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COMPETE

Competence Platform on Energy Crop and Agroforestry Systems for Arid and Semi-arid Ecosystems - Africa

Responsible Partner:
Centro Nacional de Referência em Biomassa – CENBIO, Av. Prof. Luciano Gualberto, 1.289, Cidade Universitária, São Paulo, Brazil

Project Co-ordinator:
WIP, Sylvensteinstrasse 2, 81369 Munich, Germany

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Cost-benefit analysis of new energy crop and agroforestry systems in Brazil

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1. Introduction

The integration of forestry with agricultural crops and with livestock offers an alternative to address chronic problems of environment degradation and reduces the risk of production loss. Another advantage of agroforestry systems is that, most times, trees may serve as an income source, since the wood and fruits can be exploited and sold. The combination of these factors suits agroforestry in the sustainable model.

The first part of this document describes firstly some traditional uses and classification of forestry and energy crops. Secondly, this paper presents the agroforestry systems and practices, and informs about the process of economic evaluation of projects, and analyze the results of agroforestry projects carried out in Brazil.

The sugar cane sector in Brazil produces and processes more than 300 million metric tons of sugar cane, the main Brazilian energy crop. The sugar cane bagasse provides all energy required to process the sugarcane and several mills are already generating surplus power and selling it to the grid. Thus, the second part of this paper briefly presents the sugarcane production and the amount of residue from this industry, taking into account the use of the bagasse and the trash. The document ends with the total cost of the trash recovery, focused on the enzymatic hydrolysis technology.

2. Agroforestry Systems and Practices

The modeling of an agroforestry system demands a great amount of interdisciplinary knowledge regarding botanic, agriculture soils, microfauna and microflora of land, ecophysiological function of organisms that constitute the various strata, of ecological succession and phytosanitary conditions. All this must be summed up to a previous knowledge in agronomy and forestry, since agroforestry is based on these two branches. Its goals are: food production, wood and non-wood (furniture and medicine) forest production, organic matter production, improvement of landscape, increment of genetic diversity, environment conservation, provision of hedges, windbreaks and shadow for livestock.

The same way that an agroforestry system may bring more profit than a conventional agriculture system, it may also bring more costs, since there are at least two components that must be professionally managed and maintained in an agroforestry system: the agriculture component, which includes herbaceous plants and shrubs, and the forest component, which can be represented by trees, palm trees or other forest perennial or woody plants.

2.1 Definition and concepts of agroforestry

Agroforestry systems may be defined as a combination of growing forest essences with annual agriculture crops (RODIGHERI; GRAÇA, 1996) or with livestock, in a simultaneous way (ALVIM et al, 2005).

Agroforestry or agrossilviculture is a rational and efficient system of land use. In this system, trees are grown in consortium with agriculture crops and/or livestock, which offers, among other advantages, the recuperation of soil fertility, provision of green fertilizer and weeds control. It is a type of soil management in which the crops are grown in the streets between the rows, together with trees or shrubs, usually vegetables shrubs, and the woody species are periodically pruned during cropping season.

There are three attributes which, theoretically, all agroforestry systems possess (NAIR, 1993). These are:

a. Productivity: Most, if not all, agroforestry systems aim to maintain or increase production (of preferred commodities) as well as productivity (of the land). Agroforestry can improve productivity in many different ways. These include: increased output of tree products, improved yield of associated crops, reduction of cropping system inputs, and increased labor efficiency.

b. Sustainabitity: By conserving the production potential of the resource base, mainly through the beneficial effects of woody perennials on soils, agroforestry can achieve and indefinitely maintain conservation and fertility goals.

c. Adoptability: The word "adopt" here means "accept," and it may be distinguished from another commonly-used word adapt, which implies "modify" or "change." The fact that agroforestry is a relatively new word for an old set of practices means that, in some cases, agroforestry has already been accepted by the farming community. However, the implication here is that improved or new agroforestry technologies that are introduced into new areas should also conform to local farming practices.

These attributes are so characteristic of all agroforestry systems that they form the basis for evaluation of various agroforestry systems.

2.2 Classification of agroforestry systems

One of the main characteristics of agroforestry systems is the use of the tree component in cropping systems. Thus, this component is used as a referential for systems classification.

The use of trees in the cropping system enables to increase monocultures systems diversity, control of microclimatic conditions for other components and increase or conserving physical, chemical and biological properties of soil. The classification of agroforestry system follows the criteria below:

2.2.1 Structural Classification

Refers to the composition, space arrangement of tree component, vertical stratification and temporal arrangement of components. In agroforestry systems, there are three groups of components to be managed: the forest, which can be represented by the trees, palm trees or other perennial woody plants, of forest origin; the cropping, with herbaceous or shrubby plants, including forage plants; and livestock, with small or big animals.

The spatial arrangement includes the crops density and the distribution of plants in the area. The trees may be planted in dense stands, as in the taungya method, and in the “home garden”, or open, as in the use of shadow trees for pasture.

The trees may be distributed in the area in an integrated way with the other components, as in the natural regeneration conduction systems of the forest species (“bracatinga” traditional Brazilian system, in the south of the country), or in zones, which can be narrow (micro-zoning), as in the case of “alley cropping”, or the cropping among tree rows, and of the taungya method, or wide (macro-zoning), in which trees may be planted in rows, bands or blocks away from each other, as in hedges, windbreaks, protein banks, and in tree growing in terraces for soil conservation.

2.2.2 Classification based on function of systems

This classification refers to the main function or role of the tree component in the system, which may be of goods production (timber, fruit, seeds, fodder, fuelwood, etc.) or of services (windbreaks, hedges, soil conservation) to the other species or to the system as a whole.

2.2.3 Classification based on socioeconomic criteria

It refers to the level of inputs use in the management, intensity or scale of management and to commercial goals. The agroforestry systems may attend to different production scales, reaching commercial, intermediary or subsistence levels, and may be used in different technological and management levels, as high, medium or low.

2.2.4 Ecological classification

It concerns the environment and ecological sustainability conditions of the systems, since certain types of system may be more appropriate to a set of ecological conditions.

2.2.5 Agroforestry systems and practices

There are different agroforestry systems and practices (AMBIENTE BRASIL, 2009). They are organized in three different categories according to the managed components:

Agrisilvicultural: agriculture and tree components

Silvopastoral: livestock and tree components

Agrosilvopastoral: tree, agriculture and livestock components

Agrisilvicultural

System	Description	Components	Function
Improved fallow	Growing of trees in the fallow phase	Trees: pioneers and vegetables Agriculture: common crops	Products: wood, firewood, fruits Protection: soil enhancement
Taungya / Milpa	Growing of common crops in the first years of trees stands	Tree: commercial species Agriculture: common crops	Products: wood Protection: soil conservation
Alley Cropping	Growing crops between rows or ranges of trees of trees	Tree: pioneers and vegetables Agriculture: common crops	Products: firewood Protection: soil conservation
Multiple use trees in cropping areas	Trees planted, spread randomly or not (terraces, rows or edges)	Tree: multiple use or fruit production Agriculture: common crops	Products: several tree products Protection: shadow, fixation of soil conservation
Tree cultivation with farming	Multi-stratified planting with trees for shadow for horticulture or arboreal crops	Tree: cultivated species and for shadow Agriculture: common crops and tolerant to shadow	Products: wood, fruits, etc. Protection: soil enhancement, shadow and conservation
Home garden	Multi-stratified combination of trees and crops around the house	Tree: multiple use and fruit production Agriculture: common crops	Products: several tree products Protection: soil conservation
Trees for soil enhancement or conservation	Trees grown in terraces and bands	Tree: multiple use Agriculture: common crops	Products: several tree products Protection: soil conservation.
Hedges and windbreaks	Trees planted around the crops	Tree: trees of different heights Agriculture: common crops	Products: diverse tree products Protection: fences, windbreak

Silvopastoral

System	Description	Components	Function
Trees in natural or planted pastures	Natural or artificial regeneration of trees in natural or artificial pastures	Tree: multiple use and forage crops Agriculture: grass and horticulture Livestock: cattle, pig and sheep	Products: tree products, forage and animal products Protection: shadow for animals
Pasture in reforested areas	Pasture in commercial forestry stands	Tree: commercial species Agriculture: grass and vegetable Livestock: cattle, pig and sheep	Products: wood, forage and animals Protection: shadow
Protein Bank	Growing trees in areas of protein production for direct pasture or cutting	Tree: vegetable, forages Agriculture: grass Livestock: cattle, goat and sheep	Products: forage
Pasture in areas of tree crops	Areas of tree crops under pasture	Tree: tree crops Agriculture: grass and vegetable Livestock: cattle, pig and sheep	Products: several Protection: shadow
Trees for forage production for fish	Growing of trees in slopes, tanks, dams and reservoirs for fish forage	Tree: tree forages for fish Livestock: fish	Products: forage Protection: slope stabilization

Agrosilvopastoral

System	Description	Components	Function
Home garden with animals	Multi-stratified combination of trees, agriculture crops and animals around the house	Tree: multiple use and fruit production Agriculture: common Livestock: small animals	Products: several Protection: soil conservation
Agrosilvopastoris systems in areas of forestry growing	Taungya method followed by pasture, during the phase of forest maintenance	Tree: commercial Agriculture: Grass, vegetable and forages Livestock: cattle, pig and sheep	Products: several Protection: shadow

3. Economic Evaluation of Agroforestry Systems

Economic considerations are among the most important factors that will determine the ultimate value and feasibility of agroforestry to the land user. However, the great majority of agroforestry research to date has concentrated on the biological and physical factors that affect productivity. Inadequate attention has been paid to the economic value of directly quantifiable agroforestry outputs such as fodder, green manure, fuelwood, and timber as well as significant, harder-to-quantify environmental effects including enhanced soil fertility and watershed protection. To summarize, there is a serious lack of reliable information based on actual farm conditions of the economic benefits and costs that are claimed inherent to many agroforestry combinations (NAIR, 1993).

Although the importance of economic evaluation, for farmers, which influences their adoption decisions, is more complicated. To the extent that farmers do seek to maximize returns to their productive resources, they are concerned not only — or even primarily — with returns to capital. The central resource to be optimized (that perceived to be most scarce or most valuable) may be land, labor, a particular piece of capital equipment, cash, or managerial input.

3.1 General principles of economic analysis

The proposed agroforestry system must be assessed in terms of how well its returns to the scarce factor compare with alternative production or consumption strategies. If labor is the scarce factor and satisfying fuel needs is the objective, an agroforestry technology for intercropping fuelwood trees in crops might be compared, in terms of returns to family labor, to fuelwood gathering or to production of a woodlot. If land is the scarce factor and food production is the objective, an alley-cropping system to improve crop yields should be assessed, in terms of returns to land, against cropping without trees or investment of an equivalent level of new resources in chemical fertilizer or improved crop management.

Initial farm-level analysis should explore the role and importance of agroforestry in farm livelihood strategies. A qualitative inventory can be made of how farmers meet their domestic needs for food, construction materials, fuel, cash, savings, raw materials for local processing, and emergency resources. This inventory should emphasize areas of particular scarcity to which trees products or services might contribute. It should be linked with an assessment of household resource availability, including different types of land, existing woody resources, labor and cash resources, and current patterns of resource use over time and space (CURRENT; LUTZ; SCHERR, 1995).

3.2 Financial and economic analyses

At the outset of this presentation on economic evaluation methodologies, it is important to clarify some of the significant distinctions between financial and economic analyses. To summarize, financial analysis examines the feasibility of an undertaking from the private or individual's point of view while economic analysis concentrates on the desirability of an activity from the perspective of a society as a whole. The distinction is important; for example, a proposed project which yields an expected profit for individual farmers might, because of heavy subsidization, prove of negative value to the regional or national economy.

More specifically, a financial profitability assessment of an agricultural enterprise, which used subsidized fertilizer, would include only in its cost calculations, the fertilizer price actually paid by the farmer. An economic analysis, by contrast, would also include the subsidy expense incurred by the government in calculating the venture's total fertilizer cost from the view of society. In addition, in situations where market-generated prices do not reflect an input's or output's true societal value because of tariffs, price controls, or other influences, economic analyses can utilize shadow prices for a more accurate estimation of true costs and benefits. These shadow prices can be particularly valuable in adjusting for land and labor price distortions or to value nonmarketed environmental effects.

3.3 Project analysis

The basic questions to be answered in a study of the farm-level economics of agroforestry systems are:

- What are the actual costs and benefits to farmers of this agroforestry system?
- Under what conditions, and for which farmers, will this agroforestry practice meet important household needs and be financially profitable relative to the available alternatives for meeting those needs?
- What incentives (to reduce costs, increase benefits, reduce risks, and or increase access to limiting resources) would most effectively encourage farmers to increase their use of this agroforestry practice?

There are five key elements of farm-level agroforestry economics and management that need to be evaluated: (a) the role of trees in the household livelihood strategy; (b) management characteristics of agroforestry systems; (c) rates of economic return relative to the farmer's alternatives, for farmers with access to different resource mixes; (d) sensitivity of returns to variation in key economic values; and (e) environmental arid off-site impacts (CURRENT; LUTZ; SCHERR, 1995).

3.3.1 "With" and "without" evaluations

A long-term "with and without implementation" analytical approach is particularly appropriate for economic evaluations of agroforestry systems for reasons suggested in Figure 3.1. First, agroforestry is concerned with the long-term sustainability of production (HOEKSTRA, 1990). An important benefit of its introduction may be the prevention in output decline over time inherent to the existing agricultural system. A "with" and "without" analysis will not only examine the costs and benefits of introducing agroforestry to a particular setting but can also highlight the opportunity cost of continuing with existent agricultural land-use systems. Likewise, the "with" and "without" approach is very useful to highlight the positive environmental effects of agroforestry. Second, given the initial delay in benefit realization that is characteristic of most agroforestry systems, a short-term agroforestry projection will usually underestimate its total benefits in relation to other agricultural technologies (NAIR, 1993).

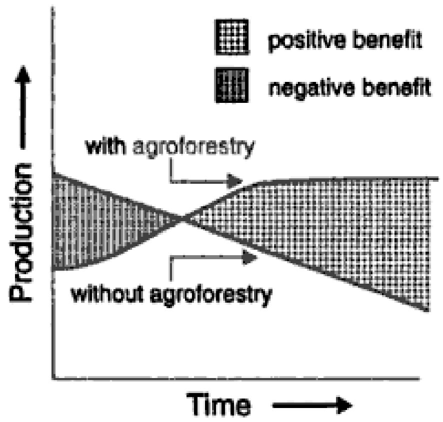

Figure 3.1 A generalized presentation of benefits with and without agroforestry

3.3.2 Discounting and the discount rate

Not all the costs and benefits of an agricultural project occur at any particular time; rather, they occur throughout its lifespan. Such costs and benefits can be compared directly with each other when incurred in the same year but they cannot be compared outright with those arising in other years. By applying an adjusting discount rate, however, it becomes theoretically possible to directly compare sums of money realized at different periods in time. In addition, it is then conceivable to compare the total long-term worth of alternative enterprises as measured from the time of proposed commencement (NAIR, 1993).

Several arguments are advanced in support of discounting. First, using no discount rate would imply that one dollar today will retain the same intrinsic value five, ten, or twenty years hence, a dubious assumption given historical global trends in inflation. Furthermore, that same dollar could be invested at a positive real interest rate; there is an opportunity cost in terms of the return to capital foregone in alternative investment. Second, if one's financial status changes over the ensuing time period between monetary comparisons, the marginal utility of that dollar to that individual's well-being will diminish or rise: a dollar is worth more to a poor person than to a rich one. Third, most people are prone to spend rather than save money; the value of a unit of money to be received in the future is less to them than if it were received in the present. In economic terms, they are said to have a positive rate of time preference. A positive discount rate reflects this preference for present over future consumption.

In actual computation, discounting is the reverse of interest compounding, Gregory (1987) presents the following illustrative example; at an interest rate of 10%, $1,000 invested today will grow to $1,610 at the end of a five-year period. At a 10% discount rate, therefore, the present value of $1,610 received five years from now is $1000. This calculation of the present value of a future sum of money can be mathematically represented as follows:

$$\text{Present Value} = X_t / (1 + i)^t$$

where:

X_t = money in the future is the amount of money in year *t*; and

i = discount rate.

Two somewhat related qualifications are important to remember when discounting is utilized in economic evaluations. First, comparisons between alternatives are only viable when the same discount rate has been used in their calculation. Second, the specific choice of a discount rate can lead to an unintentional or intentional manipulation of the results of an analysis.

The utilization of higher discount rates will favor those proposals that generate substantial benefits in early years with the majority of costs incurred later such as capital intensive agriculture on fragile tropical soils. Likewise, as the discount rate increases, the weight attached to long-term effects will diminish. Long-term environmental costs and benefits, important considerations in agroforestry-related decision-making, can thus be particularly prone to underestimation when higher discount rates are utilized.

In actual practice, private concerns usually base discount rate selection primarily on the market-determined rate or interest. For assessing public projects, particularly during times of very high market interest rates, a social discount rate established by national planning and financing authorities may be more appropriate and is often specified for utilization in government-financed project evaluations (GREGORY, 1987). Given that society has a longer-term perspective of development than its individual members, this rate would hopefully reflect not only market rates of interest but also the desire for more equitable social development.

3.3.3 Evaluation criteria

Policy and decision-makers in international development need some specific means to rank investment alternatives according to a stated preference. The economic tool most often used to evaluate investments that provide services over periods of more than a few years is Benefit/Cost Analysis (BCA). The basic function of BCA, first developed in the 1930s, is to compare the long-term benefits of proposed projects with long-term costs. Its most common criteria are the Net Present Value (NPV), the Internal Rate of Return (IRR) and the Benefit-Cost (BC) Ratio.

The NPV and the IRR are frequently utilized in the private sector as well as by governments, the World Bank, and the Food and Agricultural Organization of the United Nations (GREGORY, 1987). The usual procedure of these organizations is to determine the NPV of a venture under a range of interest rates and then to calculate the IRR. Public agencies, on the other hand, often use the benefit-cost ratio for economic assessments (NAIR, 1993).

Net present value

To calculate the NPV, all the annual net costs or benefits over the prescribed lifespan of a project or undertaking 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. Sang (1988) presents the following formula for calculating the NPV:

$$NPV = \Sigma (B_t – Ct) / (1+r)^t$$

Where:

B = benefits in year *t*,

C = costs in year t; and

r = discount rate.

As a screen for economic viability, any enterprise that possesses a net present value greater than zero is technically acceptable: long-term benefits exceed long-term costs. A caution regarding this criterion is that the NPV figure by itself provides little information about the scale of project capital requirements. Even though one proposed project may have a larger net present value than an alternative, it may require a much larger capital expenditure.

Benefit/cost ratio

In the calculation of the BC ratio, all the significant effects of a proposed project are first identified and quantified. These effects are subsequently categorized as either benefits or costs, valued by year, and then discounted at the preselected rate. The total discounted project benefits are finally summed and divided by the sum of the discounted costs to obtain a BC ratio:

$$\text{Benefit/Cost Ratio} = \frac{\text{Total Discounted Benfits}}{\text{Total Discounted Costs}}$$

If the ratio is greater than one, the project is estimated to provide a positive net return. Theoretically, the greater the ratio of benefits to costs, the more attractive the undertaking.

A particular advantage of the BC ratio is that it can be utilized for comparing projects of different sizes. There are also corresponding disadvantages. As with the NPV, the calculation of the BC ratio requires the controversial preselection of a discount rate. In addition, the criterion is very sensitive to the original definition and valuation of project benefits and costs. This is particularly so when there are associated costs outside the actual project boundary for such essentials as the development of marketing systems or road infrastructure construction.

The internal rate of return

The internal rate of return (IRR) theoretically calculates the maximum rate of interest that a project can repay on loans while still recovering all investment and operating costs. Put in other words, the IRR determines the earning power of the money invested in a particular venture, in actual calculation; it is that discount rate which will make the discounted total benefits and costs of an enterprise equal. Randall (1987) mathematically defines the IRR as:

$$\Sigma\ (B_t - C_t) / (1 + p)^t = 0,$$

where:

B = benefits accruing in year t,

C = costs accruing in year t, and

p = internal rate of return.

Projects with an IRR that is in excess of the opportunity cost of capital are technically viable: at an interest rate of 8%, an undertaking which earned a 10% IRR would be acceptable while another with a 5% IRR would not be. The general rule for selecting among alternative projects is to select those with the highest IRR.

Although useful to estimate the interest on loans that a project can cover, the calculation of the IRR is somewhat complicated as compared to those of NPV and BC (GITTINGER, 1982).

3.3.4 Farm budgets

The basic unit or model in agricultural economic analysis is most often the individual farm budget; it provides a micro-view of the costs and returns of a particular agricultural enterprise in a specific setting. Two approaches are common (DAVIS, 1989). In the first, several representative project farms are selected and modeled. The aggregate impact is then determined by multiplying the findings of the individual models by the number of similar farms and summing the results. This method can be time-consuming if a large number of different types of farms are present within a project's boundaries.

In the second method, a larger, single model is constructed to simultaneously simulate all project farms regardless of type or scale of operation. Once the net benefits and costs of the model farm are determined, they are multiplied by the total number of farms to appraise overall economic feasibility of the project. While this approach has the advantage of requiring the design of only one model, it can be very complex and unwieldy in the case of a large, heterogeneous project.

3.3.5 Quantification and valuation

The precision of any economic evaluation is dependent upon the accuracy of the data utilized. Thus, from an economic perspective, the task of designing viable agroforestry interventions depends on successfully estimating the relevant costs and returns in the proposed setting (ARNOLD, 1983), A simple production function describing the relationship between farm inputs and outputs can help identify the principal elements requiring examination:

$$Y = g(K, L, R_0)$$

where:

Y = Farm output or income,

g = the production technology employed.

K = capital goods,

L = labor (physical and mental), and

R_0 = natural resources employed (land).

<u>The valuation of costs</u>

As stated by the production function, the inputs used in agricultural production come in three basic forms: capital goods, labor and land.

Capital goods

Capital goods are all the manufactured or purchased items utilized to produce other goods and services. These goods can be quantified by weight, volume or number and are most commonly valued at their market price to the final user. Examples of capital goods: seedlings, crop seeds, herbicides, fertilizer, livestock feed, fencing, machinery.

In subsistence and small-farm agriculture, as contrasted to large commercial farming systems, capital goods will usually be scarce relative to other production factors, particularly labor. Nevertheless, even relatively simple agroforestry projects can entail a significant monetary outlay for capital goods in the first years following implementation. If expenditures for seedlings, fertilizer, fencing materials, or other capital inputs in a project will be substantial, this must be recognized before commencement in order to avoid early farm or project failure, participant farmers may require some degree of financial support or credit until adequate income is generated (NAIR, 1993).

Labor

Labor in economic analysis usually refers to the physical and mental contributions of men and women to the production of output. Labor is usually expressed in either workday or hours and is sometimes further categorized by the age or gender of its contributor. Hired labor is most often valued at the prevalent market wage, while the family labor is cost at its value in the next best enterprise – the opportunity cost.

Given limited land and capital resources, labor is typically the most important input used on small or subsistence farms. In fact, Stevens and Jabara (1988) have estimated that labor represents 80 to 85% of the total value of all farm resources utilized in traditional agricultural systems.

Land

Land in economic terms refers to the natural resources (such as soil, sunlight, and rainfall), which contribute to agricultural production. In practice, only those resources for which there is a recognized monetary value, usually land and sometimes water, are typically included in financial evaluations. In an economic analysis, however, it is appropriate to value the natural resource components of a particular enterprise in terms of what their contribution would have been in alternative ventures.

Land quantification occurs most often in terms of physical area and may be further categorized by tenure status, productive capacity, or utilization. Its valuation is straightforward, given the presence of functioning property markets.

Valuation will obviously be more difficult where land prices are not established in a market setting. In such cases, opportunity costs may be utilized to approximate value; if land resources are abundant, the opportunity cost in terms of alternative enterprises foregone can be close to zero. In densely populated areas the allocation of land to agroforestry will probably require the exclusion of other activities; the fitting valuation in these circumstances may be the monetary contribution of land to output under a known agricultural undertaking. Where land is rented the appropriate cost for land will be the rent actually paid.

The valuation of benefits

Increased production is the most common goal of agricultural development. Likewise, the clearest benefit of agroforestry introduction is the enhanced value of farm yield through either sustained or increased output or from a reduction in required inputs. This advantage can be economically quantified by converting the physical output to monetary value (HOEKSTRA, 1990).

Direct production

Valuation is simple when agroforestry products such as food crops, fuelwood, timber, or fruit are marketed through commercial channels. For these items, the appropriate analytical market price will be that occurring at the point of first sale or that price in effect when the product crosses the farm boundary (GITTINGER, 1982).

Valuation will be more difficult in circumstances where most or all of production is either bartered or consumed on-farm. The failure to include this on-farm consumption can grossly underestimate the actual returns to agroforestry investments relative to market-oriented systems (PRINSLEY, 1990). Two accepted methods for pricing such goods are the value of labor employed in their production or the cost that their consumers would be willing to pay for marketed substitutes.

The valuation of the products of the agroforestry perennial can be particularly challenging. The pricing of timber and poles is largely dependent on market utilization: timber usually being sold per cubic meter and poles by length (HOEKSTRA, 1990). The valuation of foliage products is usually more straightforward. Fodder is normally sold by green or dry weight and in the case of on-farm consumption; beneficial effects will be reflected in increased livestock production. Likewise, the value of internally-consumed green manure and leaf litter will be included in the enhanced worth of the crop harvest.

Environmental benefits

Any economic assessment of agroforestry enterprises should carefully consider the important indirect effects, such as erosion control and watershed maintenance, on the economic and social welfare of people both inside and outside the project boundary. This inclusion is critical; from society's viewpoint these environmental benefits can be key factors in the decision to promote agroforestry (MERCER, 1992). Unfortunately, these effects are often neither obvious nor easy to quantify, especially in the short-term.

Markets can provide considerable information about the demand for similar marketed goods and their valuation.

In the case of soil conservation, benefits can be ascertained through the market value of the sustained or increased crop production made possible by an agroforestry intervention.

3.3.6 Risk evaluation

The uncertainty inherent lo the adoption of any new agricultural technology, whether because of the biological lag between planting and harvesting, adverse weather, or the unpredictable nature of markets, is of critical importance to farmers. In addition, elements of uncertainly are intrinsic to the evaluation process itself (SANG, 1988):

1. The identification and measurement of most non-physical costs and benefits are dependent upon value judgments;

2. The qualitative assessments of the indirect effects and externalities of a project are essentially subjective; and

3. Relevant data and information is generally limited and inadequate, particularly in developing countries.

For these reasons, it is unrealistic to base economic evaluations on the assumptions of near-perfect knowledge and complete price stability (GITTINGER, 1982). Therefore, provisions need to be made for beneficial or, perhaps more importantly, adverse fluctuations in climate and market prices that could seriously affect farm income. This is particularly pertinent to agroforestry where the presence of a perennial component requires a long-term outlook.

Sensitivity analysis

As mentioned, substantial uncertainties will always linger about the future price of inputs, the selection of the discount rate, the expected quantity of harvests and so forth. Sensitivity analysis can be utilized in these situations to determine how an economic evaluation will be affected if crucial variables and assumptions are changed. In this analytical methodology, the effects of altered circumstances are assessed by varying the quantity or price of inputs and outputs or other important variables in an evaluation by a fixed percentage or amount and then recalculating. The results can then be presented as a range of possible outcomes and associated probabilities; the usual practice is to place the most probable estimate in the middle of the range.

Risk-benefit analysts

The underlying concept of risk-benefit analysis is that any development or change from the *status quo* will involve some degree of risk; an inherent trade-off between risk and increased productivity is recognized (RANDALL, 1987). Risk-benefit analysis presents the potential economic and agronomic benefits of an undertaking together with quantitative estimates of the risks involved in implementation.

3.4 Methodological challenges for economic analysis of agroforestry

3.4.1 Difficulties in Collecting Input and Output Data

Economic analysts of farm agroforestry pose greater methodological challenges than is often recognized. While basic theories of financial and economic analysis for agricultural systems apply equally to agroforestry, the latter can present more serious problems for data collection, analysis and interpretation.

There is often high variability in the agroforestry systems (components, site conditions, age of perennial components, spacing, management, and outputs) between farms, fields, or even within fields (SCHERR; ROGER; ODUOL, 1990). This may be further complicated by year-to-year variability in management and even in the type of harvested outputs. Although many farmers die this flexibility as a major positive attribute of agroforestry systems, it creates serious problems in sampling plots and farms for economic analysis.

Continuous physical changes in the tree component may make it essential to collect input and output data over many years, an expensive proposition. Where one cannot collect data over the entire cycle (for example, where there is a timber component), some costs and benefits have to be modeled based on locally derived estimates. Farmer recall may have to be used, although there are limitations to using recall data, particularly for nonmarketed or intermittently harvested outputs and nonpurchased inputs.

It is often difficult to attribute specific costs and benefits to particular components in joint production systems. For assessing the impacts of agroforestry in a particular field or farm, all costs and benefits can simply be attributed to the joint system, except when it is desirable to understand how these effects would vary with changes in system components or management.

The results of economic analysis can differ sharply depending upon the defined boundaries of the system. To interpret the benefits of agroforestry from a whole farm perspective, a complete farm income analysis, is required. Yet this type of analysis is usually omitted in partial budgeting exercises, where only marginal changes in the costs and benefits of adopting a new practice are evaluated.

Where agroforestry practices are a small part of whole farm production, labor and other inputs may be drawn from seasonal reserves, involve few cash inputs, or be undertaken during periods with low opportunity costs for labor. Returns may be very high at this scale, but the structure of costs and benefits might change substantially if the enterprise were undertaken at a larger scale.

An adequate technical database for agroforestry systems would require a range of information on specific tree-crop combinations, inputs, outputs, and tree-crop interactions and productivity across a range of sites and management conditions. Unfortunately, collecting such data is significantly more costly than for annual crop monocultures or single-purpose perennial orchards or grasslands, is there are more variables for which data must be collected over at least one cycle (and preferably more) of the longest-living component. Environmental effects and externalities are difficult to quantify (CURRENT; LUTZ; SCHERR, 1995).

3.4.2 Difficulties in Valuation and Analysis

In the economics literature, most analyses of the adoption of agricultural and livestock technologies involve marginal changes (such as varietal change or use of a new input) to existing systems. Priority outputs and the role of the product in the household livelihood are clear. In agroforestry, the tree components are often new and may be valued for a range of purposes: products, farm inputs, farm services, cash income, savings or environmental benefits.

A more subtle, but critical, difficulty for economic analysis is the choice of alternatives against which to compare agroforestry performance. These should represent the real opportunity costs of the resources used in agroforestry, from the farmers' perspective. Should returns from an intercropped system of annual crops and fuelwood trees be compared against returns from *(a)* annual crops alone? (b) annual crops plus an equivalent plot of fuelwood trees? or (c) annual crops plus purchased kerosene or the time value of labor for gathering? To answer the question requires field-level inquiry among farmers facing different alternatives.

Valuation of returns from agroforestry and its alternatives is complicated by poorly developed markets and nonmarketed outputs. Farmers also value agroforestry systems for their long-term benefits in land stabilization, perceived environmental effects (cooler or wetter microclimates), risk reduction, and aesthetics, or for their social roles in land demarcation. These present difficult problems of valuation and are commonly handled through qualitative analysis.

Analysis of agroforestry from a social or policy perspective raises a number of additional valuation problems, such as price distortions due to subsidies or tariff policy, and externalities by which some of the costs and benefits of agroforestry accrue to other individuals in the community or the larger society.

The discounting methods used to assess capital investment decisions are commonly applied to agroforestry, a practice borrowed from commercial forestry and conventional orchard analysis. While there is clearly a time cost to resources allocated to agroforestry, the appropriate use and rate of discounting for assessing agroforestry returns from the farmer's perspective is not always clear.

For plantation forests or orchards, which are typically planted at a single time and have no major income flows for many years, the capital investment model is appropriate. With agroforestry, however, farmers typically plant a small part of the land in trees in any given year and begin harvesting some by-products (thinnings, fodder, and so forth) within two to three years, while the crop component may provide outputs within months. Whether or not the farmers themselves apply high implicit discount rates to certain components may depend on whether their primary objective for the plot is annual food or income (which would call for a high discount rate) or an alternative means of savings (which might face a lower implicit discount rate).

The appropriate use of discounting also depends on the role of cash in agroforestry investment. In many cases, agroforestry is attractive to farmers in part because of its low cash requirements and use of household labor during periods of low demand. For agroforestry enterprises whose system of production requires significant cash inputs or those where investment funds or working capital is borrowed, conventional discounting approaches would be used.

Finally, economic analysis of agroforestry often requires consideration of multi-objective, multi-output, and multi-year flows of costs and benefits (CURRENT; LUTZ; SCHERR, 1995).

4. Agroforestry efforts in Brazil

4.1 Agroforestry systems in Brazil

In Brazil there are 8.2 million of hectares of cultivated area with forestry species also used for farming and animal pasture, in agroforestry systems (IBGE, 2009). This area corresponds to 2.5% of the total area used in Brazil.

The main agroforestry systems used in Brazil go from the oldest and most simple ones to the newest and more elaborated. According to Oliveira; Schreiner (1987) they are:

"Taungya" systems

This system may be considered as a step in the transformation process of shifting cultivation into the agroforestry system. Still dominant in the humid tropics, shifting cultivation consists in logging a small stretch of forests, which is occupied two or three years by agriculture crops. Then this field is abandoned, allowing fast forest regeneration. A new stretch of the forest is then cut off and used the same way, by the farmer, and so on, until he gets to the first area.

In "taungya" systems, forest logging is made as in shifting cultivation. However, in the season of growing agriculture crops, the farmer also plants tree species which are most valuable in the region, promoting, thus, the enrichment of “capoeiras” (secondary arboreal savanna) (NAIR, 1983).

Multi-strata systems

May be considered as a variant of "taungya". Special importance is given to the enrichment of “capoeiras” (secondary arboreal savanna) formed after the logging for the growing of agricultural crops. There are different strata in vegetation, according to the reintroduced species and the use. The highest are occupied with trees for timber production, such as mahogany (*Swietenia macrophylla*), in the Amazon. In the intermediary strata, lower growth and diversified production trees are distributed, such as coffee, guarana and banana. The layer near the soil is mostly occupied with agricultural crops and pastures.

"Alley cropping"

This system has been indicated for less developed tropical regions, humid or not, by the International Institute of Tropical Agriculture, based in Ibadan, Nigeria. It is a system in which agricultural crops, food producers, are developed in rows bordered by hedges of trees or shrubs, mainly *leucena* or other vegetable shrubs. These hedges are cut when the crops are planted and are conserved during their development, so there is no competition and shadow for them. After the harvest, the hedges of the trees may grow freely, until they cover the land. They offer several benefits, such as: a) green manure for agricultural crops; b) mulch, which shadows the soil, avoiding the arrival of invaders; c) animal feeding, production of stakes and use as fuelwood; and; e d) the vegetable, they provide nitrogen for the companion crop (KANG et al. 1984).

Forestry crops for food production

Mainly in tropical regions, it is common the use of forest species monocultures, which produce goods other than wood, such as oil, rubber, coconut, cocoa, coffee, tea, as well as several fruits, these last also produced in temperate regions. The canopy of these species, considering the space for growing, enables a good entrance of light and enough area for intercropping or pastures, especially vetable, which may benefit the main crop (NAIR, 1983).

Planting of forest

In the last years, the forest activity has been established, in the tropics, as a profitable alternative for the use of land. The developed technology for the use of tropical woods in the industry of paper and cellulose, as well as demand for fulfilling growing needs for energy, have led to the installation of great projects and to the fast change in the trend of natural forest exploitation to planted forests. In the setting of this forests, there is good acceptance for the use of agroforestry systems; first, because in the tropics agriculture was, for a long time, the main and almost exclusive economic activity; and second because systems as “taungya” have served, in many places, as a way of deploying forest stands (NAIR, 1983).

Silvopastoral systems

In the agroforestry practices described so far, we revised almost exclusively associations of forest species with agriculture crops and smaller trees, which produce food or other goods. However, forest crops or stands may also be associated with pastures, establishing the so called silvopastoral systems. These are of great interest to humid zones and even for semi-arid areas. Follow the its main benefits: a) production of meat and milk without compromising new areas dedicated exclusively for this purpose; b) low production cost, with additional gain for the farmer; c) vegetation of understory remains low, reducing fire risks and production cost.

Introduction of trees in crops and pastures.

In the systems presented, the tree is the most important component, because, in addition to providing ecological benefits, it is the main income source to the farmer, until the end of rotation. However, the typical farmer may obtain benefit from planting trees in their lands. This occurs in the formation of rows for crop shadows, rows against erosion, windbreaks, hedges, shelter for cattle, etc. In this case the priorities are switched: crop and livestock are main activities, while trees contribute providing a more favorable environment, also functioning as secondary source of income, thanks to the timber which must be periodically cut off.

4.2 Agroforestry alternatives for 4 great Brazilian regions

4.2.1 Amazon

As alternative to shifting cultivation or to large predatory projects: "taungya" system; multi-strata systems, "alley cropping".

4.2.2 Semi-arid Northeast

Procedures that enable the optimal economic use of water: silvopastoral or agrosilvopastoral systems; "alley cropping".

4.2.3 Cerrado (Brazilian Savanna)

Alternatives to large predatory projects, also considering the economic use of water: silvopastoral or agrosilvopastoral systems with native trees or trees adapted to the region; "alley cropping" in small proprieties.

4.2.4 Southeast and South

To optimize the use of land, in view of its high level of human occupation: in the planting of forests, agrisilvicultural or silvopastoral or combined; projects of trees introduction in crops and pastures (OLIVEIRA; SCHREINER, 1987).

4.3 Description of Projects Selected for Analysis

Five projects were selected for analysis:

- Executive Planning Commission for Cultivation of Cacau (CEPLAC) Experimental Station in Ouro Preto D'Oeste, Rondônia. The area comprises 100 hectares, was planted in 1997 and was occupied by a two consortium. The first one: cacao *(Theobroma cacao* L .), coffee (*Coffea canephora* Pierre ex. Froenher) and teak *(Tectoma grandis* L.F.*)* and the other a consortium growing cacao, peach palm *(Bractis gasipacs* Kunth,) and *freijo* (Spanish elm, *Cordia alliodora* (Ruiz & Paz.) Oken).
- Experimental Field of Embrapa in Machadinho d`Oeste, Rondonia. The experiment started in 1987 and assessed three agroforestry systems and five monocrops. Agroforestry systems were: Brazilian nut – banana, chilli pepper and *cupuaçu* (SAFT1); *freijo* – banana – chilli pepper - *cupuaçu* (SAFT2) e Pupunha – banana – chilli-pepper - *cupuaçu* (SAFT3).
- Companhia Mineira de Metais in Vazante, Minas Gerais. Agroforestry systems used for analysis were implemented in 1993 and have as forest component hybrid clones of eucalyptus associated with rice, soybeans and grass pasture. Animal component is composed by oxen.
- Rural producers of the north of Paraná state. Agroforestry systems were assessed: coffee – grevillea, implemented in 1996.
- Assessment of the recuperation of degraded areas in the region of Tailândia, Pará. The implementation of two agroforestry systems were assessed. The first one formed by the

consortium of *cupuacu* (*Teobroma grandiflorum*), chilli-peper (*Piper nigrum*), passion fruit (*Passiflora edulis*) and mahogany (*Swietenia macrofila*) and the second formed by açaí-fruit (*Euterpe oleraceae*), cocoa (*Teobroma cacao*) and mahogany (*Swietenia macrofila*).

There was some variation among the studies, in terms of data collection methods and relative emphasis on different factors in analysis, due mainly to variation in the availability of technical and economic data. Data collection methods also varied by scale of the project.

4.3.1 Cost-benefit analysis of two models of agroforestry systems in Rondônia, Brazil
(AIRES, 2008)

The area is located in the municipality of Ouro Preto D'Oeste in the State of Rondônia, within the Executive Planning Commission for Cultivation of Cacau (CEPLAC) Experimental Station, comprises 100 hectares and was planted in 1997. At the lime of the study, the plantations had been in operation for six years. Half of the study area was occupied by a consortium cultivating cacao *(Theobroma cacao* L .), coffee (*Coffea canephora* Pierre ex. Froenher) and teak *(Tectoma grandis* L.F.*)* and the other half for a consortium growing cacao, peach palm *(Bractis gasipacs* Kunth,) and *freijo* (Spanish elm, *Cordia alliodora* (Ruiz & Paz.) Oken).

The productivity coefficients, planting and other costs, and market values of the yields were provided by the following state institutions: Comissão Executiva do Plano para Lavoura Cacaueira (CEPLAC); Associação de Assistência Técnica e Extensão Rural (EMATER/RO); and Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA).

Initial Investments

The costs include the initial investments made in the construction of buildings for drying cacao and coffee, as well as costs of plating and maintaining the two agroforestry systems during the two first years.

This study does not take into consideration the purchase value of the land, as the farmers already owned the property at when they formed the consortia. It should be noted, however, that the exclusion of the land acquisition costs directly influences the calculation of the internal rate of return (IRR) and the net present value (NPV) which are discussed below these would change, for instance, if the land values were to have increased after purchase. In addition, the construction of administrative buildings and fences was not taken into consideration. The decision to ignore these values is justified by the fact that the agroforestry consortia are, generally, established by farmers who already own rural properties but wish to change the production system, or that have land that does not possess the requisite conditions for growing rice, beans or corn.

The total value of the initial investments in the cacao-coffee-teak consortium was USD 82,800 and the total value of the initial investments in the cacao-peach palm-teak consortium was USD 83,960.

Total costs

The annual costs of the consortia included soil preparation, seedlings acquisition, planting, cultural treatments, harvest, supplies, maintenance and labor. The annual costs, in average, in the cacao-coffee-teak consortium is USD 48,552 per annum and USD 25,578 per annum in the cacao-peach palm-teak consortium.

Estimated revenue

The projection for the production volume in the cacao-coffee-teak consortium was made on the basis of a density of 975 cacao plants/ha. The production volume was estimated at 180 kg/ha of dry cacao for the first year of production, 360 kg/ha in the second year, 720 kg/ha in the third year and 1,050 kg/ha in the fourth through to the last year of production. The estimated price for the sale of cacao was USD 1.07/kg, based on the local market price in May 2005. The cultivation of coffee was projected on a basis of a density of 1,062 plants/ha and an estimated volume of production of 250 kg/ha in the first year of production, 376 kg/ha in the second year, and 500 kg/ha from the third throughout twelfth year, when the plants are pruned, productive cycle reinitiated and maintained until the twenty-fifth year. The estimated price of coffee was considered to be USD 0.58/kg.

The projection for the production of bananas was based on a density of 975 plants/ha. Production was established at 7,800 kg/ha in the first year, 15,000 kg/ha in the second year and 23,000 kg/ha in the third year, when the crop was eliminated from the consortium. The principal objective of the banana trees was to provide temporary shade for the cacao plants, so production was evaluated only up to the consortiums third year.

The teak component has a density of 117 plants/ha and a productive cycle of twenty five years. Given the spacing used by the consortium for this component, thinning is unnecessary. Consequently all production occurs at the end of the twenty-five year cycle, when it is estimated that each tree will yield 1.5 m^3 of timber. A mortality rate of 5 percent was applied. The price applied to the projection was 500 USD per m^3 of logs with bark.

For the cacao-peach palm-*freijo* consortium, the cacao component was estimated to have a density of 1,145 plants/ha, with a projected production of 210 kg/ha of dry cacao in the first year, 420 kg/ha in the second year, 840 kg/ha in the third year, and 1,240 kg/ha from the fourth year to the end of the 25-year cycle.

The estimated production of the peach palm was based on a density of 586 plants/ha, allowing for a projected production of 600 hearts of palm/ha in the first year of production, 840 hearts/ha in the second year and 1,240 hearts/ha from the third year to the end of the 25-year cycle. The price applied in the projection was USD 0.32 per heart of palm.

The banana component of this consortium was based on a density of 975 plants/ha: 7,800 kg/ha was projected for the first year of production, 15,000 kg/ha for the second year, and 23,000 for the third year after which the crop is eliminated from the consortium.

The tree component *freijo* was estimated to have a density of 88 plants/ha and provides a productive cycle of 25 years, with two commercial thinning projected in the tenth and fifteenth years, with final harvest taking place at the end of the 25-year cycle. The mortality rate was estimated at 10 percent. A cut of 30 percent was projected for the first year and of 20 percent for the second. The final harvest of the remaining was projected at end of the 25-year cycle.

Internal Rate of Return (IRR)

Using the costs and the revenues mentioned above, an IRR of 90.15 percent was established for the cacao-coffee-teak consortium. The calculation or the IRR took the following variables into account: total revenue, profits, opportunity cost, initial investment and life span of the project. The IRR expressed as a percentage demonstrates the advantages in pursuing (his activity when one observes the margin offered in relation to opportunity cost; in this case the rate of comparison being an indicator of the Brazilian Central Bank known as the SELIC rate, and equal to 18 percent in May 2003.

An IRR of 93.4 percent was calculated for the cacao-peach palm-*freijo* consortium. This value reflects the same variables as above: total revenues, profits, opportunity cost, initial investment and the lifespan of the project. The results display a slight advantage for the cacao-peach palm-*freijo* consortium over that or the cacao-coffee-teak project, although both demonstrated significant commercial viability.

Sensitivity analysis

The sensitivity of investment was analyzed, given the possibility of 10 and 20 percent reductions in revenues. In these scenarios, the cacao-coffee-teak project showed significant liquidity; for a projected 10 percent reduction in revenue, the IRR of this consortium dropped to 75.96 percent and for a 20 percent reduction the projected IRR was 60.59 percent. Both are still financially highly attractive.

The same possibilities of a reduction of 10 or 20 percent in revenues were applied to the cacao-palm heart-*freijo* consortium. In this case, the IRRs are 81.74 and 69.79 percent respectively. These are slightly higher than the indices of the cacao-coffee-teak consortium and they also highly attractive

Net Present Value (NPV)

An analysis of the NPV for the cacao-coffee-teak consortium, with a discount rate of 18 percent for opportunity cost, indicates a profit of USD 253,450 - a profit rate of 355 percent. For the cacao-peach palm-*freijo* consortium, the NPV profit discounted for opportunity costs was USD 333,600, representing a profit rate of 452 percent. In considering these results it is important to highlight that the consortia presented higher costs than normal monocultures would. However, they also presented higher profits per hectare than monocultures.

Profitability and payback

The operational profitability and investment recuperation (payback) period for the cacao-coffee-teak consortium suggest a recovery of investment within sixteen months, taking into consideration that the production cycle of banana trees cultivated in the beginning of the consortium (up to the third year) over and above recovering investment costs generates resources for the development of the project. The operational profit of the cacao-peach palm-*freijo* consortium suggests an investment recovery within seventeen months. A summary of the profitability for both consortia is presented in Table 4.1.

Table 4.1 - Profitability summary

	Consortium 01	**Consortium 02**
Indicator	Cacao-Coffee-Teak	Cacao – Peach Palm - Freijó
Initial Investments	82,800.00	83,960.00
Total Costs (USD)	1,213,975.78	650,521.44
Internal Rate of Return [%]	90.15	93.40
Net Present Value (USD)	253,450.00	333,600.00
Payback	16 months	17 months

4.3.2 Economic analysis of agroforestry systems in eastern Amazonia, Machadinho d'Oeste – RO, Brazil (BENTES-GAMA, 2005)

We used data from the experiment "Test of agroforestry systems for the region of Machadinho (RO)", set up in February 1987, in EMBRAPA Experimental Field, in the city of Machadinho d'Oeste, state of Rondônia. The experiment covered an area of 4.68 ha, with flat relief and soil classified as clayey oxisol (LOCATELLI, 1987). Experimental area was randomized blocks (eight treatments and four blocks), from which three were agroforestry systems and five where monocultures. Agroforestry systems were: SAFT1 Brazilian nut – banana – chilli pepper - cupuacu; SAFT2 freijo-banana-chilli-peper-cupuacu and SAFT3 pupunha-banana-chilli pepper-cupuacu[1].

The analysis followed the framework of split plots: the production systems were studied in the plots, and in the subplots, time was studied.

[1] castanha-do-brasil (*Bertholletia excelsa* H.B.K.), freijó (*Cordia alliodora* (Ruiz & Pav.) Oken), pupunha (*Bactris gasipaes Kunth*), cupuaçu (*Theobroma grandiflorum* (Willd. ex Spreng.) K. Schum.), banana (*Musa spp.*) e pimenta-do-reino (*Piper nigrum L.*).

Systems cost:

During the period of evaluation considered, total costs in theses systems were R$18,254.90 (SAFT1), R$19,008.50 (SAFT2) and R$20,333.80 (SAFT3), with almost the same distribution of components of total cost – area preparation, seedlings purchase, growing, cropping treatment/maintenance and harvest, in all agroforestry systems. Cost with cropping treatment was the highest, accounting for 40% more than total costs in this phase, followed by harvest costs, 30% higher of total costs. This result is explained by the increase in the use of machinery, equipments and labor force in these phases.

Participation of labor force in the agroforestry systems was higher in area preparation, corresponding to 50% of total costs. Second higher participation of labor force in all agroforestry system referred to maintenance (crops treatment). In SAFs T1 and T2, the third largest share of labor force occurred in growing phase, while in SAF T3 such participation concentrated in harvest phase.

Financial analysis

Using an annual discount rate of 10% in the considered period, we obtained positive NPV in all treatments, indicating that agroforestry systems tested are financially viable. Considering a balanced marked situation, SAFT1 had the best financial performance. SAFs T3 and T2 presented best return rates, respectively. In SAF T1, NPV corresponded to R$45,865.26 ha^{-1} year^{-1}, with a Equivalent Annual Value (EAV) of R$4,586.53 ha^{-1} year^{-1}, corresponding to a profit five to six times higher than those obtained with deducted revenues in SAFs T3 and T2, respectively. Diversification of revenues generated by SAF T1, with positive results already from first year, until last year, generated an elevated IRR value, indicating good annual return on capital invested on this project.

Reduced profit value in SAFT2 in relation to SAFT1 is due to the low diversification of production with this arrangement of species, which presented positive results only from the fifth year on, and generation of revenue concentrated on commercialization of cupuaçu fruits.

SAFT3 originated a revenue superior to SAFT2, however, reduced value of liquid income in relation to the one obtained in SAFT1 referred to the higher oscillation of pupunha production when associated to cupuaçu.

Investment risk analysis

SAFT1 was the agroforestry system with best financial performance, table 4.2. Percentile analysis indicated a 10% probability of Net Present Value (NPV*) to present minimum values of R$39,958.21 ha^{-1} year^{-1} and 90% probability of showing maximum values of R$52.972,78 ha^{-1} year^{-1}, with standard deviation of R$5,026.00. Comparing these results with the values obtained by financial methods used, table 4.2, it is possible to affirm that SAF T1 presents high economic viability and lowest investment risk, considering that market remains stable throughout the project.

Table 4.2 - Financial analysis of the agroforestry systems in Machadinho d'Oeste, RO

Evaluation Methods	Agroforestry Systems		
	T1	T2	T3
NPV [R$/ha/y]	35,883.65	5,334.85	6,584.64
IRR [%]	86	19	24
EAV [R$/ha/y]	4,586.53	681.88	841.63
NPV* [R$/ha/y]	45,865.26	6,818.82	8,416.27
B/C	4.08	1.44	1.51

Notes: T1: Brazilian nut – banana – chilli pepper - cupuacu; T2: freijo-banana-chilli-peper-cupuacu and T3: pupunha-banana-chilli pepper-cupuacu

4.3.3 Economic analysis of a *Eucalypt-based* agroforestry system in northwestern Minas Gerais, Brazil (DUBÈ et al, 2000)

Used data was collected in the crops of Companhia Mineira de Metais (CMM), set up in a farm in the city of Vazante, Minas Gerais. Climate in this region is humid subtropical, with maximum average temperature of 32 ºC and minimum of 16 °C. Average annual rainfall vary from 1.300 to 1.800 mm. Average altitude is 550 m and relief varies from flat to gently undulating. Soil is classified as dark red oxisol.

Agroforestry systems used for analysis has as forest component hybrid clones of eucalyptus (*Eucalyptus camaldulensis* Dehnh. x *Eucalyptus grandis* W. Hill ex Maiden, *Eucalyptus camaldulensis* Dehnh x *Eucalyptus urophyila* S.T. Blake e *Eucalyptus camaldulensis* Dehnh. x *Eucalyptus tereticornis* Sm.) well adapted to local climatic and soil conditions, productive and presenting superior quality wood for multiproducts purposes, which were developed by CMM, starting from 1993 (OLIVEIRA; MACEDO, 1996).

Agriculture components are rice (*Oriza sativa* L,) and soybeans (*Glycine Max* (L.) Merr.). Although crop productivity between rows of eucalyptus is low (23.33 bags of rice and 25 bags of soybeans per hectare), it allows reducing costs of trees planting and prepares the soil for introduction of improved forage. As forage component, it was used braquiaria (*Brachiaria brizantha* Stapf). Animal component is cattle (*Bos indicus*).

Agroforestry system began in 1993 and is still in phase of implementation, occupying at the moment only 758.5 ha of 20,000 ha involved in the company agriculture and livestock project. Of the forest area already integrated to the system, only 250 ha were formed with forages; the rest is being exploited in agriculture phase. The goal of the company was to form more than 300 ha of pasture to the end of 1998 and, from 1999, incorporate to the system 500 ha/year until reach 15,000 ha of consortium forest.

Economic Analysis of Agrosilvopastoral System

Economic indicators used for economic evaluation of agrosilvopastoral system were net present value (NPV), land expectation value (LEV), periodic benefit (cost)equivalent (PB(C)E), benefit/cost analysis (BCA) and the internal rate of return (IRR).

Thirty and seven percent of costs are associated to the implementation and maintenance of eucalyptus. At first, this value may seem high, but one should not forget that 52% of the updated value of revenue comes from the selling of wood products obtain throughout the rotation of 11 years.

We highlight then the contribution of costs of formation, maintenance and depreciation of livestock, with 21%. The participation of costs associated to rice and soybeans crops are still the lowest, with 12% and 14% from total, respectively.

In revenues, the share of rice and soybeans is almost the same percentage of total revenue, 10 and 11%, respectively. Agricultural crops are responsible for one fifth of the revenue obtained in the system. The share of revenue from live cattle (27%) slightly overcomes that of sawnwood (24%) or for energy (24%), representing more then one fourth of total sales, which points out to the importance of this component in the agroforestry system adopted by the company, as well as the contribution of wood, which reaches almost half (48%) of total revenue. However, a greater allocation of timber for sawnwood, due to its more attractive price, provides a better return.

For an interest rate of 10% per year and annual cost of land of R$ 50.00/ha, system has NPV of R$ 454.74/ha, LEV of R$ 700.13/ha and PB(C)E of R$ 70.01/ha.year positive, BCA superior to 1 (1.20) and IRR superior to 10% per year. (13.49%).

We consider the agroforestry project viable economically, since its NPV is positive, according to the discount rate of 10% per year, i.e., the discount value of future revenue is superior to the investment value; has positive LEV, i.e., the net present value of perpetual periodic rotation is positive; and its PB(C)E is positive, i.e., the simple annual value of profit is positive. In relation to C/B analysis, we can affirm that the system produces an average revenue of R$ 1.20 for each R$ 1.00 invested; as for IRR, the average investment growth rate is 13.49, i.e., is greater than the alternative return rate of capital, also called hurdle rate (REZENDE; OLIVEIRA, 1993).

Economic analysis of eucalyptus monoculture

Eucalyptus forests, previously grown in CMM and spaced in 3x3 m, completed a cycle of 21 years, before being totally renovated. Each rotation took seven years, the second and third coming from regrowth. Thus, there were deployment and maintenance operations in the first rotation, and only maintenance operations in the last two rotations.

The economic analysis that follows has the goal of evaluating the viability of this monoculture, using the same hybrid clones already mentioned, as if this was current practice in the company, and then compare it to the agroforestry system currently adopted by the company.

The criteria applied for the economic evaluation of eucalyptus monoculture were the same used for the agroforestry system. For an interest rate of 10% per year, the monoculture presents positive NPV, LEV and PB(C)E, C/B superior to 1 (1.24) and IRR greater than 10% per year. (12.56%).

Economic comparison between Agroforestry System and Monoculture

The economic evaluation that follows has the goal of comparing the viability of the current agroforestry system (agrosilvopastoral) with the eucalyptus monoculture, as if it was still practiced today in CMM, aiming to analyze if the change of the system was a correct choice for CMM.

The criteria used in the economic evaluation were: land expectation value (LEV), which allows the comparison of investment alternatives characterized by different cash flows and return periods; and PB(C)E, since equivalents return obtained by rotation correct the differences of horizons of planning. We did not use NPV, since both compared economic alternatives do not have the same duration, nor IRR, due to the difference of initial investment of each alternative.

It appears that LEV and PB(C)E of the agrosilvopastoral system (R$ 700.13/ha and R$ 70.01/ha.year, respectively) are 56.7% higher to eucalyptus monoculture (R$ 446.66/ha and R$ 44.67/ha.year, respectively). These values demonstrate the greater economic attraction of rotative agrosilvopastoral system in relation to eucalyptus monoculture, as operated before by CMM. Agroforestry system offers multiple revenues coming from sale of several agriculture and livestock products obtained throughout its cycle, which allows shooting down the costs associated with deployment and maintenance of eucalyptus forests.

4.3.4 Economic viability of coffee – grevillea agroforestry system in northern state of Paraná, Brazil (SANTOS et al, 2000)

The region which was object of this study represents approximately 30% of the Parana State. It is bordered to the north by the state of Sao Paulo and to the west by Mato Grosso do Sul state; it is located between the rivers Paranapanema, to the north; river Paraná, to the west; river Itararé and Chavantes Dam to the east. It is bordered by Capricorn Tropical to the south.

We tried to cover the highest number of properties by area size and year of coffee deployment, seeking the tree component in the initial phase (less than 5 years), median phase (between 5 to 15 years), and more advanced (more than 15 years). Thus, we expected to determine values which represented an average of rural proprieties that used agroforestry system in the region. In the chosen farms for the survey of grevillea costs, the time that coffee was been grown varied between two and twenty years.

The internal rate of return and net present value were used as evaluation method, as well as calculating and comparing the profitability of each system.

For the present analysis, the following parameters were used:

Growing year..1996
Reference date for present value..............01/03/1996
Size of production unit..1 ha
Coffee density......................................1000 plants/ha
Grevillea density..58 trees/ha
Discount rate...12% a.a.
Rotation period (production cycle)................17 years

Market prices of all production factors refer to March 1996 and the price of coffee beans package represent the average price of the last five years (92 to 96), R$ 45.00.

We considered that the product of grevillea trees would be lumber, which market price, in January 1997 was R$15.00/$m^3$ standing. Trees at the age of seventeen, due to the fast growth of the species and to the extent of spacing, have an average volume of 1 m^3 of wood. We did not consider the use of branches and fine grevillea wood for fuelwood.

Investments

The report on costs per activity showed that, from the total cost of R$ 22,388.54 spent per hectare with agroforestry system, administrative activities, crop treatment/maintenance and harvest were the most significant, representing 47.3%, 32.3% and 11.9%, respectively.

The report on costs per activity showed that fixed costs represented 61.2% of total, while variable costs represented 38.8%. We verify that there was not any significant change between percentages of fixed and variable costs presented to traditional coffee system and for agroforestry system. This occurred since introduction and maintenance costs of forest species in the system are insignificant when compared to the total investment in coffee crops.

The report on costs per activity showed that the greater costs at present value occurred in the year of the system implementation (year 0), decreasing over the years. The difference in the cost of activities at present value between the monoculture production of traditional coffee and agroforestry system is R$ 11.56. Considering that total cost of activities at present value is R$ 9.501.10, agroforestry system incorporation costs represent only 0.12% of total activities costs.

Human resources and acquisition of input participated with 36% and 33%, respectively, in the total cost of the system. The implementation, cultural treatment/maintenance and harvest of grevillea represent an additional of R$ 12.10 in human resources costs and R$ 3.10 in input costs.

Economic Analysis of Agroforestry System

In the analyzed system, grevillea usually occupied areas of properties borders or contour lines between the coffee rows, i.e, an idle marginal area that would not interfere in coffee culture revenue.

The sale of wood occurs in the end of the cycle of coffee production (seventeen years), when it may be carried out the renewal of coffee crops. Considering the price of standing wood for lumber in the region, grevillea may generate a revenue of R$ 870.00/ha, which represents 24.37% of last years' total revenue. This means an increase of 32.22% in last years' revenue in relation to the revenue of the production system of traditional monoculture coffee. We observe an increase of R$ 135.40 in NPV and 0.17% in IRR, which is a reasonable increase considering the insignificance of related costs. This increase allows the farmer to cover 43.8% of the implementation costs of agroforestry system

Comparing the revenue increase, at present value (R$ 870.00), in function of the use of agroforestry system, with the total cost only in year zero (R$ 1,189.47), we observe that the revenue generated by the agroforestry system represents 73% of costs in the same year, being thus very attractive for the rural producer.

The risks of the project decrease with the presence of trees (reduction of risks due to price fluctuation or total loss of production), and it can also be analyzed at lower discount rates, which would result in improved return rates (NPV, IRR, CRR – Cost Revenue Ratio). Therefore, it is necessary to better determine this new interest rate in function of the decrease in the risks related to the introduction of the tree species. According to Baggio et al. (1997), the presence of grevillea may generate the increase of coffee farmers' production due to the reduction of wind velocity and high temperatures in a density of up to 71 trees per hectare. However, these indirect benefits were not considered in this analysis. The profitability of the agroforestry system may be compared to traditional coffee crops, through the indicators in Table 4.3, in which NPV represents the net present value, IRR represents the internal rate of return to be compared with the market discount rate and CRR represents the cost-revenue-ratio.

Table 4.3 - Rentability index for both systems

Evaluation Methods	**Production Systems**	
	Traditional Coffee	Agroforestry System
NPV [R$]	2,860.02	2,995,42
IRR [%]	23.24	23.41
CRR	1.29	1.30

The difference that comes from grevillea implementation, in addition to increasing expected revenue, actually contributes to decreasing costs of coffee renewal in values which are not discounted with this expenditure. It should be noted that scarcity of wood may increase grevillea wood prices, making this species more important in the studied system.

In the analyzed density, the income originated from wood sales in the last year allows to cover 73% of year zero costs and 43.7% of costs in year zero and one (implementation year). This means a reasonable percentile of renewal costs for coffee crops and reimplementation of grevillea. This fact becomes even more important when we consider the insignificance of costs due to the implementation of forest species.

4.3.5 Economic evaluation of agroforestry systems in Pará, Brazil (SANGUINO et alii, 2007)

The studied agroforestry system is located in the city of Tailândia, in the northeastern region of the state of Pará, and occupies an area of approximately 15 thousand hectares. It borders to the north with the cities of Acara and Concordia do Pará, to the East with the city of Tomé-Açu and Ipixuna do Pará, and to the South with the city of Ipixuna do Pará, and to the west with the cities of Mojú and Acará. The relief is flat and soil is represented by Haplustults Oxisol, in its textural phase, varying from medium to clayey and wavy topography. The climate in the area is Ami, from Köppen's classification, with annual average temperature of 27.9°C and total annual rainfall of 2,500 mm, with irregular distribution throughout the year

Vegetation is formed by secondary forest, type "*capoeirão*", which is a phase of a natural succession process, resulting from human activities related to selective wood exploitation and implementation of ground Black pepper and other agricultural crops. In the physiognomic aspect, we can highlight a predominantly timber and uniform phase, in relation to the height of dominant elements and to the presence of trees species which remained from the original forest.

Investments

The costs estimative for implementation and maintenance of agroforestry systems were originated from information obtained in the survey about unit prices of inputs, machinery, agriculture implements, labor force, and other production items, and it refers to prices practiced in the cities of Tomé-Açu and Belém, in the month of July 2002.

The Effective Operational Cost (EOC) is the sum of direct expenses of incurred by the producer in the implementation of its rural activity, such as: labor force, machinery, fuel, lubricants, and inputs (seedlings, fertilizers, pesticides, packaging, cutting, transportation, among others). Total Operational Cost (TOC) include indirect expenses, such as: depreciation of durable goods used in productive activity, social taxes of human resources, opportunity cost of land, opportunity cost of capital invested in the activity, i.e., interest over the cost capital and taxes over rural territory propriety (RTP).

In relation to the opportunity cost of used land, we considered the value of rural lease, since producers have the right of property over the studied rural establishments.

Financial costs were calculated over the average value of the effective operational costs. This is justified since the total expenses that occur in the beginning (growing) are underpaid, and the expenses concentrated in the end (harvest) are overpaid, thus generating compensation of values.

The adopted interest rate to remunerate capital was 8.75% / year, the same used in the main credit lines in agriculture, such as: Program of Modernization of Tractors and Agricultural Implements (MODERFROTA); Program of Systematization of Wetlands (SISVARZEA); Program of Incentive to Storage Units in Rural Properties (PROAZEM) and Program of Forest Commercial Growing (PROPFLORA).

Revenue was obtained with the sale of each agroforestry system production. Sale prices were the ones prevailing in the market of Tomé-Açu and surroundings, Supply Center of the State of Pará (CEASA-PA) and agribusiness Joint Cooperative of Tomé-Açu (CAMTA). Thus, the value received by producers refers to the production value commercialized in these places and the prices were adjusted to reflect the values of productive units.

Description of Agroforestry Systems

Agroforestry system A (SAF-A) is formed by 400 units of cupuacu (CU- *Teobroma grandiflorum*), 1,000 units of Black peper (BP-*Piper nigrum*) which is substituted by 800 units/ha (PF-*Passiflora edulis*) after the third year and 100 units of mahogany (MA-*Swietenia macrofila*). Thus, between the first and third years, there is cupuacu, mahogany and black pepper. From the fourth year, there is cupuacu, mahogany and black pepper. From the fourth to fifth year, there is cupuacu, passion fruit and mahogany, and starting from the sixth year on, there is only cupuaçu and mahogay, which stay until the end of the system, in its 25th year. It is important to highlight that this system is carried out by farmers, and not by formally implemented experiments.

In relation to wood production, they carry out a thinning in the 15th year and the final logging in the 25^{th} year. This wood has multiple uses. The thinning which is carried out in the 15th year aims the production of piles to support black pepper, and also in the renewal of storage sheds for production, inputs and machinery garage, fences and other rural constructions inside the agroforestry system. At the 25^{th} birthday, there is the final logging of the forest (clearcutting).

Agroforestry system B (SAF-B) is formed by the following species: açaí-fruit (AF - *Euterpe oleraceae*), cocoa (CO-*Teobroma cacao*), and mahogany (MA-*Swietenia macrofila*).

The space arrangement of this system is the following: cocoa with growing density equal to 950 units per hectare, distributed in double rows, and between the rows, 500 units of acai-fruit per hectare. Mahogany is distributed non-equally, with variable spacing, totalizing 100 units per hectare.

Cocoa is grown under the shadow of açaí-fruit, and after the mahogany plays this function. All crops are planted in the first year and stay until the end of planning horizon (25 years), when the final logging of the mahogany happens.

Annual crops are considered in the short term, and forest crops are considered in the long term. This is determined because currency has a different value when it is received in the future. To offset or neutralize this opportunity cost variation, we used an annual interest rate (i). It represents the minimum annual amount that is required by farmers for the use of their money, taking into consideration the variation of currency value in time. We used the methodology that has time as determinant element in the capital variation.

As methodology strategy, we considered the planning horizon of twenty five years, period in which one obtains profit with timber sale, due to silviculture maintenance and partial thinning of trees. During this period agroforestry systems are producing and forest can be exploited in its optimum age for logging.

Discount rate

To analyze economic viability for the two system implementation, we considered the basic discount rate at 8%/year, in accordance with the effective interest rate established by the Constitutional Financing Fundo f the North (FNO), and in accordance with dispositions of the Bank of Amazon.

To evaluate the results from this study, the net present value (NPV) and Benefit-cost ratio (BCR) were used;

Economic Analysis of Agroforestry System

It is observed that in the first production year, SAF-A (CU, BP, PF, MA) presents a negative liquid flow equal to R$ 1,324.51.

However, the second activity year registers positive values equal to R$ 8,581.40. This evolution occurs due to black pepper production, which reaches its maximum production, which shows the return of invested capital already in the second activity year.

The same economic performance is not verified in SAF-B (AF, CO e MA). Negative cash flows are observed during the first two years, occurring in losses to the farmer and difficulties in the initial years, during which the farmer has no working capital to cover necessary expenses to maintain the productive process in operation, such as acquisition of inputs, payments to employees and other every-day expenses. This negative cash flow is due to the lack of black pepper in the first production year. However, the system for the next year produces surplus.

The results of net present value, (NPV), of benefit-cost ratio (BCR) and internal rate of return (IRR) were the following: results of NPV for SAF-A and SAF-B were R$ 44,105.78 and R$ 69,650.27, respectively. This shows that agroforestry systems are economic viable, since at the end they can generate positive updated liquid revenue.

Results for BCR were 2.35 and 3.48, for SAF-A and SAF-B, respectively. This show that for each real invested in these agroforestry systems, at the end of 25 years a liquid return of R$ 1.35 and R$ 2.48, respectively is produced, reassuring the viability of the project .

Finally, IRR results were 595.7% and 51.8%, respectively for SAF-A and SAF-B, assuring the viability of agroforestry systems, since IRR was higher than the interest rate (8% per year), which represents the opportunity costs of resources from Constitutional Financing Fund of the North (FNO), applied in activities of small farmers and agroforestry systems in Amazon.

Passion fruit and black pepper crops, together with cupuaçu, assure revenue flow during the years of SAF-A, which presented cost slightly higher than revenue only in the first year. This caused an elevated return IRR. In SAF-B, since there is no short term crop, revenue flow covers costs only after the fourth year, which generated a decreased IRR. Even though, this rate was above TJLP and other long term interest rates. That is why farmers associated to Joint Cooperative of Tomé-Açu (CAMTA) practice consortium and agroforestry systems.

5. Agroforestry system advantages and disadvantages

Follow the advantages of agroforestry systems to small farmers:

- They maintain implementation and maintenance system costs in acceptable limits for the small farmer.
- They may increase family income.
- They may contribute to the improvement of rural population nutritional habits
- They help to maintain or improve productive capacity of land using trees as fertilizers, since they increase the soil physical structure.
- Facilitate the sedentarization of farmers: since they help to maintain the productivity of soil for long periods, agroforestry systems have the great advantage of keeping the farmer on the land.
- They lead to a lower risk for farmers, due to its greater production diversification, in each propriety
- Enable a better distribution of labor force throughout the year
- Contribute to a more comfortable work in the farm
- May fulfill a very important role in recuperation of degraded areas.
- May contribute to environment preservation, since there is a decrease in the need of logging forests to open new cropping areas and help to control erosion.

Agroforestry systems also present some disadvantages, such as:

- Knowledge of farmers and of technicians on agroforestry systems is still very insufficient
- In general, agroforestry system management is more complicated than annual crop species or short term crops, i.e., since agroforestry system involves a greater number of species, its planning and management are more difficult and require more complex knowledge.
- The implementation costs of certain agroforestry systems are higher, since the effective cost depends on several factors, and the seedling price may be decisive.
- The tree component may decrease the revenue of agricultural crops and livestock, in the agroforestry system, since the beneficial effects of agroforestry system depends on the species chosen to compose the forest component.
- Agroforestry systems are more difficult to accept mechanization and, currently, there are very few small farmers than can afford to buy and assure maintenance of equipment to mechanize their work.
- For now, many products generated by agroforestry system have limited markets, which cannot absorb large quantities. Also, when the trees are high and old, they can cause accidents.

5.1 Suggested Directions for Future Work

- Research is needed to assess the economic performance of each major agroforestry system under a wider range of conditions, using systematic selection of sites across a range of environmental and economic variables. For each system, a standard set of economic input and output data should be developed to facilitate cross-site comparison.
- More information on crop production is needed, especially in analyzing agroforestry systems with important intended or potential tree-crop interaction effects.
- Economists must work much more closely with technical researchers to design trials that will answer important questions about economic thresholds, economic productivity, management options, and the effects on total output of changes in system design.
- Research should pay closer attention to intra-year flows in agroforestry system, costs and benefits and their relation to farmers' seasonal resource availability.
- Future research should consider a much larger number of agroforestry and non-agroforestry (and even non-farm) alternatives in economic analyses. These should be based on real alternatives available to farmers in different settings, for producing tree products and services and increases in crop production.
- A much stronger capacity for undertaking economic analysis is needed within agroforestry projects. The projects would benefit from regular feedback on the profitability and management constraints of agroforestry to improve the targeting of interventions and extension information. More participatory approaches to designing economic assessments, involving both project staff and farmers, would improve the usefulness of the economic studies.
- Local projects need, in turn, to be linked in a more permanent way to research and information support. They need training in data collection and analysis methods, the resources for monitoring economic performance over time, and regular opportunities to interact with researchers.

6. Energy crops in Brazil – The Sugarcane Case

6.1 Sugarcane industry and production

It is known that the biomass energy supplied by the sugar cane culture is estimated in 67,080 Mcal per hectare (RIPOLI; MOLINA JUNIOR, 1991), divided in 20.09% as alcohol, 40.03% in bagasse usage as fuel in boilers and the remaining 39.88% contained in the remaining material of the harvest (edges, green leaves and straw) (MACEDO, 2000).

Nowadays, it is considered that a ton of harvested sugar cane results in, approximately, 33% broth; 33% bagasse (50% of humidity); and 33% of straw and edges with 15% of humidity. These were the parameters used in the calculations of the quantity of sugar cane residues available in the country.

The bagasse, byproduct resulting from grinding and extraction of sugar cane broth, is largely used by the sugar and ethanol industry for producing mechanic energy and steam for internal use, besides the great production of surplus electric energy, which is sold to the national network.

Residues such as straw and edges are only available when mechanized harvest is done, with later partial collection of the field's “trash” (50% of straw and edges collected) and transport to industry. In other case, such residues are burned when manual harvest with the plantation's burn is done, or they are left in the Field when transport to the industry is not economically viable.

This way, enzymatic hydrolysis - technology of second-generation ethanol production - can only be made viable with displacement of bagasse, which is currently used for cogeneration and generation of additional electricity by the industry or by recuperation of sugar cane trash obtained by means of mechanized harvest.

In this context, the study developed by Cenbio assessed the available quantity of sugar cane residues in Brazil, considering surplus sugar cane bagasse and trash, for analysis of viability of the introduction of the new enzymatic hydrolysis technology for ethanol production. Only the surplus sugar cane bagasse was considered, since the greater part of the bagasse produced in the sugar cane industry is destined to cogeneration.

As a result, it was obtained that the current sum of surplus bagasse is of about 14 million tons. However, even if this sum is expressive, the uncertainties of the possibility of displacement of the use of these residues for ethanol production through enzymatic hydrolysis in opposition to another kind of usage, as electric energy generation, are many.

Regarding the trash, the effective utilization of such residues in hydrolysis strongly depends of the operationalization and investments of the sugar and ethanol industry in mechanized harvest of raw sugar cane.

Below, the results of the research will be presented only for the straw and edges residues, since the sugar cane bagasse is considered an industrial residue.

6.2 Production of sugar cane straw and edges

Referring to the production of straw and edges from raw sugar cane mechanized harvest in the North-Northeast region, 426 thousand tons of straw and edges were produced in the 2007/2008 harvest. The sums of produced straw and edges were not recovered from the field, not being used in the industry for cogeneration, by any sugar cane plant. Therefore, such residues of straw and edges would not be available for ethanol production via enzymatic hydrolysis in the 2007/2008 harvest.

In the Center-South region, there was a significative production of straw and edges in all the producer states, except in Rio Grande do Sul. The produced amount was of 25.5 million tons. This situation is due to the implementation of public policies of gradual elimination of the sugar cane straw burn as a previous practice of harvest.

In the State of São Paulo, the State Law n. 11.241/2002, and the State Decree n. 47.700/2003 foresee the gradative elimination of sugar cane burn in mechanizable areas by 2021 (terrains above 150 hectares and with declivity smaller than 12%). In non mechanizable areas, the elimination deadline is in 2031.

In the State of São Paulo there is also an Environmental Protocol, launched in 2007 by SMA-SP, which aims to award the good practices of the sugar and ethanol sector through a conformity certificate and other benefits. To adhere to the Protocol, sugar cane producers must advance the deadline for elimination of sugar cane burn in areas with declivity up to 12% from 2021 to 2014. In areas with declivity above 12% the deadline must diminish from 2031 to 2017. As for the new enterprises in São Paulo, they are forbidden to burn sugar cane plantations, according to the SMA-SP 33 Resolution, from June 21st, 2007.

In the State of Goiás, there is legislation for elimination of sugar cane burn, specially for new power plants. The State Resolution-GO n. 082 from 2007 determines that the environmental licenses emitted for the new plants in the State must have as environmental conditioning the non utilization of sugar cane straw burn in the harvest processes.

In the State of Minas Gerais, in 2009, a Normative Deliberation was approved, which regulates the Agro-environmental Protocol of the State. The Deliberation deals with the mechanized harvest and with the elimination of sugar cane straw burn, foreseen to 2014, except for those areas with declivity above 12%, until technologies are developed for this kind of terrain.

Thus, the straw and edges production in the plants of the Center-South region depends of the harvest mechanization, which is already happening through legislation in some States of the Federation, as previously cited.

Besides, the use of these residues in the industry depends of its recuperation from the field and transport to the plant, what is not economically viable nowadays for great part of the producer units. One of the main challenges to make viable the utilization of these residues is the development of a mechanized system of harvesting that contemplates the recuperation of straw with costs and quality that make its energy usage viable.

Besides the real scenario of generation of straw and edges resulting from mechanized harvest, a projection of the sum of residues that would be generated with 100% of mechanization of the harvest in the Center-South region, for the 2007/2008 harvest, was done. The produced quantity of residues would be of approximately 55.5 million tons.

This scenario is hypothetical and not achievable in short term, since difficultly all the planted area of the Center-South region will be mechanized. One must also consider that the theoretical sum of straw and edges calculated had as a basis the 2007/2008 harvest, and that nowadays the sugar and ethanol sector is in strong expansion, that is, in the 2008/2009 harvest the sum of harvested sugar cane Will certainly be bigger, as it can be observed in the harvest comparatives since 1990.

This way, it is foreseen that there will be a great availability of straw and edges that will be able to be destined to ethanol production via enzymatic hydrolysis.

In this context, it is known that projecting the quantity of remaining trash upon a compartment, in terms of mass, after the raw material harvest, is a function of various variables, such as: varietal characteristics, age of the sugar cane plantation, number of the harvest, kind of harvest (manual or mechanized), kind of manual CUT (with or without blunt), kind and regulation (rotation of the ventilators/extractor fans) of the harvester, situation of the sugar cane plantation (burned or *in natura*); agricultural productivity of thatches, degree of uniformity of the number of industralizable thatches per meter of line (which, in its turn, will depend on the quality of the operations of planting and culture treatment) and time elapsed between the operation of thatches harvest and the collection of trash (which will cause a significant variation in the humidity degree of the material).

According to Ripoli et. al. (2002) the trash can reach values of up to thirty tons per hectare (basis in humid weight)[2], being constituted of Green leaves, dry leaves, edges, thatches and/or their fractions and added soil to these constitutants.

However, in order to have production and recuperation of the field trash, the industry must adopt, in principle, the raw sugar cane mechanized harvest system. Then, even before the assessment of

[2] The sums of trash found in sugar cane cultures vary from 9 to 32 tons/hectare, in humid weight (RIPOLI, 2001).

the transport costs of the trash to the industry, one must analyze the cost of implantation of raw sugar cane cutting mechanization, which allows the trash production.

Ripoli & Ripoli (2005) emphasize that when one deals with the implantation of sugar cane cutting mechanization, be it raw or burned, one must be aware that it is not only a matter of substituting the blue-collar worker for machines; it is a matter of a change in all harvest system composed by three subsystems, that must operate in synchrony: a) harvest, b) transport, c) reception. According to the authors, besides the harvesters acquirement, there is need of modifications in the transport units (changes in the types of bodywork), introduction of intermediary transshipment (which does not operate inside the sugar cane plantation) and modifications in the reception of raw material inside the plant.

According to the authors, to estimate this transition cost is a practice of projection based in current data, because each plant has different characteristics regarding the planted area, distances of the cutting fronts to the factory unit, capacity of daily grinding, particularities of its road systems, qualification of operators, shape and size of the compartments, among others. Such variables must be considered in the quantification of the number of harvesters, and respective transport systems needed in order for the flow of the harvest process occurs adequate to the reception conditions of the industrial unit.

The acquirement costs of harvesters and new transport units are also added, as well as the costs to reform trucks bodywork and trash reception systems in the industry. Besides, to collect the field trash there will be need for binders (or another viable collection system), in order to increase its density to make transportation viable.

It is also necessary to analyze the trash collection system adopted by the plant, which involves many variables that are difficult to be “standardized” in an only value, such as: quantity of mineral material contained in the trash, distribution of the trash in the harvested area and the very variable density of this material, costs of manipulation in field and transportation, variability of size and humidity of the constitutants of the material, storage, system management, among others.

When reporting to the collection costs of trash from the field, Duarte et. al. (1988) emphasize that the costs of operation involving the use of machines depend as much of the characteristics of the machines and implements, as of the work environment and the nature of the operations performed, which also include the cost of opportunity of the production factor as a way of determining the costs of resources employed.

According to Ripoli et al. (2002) two data are paramount when trash collection is studied: what is the system that presents the smaller cost per ton and what is the percentage of soil existent in the trash used in the plant. The factors that influence the quantity of soil contained in the trash are the procedures adopted for harvest and loading, type of machinery used and kind of soil for sugar cane culture, among others. The authors met different percentages of soil contained in the trash for different types of collection: 4.50% of soil in trash collected in bulk; 1.39% of soil in full harvest and 0.63% in bound trash.

Molina Jr. et. al. (1991), while studying the collection of residues of manual sugar cane harvest without burn, by using a binder of cylindrical burdens, reached values of total cost of the collection system of R$ 44.13/ton of sugar cane. In its turn, COOPERSUCAR (2001) reached values of total costs of R$ 57.81/ton of sugar cane for trash collection using binders.

Further information about transport costs of edges and straw to the plant, considering alternatives, can be found in the Project BRA/96/G31 - *Biomass Power Generation – sugarcane bagasse and trash* developed by the Brazilian Sugar Cane Technology Center (CTC) and PNUD (HASSUANI, LEAL and MACEDO, 2005). In this study the final costs of edges and straw (residues at the plant) vary from US$ 13.70 to US$ 31 per ton, and may vary depending on the distances to be covered and on the geographic conditions of each region, as it will be presented next.

6.3 Field straw and edges recovery cost

The economic model for trash recovery cost assessment has been conceived to cover the three potential routes of cane harvesting with trash recovery. These alternatives assume that some trash is recovered and made available at the mill as supplementary fuel to bagasse, namely:

1 – The straw and edges left in the field is baled, transported to the mill and shredded. *Efficiency of straw and edges withdraw = 75.7%;*

2 – The straw and the edges are not separated by the cane harvesters and are transported alongside the harvested cane until the plant and are separated there. *Efficiency of straw and edges withdraw = 5.5%;*

3 – The harvester withdraws the straw and edges of only part of the harvested cane, leaving the residue in the Field. Part of the sugar cane is taken to the plant with the straw and edges, which will be separated there. *Efficiency of straw and edges withdraw = 29.2%;*

The transportation cost of the sugar cane residues is not a result of a specific production process and it may have different values, according to the technology required for the change between the current cane harvest process and the alternative that is being analyzed, varying greatly in accordance to each specific case. This economic model was structured to take into consideration these differences, provenient both from the used technology and from the different residue sums left in the field or transported to the plant.

The economic model also quantifies in the incremental form the effects (positives or negatives) of the trash blanket that remains in the field after unburned cane harvesting, always having as reference the technical configuration of the baseline, calculating in this way the trash cost for each alternative challenging the baseline.

The cane harvesting with residues recovery causes a series of modifications in the operations of soil preparation, planting and tillage. The efficiency and productivity of the harvesters are also affected by the speed of the cleaning fans that determines the amount of residue that is left on the ground or taken to the mill mixed with cane.

Besides the variation of the operating parameters of each activity performed, among the technical alternatives being economically compared, it has been noticed that the amount of residues being handled is a function of other "non-controllable" parameters that have some influence in the calculation of the trash cost of that route under analysis, such as:

- The quantity of trash depends on cane variety, age and other factors;
- The sprouting of the cane under the trash blanket is slow;
- The trash blanket inhibits weed growth; some types of weeds such as Cyperus rotundus are not affected by the trash blanket;
- The trash blanket increases microbial activities in soil surface layers;
- The trash blanket may decrease necessity of nitrogen fertilizers;
- The trash blanket in humid regions may cause ratoon rotting;
- The trash blanket helps to prevent soil erosion and hinders the photodecomposition of the organic matter;
- Mechanized cane harvesting reduces local emissions of smoke and soot as well as loss of water;
- The trash blanket increases fire hazards.

These effects are hard to quantify but, nevertheless, in the Project *BRA/96/G31* a series of experiments were planned and executed, in an attempt to put figures in what has been considered to be the major impacts. Although the parameters determined in those tests are affected by specific local conditions, they can be considered as reliable preliminary estimates.

The data used for sugar cane in the field were:

- Average cane productivity: 83.23 t cane/ha;
- Pol % cane: 14.32%;
- Fibras: 13.44%;
- Trash % cane (dry basis): 14% - the resulting average availability resulting from trash is, however, of 11.65 t trash/ha.

For estimation of costs, a simulation model was used, necessary due to the fact that a great number of interdependent activities of sugar cane harvest and transportation makes difficult to establish an adequate group of equations. Besides, the time required to perform each event has a stochastic distribution and the needed resources for some operations may be disputed according to the logic criteria. In this way, the simulation tool presents itself as a viable technique to take all these parameter into consideration and to give a good support for the equipment and systems sizing.

The application of a simulation model to measure equipments for harvest and fleet for transportation requires a great quantity of information obtained during field works. These works consist in the measurement of time required for each specific event that happen during the activities and processes that sometimes interfere in the efficiency of the activity.
The quantified results and parameters used in the simulation of cane harvesting and transportation for alternatives 1, 2 and 3, previously presented, are summarized in table 6.1.

Table 6.1 – Simulation of technical parameters.

Items	**Baseline**	**Alternative 1**	**Alternative 2**	**Alternative 3**
Harvested cane (t/day)*	6,474	6,474	7,231	7,265
Delivered cane to the plant (t/day)*	1,301,290	1,301,290	1,511,275	1,445,744
1. Harvesters				
Total quantity	10	10	13	10
Operating capacity (t/h)	24.1	24.1	24.1	25.7
Efficiency (%)	43	43	42.2	47.8
2. Towing tractors				
Total quantity	21	21	30	20
Operating capacity (t/h)	12.9	12.9	10.4	15.1
Efficiency (%)	32.2	32.2	74.5	55.8
3. Transloaders				
Total quantity	42	42	60	40
Operating capacity (t/h)	6.4	6.4	5.2	7.5
4. Trucks				
Total quantity	21	21	33	23
Average trips/day-vehicle	10.46	10.46	10.68	11.19
Operating capacity (t/trip)	29.59	29.59	21.31	28.09
Average distance (km)	18.93	18.93	19.02	18.84
Technical coefficient (km/t cane)	1.27	1.27	1.78	1.34

(*) Cane + vegetable impurities (trash).
Source: CTC, 2005.

Analyzing table I it can be seen that Alternative 2 – no trash cleaning from the field – resulted in large deviations from the baseline, when compared with the other two. These deviations are consequences of the difference in cleaning efficiencies considered for Alternatives 1, 2 and 3 as 75.7%, 5.5% and 29.2%, respectively. The larger amount of vegetal impurities, or extraneous matter, in the sugar cane in Alternative 2 results in considerable reduction in the density of the transported cane and an increase of total tonnage of the material delivered to the mill (cane +

impurities) causing a large impact to the number of tractors, transloaders (infield side tipper cane-transport equipment) and trucks required.

All alternatives considered transport trucks with three trailers, with dimensions and load within the legal highway limits. For alternative 1, load limits allowed accommodating 2 transloaders load per truck trailer (the cane loaded in the transloaders in the field by the harvester, during the harvesting operation, is transferred to the truck trailer at the side of the field), while alternatives 2 and 3 accommodated three loads (where the limitation of volume was achieved before load limitations).

The typical mill considered in the analyses had the following conditions:

- Cane field useful life of 5 anos;
- Average distance from the harvesting fronts to the mill of 19 km;
- 3 fronts harvesting simultaneously;
- Cane field yield (average 5 cuts) of 83.23 t/ha; and
- Total cane in the fields, as clean cane stalks = 1.3 million t/year.

The technical parameters for the cane harvesting with trash recovery alternatives selected for this study are shown in table 6.2 below.

Table 6.2 – Technical parameters for sugar cane harvesting.

Items	**Alternative 1**	**Alternative 2**	**Alternative 3**
Mineral impurities (%)	0.11	0.30	0.19
Vegetal impurities (%)[a]	3.37	11.30	8.85
Moisture content (%)[a]	55.0	38.0	41.0
Trash cleaning efficiency (%)[b]	75.7	5.50	29.2
Visible losses (%)	3.45	1.20	1.60
Invisible losses (%)	3.40	3.40	3.40

(a) Dry basis;

(b) Humidity content in trash delivered to the mill with the cane;

(c) Harvesting cleaning efficiency during harvesting.

Source: CTC, 2005.

The general data for operation of the plant during harvest are presented in table 6.3 below.

Table 6.3 – General data for sugar cane impurities.

Items	**Baseline**	**Alternative 1**	**Alternative 2**	**Alternative 3**
Material delivered to mill (t) [a]	1,301,209	1,301,209	1,511,275	1,445,744
Vegetal impurities (t)[b]	97,577	97,577	275,418	216,837
Mineral impurities (t)	1,431	1,431	4,534	2,747
Clean cane at the mill (t)	1,202,282	1,202,282	1,231,323	1,226,160
Harvesting losses (t)	88,413	88,413	59,372	64,535
Cane in field (t) [a]	1,290,695	1,290,695	1,290,695	1,290,695

(a) Clean cane (stalks) + mineral and vegetal impurities;

(b) Total vegetal impurities (wet basis) delivered to the mill with the cane;

(c) It has been assumed the same amount of clean cane (stalks) in the fields to be harvested.

Source: Hassuani, Leal and Macedo, 2005.

For the typical mill plant considered in study, the cane harvest total area can be estimated in 15,509 ha. Considering that 20% must be available for planting (3,102 ha) and 10% of area for plantation must be reserved for recovery (310 ha), it can be concluded that the total field area necessary for sugar cane is of 18,921 ha.

Regading sugar cane trash, the basic parameters estimated for the average conditions of the trash recovery operations are:

- Binder machine efficiency = 84%;
- Wet bale weight = 305.8 kg;
- Dry bale weight = 215.5 kg;
- Mineral impurity = 4.7%;
- Humidity = 15.3%;
- Efficiency of cane Dry Cleaning Station = 70% for vegetal impurities* and 80% for mineral impurities (to be reached after improvement of the cane Dry Cleaning Station).

From these parameters, the balance for trash recovery was summarized in table 6.4.

Table 6.4 – Sugar cane trash (t dry basis).

Descrição	**Baseline**	**Alternative 1**	**Alternative 2**	**Alternative 3**
Trash in cane field	180,697	180,697	180,697	180,697
Trash transported with cane	43,909	43,909	170,759	127,934
Trash on the ground after harvesting	136,788	136,788	9,938	52,764
Baled trash	-	114,902	-	-
Quantity of bales in the field	-	533,187	-	-
Trash left in the field	136,788	21,886	9,938	52,764
Trash removed by the cleaning station	-	-	119,531	89,554
Total trash available at the mill	-	114,902	119,531	89,554

Source: Hassuani, Leal and Macedo, 2005.

Concerning the industrial area, the parameters that affect any of the cane processing operations, specially milling, have some impacts on the final amount of sugar, alcohol and bagasse produced.

In the cane preparation and milling stage, the parameters are:

- Sugar losses in cane washing operation = 0.81%;
- Loss of sugar in dry cleaning station = 1.69%;
- Fiber % in trash = 50%;
- Fiber % in cane = 13.44%;
- Daily milling rate = 7,110 t cane/day;
- Cane milling % time available = 90%;
- Milling extraction efficiency = 96.24%;
- Pol of bagasse = 1.89%;
- Moisture % in bagasse = 48.67%.

It is assumed that the milling capacity of the mill tandem is a function of fiber of the milled material; this relationship can be expressed by the following equation:

$$MR = MN*[1-0.5*((FMM-FP)/FP)] \text{ t cane/day}$$

MR= Milling capacity (t cane/day) for the average fiber of the milled material

MN= Milling capacity for standard cane fiber (7,110 t/day)

FMM= Average fiber of the milled material (cane + impurities)

FP= Standard average fiber for the typical mill (13.44%)

Table 6.5 summarizes the characteristics of the processed material by the milling tandem:

Table 6.5 - Characteristics of the material processed by the milling tandem.

Items	Baseline	Alternative 1	Alternative 2	Alternative 3
Quantity of cane at the cleaning station (%)	-	-	100	100
Pol % material at the mill (%)	14.32	14.32	14.08	14.08
Mineral impurity at the mill (%)	0.11	0.11	0.07	0.04
Vegetal impurity at the mill (%)	7.50	7.50	6.28	5.04
Fiber % vegetal impurity (%)[a]	45.0	45.0	62.0	59.0
Fiber % material at the mill (%)	15.81	15.81	16.49	15.73
Fiber variation (%)[b]	17.6	17.6	22.7	17.1
Quantity of milled material (t/year)	1,301,290	1,301,290	1,314,855	1,291,761
Effective milling rate (t/year)	6,484	6,484	6,302	6,503
Effective milling season (days)	201	201	209	199

(a) Wet basis;

(b) Related to % of cane fiber.

Source: Hassuani, Leal and Macedo, 2005.

In the sugar and ethanol fabrication stage, the cane juice extracted by the milling tandems is sent to the sugar and ethanol factories as 48% and 52%, respectively.

The following parameters have been considered for the performance analysis of the two industrial processes:

- Overall sugar fabrication efficiency: 96.43%;
- Overall alcohol fabrication efficiency: 90.30%;
- Alcohol grade (%w/w): 99.5%;
- Conversion factor of TRS to sucrose: 4%;
- Conversion factor of alcohol to sucrose: 1,467;
- Bagasse consumption by the mill: 231 kg/t material at 48.67% moisture content.

With the parameters characterized as above the production of sugar, alcohol and bagasse can be determined for each alternative, as summarized in table 6.6.

Table 6.6 – Mill production data.

Items	**Baseline**	**Alternative 1**	**Alternative 2**	**Alternative 3**
Bagasse production (t/year)[a]	416,037	416,037	438,591	411,104
Bagasse consumption (t/year)[a]	300,806	300,806	303,942	298,603
Bagasse surplus (t/year)[a, b]	115,230	115,230	134,649	112,501
Sugar production (t/year)	79,092	79,092	79,455	79,355
Alcohol production (m^3/year)	54,969	54,969	55,221	55,151

(a) Wet basis;

(b) Bagasse surplus = Bagasse produced – bagasse consumed in the boilers.

Source: Hassuani, Leal and Macedo, 2005.

The cost to be assigned to a byproduct is normally difficult to characterize and involves subjective criteria in the attempt to split some of the processing costs between the main products and the byproduct.

The biomass resulting from cane harvesting and processing, bagasse and trash, is a good example of this situation. To obtain the preliminary economic results it has been assumed that the initial reference condition (baseline) would be when the mills are mechanically harvesting chopped unburned cane, with the harvester separating the trash from the cane and leaving the trash in the field.

The economic analysis has also been performed considering as baseline the present situation (year 2003) where burned cane is harvested manually, which reflects the condition of approximately 80% of the cane milled in Brazil. However, it has been also realized that the change from manually harvested burned cane to mechanically harvested unburned cane would not be primarily driven by the necessity or interest to recover and use the trash, but by other reasons such as environmental, legal and population pressure, labor shortage, cost and others. This change will probably take place gradually, independent of the interest in using or not the trash.

For the sake of simplicity, the report from PNUD presents only the cases where the baseline is mechanically harvested chopped unburned cane with the trash left on the ground in the form of a uniform blanket. The mills that are today partially in this situation are the ones that have shown interest in recovering and using part of the resulting trash.

Starting from the baseline, all the specific changes introduced in the sugar cane production and processing activities to recover the trash are determined and the corresponding incremental costs, either positive or negative, are charged to the total cost of this byproduct – the trash. The concept adopted is to divide the two quantities:

- The difference between the economic results of the baseline situation and those of each alternative analyzed;
- The quantity of trash recovered in each alternative.

Since the activities that form the processes are well known as well as the corresponding equipment, machines, vehicles and accessories required to perform them, the unit cost of each activity can be obtained and, consequently, the unit cost of each process. The sugar cane production processes are: soil preparation, planting, harvesting, transport and tillage.

In the alternatives evaluated here there are variations in the activities as well as in the operating capacity of the equipment involved. The processes listed in the preceding paragraph can be executed in two ways:

- Without the trash blanket;
- With the trash blanket in the soil.

Table 6.7 below shows the unit cost for each of these processes in the alternatives being evaluated.

Table 6.7 – Process unitary costs of sugarcane production.

Items	**Baseline**	**Alternative 1**	**Alternative 2**	**Alternative 3**
Soil prepatation (US$/ha)	215.22	183.37	183.37	215.22
Planting (US$/ha)	482.84	482.84	482.84	482.84
Harvesting material (US$/t)	4.82	4.82	5.99	4.51
Tillage (US$/ha)	86.41[a]	144.74	144.74	86.41[a]

(a) Without the herbicide effect of the trash this value is US$ 130.90/ha.

Source: Hassuani, Leal and Macedo, 2005.

The selling prices for sugar, alcohol and sugar cane bagasse considered in this analysis were:

- Sugar: US$ 120.00/t;
- Alcohol: US$ 145.00/m^3;
- Bagasse: US$ 5.00/t (wet basis).

And the production variable costs were considered as:

- Cane washing: US$ 0.60/t material;
- Cane milling: US$ 1.00/t material;
- Sugar fabrication: US$ 40.00/t sugar;
- Alcohol fabrication: US$ 55.00/m^3 alcohol;
- Taxes on milled cane: US$ 0.60/t cane.

It has been estimated that the average loss of productivity of the cane fields is around 11% and 5% in areas of clay or sandy soils, respectively, due to the effects of soil compaction and rotoon damage resulting from the operations to recover the trash in Alternative 1.
Considering that in the State of São Paulo the cane fields are 72.7% in clay soil areas, we would have a weighted average productivity loss of 6.23 t cane/ha, already assuming that the loss will happen after the first cut and an average cane yield of 83.23 t cane/ha. These results have an additional cost of US$ 17.85/ha-year, charged to the trash, corresponding to US$ 2.41/t (dry basis) namely for the agricultural impacts – loss of productivity, due to soil compaction and ratoon damage. Table 6.8 shows the costs of the agricultural processes for each alternative.

Table 6.8 – Technical parameters and costs of agricultural processes.

Items	**Baseline**	**Alternative 1**	**Alternative 2**	**Alternative 3**
Soil preparation costs (US$/ha)	215.22	183.37	183.7	215.22
Tillage costs				
- With herbicide effect (US$/ha)	86.41	144.74	144.74	86.41
- No herbicide effect (US$/ha)	130.96	144.74	144.74	130.96
Trash in the process?	Yes	No	No	Yes
Is there the herbicide effect?	Yes	No	No	No
Cane field useful life (years)	5	5	5	5
Change in preparation costs (US$/ha)	-	-31.85	-31.85	-
Change in annual preparation costs (US$/ha-year)	-	-7.75	-7.75	-
Change in tillage costs (US$/ha)	-	58.32	58.32	44.55
Change in annual tillage costs (US$/ha-year)[a]	-	49.14	49.14	37.53
Difference in preparation costs (US$/t of trash db)	-	-1.05	-1.01	-
Difference in tillage costs (US$/t de trash db)	-	6.63	6.38	6.50
Opportunity cost of trash (US$/t db)	-	5.59	5.37	6.50

(a) Only for the last four years of useful life of the cane field;
(db) Dry basis.
Source: Hassuani, Leal and Macedo, 2005.

The trash recovery, in alternatives 2 and 3, requires a trash removal station in the plant. This process that separates the trash from the cane prior to the milling operation is necessary to avoid the deleterious effects that the excessive impurities in the cane would create during its processing in the factory. Table 6.9 below presents the costs of a trash preparation unit.

Table 6.9 – Trash preparation unitary costs.

Items	Baseline	Alternative 1	Alternative 2	Alternative 3
Total recovered trash (t db)	-	114,902	119,531	89,554
Annual trash processing cost (US$)	-	102,115	102,115	102,115
Unit preparation cost (US$/t trash db)	-	0.89	0.85	1.14

(db) Dry basis.

Source: Hassuani, Leal and Macedo, 2005.

The technical parameters related to the cane Dry Cleaning Station that are necessary to determine the cost of this activity are:

- Annual capital recovery cost (CRC): US$ 186,939;
- Annual maintenance cost: 20% do CRC;
- Annual administration cost: 10% do custo total;
- Electric power consumption: 228 kW;
- Power cost: US$ 47.06/MWh;
- Cost of 1 person per shift: US$ 1.78/h.

Considering that the cane Dry Cleaning Station will operate as long as the milling tandem is in operation, the total operating costs of the station assigned to the trash are shown in table 6.10. The benefits of processing a cleaner cane are taken in account in the final production data.

Table 6.10 – Trash separation costs.

Items	Baseline	Alternative 1	Alternative 2	Alternative 3
Total operating (days/year)	-	-	233	222
Operating capacity (t db/h)	-	-	23.83	18.75
Trash separation cost (US$/t db)	-	-	2.79	3.69

(db) Dry basis.

Source: Hassuani, Leal and Macedo, 2005.

Concerning the trash transportation to the industry, the cost in alternative 1 can be obtained in a very straightforward manner, just by adding the cost of each activity along the process. However, for alternatives 2 and 3 the trash is transported together with the cane, interfering in the normal process parameters.

The economic model used establishes that the differences in costs of the activities of harvesting and cane transportation between the Alternative in question and the baseline shall be charged to the trash and not to the cane. The trash transportation costs for the different alternatives are shown in table 6.11 below:

Table 6.11 – Trash transportation costs.

Items	**Baseline**	**Alternative 1**	**Alternative 2**	**Alternative 3**
Total transportation cost (US$/year)	6.275.197	6.275.197	9.052.092	6.520.401
Difference charged to trash (US$/year)	-	-	2 776.896	245.204
Total trash at the mill (t/year db)	-	114.902	119.531	89.554
Cost of trash at the mill (US$/t db)	-	-	23,23	2,74

(db) Dry basis.

Source: Hassuani, Leal and Macedo, 2005.

The delivery cost of trash in alternative 1 has been determined as US$ 9.61/t dry basis as result from adding the various activities costs for the whole process, since there is no change in the characteristics of the material (cane + impurities) delivered to the mill as compared with the baseline.

The unit costs (US$/t of trash) of alternative 1 are:

- Trash windrowing: US$ 0.60/t (dry basis);
- Baling: US$ 3.94/t (dry basis);
- Bale loading: US$ 1.43/t (dry basis);
- Trailer towing: US$ 1.18/t (dry basis);
- Bale transportation: US$ 1.95/t (dry basis);
- Bale unloading: US$ 0.51/t (dry basis).

Below, the costs and technical parameters of the material transported to the mill are estimated:

Table 6.12 – Technical parameters and cost of material (cane + vegetal and mineral impurities) at the mill.

Itens	Linha de Base	Rota 1	Rota 2	Rota 3
Mineral impurity (%)	0.11	0.11	0.30	0.19
Vegetal impurity (%)[a]	7.50	7.50	18.22	15.00
Humidity content of vegetal impurity (%)	55.00	55.00	38.00	41.00
Quantity of material (t)	1,301,290	1,301,290	1,511,275	1,445,744
Material transportation cost (US$/t)	4.82	4.82	5.99	4.51

(a) Wet basis.

Source: Hassuani, Leal and Macedo, 2005.

Knowing the final expected production of sugar, alcohol and bagasse; the corresponding selling prices; and the associated production costs, the changes in the industrial processing results can be determined. This difference, in terms of margin of contribution, in comparison with the baseline, for each Alternative, is shown in table 6.13.

It is important to point out that the total cost includes a margin of 10% assigned as administration costs to be on the conservative side. For all alternatives, it has been considered that the trucks would have to obey the truckload limitation by Federal and State Laws. In cases where trucks travel mainly on private or side roads, sugar cane truck load would be increased for the baseline, resulting in an increase of trash costs for alternatives 2 and 3.

Table 6.13 – Trash cost (US$ thousand/year) – Industrial effects.

Items	**Baseline**	**Alternative 1**	**Alternative 2**	**Alternative 3**
Income	18,037.7	18,037.7	18,214.8	18,082.0
Sugar	9,491.1	9,491.1	9,534.5	9,522.7
Alcohol	7,970.5	7,970.5	8,007.0	7,997.0
Bagasse	576.2	576.2	673.2	562.5
Costs	7,488.3	7,488.3	7,530.2	7,499.3
Milling	1,301.3	1,301.3	1,314.9	1,291.8
Sugar fabrication	3,163.7	3,163.7	3,178.2	3,174.2
Alcohol fabrication	3,023.3	3,023.3	3,037.1	3,033.3
Mixed margin of contribution	10,549.5	10,549.5	10,684.6	10,582.8
Difference from the baseline	-	-	-135.2	-33.3
Total trash delivered (t/year)	-	-	119,531	89,554
Trash cost (US$/t db)	-	-	-1.13	-0.37

(db) Dry basis

Source: Hassuani, Leal and Macedo, 2005.

Table 6.14 – Total trash cost (US$/t dry basis).

Items	**Alternative 1**	**Alternative 2**	**Alternative 3**
Delivered trash to mill	9.61	23.23	2.74
Loss of productivity	2.41	-	-
Opportunity cost of trash in field	5.59	5.37	6.50
Trash separation from cane	-	2.79	3.69
Trash processing	0.89	0.85	1.14
Difference of industrial results	-	-1.13	-0.37
Trash total cost	18.49	31.12	13.70

Source: Hassuani, Leal and Macedo, 2005.

7. Conclusions

The ultimate feasibility of agroforestry will depend on the actual impact that it has on farmer economic and physical well-being. No matter how convincingly that biological scientists argue in favor of agroforestry in terms of long-term organic matter maintenance and nutrient recycling, such attributes will remain largely invisible to farmers, extension agents, international donors, and others in agricultural development until they can be translated into tangible lower costs of production and increased output. This will entail numerous challenges, in the years ahead. Valuation of land and labor, as well as agricultural and perennial products, may be particularly difficult in some developing country circumstances. Furthermore, the potential environmental benefits of agroforestry will demand a longer-term perspective than is now common with many contemporary financial and economic analyses.

To conclude, economic and financial analysis can serve three important roles in encouraging agroforestry dissemination. First, through careful *ex ante* comparisons of the cost and benefits of alternative agroforestry investments as well as of *post* studies of implemented activities, the chances for future success can be enhanced thereby improving farmer confidence in agroforestry viability. Second, valid pre-project assessments can become an important vehicle for obtaining outside assistance through a mutual concurrence by host countries and external funding agencies on the project benefits and costs that are likely to be realized. Third, ongoing agroforestry enterprises can be modified and improved through a realistic assessment of financial feasibility and changing market opportunities.

Regarding to the sugarcane production and industry, they have existed for centuries and it is expected to continue to exist for many decades to come; it will even grow stronger when a really free international sugar market creates conditions for cane sugar to take over beet sugar space.

According to Hassuani, Leal and Macedo (2005), considering the present size of the sugar cane industry in Brazil (more than 300 million tons of cane/year) and worldwide (1.3 billion tons of cane/year) and that unburned sugar cane harvesting is slowly, but steadily, becoming more used and has a fully developed and mature technology, the use of bagasse and trash with energetic purposes is enormous. Besides, the use of this technology use can spillover to other renewable fuels such as different agricultural (rice, corn, wheat, etc.) and forestry residues as well as woodchips, from short rotation coppice or planted forests.

The interest in power generation in sugar mills is growing worldwide. In Brazil, it is estimated that an additional 500 MW have been installed in mills in the past three years. In Mauritius and Reunion energy from sugar mills represents a significant fraction of the total electric energy consumption in the islands; in India there is a strong push from Federal and State Governments to implement new power generation capacity in sugar mills.

Therefore, the forces and conditions favoring power generation in sugar/ethanol mills are likely to persist or even grow stronger in the mid and long terms.

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COMPETE Project Coordination
WP7 Coordination - Dissemination

WIP Renewable Energies
Sylvensteinstr. 2
81369 Munich
Germany
Contact: **Dr. Rainer Janssen**
Dominik Rutz
Phone: +49 89 720 12743
Fax: +49 89 720 12791
E-mail: **rainer.janssen@wip-munich.de**
dominik.rutz@wip-munich.de
Web: www.wip-munich.de

COMPETE Project Coordination
WP3 Coordination - Sustainability

Imperial College London
Centre for Energy Policy and Technology
South Kensington Campus, London, SW7 2AZ
United Kingdom
Contact: **Dr. Jeremy Woods**
Dr. Rocio Diaz-Chavez
Phone: +44 20 7594 7315
Fax: +44 20 7594 9334
E-mail: **jeremy.woods@imperial.ac.uk**
r.diaz-chavez@imperial.ac.uk
Web: www.imperial.ac.uk

WP1 Coordination – Current Land Use

University of KwaZulu-Natal
School of Environmental Sciences
South Africa
Contact: **Dr. Helen Watson**
E-mail: watsonh@ukzn.ac.za
Web: www.ukzn.ac.za

WP2 Coordination – Improved Land Use

Utrecht University
Dept. Science, Technology and Society
The Netherlands
Contact: **Dr. Andre Faaij**
Dr. Edward Smeets
E-mail: **A.P.C.Faaij@uu.nl**
E.M.W.Smeets@uu.nl
Web: **www.chem.uu.nl/nws**

WP5 Coordination – Financing

Energy for Sustainable Development
United Kingdom
Contact: **Michael Hofmann**
Stephen Mutimba
E-mail: **michael.hofmann@esd.co.uk**
smutimba@esda.co.ke
Web: www.esd.co.uk

WP4 Coordination – International Cooperation

Winrock International India
Contact: **Sobhanbabu Patragadda**
E-mail: **sobhan@winrockindia.org**
Web: www.**winrockindia.org**

Stockholm Environment Institute

Contact: **Francis Johnson**
E-mail: **francis.johnson@sei.se**
Web: www.**sei.se**

European Biomass Industry Association

Contact: **Stephane Senechal**
E-mail: **eubia@eubia.org**
Web: www.**eubia.org**

WP6 Coordination – Policies

Food, Agriculture and Natural Resources
Policy Analysis Network of Southern Africa
South Africa
Contact: **Khamarunga Banda**
Lindiwe Sibanda
E-mail: **khamarunga@hotmail.com**
lmsibanda@fanrpan.org
Web: www.**fanrpan.org**

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