE REVIEW

### 2.1 Introduction

Modern agroforestry systems are efficient in terms of resource use and provide options for maximizing productivity on a limited land base [Nair 1993]. Agroforestry combines forestry with agriculture to create integrated and sustainable land uses. This system provides fruit, fodder, forage, nutrients, timber, and shade. An example of this practice is TBI, where an agricultural crop is grown simultaneously with a long-term tree crop to provide annual income while the tree crop matures.[1] Carruthers (1990) stated that agroforestry is an integrated approach that can enhance ecologically-sound agricultural production and achieve environmental benefits. Gordon et al. (1997) define agroforestry as

> *"a collective name for land use systems and technologies where woody perennials (tree, shrubs, palms, bamboos, etc.) are deliberately used on the same land management unit as agricultural crops/or animals, either in some form of spatial arrangement or temporal sequence. In agroforestry systems, there are both ecological and economic interactions between the two different components".*

Agroforestry systems provide a farmer the opportunity to increase short- and long-term income. The yield of some agricultural crops will increase with time under forest agroforestry[2] (due to a positive shading effect) and the value of the forest crop increase with growth [Filius 1982]. This system could improve agricultural sustainability,

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[1] http://www.greeniacs.com/Glossary.html download on June 19, 2009

[2] In intercropping one crop can benefit from the shelter (against sun or wind) or the effect on soil fertility of the other crop. *Cordia alliodora* and several *Erythrina* species are used as shade trees for coffee and cocoa.

provide opportunities to diversify farm income, provide new products to the wood industry, and create new landscapes of high value [Dupraz and Newman 1997]. This system also allows for a more holistic use of the land, with the potential to combine agronomy and forestry techniques to reduce soil erosion and increase economic gains [Country and Murrow 2000]. The optimum crop combination depends partly on the price ratio of forest products to agricultural products [Filius 1982].

Over the last 20 years, there has been a growing interest in scientific research about intercropping agroforestry in temperate regions [Gordon et al. 1997]. The common agroforestry practiced in Canada and the United States include windbreak systems (woody plant barriers used to reduce wind at the soil surface), silvopasture (trees grown in pasture with livestock), riparian forest buffers (streamside forests consisting of tree, shrub, and grass plantings), forest farming (specialty crops grown or harvested from the forest), and intercropping (inter-planting rows of trees with rows of crops) [Williams et al., 1997]. Within North America, agroforestry systems are appealing to those looking for alternative agricultural practices that provide improved economic and environmental sustainability [Kurtz et al. 1991]. Economic output potential per land unit area is increased by the combination of product revenue from the trees plus the crop and/or livestock [Williams and Gordon 1992].

Farmer behaviour is considered to be "risk-averse" [Antle, 1987] especially if a new system causes fundamental changes in farm management and resource-use. The other obstacle in adopting intercropping systems is to conceptualize the planting, cultivation, fertilization, spraying, and harvesting of more than one crop in the same field. Furthermore, given the numerous intercrop combinations possible and the myriad of climatic and soil conditions involved, general recommendations may not be possible. Once the potential benefits of intercropping are realized and the systems adopted, mechanization could be developed for these potentially beneficial systems. It might take a long time before mechanized intercropping systems will rival the current monoculture systems.

## 2.2 Agricultural systems

The success of agricultural systems is major accomplishment in the history of humankind. Food and other important biological materials (fuel, fiber) are produced mainly by agriculture but also by forestry. There are many different types of agricultural systems in practice at present. The two most common are mono-cropping and intercropping.

### 2.2.1 Mono-cropping system

Mono-cropping dominates farming, having replaced traditional intercropping agriculture systems, and describes the practice of planting crops with the same patterns of growth resulting from genetic similarity. With mono-cropping, a single crop species is planted in an area, and other plants are removed. The advantage of mono-cropping is that it allows for specialization on a specific unit of land. Inputs, such as machinery and seed will also be specialized, which means investment in machinery can be designed specifically for crops of that type, along with seeds of high-yielding cultivars. This system is capable of generating great yields by utilizing plants' abilities to maximize growth when competitive pressure from other plant species is removed and a uniform plant population is grown. Sometimes, this scheme does not go as planned if demand and price declines drastically. At that time, a farmer's mono-cropping system may become a liability.

Modern industrialized agriculture, which typically relies on monocultures, has increased yields enormously (i.e. U.S.A., France, Germany), but the improvement has not been without its economic costs. Mechanization became an important impetus in the switch from inter-crops to monocultures because equipment to plant and harvest a single crop per field became available and there were economies of scale. Mono-cropping can be chemical and energy intensive [Nelson, 2006]. Another criticism of mono-cropping is that a single crop can be adversely affected by weather conditions, pest outbreaks and market prices, which greatly affects the level of production and the effective marketing of a commodity.

### 2.2.2 Intercropping system

Intercropping systems cultivate two or more crops simultaneously on the same field[3], producing two or more products at the same time on a piece of land. Intercropping is common in the developing world because it offers greater economic stability than mono-cropping [Horwith 1985, Williams and Gordon 1992]. In Africa and South Asia, where environmental stress is common, intercropping is an insurance against total crop failure [Horwith 1985]. Interest in intercropping has increased in temperate regions in recent years [Graves et al. 2004; Connolly et al. 2001]. The most well documented advantage of intercropping is reduced damage from insects, nematodes, and disease [Machado 2009]. The success of an intercrop system depends on understanding the physiology of the species to be grown together, their growth habits, canopy and root architecture, and water and nutrient use [Machado 2009]. In the tropics, where the term alley cropping is used, the system generally include hedges of woody leguminous species, which are regularly coppiced to provide animal feed and biomass in order to maintain/restore soil fertility.

[3] http://www.oisat.org/control_methods/cultural__practices/intercropping.html, download on June 24, 2009

The woody component in temperate zones usually comprises species that provide high-value timber, veneer and/or fruit and are pruned to reduce shade effects on the intercrop. The following is a description of five common agroforestry systems that could be adopted in Canada:

i. **Windbreaks or shelterbelts:** This system features a linear planting of trees or shrubs, which protects either crops or farm structures from wind and/or snow buildup, decreasing heating cost, and the energy consumption in livestock facilities during winter. A windbreak can prevent damage to fragile crops and increase air temperature near the windbreak, often increasing plant growth rates [Brandle et al. 2004; Gordon et at. 1997]. Shelterbelts generate private as well as external benefits, such as bird watching or photography of aesthetically pleasing landscapes [Kulshreshtha and Kort 2009]. Crop yield improvement and reduced wind erosion are private benefits to the producer.

**ii. Silvopastoral systems:** This is an agricultural system where there is an interaction between trees and livestock. This interaction occurs when trees provide shelter for livestock or when woodlands are grazed. Silvopastoral agroforestry is also known as wood pasture. This system can provide a range of on-site benefits [Dagang and Nair 2003]. These systems attempt to optimize the interactions among pasture plant species, woody perennials, and grazing animals to increase production efficiency and sustainability of the entire system [Bambo et al. 2009]. The incorporation of woody plants into farming systems may increase economic productivity and environmental sustainability [Dagang and Nair 2003; Graves et al. 2005]. The increased complexity of silvopastoral systems relative to traditional pastures means they often bring important biodiversity benefits [Dagang and Nair, 2003]. Unfortunately, the economic advantages of intensively managing land for timber and livestock production are not widely recognized by landowners [Clason 1995]. Despite their many biological benefits, silvopastoral systems have limited adoption world wide [Dagang and Nair, 2003].

**iii. Tree-based intercropping:** Tree-based intercropping (TBI) is a system when cropping is established between rows of planted trees. Agricultural crops are grown between rows of regularly spaced woody species [Tolunay et al. 2007]. The distance between tree rows is determined by the size of machinery used for crop maintenance. Many factors affect TBI performance: the choice of tree and crop species, alley width, biomass production, number of crop cycles, time and frequency of pruning, tillage, fertilization and weed dynamics. These factors were well described by several authors [Kang et al. 1981; Yamoah et al. 1986; Salazar et al. 1993; Palm 1995] but the bottom line is alley cropping works with favorable site-specific conditions. One major benefit of intercropped systems to farmers in temperate zones is the increased solar energy utilization efficiency achieved when monocropped agricultural systems are converted to intercropping. Energy use efficiency increases because a greater variety of species permits more energy capture through the various plant growth cycles and trophic levels in the system [Gordon et al. 1997; Thevathasan and Gordon 2004]. Despite the potential of this system, there are few examples of long-term tree-based intercropping in Canada.

According to Young (1997), trees introduced into annual cropping systems help to overcoming degraded soil conditions by providing a slowly decomposing litter layer that protects the soil from splash impacts of rainfall, reduces runoff and maximize water and nutrient resource use. Trees add substantial amounts of organic matter through litter layer and root turnover, allowing for a gradual recovery of soil structure and capturing nutrients from deeper soil layers or intercepting current leaching losses, depending on their root distribution. Trees must provide direct and indirect economic value, to offset their resource capture in competition with annual crops [Huxley 1999]. Farmers strongly favor tree species from which high returns can be or have been obtained in the past, or a species for which planting cost is low in cost and readily available [Nair 1993]. Trees could be combined that have different and complementary characteristics to provide ideal shade for crops and revenue [Anim-Kwapong and Osei-Bonsu, 2009].

iv. **Riparian systems**: These systems are the most commonly used and widely recognized agroforestry systems in North America [Mathews et at. 1993; Oelbermann and Gordon 2001]. Riparian systems occur along rivers and streams that periodically crest their channel confines, causing flooding[4]. These systems are complex and composed of interconnected physical (i.e. water and sediment) and biological (i.e. fauna and flora) compartments [Corenblit et al. 2009]. Under this system, trees act as a "buffer" to create space between cropland and waterways. Riparian systems can protect waterways from

[4] http://www.britannica.com/EBchecked/topic/75627/boundary-ecosystem/70761/Riparian-systems download on June 24, 2009.

sediment deposition due to erosion, nutrient loading from surrounding fields through the uptake of excess nutrients such as nitrogen, block cattle access to streams, and can even reduce water temperatures through shading, which improves stream habitat. Riparian zones may increase the health of stream ecosystems by providing leaf litter as a food source for aquatic communities.

**v. Forest farming** Forest farming is not a new agricultural system. For centuries, farmers have been practicing forest farming by selecting and planting multi-purpose trees and plants. Typically, the system is established by thinning an existing forest, leaving the best trees to grow for wood production and creating favorable conditions for under-storey crop growth. Intensive management of the under-storey crop provides short-term income. Areas used for forest farming usually focus on a single crop plus timber, but can be designed to produce several products.[5] The regular harvest of timber and other

[5] http://www.agroforestry.co.uk/forfarm.html, download June 20, 2009

economically valued products from woodlots is a type of forest farming. Examples of economically valued products harvested from woodlots in temperate regions are maple syrup, mushrooms and ginseng [Gordon et al. 1997].

***Ginseng cultivation (USA)*** *Source: AFTA (2004)*

## 2.3 Conceptual frameworks for economic assessment of agroforestry system

There is growing interest and need for enhancing economic and policy research in agroforestry. Research over the past two decades has focused on exploring the biophysical and ecological aspects of agroforestry with a limited emphasis on economic aspects of agroforestry [Mercer and Miller 1998]. Indeed, the first World Agroforestry Congress (June 2004, Orlando, Florida, USA) identified economics as one of the key areas for enhancing the adoption of agroforestry. Producers are interested in knowing whether agroforestry land-use systems will have a higher output value at the same resource cost and/or have the same output value at a lower resource cost than non-agroforestry land-use systems [Hoekstra 1987].

### 2.3.1 Landscape

The introduction of agroforestry into a predominantly arable landscape will generally increase the diversity of habitats in that landscape [Graves et al. 2005]. A strong interaction between the permanent (tree) component and the crop component, adds a new habitat to the arable landscape matrix [Burgess et al. 2003]. The landscape approach permits integrated agroforestry diagnosis and design beyond the single farm or the individual plot [Gholz 1987]. The popular view of agroforestry still tends to be somewhat narrow, dominated by plot-level technologies such as TBI. This common view is applied to most studies for economic and environmental analysis [Graves et al. 2005; Dyack et al. 1999]. The focus on plot-level management, rather than the larger landscape, ignores the off-site effects of land use decisions on water quality, nutrient losses, agrochemical contamination, and biodiversity.

### 2.3.2 Net Present Value – investment in trees, annual crop revenues, harvest of trees

Net present value (NPV) is frequently used for agroforestry analysis [Graves et al. 2005; Country and Murrow 2000; Dyack et al. 1999]. An NPV ranking provides a decision criterion for comparing the economic returns from alternative farming systems over time [Nelson and Cramb 1998]. Net present value is the difference between the present value of cash inflows and cash outflows. For economic analysis, NPV compares the value of a dollar today to the value of that same dollar in the future, taking inflation, risk and returns into account. If the NPV of a prospective project is positive, it is financially feasible. However, if NPV is negative, the project is not viable because cash flows will never exceed costs. To calculate the NPV, all the annual net costs or benefits over the prescribed life span of a project are first discounted at a preselected rate. These are then summed as a single indicator of project long-term value as estimated at the time of implementation [Nair 1993].

Dyack et al. (1999) developed an economic model for temperate tree-based intercropping systems that uses a simulation approach to determine the threshold economic value, determined by NPV. The NPV can include on-farm and off-farm benefits, and interaction effects necessary for intercropping to be feasible and socially desirable. Their simulation approach also calculates the gap in NPV that exists between the NPV of intercropping and of either annual cropping or forestry alone, whichever is the next most valuable land-use option.

Country and Murrow (2000) used NPV to determine the feasibility of contour tree strips with ash, blacknut, red oak and white oak. They also analyzed four contour strip-cropping regimes: corn/hay/soybean, corn/pasture/soybean, corn-pasture with legume/soybean, and corn/oats/soybean. They found the NPV was greater from contour tree buffer strips that had been pruned to provide better quality sawlogs. They concluded that contour tree buffer strips allow landowners to diversify their operations to obtain an annual income from row-cropping, while some land is allocated to trees for erosion control and a future harvest with a greater NPV.

One of the key policy issues is how to deal with the fact that agroforestry returns are not realized during the first 20-50 years, depending on the tree species. Another is the real discount rate farmers intuitively apply to the future tree revenue. Interventions to help farmers financially during this period of reduced cash flow before the trees can be harvested and sold is a major issue in agroforestry policy research. In some cases, farmers are perfectly willing to wait out this period, particularly when they have land tenure and fully value the importance of tree products or ecosystem services. The challenge to policy research is to identify critical entry points and create appropriate incentives. Incentives for tree nursery development by farmer groups are a high-priority policy research issue. Recapitalization of soil fertility in nutrient-depleted lands is another concern [Sanchez 1995].

Economic theory states that the highest social utility is attained when producers adopt practices generating the highest rates of return to all available resources, including all costs and benefits [Scherr 1992]. Planners prefer investment in those activities yielding the highest rates of return to total resources or total labor used. The assessment of agroforestry systems is aimed at identifying their capacity to fulfill the diagnosed needs and potentials in a farming system, as well as their viability in terms of the available resources [Hoekstra 1987]. Another important aspect considered in the analysis of agroforestry systems is the valuation of the service role of the tree component with regard to the sustainability of the crop [Hoekstra 1987]. Success of agroforestry is largely determined by the extent to which individual forest and agricultural components can be integrated to capitalize on synergies.

### 2.3.3 Prices and costs (trees)

Since timber prices plays an important role when evaluating an optimal tree harvesting problem, a brief review the forest products industry is in order as well as the presentation of some descriptive statistics for Canadian spot lumber prices over the past decade.

Forest products, including logs, lumber, and paper, are traded worldwide and Canada is a major player in this market, accounting for 14% of the value of world forest product exports in 2006. Forest products are a significant component of Canada's balance of trade, with forest product exports amounting to $29 billion (Canadian) in 2006[6], which was 5.4% of total exports of goods and services. The export market for forest products peaked at $43 billion in 2000, illustrating volatility in this sector. Canada's forest product exports are mainly destined for the United States (over 75% went to the U.S. in 2006) and Canada is the source of more than 80% of lumber imported into the U.S. More than half of Canadian lumber exports come from British Columbia, followed by Quebec and Ontario. Financial data on the revenue and costs associated with mono-cropping and agroforestry systems are available from government documents and the private sector.

### 2.3.4 Socioeconomic modeling

Understanding of socio-economic issues typically occurs at the level of some relatively small unit of analysis, usually at the experimental plot, field or farm level. There are still gaps in our understanding of how socio-economic, and policy factors interact to affect farming systems. Studies at the components and farming systems level cannot be generalized since the relationships between soils, climate and vegetation are scale dependent and spatially specific [Fresco 1995; Jansen 1995]. This is particularly important when dealing with more than one agroecosystem and where heterogeneity of the physical and socio-economic environment is extreme.

There are many types of agroforestry systems presented in agroforestry literature. Five poplar agroforestry systems with reference to temperate regions were reviewed in this chapter. Tree-based agroforestry system is the system of interest for in this study. Many researchers used net present value techniques for the analysis of agroforestry

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[6] Source: FAO stat database, Food and Agricultural Organization of the United Nations, http://faostat.fao.org/site/381/DesktopDefault.aspx?PageID=381

systems. Various socioeconomic models are available for agroforestry analyses which are discussed in the chapter 3.

# Chapter 3

## METHODOLOGICAL ISSUES

### 3.1 Introduction to agroforestry models

Agroforestry systems are more ecologically complex than mono-cropped systems because several crop species are grown together, which creates challenges for researchers working on socioeconomic issues. The socioeconomic dimension of agroforestry is complex because of the temporal and spatial variability in timber and crop production, scale factors, the multiplicity of products and services including inputs and outputs from the system, the economic, social and ecological processes involved, the methods of characterization and diagnosis, and the diversity of institutions involved [Sanchez 1995]. Mechanistic and simulation models describing agroforestry systems are still simplistic [Parton et al. 1994; Spek and Van Noordwijk 1994] due to the fact that there are few field-scale experiments with the rigorous statistical design necessary to predict the growth increment of trees and agricultural crops during multiple growing seasons and over large spatial scales [Rao and Coe 1992]. Although agroforestry lacks the large research foundation of its agriculture and forestry counterparts, the development and use of computer-based tools in agroforestry are projected to increase as the recognition of the productive and protective (service) roles of tree-based farming practices.

To date, decisions about the management of agroforestry systems have been largely guided by ecological models aimed at ecological sustainability instead of economic efficiency. Where economic reasoning has been applied, it has been based on the aim of maximizing the average annual net income, although there are other valid approaches that will be discussed further in this chapter. Economists have shown that economic theory may be applied to the study of agroforestry systems [Mercer and Hyde 1992], which has led to the development of computer-based agroforestry models capable of handling the many economic variables that must be considered when assessing agroforestry systems. Incorporating economic theory into agroforestry models provides information that can assist in evaluating agroforestry alternatives and testing research hypothesis.

### 3.1.1 Agroforestry models

There are many computer-based agroforestry models reported in recent agroforestry literature. The first crop simulation model was developed by Loomis and Williams [1962] to estimate light interception and photosynthesis. The first forestry simulation model was developed in 1974 to understand the effect of management practices on stand development [Fries 1974]. Computer-based biophysical simulations of agroforestry models started in the 1980s. The first biophysical model evaluated the potential of agroforestry on grazing land in New Zealand [Arthur-Worsop 1984], and the second one evaluated the intercropping of crops with pine (*Pinus taeda*) in North Carolina, United States [McNeel and Stuart, 1984].

Early computer-based economic agroforestry models tended to concentrate on silvopastoral systems. These economic agroforestry models simulate financial returns from trees [Arthur Worsop, 1984]. In China, computer-based models were used to optimize the intercropping of Paulownia (*Paulownia elongata*) with arable crops based on economic, ecological, and social objectives [Jiang et al. 1986; Qun 1991]. Etherington and Matthews [1984] described a computer program that was used for developing partial and whole-farm budgets for land-use systems involving trees. Consequently, the development of a series of computer-based models of agroforestry economics has occurred, including POPMOD [Thomas 1991], ARBUSTRA [Liagre 1997] and the Agroforestry Estate Model [Knowles and Middlemiss 1999]. The European Union has introduced a series of measures to promote the integration of trees within existing farm businesses after 1991. A project entitled "Silvoarable Agroforestry for Europe" (SAFE) was initiated by the European Commission in 2001 to reduce uncertainties regarding agroforestry systems in Europe. An important objective of the project was the development and use of a computer-based model of agroforestry economics to compare the profitability of arable, forestry and agroforestry systems at a one-hectare scale and to determine the feasibility of agroforestry systems at the farm scale level.

Computer simulations can be used to dynamically represent conceptual models of arable, forestry, and agroforestry economics. Such models generally compare the profitability and feasibility of agroforestry systems with competing alternatives, for example, arable and forestry systems [Graves et al. 2005]. However, although some literature describes the results and analysis obtained from using computer models of arable, forestry and agroforestry economics [Thomas 1991; Willis et al. 1993; Dupraz et al. 1995; Graves et al. 2005], relatively little literature describes the model details and how they were developed.

Theoretically diversified models of long-term farm projects can be represented in computer simulations. These models can depend on modeling objectives and different analytical approaches. Computer-based models of farm economics have been applied to evaluate the economic performance of different farm enterprises, for instance, optimizing resource use, and forecasting the behaviour of farmers to economic or policy incentives.

These models are also used for analytical techniques, such as cost-benefit analysis [Graves et al. 2005].

A farm-scale model, called Farm-SAFE, was developed by Graves et al. (2005). This model was originally developed as part of the Silvoarable Agroforesty For Europe project (Farm-SAFE). It is a spreadsheet based model for determining the long-term profitability and feasibility of agroforestry relative to arable and forestry systems. It is a user friendly model which can be used by both researchers and policy makers. It examines profitability using an annual time-step over a period up to 60 years. At a farm-scale, it can integrate the results from up to four types which may have different arable, forestry or agroforestry systems. The results of each system are expressed in terms of a net present value (NPV) and other economic indicators at a specified discount rate. Farm-SAFE also provides a variety of means of applying the crop and tree component grants in agroforestry systems. Another advantage of this model is that the user can choose to manually override the agroforestry crop rotation with another crop, for instance, if the original crop becomes unprofitable because tree yield is being reduced. The option in this model provides a manual override. If the user wishes no override, then the user should type "none" instead of typing a commencement year for the replacement crop. The graph manager option in this model allows the users to manipulate the relative value of the discount rate, prices, grants, and inputs. The user can use the model to run a sensitivity analysis for the effect on the net present value (NPV) of changes in the relative value of discount rate, production, prices, grants and cost. The user can set a different time period for the financial simulation. Owing to the above mentioned advantages, the Farm-SAFE model is used to analyze TBI systems at Guelph, southern Ontario, Canada

### 3.1.2 Forestry models and harvesting age

Harvested timber provides benefits to growers equal to the stumpage value of the standing trees. The net value of the timber growing on an area of forest land is termed the stumpage value - the value of the timber “on the stump”. The value is the competitive price of the timber less harvesting and transportation costs. The cutting cycle which maximizes the present value of stumpage is the optimal rotation length; this could involve a single harvest from the forest, or a succession of harvest cycles and regrowth. The present value of stumpage can be compared with its present value in alternative uses. Net return can fluctuate widely, determined by tree quality, hardwood and softwood prices, individual management, labour cost, land, and equipment. The optimal rotation is the age at which the trees should be cut if the objective is to maximize the value of land in commercial timber production.

#### 3.1.2.1 Maximum sustained yield

Maximum sustainable yield (MSY) is one criterion to determine the optimal harvest age for timber [van Kooten and Folmer, 2004]. The MSY aims to maintain the population size at the point of maximum growth rate by harvesting individual trees that would normally be added to the population, allowing the population to continue to be productive for an indefinite time period. The allowable annual cut (AAC) is based on the MSY concept, which defines the maximum annual rate at which timber can be harvested in a region on a sustainable level into the future.

Denote the volume of timber over time by $v_t$. In terms of production economics, this is the total product function, where the input time or age, *t,* represents the standard economic inputs, labor or capital. Figure 1 illustrates the current annual increment (CAI) of timber volume which can be thought of as the marginal product of time, CAI = $v_t' = dv_t / dt$. Figure 1 also shows the mean annual increment (MAI), which is given by $v_t$ */t.* The point of intersection between the marginal product and average product curves is the peak of the average product curve, the maximum value for the average product. This line has the maximum slope of any such line from the origin that still reaches $v_t$. This is the point in time (the age) at which MAI attains its highest, at age $a_2$ in Figure 1.

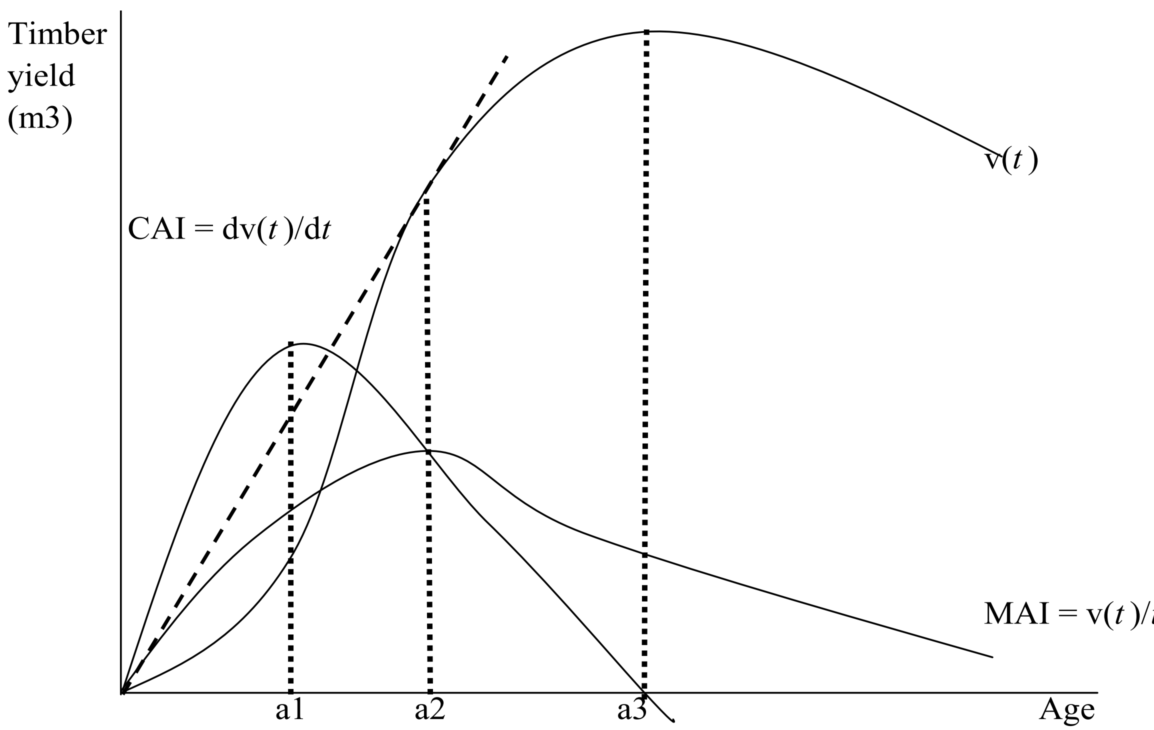



**Figure 3.1 Relationships between cumulative timber yield and the age of trees, showing the mean annual increment (MAI) and current annual increment (CAI) values.**

The current annual increment CAI intersects MAI from above at the latter's maximum with $v_t'$ falling beyond this point. Finally, at age $a_3$, $CAI = 0$ when $v_t$ reaches a maximum. This implies a reduction in timber biomass as trees age further, but this is unlikely. The increase in biomass slows down as biomass approaches some asymptotic maximum (so that the growth function is more like an S curve). The volume of timber per hectare on a stand in any year is denoted by $v_t$. The MSY rotation age, $t_M$, is simply the culmination of mean annual increment, and is found by setting the MAI=CAI:

$$\frac{v_t}{t} = v_t' \qquad 3.1$$

To maximize the volume of timber obtained each year from the forest to obtain sustainable yield, choose a value of *t* to maximize biological function *(v)* and get:

$$\frac{v'_{tm}}{v_{tM}} = \frac{1}{t_M} \qquad 3.2$$

where $t_M$ is the rotation age that maximizes the sustainable yield from the standard forest. This equation explains that the rotation age should be set where the growth rate of timber equals the reciprocal of the age of the trees. The left hand side of equation 3.2 is the rate of growth of the timber stand.

**3.1.2.2 Maximum benefits from a single cut: Fisher rotation age**

The maximum benefits from a single cut criteria was developed by Irving Fisher (1930), which is also referred to as 'Fisher's Rule'. There are three possibilities of this rule: (1) cut the timber now and put the money in the bank; (2) keep the stand of timber no matter what; or (3) maintain the stand of trees as long as the stumpage value is growing faster than the rate of interest, and then harvest and shift your assets to the bank.

Suppose the objective of forest operations is to maximize the net benefit from a one-time harvest of the forest, ignoring the future use of land for timber production. The forestland owner will harvest growing trees when the net discounted return achieves a maximum value. Mathematically, the objective function is to

$$\text{Maximize } (p - c)\, v(t)\, e^{-rt} \qquad 3.3$$

where $p$ is the price of logs at the mill, $c$ is the associated cost of felling, bucking, yarding, loading and hauling the logs to the mill, and $e^{-rt}$ is the continuous-time discount factor. The stumpage value is $(p - c)$. Suppose that the cost per $m^3$ of harvest remains the same, apart from of harvest level. Subsequently, the first-order condition for a maximum value is given as:

$$\frac{v'_{ts}}{v_{ts}} = r, \qquad 3.4$$

where $r$ is the (instantaneous) rate of discount which is equal to interest rate available from the financial institutions. As a result, trees should be left standing as long as the rate of growth of the value of the trees exceeds the discount rate. As long as the investment in growing trees yields a higher return than can be earned elsewhere in the economy (as determined by $r$), trees should be left to grow. On the other hand, if investment yields a higher return, then the trees should be harvested and the funds invested at rate $r$.

**3.1.2.3 Faustmann (financial) rotation age**

Faustmann (1849) introduced a forest rotation age model, which has become the best known for providing a benchmark model for determining optimal timber rotation age. His theoretical framework assumed that forest land is to be used only for the purpose of growing and harvesting trees. After trees are harvested, the land is replanted. According to the Faustmann theorem, a forest stand shall be harvested when the rate of change of its value with respect to time is equal to the interest on the value of the stand plus interest on the value of the forest land. To achieve economic efficiency, the decision to harvest depends upon a number of factors. The basic logic of the Faustmann model (or land expectation value, LEV) is as follows: for even-aged timber production, the net present value is basically formed by a perpetual periodic series of clear-cutting revenues at the end of every rotation of T years. By compounding each rotation's regeneration and other possible costs (as well as possible revenues from thinning to the end of rotation), all (compounded) cash flows can be added to the end of rotation and apply a general present value formula for a continuous periodic series:

$$Vo = \frac{p - C}{(1+r)^t - 1} \qquad 3.5$$

where

$V_0$ = discounted value of returns over 0 rotation;

p = the amount of fixed payment occurring every;

t = years in a series. More importantly, the first payment in this formula is at the end of first period;

C = cost of planting trees on the site immediately after harvest (as required in most jurisdictions by law); and

*r* = the discount rate, which may include a risk premium.

Suppose that soil productivity and all prices and costs remain constant for all future time. The total present value of all future harvest can be expressed as:

$$Vn = \frac{(p-C)v(t) - C}{(1+r)^t} + \frac{(p-C)v(t) - C}{(1+r)^{2t}} + ..... + \frac{(p-C)v(t) - C}{(1+r)^{nt}} \qquad 3.6$$

where

V*n* = discounted value of returns over *n* rotations;

If trees regenerate naturally and C=0, the expression can be rewritten as:

$$\frac{v' t_F}{v t_F} = \frac{r}{1 - e^{-rtF}} \qquad 3.7$$

The Fisher (single-harvest) case is the possibility that, once timber is harvested, a new stand of trees can be generated on the land. The second growth can be harvested at a later date. By taking into account the potential of the land to grow another stand of trees, the harvest period is actually shortened. The reason is that, by cutting trees sooner, it also makes available subsequent harvests sooner than would otherwise be the case.

A comparison of the three criteria for spruce and hybrid poplar has determined the growth period to achieve optimal economic yield of commercial timber stands [Van Kooten and Folmer 2004]. The Faustmann criteria indicated an optimal growth period of 23 years for spruce and 11 years for hybrid poplar, which is shorter than the growth period predicted by the MSY (50 and 13 years) and Fisher (33 and 17 years).

For spruce, the Faustmann rotation age is 23 years of age, while it is about 11 years for hybrid poplar. The financial rotation age is below that which maximizes sustainable yield. Where institutions permit (e.g., public ownership), biological considerations have led governments to legislate harvest ages that exceed the Faustmann age. While this has resulted in lower timber revenues for the landholder, the regulations controlling harvest age may result in greater overall benefits [van Kooten and Folmer 2004].

Theoretically, under MSY criteria, for plantation forests of hybrid poplar, the AAC is set equal to the MSY. In its simplest conditions, maintaining a sustainable yield requires every tree cut down to be replaced by a viable seedling, but that is only the first step. Some hardwood trees can take fifty to 100 years to reach maturity, so an allowance must be made for that time lag and the harvest rate adjusted accordingly. This is commonly achieved through calculation of an AAC. The AAC is based on such factors as the age and growth rates of species. If the AAC provides an accurate representation of the biological productivity of the forest, and when the actual harvest does not exceed the AAC, the sustainability of the forest can be preserved.

The shortcoming with the MSY method is that harvesting will exceed the sustainable level if growth does not occur at the expected level. Some reasons for slow tree growth could be unfavorable weather conditions, fire and disease. Another important limitation of the MSY idea is it does not consider the time-span between production inputs and timber output, and prices and costs are not incorporated in the equations [Van Kooten and Bulte, 2000]. Despite these limitations, the idea of maximising the average annual cash flow remains popular when estimating the value of forest plantations.

## 3.2 Model section

Agroforestry models assist researchers and policy makers in many ways. Some important uses include the ability to predict future yields and to explore agroforestry options. Using agroforestry models, researchers and policy makers can examine the expected outcomes, both with the intended and alternative cutting limits, and can make their unbiased decisions. Agroforestry models can provide an efficient way to prepare resource forecasts, but a more important role may be their ability to investigate management choices and agroforestry alternatives. Therefore, agroforestry modeling approaches are required which can make the connection between the farm- and landscape-scale management. To achieve this, a high level of model detail (theoretical and econometrical) is required in order to minimize modeling error. Models of agroforestry economics may operate as “impartial” economic models, using crop and tree yield data from external sources. These resources may operate as "bio-economic" models that generate their own biophysical data [Graves et al. 2005].

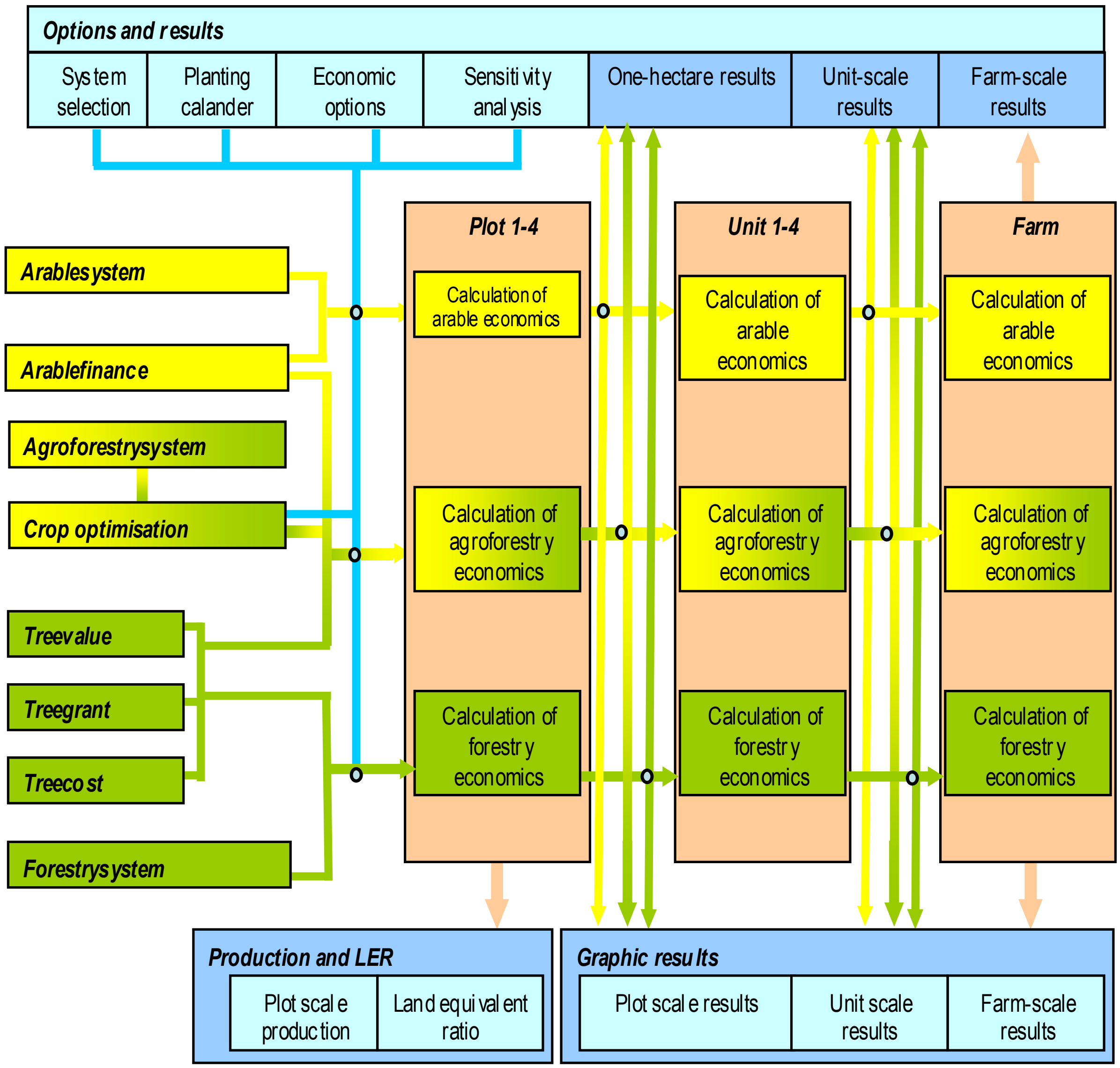
### 3.2.1 Agroforestry 'theoretical' model

During the past two decades, increased emphasis has been put on the development and description of methods and tools to assess the agroforestry potential of different land-use systems. The main concept of this strategy has been the development of the diagnosis and design methodology. Agroforestry economic analysis is not meant to be – nor is it designed to be – a one-time activity. This is designed to be a road map for a dynamic and living system. The economic assessment methodology has focused on the farming and agroforestry systems as a whole. The assessment of agroforestry systems is aimed at identifying their capacity to fulfil the diagnosed needs and potentials within a farming system, and their viability in terms of the available resources [Hoekstra 1987]. Brown (2000) noted the importance of understanding the objectives of the model, the mathematical approach used and defining the temporal and spatial scales. Swinkels and Scherr (1991) described six types of economic analyses including cost-benefit analysis and optimization, and seven levels of analyses including the research plot, farm, project, and region.

#### 3.2.1.1 The model specification

The modeling of optimal tree harvesting and the valuation of land devoted to commercial timber harvesting is an active research area. Among the types of analysis represented in the literature, the agroforestry sector and cost–benefit analysis stand out above the rest in terms of numbers. It should be noted that the majority of studies during the past two decades utilized econometrics and optimization analysis. The model chosen to describe timber prices can have a significant effect on optimal harvesting decisions and land valuation. For empirical analysis it is important to define agroforestry analysis in terms of appropriate quantitative measures.

Figure 3.2 Farm-SAFE Model Chart




(Source**:** Graves, A. R., (2005) Ph.D. Thesis).

The Farm-SAFE model [Anil et al. 2005] will be used in this study for economic analysis of TBI systems.. The flow of information within Farm-SAFE is graphically shown in Figure 3.2. The main point of control for manipulation of simulations is

"Options and results" where physical and financial data are selected from the data storage worksheets within the model and further options for the simulation are set, for example, for the years of planting in multi-planting schemes, the duration of the rotation, the discount rate, sensitivity analysis, or phased and one-off changes in input parameters.

#### 3.2.1.2 Comparative statics analysis of harvest age and profitability

The ability to differentiate between current and future stumpage prices, regeneration costs, as well as interest rates also yields much richer results regarding the effect of changes in these timber production parameters on the optimal harvest age. Under the classic Faustmann model, with a one-time increase in the stumpage price level, the harvest age decreases. When the regeneration cost increases, the harvest age increases. Similarly, when the interest rate goes up, the optimal harvest age decreases (Chang 1984). Under the generalized Faustmann model, changes in current and future stumpage price, regeneration cost, and interest rate have an impact on the current harvest age. The impacts due to changes in current and future stumpage price levels on the optimal harvest age are particularly important.

Sensitivity-analysis of a number of key variables is usually undertaken so that the implications of changes in assumptions can be understood, and to test the robustness of the proposed technology to possible changes in 'external' factors, such as prices. In each case, the judgement regarding the recommendation for the adoption of a new technology is based on the comparison of the 'with' and 'without' situations.

### 3.2.2 Empirical model

The empirical model consists of a function that fits the data. Most of agroforestry economic models (i.e. Farm-SAFE) are based on empirical techniques such as cost-benefit, optimization, and mathematical programming approaches. Several economic valuation methods and techniques, for instance NPV and land equivalent ratio, can be used to estimate agroforestry returns. While, these methods are widely used in agricultural, natural resource, and environmental economics, they are relatively new to agroforestry. Valuation of agroforestry goods employs estimating economic costs and benefits of agroforestry policies using appropriate methodologies.

**3.2.2.1 NPV model with trees and arable land**

Agroforestry has benefits and costs that occur over many years. To make a valid comparison, the discounted net benefit is used to define the “present” value of future costs and benefits. NPV analyzes the economic performance and helps producers and economists understand the economic performance of agroforestry practices.

The profitability of agroforestry and mono-cropping systems will be compared in this study by using NPV. In mono-cropping systems, profitability is typically compared on an annual and per unit area basis by adding the revenue generated (*R*) to the variable costs associated with generating that revenue (*V*) to give a gross margin which is equal to (*R* − *V)* [Nix, 1999]. However, other costs such as labour and machinery, sometimes termed “assignable fixed costs” (A), are modifiable over a long time period. Mono-cropping (i.e. wheat, corn) and agroforestry system returns are compared on the basis of their net margin (*R* − *V* − *A)* [Willis et al. 1993; Burgess et al. 2000]. The NPV is expressed as:

$$NPV = \sum_{t=0}^{t=T} \frac{Rt - Vt - At}{(1 + r)^{t}} - C_{0} \qquad 3.8$$

where

*NPV* is the net present value of the mono-cropping or agroforestry systems ($ $ha^{-1}$), $R_t$ the revenue in year *t* ($ $ha^{-1}$), $V_t$ the variable costs in year *t* ($ $ha^{-1}$), $A_t$ the assignable fixed costs in year *t* ($ $ha^{-1}$), $C_0$ is the cost of tree establishment for the agroforestry systems at the beginning of the period ($ $ha^{-1}$), *T* is the total time period (years), and *r* was the discount rate.

Depending on the tree species selected, the optimal rotation period for an agroforestry system could vary from less than 17 years [Van Kooten and Folmer, 2004] when hybrid poplar are used to more than 60 years for slow-growing hardwood and softwood species. To evaluate agroforestry systems with different rotation lengths, it is essential to calculate an infinite NPV. This is the NPV defined over an infinite rotation, in which each replication had a rotation of *n* years. The infinite net present value (*i*NPV) is defined as:

$$iNPV = NPV \frac{(1+r)^n}{(1+r)^n - 1} \qquad 3.9$$

where

*i* represents on infinite time period.

#### 3.2.2.2 Equivalent Annual Value

Another common indicator of economic performance that can be derived from a cashflow plan is an equivalent annual value (EAV). The EAV method expresses the NPV as an annualized cash flow by dividing it by the present value of the annuity factor. Comparing the annual net return of annual crops with longer-term crops requires that the NPV is converted to an EAV which can then be compared to a gross margin (for similar areas and climatic zones):

$$EAV = NPV_{infinite} \times r \qquad 3.10$$

Where

*EAV* represents Equivalent Annual Value

$NPV_{infinite}$ represents Net Present Value of infinite period

*r* represents interest rate

To calculate the EAV using this equation, the *NPV*, *n*, and *r* must be known. The *cashflow* is the annual equivalent value that is being calculated. The equation can be computed as follows:

$$Cashflow = \left[ \frac{NPV}{\sum_{t=1}^{n} \frac{1}{(1+r)^t}} \right] \quad 3.11$$

The summation portion (annuity discount factor) of the equation can be simplified as follows:

$$\sum_{t=1}^{n} \frac{1}{(1+r)^t} = \frac{1}{r} - \frac{1}{r(1+r)^n} \quad 3.12$$

**3.2.2.3 Benefit-cost ratio**

A benefit-cost ratio (BCR) is an indicator, used in the formal discipline of cost-benefit analysis to summarize the overall value for money of a project or proposal. A BCR is the ratio of the benefits of a project or proposal, expressed in monetary terms, relative to its costs, and compares the discounted benefits to discounted costs of each land use system. It is calculated based on the following equation:

$$BCR = \frac{\sum_{i=1}^{t} \frac{B_t}{(1+r)^t}}{\sum_{i=0}^{t} \frac{C_t}{(1+r)^t}} \quad 3.13$$

where

$B$ represents benefits of the project

$C$ represents costs of the project

A benefit-cost ratio greater than 1 indicates the land use system is profitable and a ratio less than 1 indicates that it is unprofitable.

When making decisions on adoption of new technologies, farmers are concerned with the costs and benefits associated with the decision. The key variables considered are inputs used (such as labour, seeds and planting materials, fertilizers, and cash expenses) and outputs produced for various activities, including field crops, horticulture, fodder and grasses, fuelwood and timber. Existing and intervened modes of farming requires an analysis of costs and benefits of the project. Benefit-cost analysis is used to check the profitability of the two systems.

# Chapter 4

## DATA SOURCES

### 4.1 Introduction

Data required for Farm-SAFE simulations fall into two categories – biophysical data and economic data. This chapter presents more detail concerning methodological issues regarding data which is used in this thesis. Section 4.1 describes the data site and its location and character. Section 4.2 presents the definition of tree and crop species. Four crop and three tree species are used in this analysis. Timber growth related issues are discussed in section 4.3. Section 4.4 discusses the characteristics of three selected tree species, hybrid poplar, Norway spruce and red oak and computer software Ecosys© which used to extrapolate the tree height and diameter. Tree production revenue and cost data is described in section 4.5. Mono-cropping production revenues and cost are presented in 4.6. The last section 4.7 is based on sensitivity analysis.

### 4.2 Identification and characterization of landscape at the Guelph TBI system

The University of Guelph Agroforestry Research Station was established at Guelph, southern Ontario, Canada in 1987 and is operated by the University of Guelph and the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA). The research site consists of 30 hectares (430 m by 650 m), of agricultural land which was converted to a TBI system with ten different tree species permanently planted into widely-spaced rows, leaving alleys where annual crops are grown. The research site was designed to collect knowledge on tree growth in combination with annual crops, to determine overall system productivity, and to determine how well different cropping practices work with various tree species. The field plots were designed to allow investigation of the effect of tree row spacing on tree and crop growth [Thevathasan and Gordon 2004; Williams and Gordon

1992]. The landform is a drumlin oriented approximately north/south (43°32'28" N latitude, 80°12'32" W longitude) with the lowest point approximately 334 m above sea level. The soil type is sandy loam (Topic Hapludalf) with moderate agricultural potential. There is year-to-year variation in climate conditions at this site. The average frost-free period is 136 days (May 15–September 28) and annual precipitation averages 833 mm, with approximately 334 mm falling during the growing season [Thevathasan and Gordon 2004].

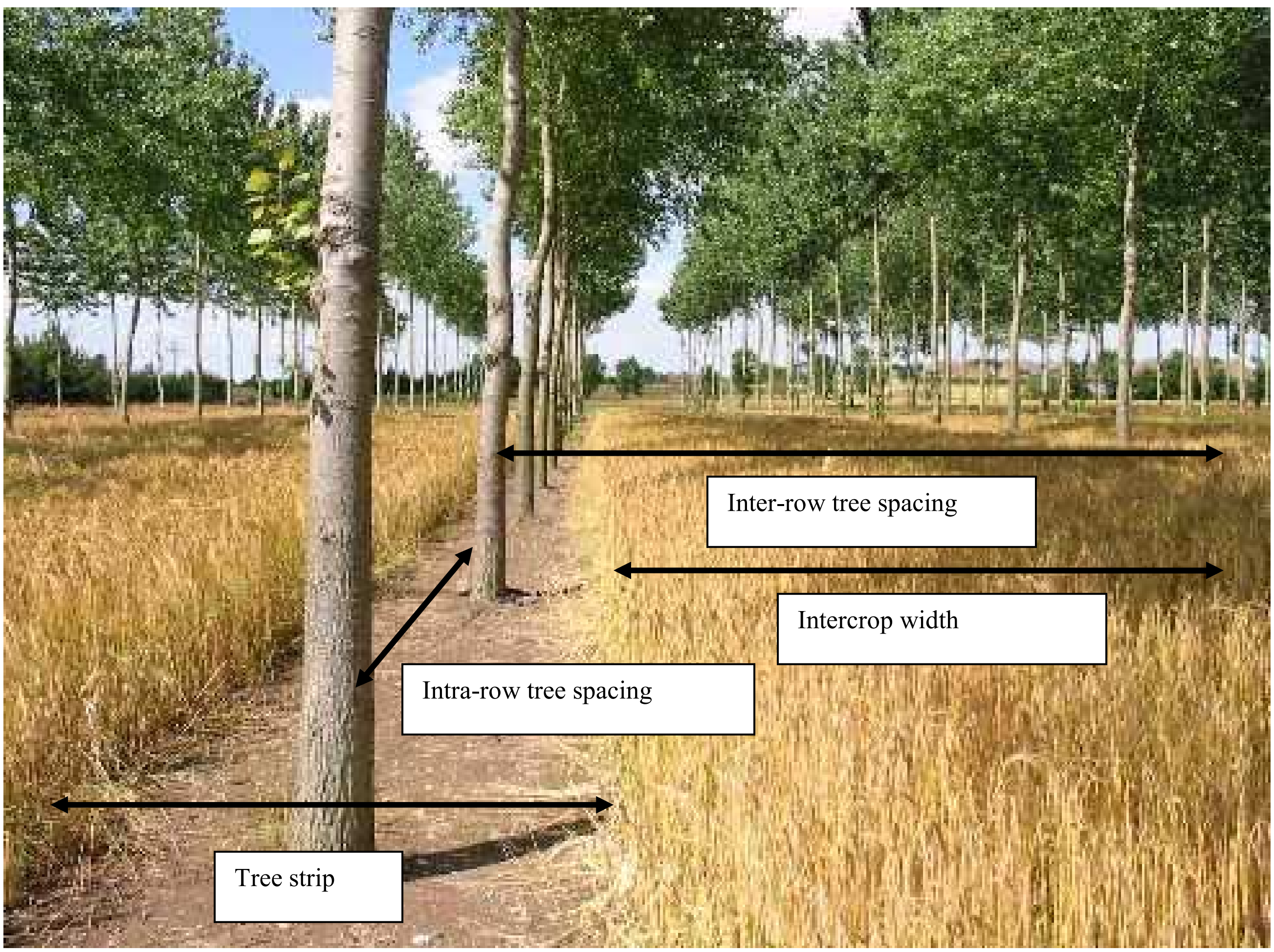



Figure 4.1 TBI system with widely-spaced poplar rows and wheat intercrop.
(Source: Graves, A. R., (2005) Ph.D. Thesis)

Crops were planted between the tree rows every year using common production practices. Tree rows were oriented along the long axis (N–S) of the drumlin, and on the west side of the drumlin, with each species planted in groups. Inter-row tree spacings were either 12.5 or 15 m. Initially, the tree strip itself was 1 m in width (i.e., 6.7 or 8.0% of the available land area). By 1997, larger tree crowns approximately doubled the width of the tree rows to about 2 m. As the trees were evenly spaced intra-row and the tree canopy was relatively uniform within each species, only a few tree canopies had begun to overlap [Gordon et al. 1997].

### 4.3 Definition of tree and crop species

Annual growth of trees and crop yields in mono-cropping and agroforestry systems are required for each land unit as inputs for the economic analysis. The crop species selected for mono-cropping and agroforestry systems are the most common annual crops grown such as wheat, corn, soybean and barley on farms in southern Ontario. In agroforestry, particular attention is placed on multiple purpose trees or perennial shrubs. In order to plan for the use of these trees in agroforestry systems, considerable knowledge of their properties is necessary [Martin and Sherman 1992]. Desirable information includes the climatic adaptations of the species, including adaptations to various soils and stresses, the size and form of the canopy as well as the root system, and the suitability for various agroforestry practices such as tree based agroforestry.

The ten tree species grown at the Guelph Agroforestry Research Station included: *Acer saccharinum* (silver maple), *Corylus avellana* (hazelnut), *Franxinus americana* (white ash), *Juglans nigra* (black walnut), *Picea abies* (Norway spruce), *Populus sp.* (poplar–hybrid), *Quercus rubra* (red oak), *Robinia pseudoacacia* (black locust), *Salix* *discolor* (willow) and *Thuja occidentialis* (white cedar). Inter-row tree spacing was 12.5 m or 15 m, and intra-row spacing was 3 m or 6 m. The 12.5 m and 15 m spacings were annually intercropped with either corn (*Zea mays*), soybean (*Glycine max*), winter wheat (*Triticum aestivum*) or barley (*Hordeum vulgare*).

### 4.4 Timber growth

Timber growth varies according to a wide range of variables, including soils, tree species, agroforestry treatments, age, and regional factors that influence growth. Biological growth is not constant in the life of a tree. The growth rates are higher in terms of height and diameter for young trees than older trees. But very young trees put most of their growth into height, adding little volume. Older trees will put less growth into height and more into diameter, which contributes volume to the stand.

As trees grow in diameter and add volume, the commercial use of the timber can change, as can the value. Higher valued lumber can be cut from a log with a large diameter than a small diameter, increasing the value of the timber. The value of timber in a forest can increase even if timber prices and total volume of timber remains constant because the quality of the stand will increase. This increase in value can help timberland maintain value even if land and timber prices are declining. If timber is harvested at the rate the value of the trees are growing, timberland can generate income with no loss in value to the asset.

Natural growth is a unique characteristic of timberland. Faster growing trees, such as hybrid poplar, are often assumed to provide a better investment because of a higher rate of growth. While faster growing trees may produce a higher rate of timber growth, the growth in value could be lower because of lower stumpage. A fast growing tree (hybrid poplar) produces wood with low density that is usually suitable for papermaking or as a biofuel. Therefore, the value of hybrid poplar in terms of timber volume is lower than for a slow-growing oak or maple, which is in demand by furniture manufacturers and for fine woodworking. This example illustrates that the rate of growth in return and value are not necessary the same.

The average height and diameter of the nine tree species at the Geulph TBI site are presented in Figures 4.2 and 4.3. Hybrid poplar has significant growth rate in terms of height and diameter as compared to other tree species. Hybrid poplar growth was also greater than other species in Europe considered in the Silvoarable Agroforestry for Europe (SAFE) project (Graves et al. 2005). White cedar had the second highest growth in terms of height but it has third in terms of diameter growth. Hardwood tree species like Red Oak and Black Walnut have lesser growth in terms of height and diameter as compared to fast-growing species like Hybrid poplar, white ash and silver maple. Red Oak and Black Walnut growth patterns were similar to data reported in the SAFE project (Graves et al. 2005).

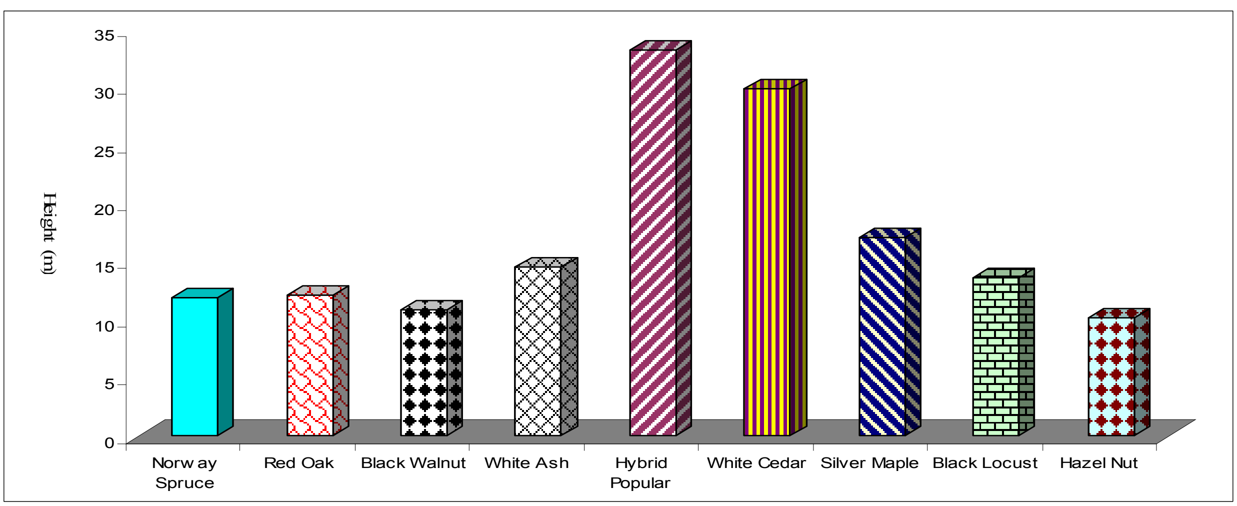



Figure 4.2 Nine tree species average height (m) in 2008 at the Guelph TBI Research Station. (Source: N. Thevathasan, unpublished data).

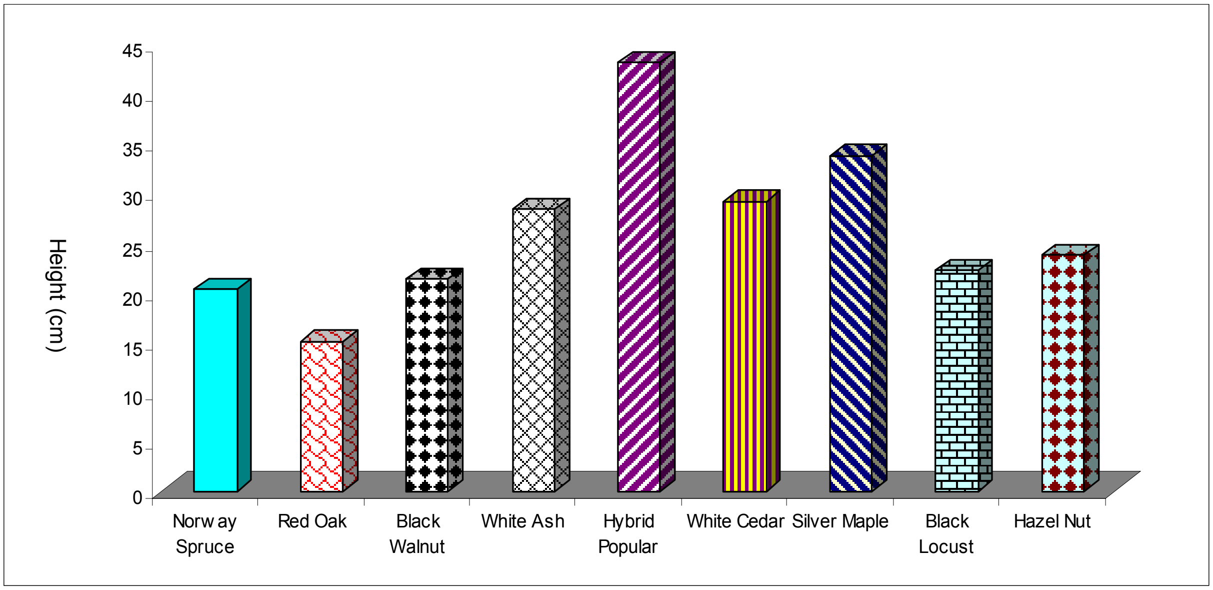



Figure 4.3 Nine tree species average diameter (cm) in 2008 at the Guelph TBI Research Station. (Source: N. Thevathasan, unpublished data).

## 4.5 Selected tree species for tree based intercropping

Three tree species-hybrid poplar, Norway spruce and red oak-were selected for the mono-cropping and agroforestry analysis. Hybrid poplar is a fast growing tree species, which will be used to represent all other fast growing tree species. Hybrid poplar has the highest growth rate in terms of height and diameter when compared with most other species (Figures 4.2 and 4.3). Norway spruce is a tree with a medium growth rate. On the other hand, red oak has a slow growth rate, and could take more than 100 years to mature. In addition to growth differences, the wood from these three species has different value because of different end use. The Bio-physical model Ecosys© is used to estimate product tree growth.

The bio-physical data in this thesis was generated with Ecosys© software, based on a single script containing 11 scenarios, every scenario accounting for a single year except for the last one, which encompasses 12 years. The model was based on a single grid cell of 430 m by 650 m, which represents the actual area of the Guelph TBI system. It is important to note that this choice was purely esthetical, because all plants and trees in this grid cell are uniformly dispersed following their respective density and every output is given on a $m^2$ basis, so a model based on a single grid cell can choose any area without changes in its outputs. The parameters used in the model to describe the growth of each tree and crop species were determined from published equations and calibrated with site-specific data from the Guelph Agroforestry Research Station (C. Beaudette, personal communication).

### 4.5.1 Hybrid poplar

Hybrid poplar (*Populus spp.*) is among the fastest-growing trees in North America and are well suited for the production of bioenergy (e.g., heat, power, transportation fuels), fiber (e.g., paper, pulp, particle board, etc.) and other biobased products (e.g., organic chemicals, adhesives). Important reasons for planting hybrid poplar include rapid growth and ease of vegetative propagation from stem cuttings. Use of hybrid poplar for fuel holds promise, although poplar is not considered highly desirable for firewood due to its low wood density and high moisture content when green. However, hybrid poplar used as pelletized fuel holds greater promise than use as cordwood. The rotation age ranges from 10 to 26 years in Canada depending on a number of factors, including climate, site, and management regime[7]. Figure 4.5 shows the height and growth pattern of hybrid poplar. The linear trends of diameter curve shows that diameter growth is increasing continuously with passage of time. Hybrid poplar standing and total timber volume simulation presented in appendix graph 4.6A.

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[7] The Silviculture of Hybrid Poplar Plantations, Extension notes, http://www.for.gov.bc.ca/hfd/pubs/docs/en/En47.pdf Downloaded dated 06-02-2010


Figure 4.4 Hybrid poplar average height (meter) and diameter (centimetre) at the Guelph TBI Research Station.
(Source: N. Thevathasan, unpublished data)

### 4.5.2 Norway spruce

The Norway spruce (*Picea abies*) is a native of Europe and due to its hardiness and adaptability it has been introduced around the world and thrives in the plant hardiness zones of 2 to 8 where there is adequate rainfall (500mm per year).[8] Norway spruce is economically and ecologically one of the most important tree species in Scandinavian countries. In areas of lower rainfall, additional water will be necessary especially when young. The trees are Norway spruce can grow 0.6-0.9 meter per year the first 25 years under good conditions; in heavy or poor soils they may average 0.30 meter per year. If given sufficient room, it will grow to over 30 meter in height with a 12 meter wide

[8] http://en.wikipedia.org/wiki/Norway_Spruce downloaded January 10,2010

canopy with spreading branches at the base. The Norway spruce is the most widespread, fastest growing, largest and most disease resistant spruce. It is used extensively for windbreaks throughout Canada and the United States. It can tolerate high winds and still grow well. Figure 4.6 shows the average height and diameter of Norway spruce of Victoria Research Centre, University of Guelph. Norway spruce standing and total timber volume simulation presented in appendix graph 4.7A.

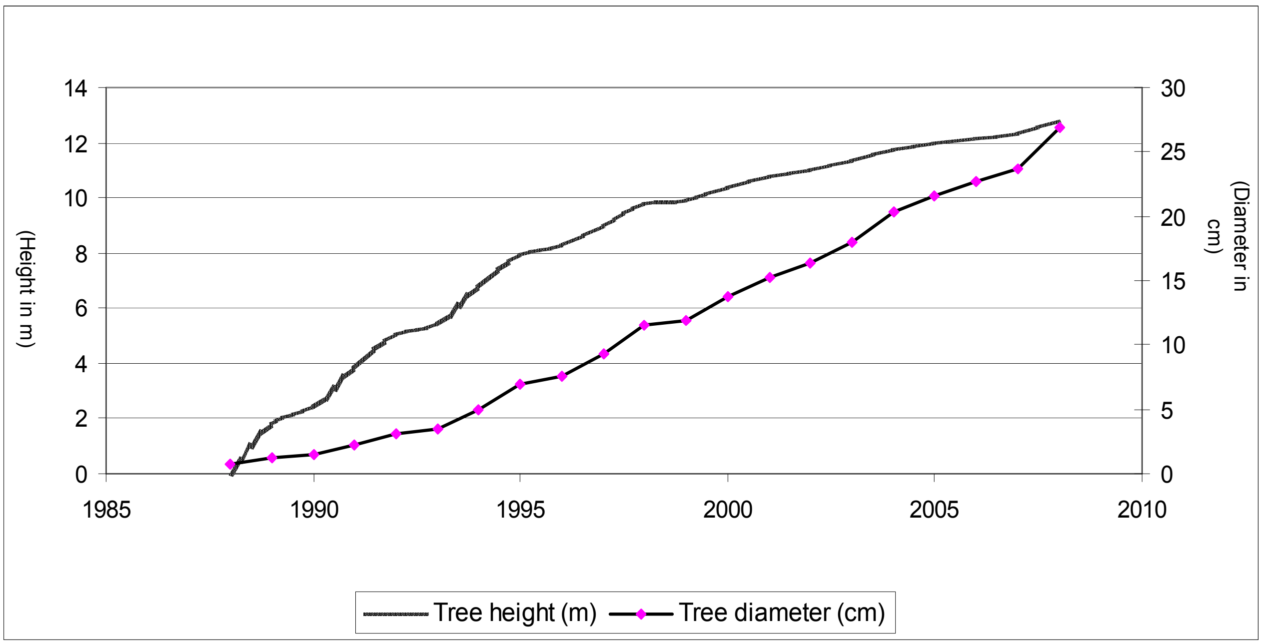


Figure 4.5 Norway Spruce average height (meter) and diameter (centimetre) at the Guelph TBI Research Station. (Source: N. Thevathasan, unpublished data)

### 4.5.3 Red oak

Red oak is one of Ontario's largest and most valued trees for wood manufactured products. It is also the more common of the two native oaks found in the Maritime Provinces. Also known as northern red oak, its abundant and nutritious acorns are an important food for wildlife. It is also prized as an ornamental tree for landscaping because of its symmetrical shape. Mature trees reach heights of 18 to 25 metres, with diameters of 30 to 90 centimetres.[9] Red oak trees growing in the open generally develop short, sturdy trunks with large branches that support wide, rounded crowns. Trees growing in forests have straight trunks with branches that begin at the midpoints and rise to form narrow, rounded crowns. Optimal growing conditions for red oak trees are fresh sites with fine, deep soils that have a loam or silt-loam texture. Red oak is used for flooring, furniture, millwork, railway ties, tool handles, fence posts, plywood, veneer and barrels for storing dry goods. The wood is hard, heavy, strong and pink to reddish-brown. Figure 4.7 shows the height and growth pattern of red oak. The linear trends of diameter curve because of its early years data which presents a smooth growth pattern. Red oak has a slow growth tree and its maturity time is more than 100 years [Brody, and Stone 1980]. Although on average the red oaks as a group grow faster in diameter than the white oaks, both groups are characterized by large variation in growth [Johnson and Shifley 2002]. Red oak standing and total timber volume presented in appendix 4.7A.


Figure-4.6 Red oak average height (meter) and diameter (centimetre) at the Guelph TBI Research Station. (Source: N. Thevathasan, unpublished data)

[9] http://en.wikipedia.org/wiki/Quercus_rubra downloaded January 10, 2010.

### 4.6 Economic data sources

Tree and crop related revenue and cost data are presented in the following this section.

#### 4.6.1 Tree production revenues and costs

The standing value of the trees was established from the relationship between standing timber value and volume. Tree revenue is based on timber and tree product revenue. Stumpage price data of three species are presented in Table 4.1 Owing to non-availability of Ontario province timber price data, stumpage price data were gathered from two documents: (1) Pennsylvania Woodlands, Timber Market Report[10]; (2) New York State Dept. of Environmental Conservation, Stumpage Price Report[11]. These two U.S. states are located close to Ontario. Trade in timber should result in similar prices in the two countries.

**Table 4.1 Tree stumpage prices (\$/m$^3$)**

| Tree species | Minimum | Maximum | Average |
|---|---|---|---|
| Hybrid poplar | 83 | 217 | 150 |
| Red oak | 139 | 423 | 281 |
| Norway spruce | 130 | 280 | 200 |

Source: Pennsylvania Woodlands, Timber Market Report, January-March 2008

The costs associated with the tree component of the agroforestry systems were based on numerous sources including Graves (2005). The costs of establishing agroforestry on existing permanent fields, where no reseeding is to be undertaken, are

[10] http://www.sfr.psu.edu/TMR/2008/2-08%20TMR/PriceReport.pdf, downloaded December 12, 2009
[11] http://www.dec.ny.gov/docs/lands_forests_pdf/spr2008summer.pdf, downloaded December 12, 2009

based on the purchase of tree seedlings, provision of tree protection and on pre-treatment and maintenance with herbicides. Tree maintenance costs of the species considered in this study are presented in Table 4.2.

**Table 4.2 Tree maintenance cost ($/ha) of different species**

| Category | Unit | Norway Spruce | Red Oak | Hybrid Poplar |
|---|---|---|---|---|
| Cost of plant | ($/tree) | 1.25 | 1.25 | 1.44 |
| Labour for ground preparation | (hr/ha) | 6 | 6 | 6 |
| Labour for marking out | (hr/ha) | 4 | 4 | 4 |
| Labour for planting trees | (min/tree) | 2 | 2 | 1 |
| Year of first weeding | (year) | 1 | 1 | 1 |
| Year of last weeding | (years) | 3 | 3 | 3 |
| Annual labour for weeding | (min/tree) | 1 | 1 | 1 |
| Annual cost of herbicide for weeding | ($/tree) | 0.5 | 0.5 | 0.5 |
| Height at first prune | (m) | 1 | 1 | 1.5 |
| Minutes per tree at first prune | (min/tree) | 2 | 2 | 3 |
| Height at last prune | (m) | 4.5 | 4.5 | 8 |
| Minutes per tree at last prune | (min/tree) | 7 | 7 | 10 |
| Removal of pruning | (min/tree) | 4 | 4 | 4 |
| Removal of tree | (min/tree) | 5 | 5 | 5 |
| Removal of tree (thinning) | (min/tree) | 2 | 2 | 2 |
| Clear felling (labour) | | 5 | 5 | 5 |
| First year of cost | (years) | 1 | 1 | 1 |
| Last year of cost | (years) | 60 | 60 | 60 |
| Amount | ($/ha) | 50 | 50 | 50 |

Source: Graves, A. R., (2005) Farm-SAFE model

### 4.6.2 Mono-cropping production revenues and costs

Revenue from annual crops, such as wheat, depends on yield and price. For the crop component of the agroforestry system, the variable and assignable fixed costs are applied according to the proportion of intercrop area in the system, which is constant. Table 4.3 presents the average crop production from mono-cropping and agroforestry systems at the Guelph Agroforestry Research Station. The annual variation in yield due to seasonal differences in weather tended to be greater than the differences between the mono-cropping and agroforestry system. However, the average yield of soybeans was 2.08 t $ha^{-1}$ in the mono-cropping system, which was higher than the 1.63 t $ha^{-1}$ reported in the TBI system. Corn and wheat average yield under mono-cropping system were also higher than the TBI system. By contrast, barley yield under mono-cropping system was lower than the TBI system. Crop production simulation presented in appendix in 4.5A.

**Table 4.3 Annual crop yields (t $ha^{-1}$) under Mono-Cropping and TBI systems from 1987 to 2007 at the Guelph Agroforestry Research Station**

| Crop | Minimum | Mean | Maximum | % Difference Mono-cropping/TBI system |
|---|---|---|---|---|
| **Mono-cropping** | | | | |
| Soybeans | 1.4 | 2.1 | 2.4 | 127.6 |
| Corn | 4.1 | 6.4 | 9.0 | 113.0 |
| Wheat | 4.1 | 4.1 | 4.1 | 138.5 |
| Barley | 1.8 | 2.9 | 4.1 | 76.0 |
| **TBI System** | | | | |
| Soybeans | 0.8 | 1.6 | 2.2 | |
| Corn | 3.0 | 5.6 | 7.1 | |
| Wheat | 3.0 | 3.0 | 3.0 | |
| Barley | 3.2 | 3.9 | 4.5 | |

Source: N. Thevathasan, unpublished data

Table 4.4 shows five years of crop price data that was used to calculate NPV of arable and agroforestry systems. A five year average value was used to reduce the seasonality effect of prices.

**Table-4.4 Crop prices from 2003 to 2007 (**$/tonne)

| **Crop** | **2003** | **2004** | **2005** | **2006** | **2007** | **Average** |
|---|---|---|---|---|---|---|
| Wheat | 148 | 130 | 125 | 120 | 251 | 154.8 |
| Corn | 143 | 116 | 107 | 149 | 161 | 135.2 |
| Soybeans | 363 | 283 | 249 | 266 | 371 | 306.4 |
| Barley | 127 | 114 | 102 | 133 | 192 | 133.6 |

Source: Crop Budgets 2008, Ontario Ministry of Agriculture, Food, and Rural Affair (OMAFRA)

Table 4.5 presents crop budget data. The crop budgets are a simple format for estimating expenses. Cost data consists of two components: variable costs and assignable fixed costs.

**Table 4.5 Crop costs ($/ ha) of different crops**

| Category | Wheat | Corn | Soybeans | Barley |
|---|---|---|---|---|
| Seed | 44.95 | 59.75 | 67.40 | 70.00 |
| Fertilizer | 45.05 | 84.05 | 25.60 | 110.00 |
| Spray | 6.40 | 37.15 | 34.20 | 2.00 |
| **Total variable costs** | **96.40** | **180.95** | **127.20** | **182.00** |
| Fuel and repairs | 26.00 | 31.70 | 34.30 | 90.00 |
| Land Rent | 55.00 | 30.95 | 5.05 | 55.00 |
| Drying | 78.00 | 25.85 | 44.80 | 78.00 |
| Others | 4.35 | 5.00 | 13.15 | 5.00 |
| **Total fixed costs** | **159.00** | **88.50** | **84.15** | **223.00** |

Source: Crop Budgets 2008, Ontario Ministry of Agriculture, Food, and Rural Affairs.

## 4.7 Sensitivity Analysis

Sensitivity analysis is used to determine how "sensitive" a model is to changes in the value of the parameters of the model. The sensitivity analysis is carried out to study the effects of the change in variable factors such as input and output prices, yield of product and discount rates [Rahman et. al 2007]. Typically, different *NPV*s for corresponding levels of relative variation in the specified input are obtained to check the sensitivity of variation in the specified input. Sensitivity analysis would be helpful for policy makers to check the impact of different parameter values on the profitability of the system.

**Table 4.6 Description of different sensitivity analysis scenarios**

| **Scenario** | **Description of the Change** | **Expected Results** |
|---|---|---|
| Tree price + | Timber prices 50% higher | Agroforestry profitable |
| Change costs+ | Tree and Crop costs 50% higher | Unknown |
| Crop price+ | Crop price 50% higher | Mono-cropping profitable |
| Discount rate + | Discount rate = 8% | Not favouring agroforestry |
| | Discount rate = 1% | Favouring agroforestry |
| Grants | Grants for planting cost | Agroforestry can be profitable |
| | Grants for equal panting tree area | |
| Change in number of trees | Number of planting trees used 50, 100, 125, 150 ($ha^{-1}$) and crop area used by 95, 90, 85,80 percent respectively | Agroforestry profitable |

Different specifications of input variables are used in this study (Table 4.6). Tree and crop prices are important variables for agroforestry profitability. If prices are higher (or lower) due to economic factors in the industry, this will impact mono-cropping and agroforestry profitability. Tree price information is limited and price will differ by quality of the tree. The sensitivity analysis on tree price will also provide insight into how the quality of the timber will impact the profitability of TBI. Crop and tree production costs are increased by 50 percent (extreme case) due to economic shocks then what will be effect on the profitability of agroforesty.

Another important variable is the discount rate. Three discount rates were selected for this study (1, 4 and 8 percent), 4% is the base used in all other model runs. The 1% indicates very low discounting of the future and would reflect someone who is places a high value on the future. The lower discount rate would also be more favourable for agroforestry because the return from tree would be discounted less.

**Table 4.7 Grants by category for agroforestry system**

| Category | No. of Years | Unit | Norway spruce | Red oak | Hybrid poplar |
|---|---|---|---|---|---|
| Establishment | Year of fisrt planting grant | (year) | 1 | 1 | 1 |
| Payment | Value of first planting grant | ($/ha) | 125.0 | 125.0 | 144.0 |
| | Year of planting grant | (year) | 2 | 2 | 2 |
| | Year of second planting grant | (year) | 5 | 5 | 5 |
| Compensation | Initial year of receipt | (year) | 1 | 1 | 1 |
| Payment | Final year of receipt | (year) | 10 | 10 | 10 |
| | Amount | ($/ha) | 50.0 | 50.0 | 50.0 |
| Maintenance | | | | | |
| payment: | Initial year of receipt | (year) | 1 | 1 | 1 |
| Period 1 | Final year of receipt | (year) | 15 | 15 | 15 |
| Period 2 | Amount | ($/ha) | 50 | 50 | 50 |

Tree grants might be important to establish TBI systems in Canada. Grants can be used to off-set the cost of planting trees and equal to tree area under TBI systems which can be equal  percentage earning from the crop yield area. If TBI system is not privately profitable and the public wants the system, it would need to supported TBI system through grants.

There are four types of tree grants used in this study to examine its effect on profitability of the agroforestry systems. The grants include establishment payments, compensation payments, maintenance payments period1 and maintenance payments period 2 (Table 4.7).  The establishment grant is equal to the cost of 100 trees $h^{-1}$ for Norway spruce ($125), Red oak ($125) and Hybrid poplar ($144). On the other hand, compensation grant $100 $h^{-1}$ is equal to trees area (approximately 10 percent of the crop area) is used for TBI systems. A maintenance grant ($100 per hectare for all TBI systems) is used to compensate the maintenance cost such pruning, herbicide for weeding, etc.

# Chapter 5

## RESULTS OF THE STUDY

### 5.1 Introduction

The results presented here are based on a long-term TBI research project initiated in 1987 on a 30-ha field at the University of Guelph Agroforestry Research Station, Guelph, Southern Ontario, Canada. The purpose is to compare the economic profitability of adjacent mono-cropping and TBI systems. Several scenarios were evaluated to check the profitability of the two farming systems using the Farm-SAFE model. The analysis concentrates on the set of most limiting resources and operates in discrete steps rather than the nicely judged 'more or- less' of marginal analysis. Section 5.2 describes the economic value of selected crop and tree species using base scenario. Sensitivity analysis is discussed in section 5.3. Summary and conclusions of the chapter are provided in section 5.4.

### 5.2 Results of selected crop and tree species

The results described in this section were derived from economic and biophysical data to compare the profitability of the reference mono-cropping and TBI systems. Initially, 100 trees $ha^{-1}$ for TBI systems and 90 percent of the area used for annual crop production under TBI system. This was done on the basis of the NPV and EAV (discount rate =4%) and examined with no government grants.

#### 5.2.1 Profitability of the systems

The present value of benefit (without deducted present value of cost) over a 60-year period from mono-cropping annual crops was $16,723 (Table 5.1). The present value of benefit for mono-cropping was less than for TBI with hybrid poplar, but greater than the TBI with Norway spruce or with oak. Benefit-cost ratio of mono-cropping system is 2.7, which shows that mono-cropping system was less than hybrid poplar equal to Norway spruce profitable than the TBI system red oak. The ratio of the TBI system using hybrid poplar system is higher than mono-cropping system which shows that hybrid poplar TBI system is more profitable as compared to mono-cropping system. The mono-cropping system and Norway spruce TBI system were equally profitable (benefit-cost ratio = 2.7). The net-margin of TBI and mono-cropping systems presented in appendix graph 4.1A to graph 4.4A.

**Table-5.1 Present values of benefits and costs, and the benefit-cost ratio of mono-cropping and TBI systems**

| Cropping system | Present value of benefit | Present value of cost | Benefit-cost ratio |
|---|---|---|---|
| Mono-cropping | $16,723 | $6,155 | 2.7 |
| TBI systems: | | | |
| Hybrid Poplar | $17,764 | $6,057 | 2.9 |
| Norway Spruce | $16,230 | $6,103 | 2.7 |
| Red Oak | $14,958 | $6,083 | 2.5 |

The NPV of mono-cropping is $9,132 (Table 5.2). The NPV and EAV of the TBI system under hybrid poplar is more profitable, compared to the mono-cropping system. By contrast, mono-cropping system was more profitable than TBI systems of Norway spruce and red oak. The profitability of the TBI system using hybrid poplar generated more revenue, compared to the mono-cropping system. The EAV is higher for hybrid poplar TBI system than the mono-cropping system.

**Table 5.2 Net present value (NPV) and Equivalent annual value (EAV) of mono-cropping and TBI systems**

| Cropping system | NPV | EAV | Benefit-cost ratio |
|---|---|---|---|
| Mono-cropping | $9,132 | $404 | 2.7 |
| TBI systems: | | | |
| Hybrid Poplar | $10,354 | $541 | 2.9 |
| Norway Spruce | $8,827 | $414 | 2.7 |
| Red Oak | $7,522 | $332 | 2.5 |

## 5.3 Sensitivity Analysis

Sensitivity analysis is used to determine how "sensitive" a model is to changes in the value of the parameters of the model. The sensitivity analysis is carried out to study the effects of the change in mutable factures such as input and output prices, yield of product and discount rates [Rahman et. al. 2007]. Economic indicators in the sensitivity analysis changed due to changes in the value of key variables. To check the sensitivity of the NPV of mono-cropping and TBI systems, we analyzed a change in discount rate, tree and crop production, prices, grants, costs, and labor requirements. Simulations of the above mentioned variables were presented in appendix Graph 4.9 to Graph 4.12.

### 5.3.1 Change in discount rate

NPV measurements are used to assess the 'discount factor' consequence of a long-term investment. For each system, NPV is calculated at discount rates of 1, 4, and 8 percent to check the profitability of the systems under different discount rates. The higher the discount rate, the more heavily weighted are the benefits received in the early years of the project. Farmers' actual discount rate may vary according to their level of savings, alternative income sources, risk management preferences and so forth. The result shows that the TBI system under hybrid poplar is more profitable than the other three species at all the discount rates (Table 5.3). When the returns over the 60 years are discounted to the NPV, a discount rate of 1%, the cumulative returns are highest for hybrid poplar ($28,531). At the high 8% discount rate, the NPV was highest for hybrid poplar ($5,262).

**Table 5.3 Sensitivity of the net present value (NPV) and equivalent annual value (EAV) of mono-cropping and TBI systems to change discount rate (base rate=4%)**

| Systems | NPV | | | EAV ($) | | |
|---|---|---|---|---|---|---|
| Discount rate | 1% | 4% | 8% | 1% rate | 4% rate | 8% rate |
| Mono-cropping | $26,942 | $9,132 | $5,057 | $599 | $404 | $409 |
| TBI system: | | | | | | |
| Hybrid Poplar | $28,531 | $10,354 | $5,262 | $811 | $541 | $449 |
| Norway Spruce | $26,974 | $8,827 | $4,139 | $779 | $414 | $367 |
| Red Oak | $27,564 | $7,522 | $2,522 | $613 | $332 | $285 |

### 5.3.2 Change in timber price

There are three main reasons of changing timber prices in future. The first reason is that timber demand can increase. The second reason is that inflation factor can increase real timber prices. The last reason is that maybe a higher price also includes some payment for carbon sequestration. The results of a fifty percent increased in timber prices are the same as compared to the previous scenario (Table 5.4). Hybrid poplar agroforestry system was again more profitable as compared to mono-cropping and other two agroforestry systems. Norway spruce agroforestry system was also profitable in this scenario but red oak agroforestry system was still unprofitable compared to mono-cropping and the other two TBI systems. The reason is that red oak is a slow growing species that requires years to mature and the NPV at harvest is highly discounted. During 60 years, it has not enough timber yield to generate a profit for the landowner.

**Table 5.4 Sensitivity of the net present value (NPV) and equivalent annual value (EAV) of mono-cropping and TBI systems to change 50% increased tree price**

| Cropping System | NPV | | EAV | |
|---|---|---|---|---|
| | Base value | 50% increased | Base value | 50% increased |
| Mono-cropping | $9,132 | $9,132 | $404 | $404 |
| TBI system: | | | | |
| Hybrid Poplar | $10,354 | $12,057 | $541 | $666 |
| Norway Spruce | $8,827 | $9,987 | $414 | $481 |
| Red Oak | $7,522 | $8,076 | $332 | $357 |

### 5.3.3 Change in crop price

Crop price change has significant impact on profitability of mono-cropping system (Table 5.5). When 50 percent increased in crop prices, mono-cropping system is more profitable than the three TBI systems. On the other hand, when 50 percent decreased in crop prices, all TBI systems are more profitable than the mono-cropping system. Hybrid poplar is relatively more profitable than to Norway spruce and red oak TBI systems. There are two reasons. The first reason is that 90 percent of land area is annual crops under the TBI system. Therefore, increased crop prices will also affect both the mono-cropping system and agroforestry systems' profitability. The second reason is the hybrid poplar is a fast growing species, so that its profitability is not affected as much as the other two tree species.

**Table 5.5 Sensitivity of the net present value (NPV) and equivalent annual value (EAV) of mono-cropping and TBI systems to change 50% crop value**

| Cropping System | NPV | | | EAV | | |
|---|---|---|---|---|---|---|
| | 50% decreased | Base value | 50% increased | 50% decreased | Base value | 50% increased |
| Mono-cropping | $786 | $9,132 | $17,540 | $35 | $404 | $775 |
| TBI system: | | | | | | |
| Hybrid Poplar | $3,459 | $10,354 | $17, 248 | $234 | $541 | $846 |
| Norway Spruce | $2,063 | $8,827 | $15,490 | $120 | $414 | $608 |
| Red Oak | $627 | $7,522 | $14,416 | $25 | $332 | $637 |

### 5.3.4 Grants for planting cost

Using grants (planting cost), the pattern of profitability across the different systems was accentuated (Table 5.6). The NPV of mono-cropping system is constant in this analysis. The NPV of TBI systems show that the hybrid poplar and Norway spruce TBI systems are more profitable than mono-cropping system.

**Table 5.6 Sensitivity of the net present value (NPV) and equivalent annual value (EAV) of mono-cropping and TBI systems to change using grants (planting cost)**

| Cropping System | NPV | | EAV | |
|---|---|---|---|---|
| | Without grants | With grants | Without grants | With grants |
| Mono-cropping | $9,132 | $9,132 | $404 | $404 |
| TBI system: | | | | |
| Hybrid Poplar | $10,354 | $10,874 | $541 | $579 |
| Norway Spruce | $8,827 | $9,326 | $414 | $443 |
| Red Oak | $7,522 | $8,021 | $332 | $354 |

### 5.3.5 Grants equal to the planting tree area

All TBI systems are more profitable than the mono-cropping systems (Table 5.7). As with the planting grant, illustrates that hybrid poplar is more profitable compared to the other systems. The second most profitable system though is red oak, which was unprofitable with a tree cost grant (Table 5.6). NPV and EAV are higher of all TBI systems as compared to mono-cropping system. NPV of mono-cropping system is constant in this analysis.

**Table 5.7 Sensitivity of the net present value (NPV) and equivalent annual value (EAV) of mono-cropping and TBI systems using grants (planting and tree area)**

| Cropping System | NPV | | EAV | |
|---|---|---|---|---|
| | Without grants | With grants | Without grants | With grants |
| Mono-cropping | $9,132 | 9,132 | $404 | $404 |
| TBI system: | | | | |
| Hybrid Poplar | $10,354 | 11,498 | $541 | $625 |
| Norway Spruce | $8,827 | 9,968 | $414 | $480 |
| Red Oak | $7,522 | 10,718 | $332 | $473 |

### 5.3.6 Change in number of planting trees ($ha^{-1}$)

The model was also used to predict the difference in tree yield at four densities. The NPV of three TBI systems were changed when number of trees ($ha^{-1}$) changed. 5 percent area was allocated for 50 trees ($ha^{-1}$) and 15 percent area was allocated for 150 trees ($ha^{-1}$) of the total crop area. So, there is a trade-off between crop area and number of trees ($ha^{-1}$). As expected relative crop yields were greatest in the 50 trees $ha^{-1}$ system and relative yield ($m^3$ $ha^{-1}$) were greatest with 150 trees ($ha^{-1}$). 125 or plus trees ($ha^{-1}$) are more profitable under hybrid poplar and Norway spruce TBI systems as compared to mono-cropping system (Table 5.8). All TBI systems are unprofitable compared to mono-cropping under 50 trees ( $ha^{-1}$).

**Table 5.8 Sensitivity of the net present value of mono-cropping and TBI systems to change number of trees.**

| Cropping System | Net Present Value | | | |
|---|---|---|---|---|
| | 50 trees | 100 trees | 125 trees | 150 trees |
| Mono-cropping | $9,132 | $9,132 | $9,132 | $9,132 |
| TBI system: | | | | |
| Hybrid Poplar | $8,985 | $10,354 | $11,039 | $11,722 |
| Norway Spruce | $8,051 | $8,827 | $9,216 | $9,603 |
| Red Oak | $7,569 | $7,522 | $7,499 | $7,444 |

### 5.3.7 Change in both tree and crop yields

A variation of 20 percent in both tree and crop yields was used to examine sensitivity to production level used in the analysis. Within each system, the NPV of the hybrid poplar and red oak TBI systems were respectively the least and most sensitive to changes in production. Red oak TBI system's NPV is increased by 41.4 percent which is higher as compared to other systems' NPV (Table 5.9). The NPV of mono-cropping system is changed 36.6 percent which is higher only from hybrid poplar TBI system but it is lesser than Norway spruce and red oak TBI systems. The reason is that 90 percent area was allocated for crop area under TBI system. Therefore, mono-cropping and other two TBI systems (Norway spruce and red oak) were more sensitive. Hybrid poplar TBI system is marginally less sensitive than all other systems. The benefit-cost ratio of hybrid poplar TBI was higher than the all three systems.

**Table 5.9 Mono-cropping and TBI systems with 20% increased crop and tree production**

| Cropping system | Base NPV | NPV | % Difference | Benefit-cost ratio |
|---|---|---|---|---|
| Mono-cropping | $9,132 | $12,477 | 36.6 | 3.3 |
| TBI system: | | | | |
| Hybrid Poplar | $10,354 | $14,027 | 35.5 | 3.5 |
| Norway Spruce | $8,827 | $12,073 | 36.8 | 3.2 |
| Red Oak | $7,522 | $10,634 | 41.4 | 3.0 |

### 5.3.8 Change in crop and tree production costs

Tree and crop costs were increased by 20 percent and had no impact on benefit-cost ratio (5.10). Crop costs included seeds, fertilizer, machinery, etc. Tree costs included plant price, weeding, sward establishment, pruning and thinning. Mono-cropping system is less sensitive as compared to TBI systems when crop and tree production costs increased by 20 percent. Within TBI systems, the hybrid poplar TBI system is less sensitive and the red oak TBI system is more sensitive when costs increased by 20 percent. The red oak TBI system has lowest benefit-cost ratio as compared to other three systems. The mono-cropping system has 2.3 benefit-cost ratio also higher than the Norway spruce and red oak TBI systems which shows that mono-cropping is more profitable than Norway spruce and red oak TBI systems. But, hybrid poplar TBI system is more profitable than the mono-cropping system when cost is increased by 20 percent.

**Table 5.10 Mono-cropping and TBI systems with 20% increased crop and tree costs**

| Cropping system | Base NPV | NPV | % Difference | Benefit-cost ratio |
|---|---|---|---|---|
| Mono-cropping | $9,132 | $7,645 | -16.28 | 2.3 |
| TBI system: | | | | |
| Hybrid Poplar | $10,354 | $8,953 | -13.53 | 2.5 |
| Norway Spruce | $8,827 | $7,370 | -16.51 | 2.2 |
| Red Oak | $7,522 | $6,116 | -18.69 | 2.1 |

### 5.3.9 Infinite net present value

Table 5.11 presents results of the infinite NPV using 4% discount rate. Economic feasibility was assessed by multiplying the one-hectare results for each land unit by their area and adding farm fixed costs. The infinite NPV of the farm used to evaluate the economic effect of planting 10% of the farm with TBI system in comparison with mono-cropping system. Planting was assumed in year 1 and hybrid poplar, Norway spruce, red oak were harvested to provide revenue in year 60. A rotation of 20 years was assumed for hybrid poplar, and by re-planting in years 21 and 41, three full rotations of hybrid poplar were completed in 60 years. A rotation of 30 years was assumed for Norway spruce, and by re-planting in year 31, two full rotations of Norway spruce were completed in 60 years. Fisher criteria (described in chapter-3, table 3.1) was used for the rotation of hybrid poplar and Norway spruce. The results show that hybrid poplar and Norway spruce systems of TBI are more profitable as compared to mono-cropping system. Red oak TBI system is less profitable as compared to mono-cropping system.

**Table 5.11 Mono-cropping and TBI systems with infinite discount rate**

| Cropping System | NPV | Present value of benefit | Present value of cost | Benefit-cost ratio |
|---|---|---|---|---|
| Mono-cropping | $10,091 | $18,480 | $6,801 | 2.7 |
| TBI system: | | | | |
| Hybrid Poplar | $18,629 | $32,260 | $11,142 | 2.9 |
| Norway Spruce | $12,614 | $23,317 | $8,823 | 2.7 |
| Red Oak | $8,312 | $16,529 | $6,722 | 2.5 |

## 5.4 Summary and conclusions

TBI systems have been suggested as alternate land use systems in Canada. Three species' bio-physical data were selected to analyze the mono-cropping and TBI systems. A biophysical data was parameterised and calibrated for long-term tree and crop yields. Reasonable fits between predicted and measured data sets were obtained. Financial data for mono-cropping and TBI production of each specie were collected from many sources.

The Farm-SAFE model was used to analyze tree and crop yields of mono-cropping and TBI systems for hybrid poplar, Norway spruce, red oak and cereals wheat, corn, soybeans and barley. The bio-physical data of tree and crop yields were used in the Farm-SAFE model. Without grants, only the hybrid poplar TBI system had greater NPV and EAV, as compared to the mono-cropping system. However, Norway spruce and red oak TBI systems were less profitable than mono-cropping systems. With grants and without grants, there is significant change in the results.

The profitability of mono-cropping and TBI systems was compared using discounted cost benefit analysis (discount rate = 4%). Because rotation lengths were different, NPVs were calculated and EAVs derived from these to compare the different systems. The profitability of each system was examined using zero-grants and with-grants. Assuming no government support, the *EAV* (Table 5.6 and 5.7) for optimized TBI systems using hybrid poplar species was greater than the mono-cropping system. Hybrid poplar TBI system was substantially more profitable than the next most profitable TBI systems. The net benefit was due to relatively high timber production and a short rotation. The net benefit of Hybrid poplar TBI system was due to the profitability of the intercrop and a larger final timber volume per tree, which resulted in a higher per cubic metre value. Norway spruce and red oak TBI systems had lower NPVs and EAVs than the mono-cropping system, which suggested that under current prices and costs, TBI systems in low timber volume would be unprofitable compared to a mono-cropping system.

Sensitivity to discount rate (Table 5.3) was greatest in TBI systems, where significant long-term revenue was received. The three TBI systems were profitable at zero percent discount rate, compared to the mono-cropping system. Only hybrid poplar TBI system was profitable at the 8 percent discount rate. Sensitivity to production (Table 5.9) was greater for red oak TBI system than mono-cropping and other TBI systems because this caused a greater change in aggregate timber crop revenue, which was reduced by discounting. TBI systems were relatively sensitive to variation in productivity of the intercrop but less sensitive to variation in timber production.

Variation in crop and tree prices (Table 5.4 and 5.5) showed that mono-cropping and TBI systems were relatively sensitive to crop price variation and TBI systems were relatively insensitive to timber price variation. Variation in number of trees ($ha^{-1}$) showed that 125 or plus trees for hybrid poplar and Norway spruce TBI systems are more profitable (Table 5.8). Variation in costs (Table 5.10) showed that red oak TBI system was more sensitive to cost changes than three other systems. The other systems were relatively less sensitive to change in cost. For TBI systems, variation in prices and costs were most important and the size of changes in inputs was most closely linked to the effect these changes had on the intercrop.

From the preceding analysis, it is clear that TBI systems can under certain circumstances provide a productive, profitable and feasible alternative to mono-cropping system. Tree and crop production was invariably more efficient in the use of land when combined in TBI systems (hybrid poplar and Norway spruce) than when separated in mono-cropping system. Farmers can use a combination of fast-growing species e.g. (hybrid poplar) and slow-growing species e.g. (red oak) trees simultaneously to increase their profit from a TBI system.

# Chapter 6

## SUMMARY AND RECOMMENDATIONS

Bio-physical and financial data were used to analyze the mono-cropping and TBI systems. The economic performance of the systems was compared with different scenarios such as with grants and without grants. The mono-cropping system was marginally more profitable than TBI systems with Norway spruce and red oak. The presence of woody elements usually enhances the landscape value. The park-like landscape of wide spaced and well managed trees on arable land would be more attractive for recreation than the open land.

TBI system is a relatively complex and multifaceted topic that is relevant across a number of scales – farms and landscapes – and sectors – agriculture, forestry, and environment. This increases the importance of attempting to review and distill lessons or simply examples of good practice from policy experiences throughout the world. However, both the hybrid poplar and Norway spruce TBI systems were more profitable than red oak TBI system. In order for TBI system to increase its contribution to meet the needs of farmers and society within this changing operational and policy environment, it needs to be more profitable.

### 6.1 Usage of machinery for TBI system

Harvesting and operating methods vary across the provinces in Canada. Difficult application of machinery within a TBI system is a major drawback. In modern TBI systems, trees are typically arranged in lines at a certain distance. The distance between tree lines should be large enough to allow efficient use of the usual machinery. Machinery should be given plenty room, otherwise chances are higher to damage or even pull out trees (Oosterbaan 2000). It may even be necessary to choose for a wider spacing than initially necessary, keeping in mind the future purchase of bigger machinery. If the TBI system design and the machinery are matched however, mechanization in TBI system will have few limitations.

Generally a crop free zone of one to two meter is kept on either side of the tree line and the lower branches are pruned. This not only allows the machinery to pass through easily, but also reduces light competition. Furthermore, it is important to reserve enough space at the headland to allow machinery to easily turn in and out of the intercrop strip between the trees, otherwise turning takes too much time and trees may be damaged. Dupraz and Newman (1997) suggest a 14m distance between the tree rows in experimental designs, as this would accommodate most of the mechanization constraints and allows for a 1-2 m bare strip along the trees. For intensive commercial farms a larger spacing (20 to 30 m) may be required, regarding the usual width of machinery. In TBI systems, where forage is also harvested for food or fodder, trees and individual tree shelters (if present) will mean little yield loss and lower labour-efficiency, since one has to circle around the trees. Oosterbaan (2000) found that higher tree densities have higher harvesting costs, higher yield loss and more tree damage than lower densities. Also in TBI systems, trees may mean that measures as ploughing, weeding, spraying and harvesting take more time per square meter of intercrop. On a hectare basis, it may take less time though, since a strip along the tree rows is usually passed over. Establishment, thinning, pruning of trees and transport of the wood will also take time, but this can be done in the quiet season and is less bound to specific times or weather conditions than other agricultural activities as ploughing, sowing and harvesting.

If the TBI system includes fruit or nut trees, harvesting of these fruits/nuts may also mean extra labour, especially in case of unmechanized harvesting. Furthermore, the picking of fruits/nuts may limit the intercrop practices. Nuts for example will fall on the ground in autumn and can not be picked when an intercrop is present. Mechanical picking has proven to work best on grass. For this and other reasons, Dupraz and Newman (1997) predict that future changes in TBI system designs will probably see a shift from growing fruit trees to growing timber trees.

### 6.2 Investment on TBI system

The development of TBI systems generally require high investment costs, which pay back on the long term. Good planting stock, tree-protection (individual tree shelters or fencing) and the labour needed to establish the tree plantation represent initial investment costs. The purchase of machinery, for example for pruning or picking of nuts, may be a secondary investment. An indirect investment is related to the decline in cropped land area due to the occupation of productive land by trees, of which the economic returns only come in a later stage. It may be difficult for farmers, who are used to quick returns on investments, to make such long term investments. To reduce initial cost of the TBI system, government can provide grants for TBI system.

### 6.3 Management strategies

Good management practices can increase farmers profit when they adopt TBI system. Some management practices are important which discussed below:

#### 6.3.1 TBI and information

While TBI system is an old practice, TBI management options and principles continue to increase (locally and through research), but mechanisms for moving this information to

TBI managers are lacking. Some of the specific constraints are access to public/private extension services, language or literacy barrier, difficulty in separating publicity from fact (e.g. 'more tree planting is always good') are generalizations seen in the press. There is quite a need for more informed public information about TBI.

### 6.3.2 Knowledge and skills

Building on the constraint of information, several TBI systems are thought to be knowledge intensive, that is where knowledge is the most critical factor in success relative to land, labor, or capital. Some of the more impactful TBI practices found in certain locations are not known by tradition in other areas, and hence there is often need for technical support in transmitting this knowledge above and beyond simple 'awareness creation'.

### 6.3.3 Time perspectives

There can be no escaping the fact that many TBI practices take longer (i.e., red oak) to yield benefits than mono-cropping systems. However, the benefit stream can be advanced in some cases through improved propagation and management, and it can be better aligned with costs through credit or upfront investment cost sharing through private contractual arrangements.

### 6.3.4 Risk factor for TBI system

Although trees adapt well to climate variability due to their vast rooting systems, a number of other risks are particularly problematic for TBI system. The risk of loss due to livestock, theft (when trees are located far from homes), and from pest and disease (because relatively little investment goes into tree health as compared to crop or livestock health).

### 6.3.5 Value addition factors

In addition to managing the production of TBI, there are potential opportunities for value adding at the TBI manager level. This could be in terms of preserving fruits or processing wood, for example. However, there are only fragmented efforts to promote TBI products, often involving a small group of people in a given community. Aspects of quality control, storage, processing, and certification for TBI products are important factors to enhance profitability of TBI system. As with any commodity or service, the benefit or price paid for TBI products and services needs to be sufficient (i.e. to compensate for costs, efforts, risks, etc.) in order to make greater TBI investment.

## 6.4 Socioeconomic issues

Of the economic outcomes analyzed in this study, economic and non- market benefits stand out as the most prevalent in the literature survey. This seems logical, as many funding and government agencies would be interested in promoting TBI as a good investment and/or social service. Household benefits and institutional concerns follow closely. These issues, too, represent a straightforward concern for TBI funders, scientists, and on-the-ground implementers. Macroeconomics and markets would also merit further emphasis from the academic community.

## 6.5 Government grants

Even though the net primary productivity of land devoted to TBI system may be higher than that of mono-cropping systems, the economic output of a land use systems can vary enormously with the availability of grants. The payments compensate farmers for the additional costs due to the presence of trees on their land. It is an additional five-year payment to cover the costs of forming an TBI system of at least 100 trees/ha, and the payment is equivalent to $200/ha/yr for trees with crops. However, there may also be examples, where TBI is economically viable under the current situation. Oosterbaan (2000) calculated that walnut orchards with cattle grazing the grass-intercrop would give a higher net benefit over 40 years than a grass mono-cropping.

### 6.6 Further research

The purpose of this study is to continue improving the estimation of the economics of TBI systems by identify and measuring the net economic value of interaction effects between tree crops and annual crops. The results of this study generally suggest that the TBI science is continuing to broaden from its established basic biophysical research in temperate farming systems. The data support the assertion of Garrett et al. (2000) that TBI is expanding into temperate regions, and with this expansion comes the need for a broader range of economic and social research. A broader range of countries active in published literature presents an opportunity for scientific researchers and TBI practitioners alike to share experiences across cultures and ecosystems. Given current trends, we might expect to see policy-makers requesting more information on macroeconomic implications of TBI system and adopters and agencies looking into increasingly complex financial analyses. The next challenge that the field may face is that of many interdisciplinary studies: providing integrative research with both scientific depth and a broad appeal. The prevalence of TBI research in a wide range of publishing venues offers one solution, but requires an increasing creativity from academic researchers and making information accessible to those implementing TBI.

The biggest obstacle in adopting TBI systems is to conceptualize the planting, cultivation, fertilization, spraying, and, particularly, harvesting of more than one crop in the same field (Machado, 2009). Given the advantages to be enjoyed from TBI and the environmental and economic problems with current farming systems, it seems reasonable to continue research on the possibilities of growing more than one crop in a field at the same time (Machado, 2009).

### 6.7 Conclusions

Many of the constraints listed above are clearly linked to specific policy areas, while others may be more difficult to trace to specific policy needs. It is useful to make a few remarks about the rationale for policy intervention to support TBI. Several of the items in the list above are not exclusive to TBI, for example, marketing constraints of some type affect many of the products from smallholder farmers. But there are two reasons why re-examining policies specifically with a TBI perspective is sensible: (1) TBI practices generally provide positive externalities in the form of environmental services (e.g. watershed protection) that society, rather than TBI managers benefit from. In order to encourage a level of TBI that society desires, it is necessary for policy interventions to develop incentives or mechanisms by which this can happen, and (2) TBI investment is mainly a long term investment and risks faced by smallholder communities, these types of investments tend to be significantly under-observed. Government grants can play a significant role to establish TBI system in Canada. The other option is that farmers can plant a combination of fast-growing (hybrid poplar) and slow-growing (red oak) trees simultaneously to increase their profit from a TBI system.

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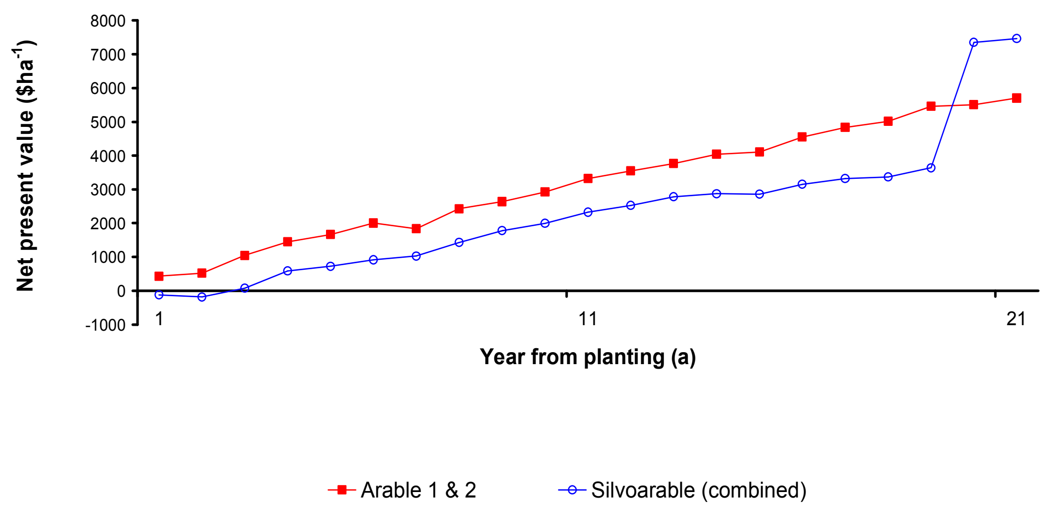
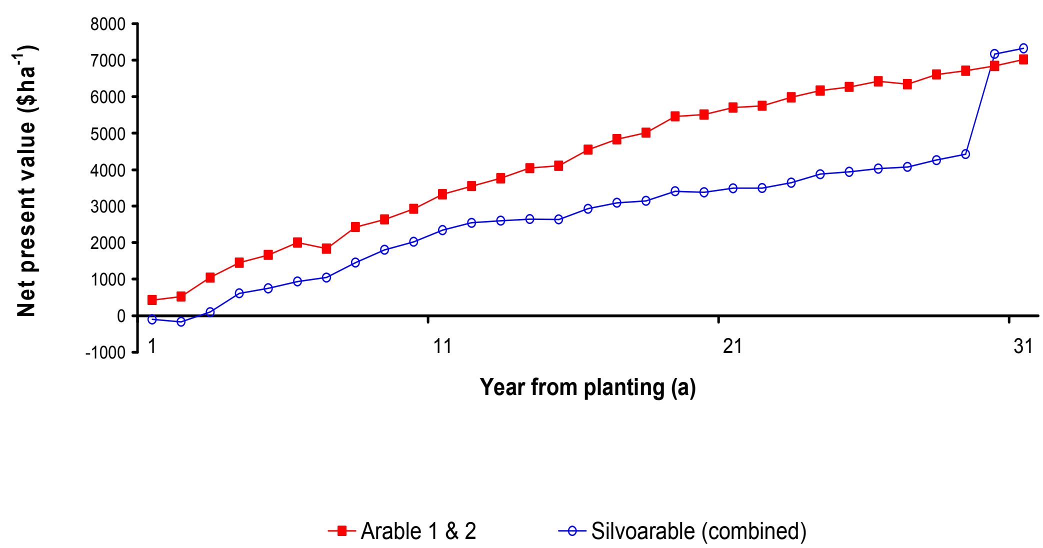
# Appendix

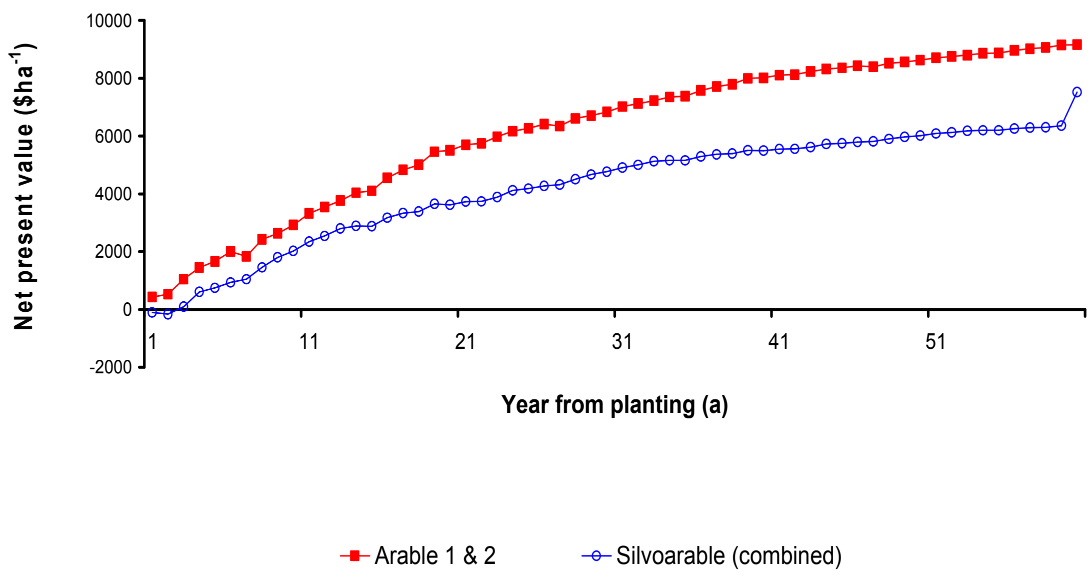
## Graph 4.1A Cumulative net margins in a hybrid poplar TBI system



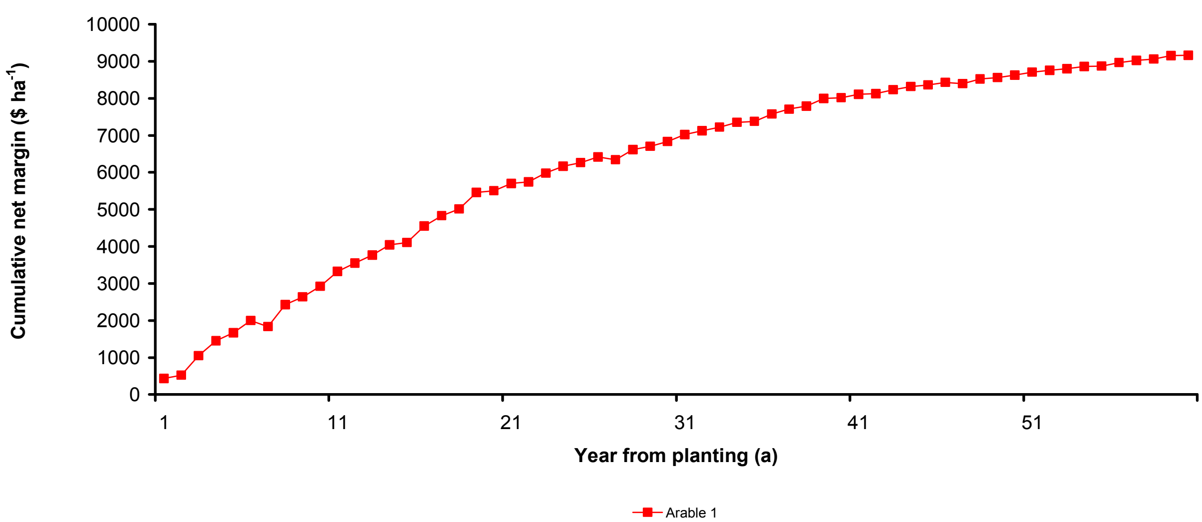

## Graph 4.2A Cumulative net margins in a Norway spruce TBI system



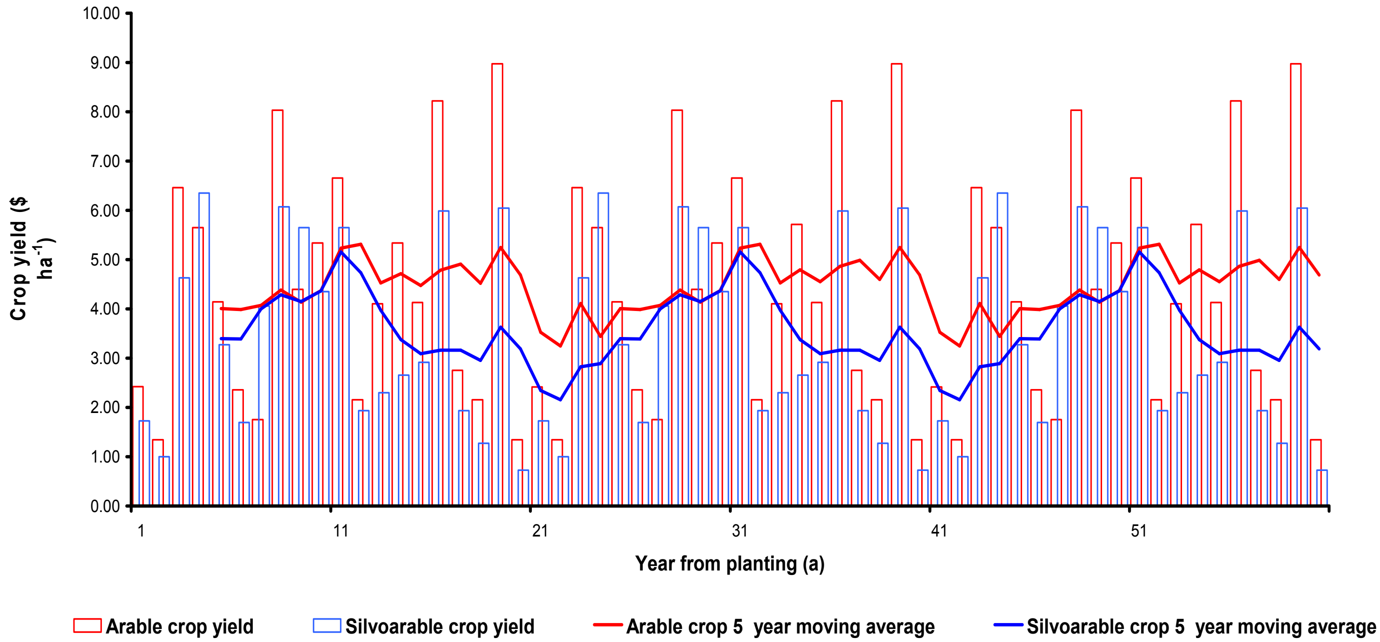
**Graph 4.3A Cumulative net margins in a red oak TBI system**



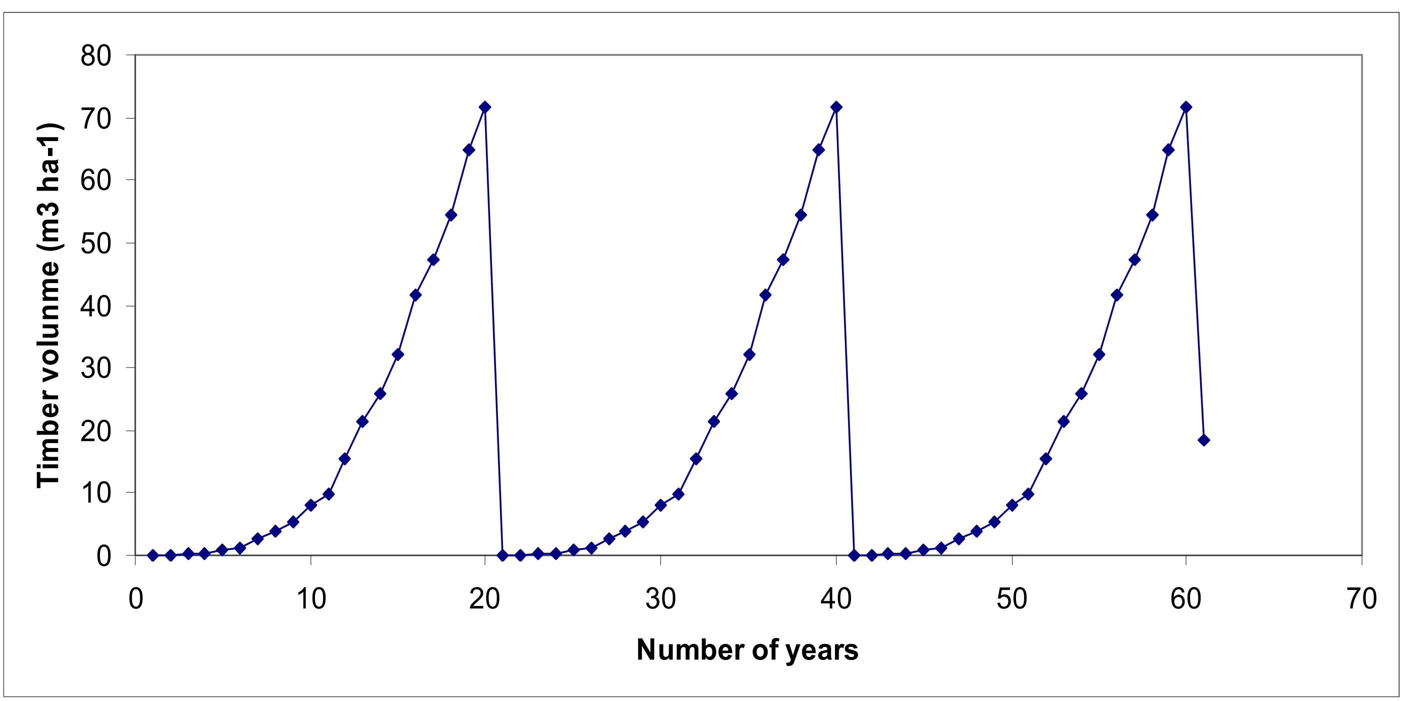

**Graph 4.4A Cumulative net margin of mono-cropping system.**



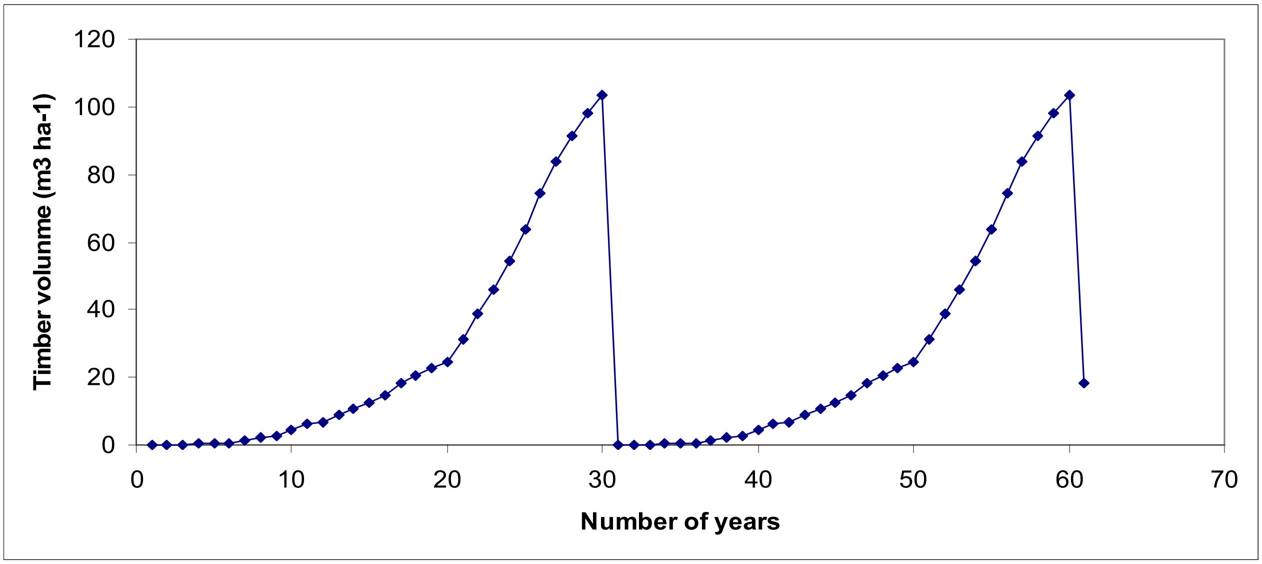
**Graph 4.5A Crop production of mono-cropping and TBI systems**



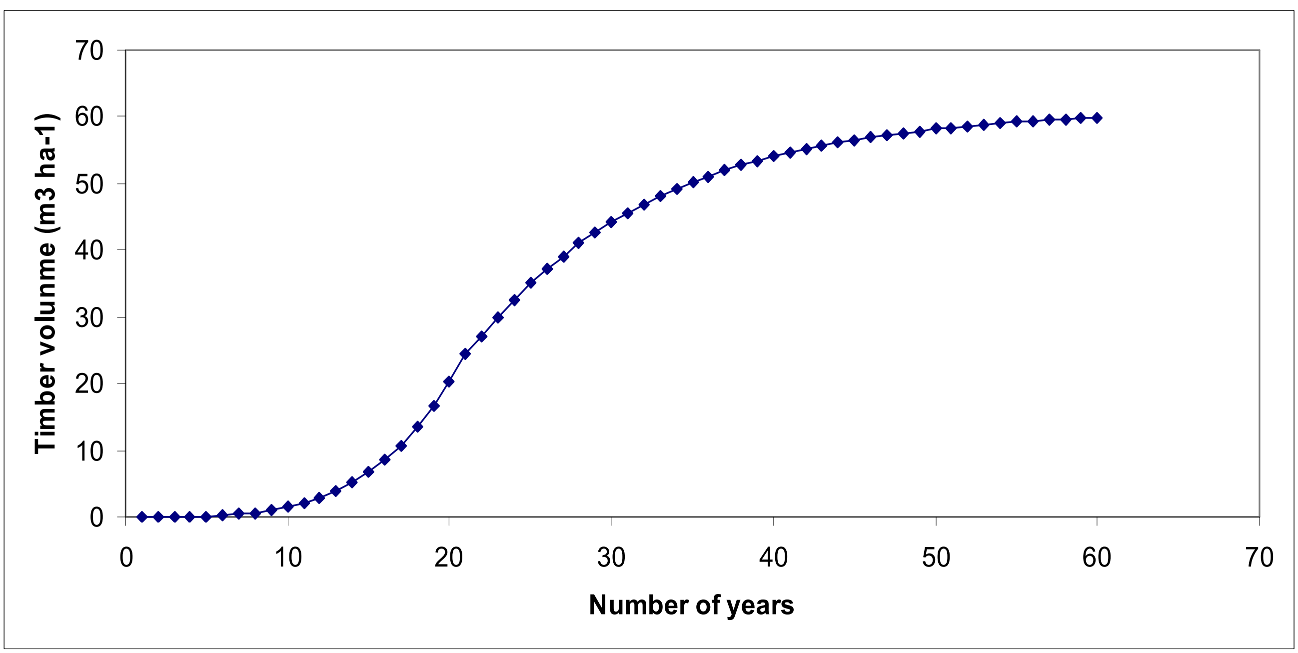

**Graph 4.6A Hybrid poplar standing and total market timber volume**



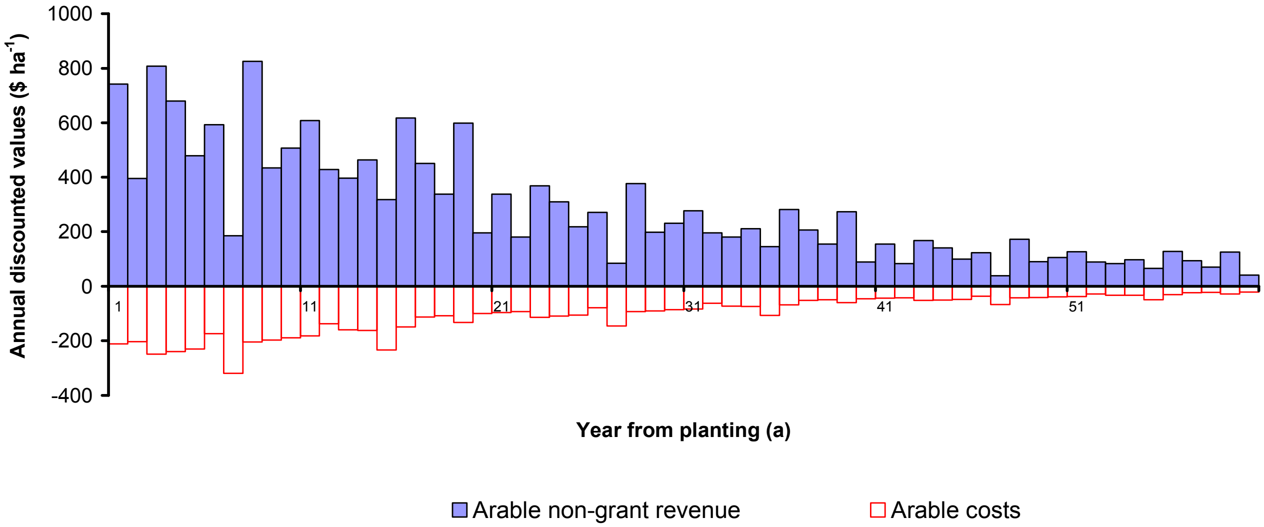
**Graph 4.7A Norway spruce standing and total market timber volume**



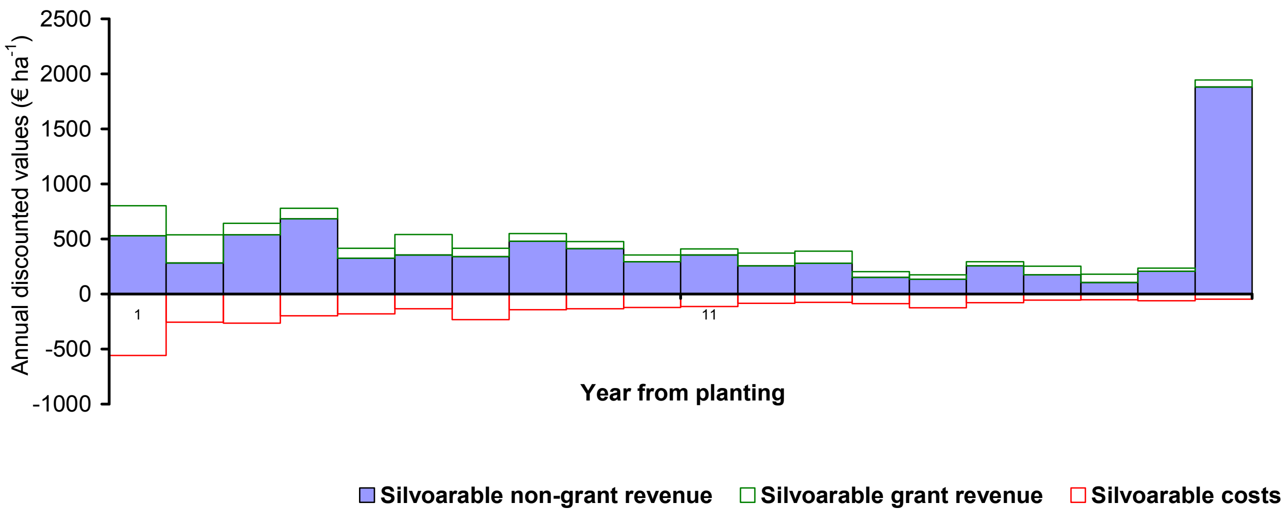

**Graph 4.8A Red oak standing and total market timber volume**



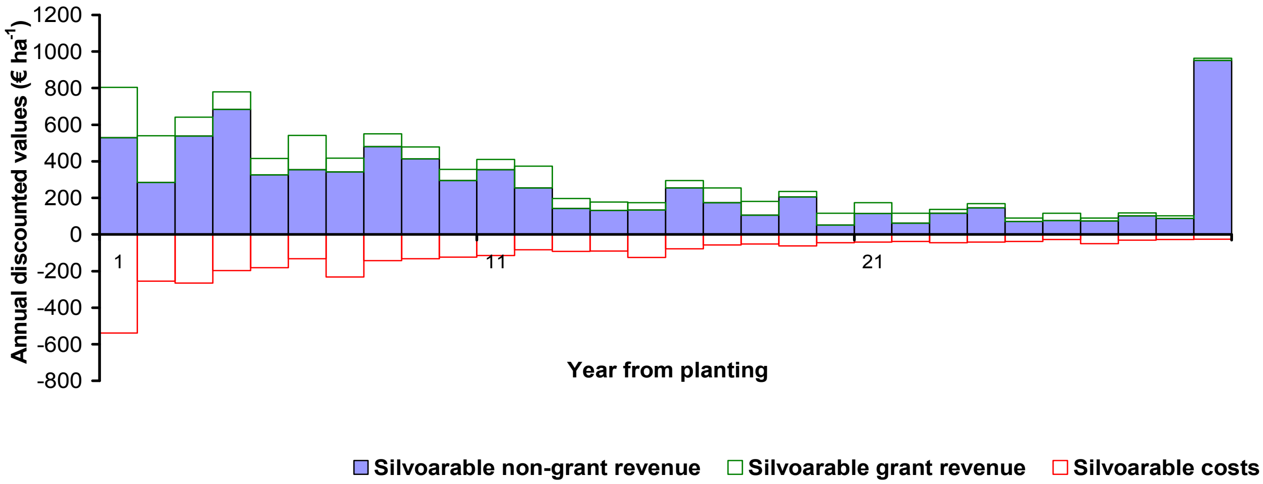
**Graph 4.9A Pattern of mono-cropping revenue and costs**



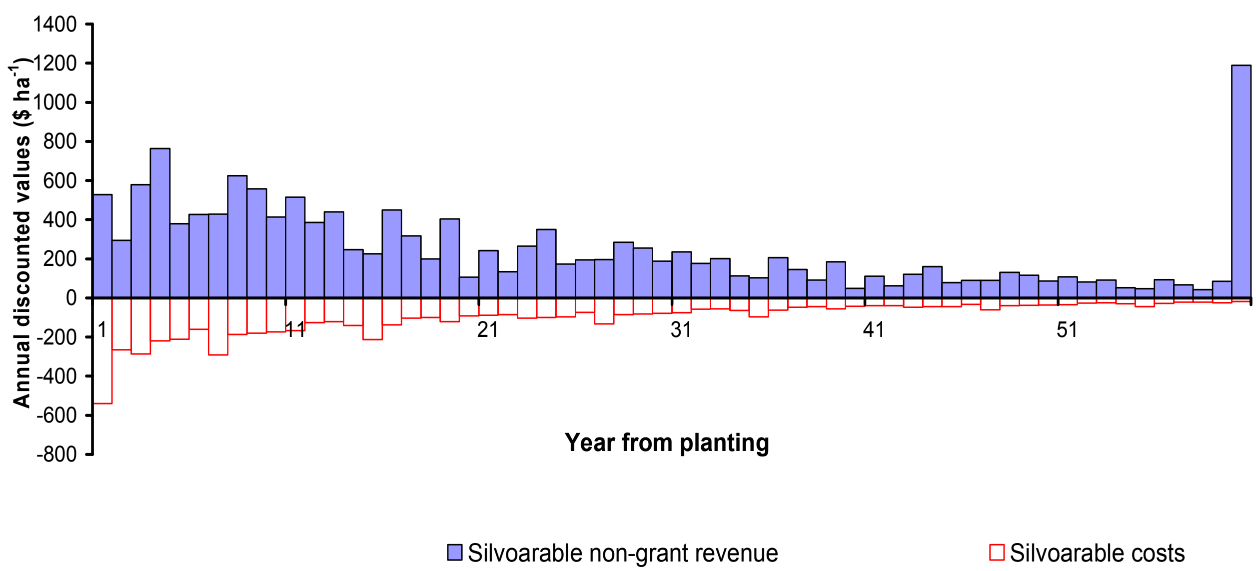

**Graph 4.10A Pattern of TBI hybrid poplar system revenue and costs**



## Graph 4.11A Pattern of TBI Norway spruce System revenue and costs




## Graph 4.12A Pattern of TBI red oak system revenue and costs



**Graph 4.12A Labour pattern of mono-cropping and TBI systems**