Agroforestry Systems 7: 17–31 (1988)

Planning optimal economic strategies for agroforestry systems

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Key words: Agroforestry, planning, production economics, linear programming

Abstract. Design of agroforestry systems requires a land management planning process that clearly specifies wants, needs and objectives along with the land's suitability for potential agroforestry practices. Within this planning process economic analysis can be used to analyze agroforestry alternatives to help determine the proper system to apply. Specifically, production economics coupled with capital theory and valuation techniques can provide measures of economic performance in terms of present net values, benefit-cost ratios and internal rates of return. These economic performance measures can be used to determine the best joint production level for a particular agroforestry practice. Once these best combinations have been defined, linear programming can be applied using these 'best' joint production combinations as decision variables along with considering a wide range of additional constraints and requirements. A hypothetical example is used to illustrate the planning process and how these economic tools can be combined as a package to help determine optimal agroforestry strategies.

Introduction

The overall goals of an agroforestry (AF) system are: to improve the existing situation through increasing both the quantity and quality of production, to generate a sustained agricultural products base, to reduce environmental damage, and to raise the living standard of the human population. The purpose of this paper is to outline a planning approach to help determine optimal AF systems that best meet these goals. This planning approach will emphasize the use of several economic concepts and analytical tools and how they fit together as a package in the AF land use planning process.[1]

Table 1. The land use planning process

Systems approach terminology	Major phases	Detailed phases
Set objectives	I. Issue and objective identification	*Identify issues and set objectives* – Define degree of constituency involvement – Define critical issues and their source – Define wants and needs – Define assumptions concerning decision environment – Define set of goals – Define criteria to be used to test performance
System design	II. development of resource system & management options	*Define resource system* – Stratify land base to address issues – Designate management options – Define resources and products – Define suitability for use *Define the responses* – Identify information needs, sources of information and detail necessary – Determine resource and economic responses to management activities
System analysis	III. Analysis of alternatives and decision	*Analyze the resource system* – Define the processes to be used in analysis – Generate alternative management strategies – Define tradeoffs between strategies – Develop a scenario to describe tradeoffs – Test each alternative in terms of meeting criteria of performance – Test sensitivity of changes
Decision and feedback		*Decision* – Select a preferred alternative – Prepare a written plan directive *Feedback* – Describe procedures for monitoring plan implementation and revision when necessary

The land use planning process and agroforestry

Fundamentals of land use planning are the same regardless of the specific land use being considered. Although the overall process may be described in many ways, the major phases shown in Table 1 are: (1) identification of issues and objectives; (2) development of the resource system and management options; (3) analysis of alternatives with a final decision [2].

Using these major phases as a guide, the first step in AF land use planning requires careful identification of issues and objectives considering the wants, needs and priorities of rural people. The central issues ordinarily revolve about rising population and resource scarcity and in this context wants and needs include: food, potable water, building materials, shelter, roads, energy, health care, education and supplemental income. An AF land use strategy must consider these wants and needs in clearly defining objectives.

The second step necessitates determining the land's suitability for various types of AF practices. This requires a land classification system considering both biophysical as well as legal and social considerations [3]. This classification scheme may define certain areas to be more suitable for singular uses (e.g. agricultural crops, forests) while others may be best suited to joint production (e.g. AF). Those areas determined suitable for AF systems must be analyzed to determine their capability for various production possibilities in light of differing soil productivity and topographic conditions.

Once land has been classified, the next step involves defining management options. Agroforestry management options should be matched to those areas which are suitable, biophysically speaking, while also considering the current land use patterns, as well as the villages' institutional framework, customs and traditions. In order to facilitate adoption and eventual implementation plans should consider AF practices that are adaptable, simple, low risk, sustainable, applicable to wide areas, and acceptable to the majority. In short, to insure implementation the management options should meet the objectives and serve the wants and needs of the people as well as be suitable for the land base.

Given the previous steps have been followed, the last involves analysis to determine the best or optimal strategy to use. This phase relies heavily on the use of economic tools and concepts to answer (1) what is the optimal or best joint production possibility for a specific AF management option?; and (2) what is the best or optimal mix of AF management options to apply to a given area? The analysis tools used to help answer such questions may involve production economics, capital theory, valuation techniques, benefit-cost analysis and linear programming.[2]

The remainder of this paper illustrates an application of the land use planning process to village-level agroforestry problems with special emphasis on how the economic analysis tools are linked together to form an analytical package for planning.

Economic tools for AF planning

Economics is the study of how societies choose to employ scarce resources to produce commodities, then distribute them for consumption. Economic analysis helps determine the 'What? How much? and For whom?' of production. While economic analysis can apply to a wide spectrum of problems, from the national level to the small-scale enterprises, we will concentrate on economics as it pertains to an AF system at the village level.

Benefits, costs and valuation

Most economic analysis tools require some monetary measure of costs and benefits. Typically there are both public and private costs and benefits associated with AF systems. The basic difference between the two is that private benefits and costs ordinarily are 'internalized' into a particular production unit while in the public arena they generally accrue to society as a whole and are 'external' to the production unit. For example, an AF system might increase an individual farmer's personal income, a private benefit, and at the same time lessen siltation downstream from his property, a public benefit. A more complete listing of AF public and private benefits and costs is given by Arnold, 1982 [1].

Given the nature of some AF benefits and costs they may not always be easily quantifiable in monetary terms. For example, in subsistance farming, market values for products and production inputs may not exist. In these instances 'proxies' for the items' value might be used. For example, if no market price exists for fuelwood it might be valued by the labor time required to collect it or the cost of a substitute fuel such as kerosene. The value of the fodder might be estimated by the increased amount of cattle production or tree litters value by its effect on crop production or the cost of substitute fertilizers. The monetary benefits of erosion control could be measured by the difference in value between undegraded vs. degraded lands. While these valuation approaches do not reflect true market value they can be used to derive monetary estimates necessary for an economic analysis. It should be recognized that these type 'valuation' techniques may often be needed in economic analyses of AF systems.

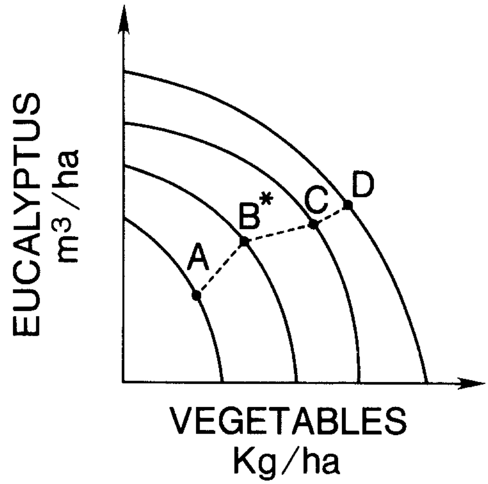

Fig. 1. Joint production possibilities curves for four cost outlays. The points that are lettered on each curve represent the optimal (highest PNV) combination for that cost outlay. The line (---) denotes the 'expansion path' or optimal combination as inputs or costs are increased. In this case point B has the highest PNV of the four and is the best joint production combination overall. This AF practice would be a candidate for a decision variable in an AF linear programming model. Note that the corner points of each curve represent singular production of either Eucalyptus or vegetables at that cost outlay.

Agroforestry systems represent simultaneous mixing in both time and space of some combination of perennial and annual plants and/or animal production. The basic premise of an AF system is that total net benefit is greater where joint rather than singular production exists. In economic terms this is a joint production enterprise. Several authors have studied the use of joint production economics in analyzing AF systems [6,7,9,10].

It is important to recognize the various possibilities of AF joint production. First, there are many distinct combinations of AF products that might be jointly produced such as honey and fruit trees where an increase in fruit trees also increases honey production (called complementary production); or coconut and cocoa, where increasing coconut production has little influence (to a point) on cocoa production (this is called supplementary production); or Eucalyptus and vegetables where an increase in Eucalyptus will decrease vegetable production (called competitive production). Within each of these different categories there may be several distinct tree/food crop production combinations. The land use process described earlier can be used to help decide which particular tree/food crop might be applied and where.

Second, once a tree/food crop species is defined, each must be analyzed to determine the best product combination (of many) to produce. For example, for a given cost outlay several different combinations of Eucalyptus and vegetables may be produced. Given the value of Eucalyptus and vegetables, one particular combination maximizes present net return (Fig. 1, point A).[3] For another tree/food crop, like Eucalyptus and maize, the same cost outlay might yield a different optimal combination and net return. Thus, proper AF planning would consider this type analysis for all the different AF practices deemed suitable for the area and that have the same cost outlay.

The analysis above considered only one level of cost outlay. As inputs and costs are expanded there will ordinarily be an increase in the amount of joint production. Thus, as a third step in applying production economics it is necessary to determine what is best overall in terms of maximizing net returns while increasing cost outlays (for example, when applying additional fertilizer). The optimal production combinations as costs are increased is defined by what is called the expansion path. Of the several joint production possibiliies as cost are increased, only one point on the expansion path may be best overall (Fig.1, point B*).

Discounting and present net value

The typical AF practice such as those mentioned above, involve multi-period production with monetary investments and returns occurring at different points in time. The analytical tool used to analyze such problems involves capital theory and the process of discounting to determine present net values (PNV). The various joint production possibilities discussed earlier may each have a different time stream of costs and returns and, correspondingly, a different PNV.

In order to use discounting, monetary estimates of benefits and costs are needed as well as a rate to use for discounting these monetary values. The rate to use may be based on such factors as the rate of return for the investors best alternative investment (equity), the rate paid for borrowed capital (debt), or a rate based on some mix of debt to equity. In many instances these approaches to determining rates for investments are not applicable to AF, particularly in the case of subsistance farmers. In these cases, Hoekstra (1985) has suggested using time preference rate based on several factors regarding the farmers current status, his outlook, the risk of the AF practice being unsuccessful, and the length of time to wait before consumption [8]. Using this approach under conditions where the farmer is well fed, and foresees future production problems without AF, and where the AF practice is proven, has low risk and yields crops soon, the farmer's time preference rate should be low and PNV higher. Opposite conditions will give higher time preference rates and subsequently a lower PNV.

While the time preference concept provides some indication of the relative magnitude of the rate it does not specifically quantify the rate to use. Thus, it might be coupled with the use of some of the other techniques (e.g. best alternative rate) mentioned earlier. In any case, because of the difficulty in specifying discount rates, AF practices ought to be analyzed using a range of rates to determine whether the selection of the 'best' production combination is sensitive to the rate being used.

Internal rate of return

As with PNV, the internal rate of return (IRR) can be used to measure economic performance of time-related investments. This particular rate of return is the rate which results in the PNV being 0. Its the maximum rate of return possible or, in the context of the previous discussion, the maximum time preference rate for the farmer. The key benefit of using IRR's to compare AF investments is that no specific time preference rate must be determined. However, its sole use cannot be recommended as it ignores the timing and relative magnitude of costs and returns.

Benefit-cost ratios

As with PNV, benefit-cost ratios (B/C) require discounted values for benefits (returns) and costs and therefore a discount rate or time preference rate is necessary. Benefit-cost ratios are simply the ratios of discounted benefits to discounted costs. It is the monetary benefit per unit of money (e.g. dollar) invested. Benefit-cost ratios do provide additional economic information useful to determine the 'best' AF practice. For example, PNV values alone are a net value that says nothing about the relative magnitude of benefits and costs. Two AF practices may have the same PNV but have quite different B/C ratios. Under these conditions which practice is 'best' depends on the goals, objectives and constraints involving the AF system.

Linear programming

The economic tools discussed thus far can be used to analyze particular AF joint production possibilities. To use these tools, benefits and costs must be defined, and the many different production possibilities should be analyzed using criteria such as PNV, IRR and B/C. Properly applied, these analysis tools can help identify the best agroforestry practice to apply and its scale. However, within this analysis we have ignored certain other constraints and requirements that may exist. For example, there may be (and probably are) limits on land, labor, and budget available, as well as requirements for certain production levels of fuelwood or nutritional elements. These must also be carefully considered in the analysis. Linear programming (LP) is an analytical tool which can be used to analyze AF systems where such conditions exist. Considering these additional constraints and requirements we can determine through LP, whether a *mix* of these 'best' AF practices (specified through joint production analysis) is optimal overall. Although LP has been applied to a wide variety of forestry/agricultural problems, to date there have only been a limited number of AF applications [4,5,11]. The next section describes, through a simplified hypothetical example, how these economic tools may be applied individually and combined as a package to determine an 'optimal' AF system.

An AF application of the planning process and economic analysis

The scenario

In this example, we'll assume the village is experiencing an increase in population and major concerns involve food production, fuelwood for cooking and to a lesser extent, supplement income. Most of the fuelwood has been collected from native forests where supplies have now been depleted and deforestation is considered a major concern. The food crops now grown are provided by 'Cottage' type arrangements which include some combination of vegetable, grain and cattle production. The current production is limited by available land, labor shortages during certain seasons and money available for materials, seeds, etc. Although farmers are fairly well fed now, the rising population and general downward trend in current crop production are foreseen to be major problems. In particular malnutrition points to a nutritional need of more protein in the diet.

Goal

The overall goal is to satisfy the village's food and fuelwood needs.

Land suitability

Given the goal the land must be classified, on the basis of soil productivity, topographic conditions and proximity to village population. The primary population is located along a river bottom with productive soils and gentle slopes. These areas are best suited for singular production such as open grown crops, particularly vegetables. Adjacent to the village, the landscape is rolling with the soils having fair productivity. These areas are considered suitable for application of AF practices. Other areas surrounding the village have steeper slopes with soils subject to erosion. These sites are not considered suitable for cultivation and should remain as native forest or reforested as appropriate.

Management options

Management options are assigned to the sites based on the site's suitability as defined above. We'll concentrate on the rolling terrain adjacent to the village since it is best suited for AF management options. Given the goals, current production patterns, village customs and traditions as well as land suitability two AF management options are determined to have potential – either intercropping Eucalyptus with beans or with maize. In this case, a three-year rotation for Eucalyptus is chosen in order to reduce risk and achieve the benefits in terms of additional fuelwood soon. This should help to gain acceptance of the practice by the farmers.

Benefits, costs and valuation

There are local market values for beans (.50 US/kg) and maize (.25 US/kg) but none for fuelwood. Since there are no fuelwood market values, Eucalyptus fuelwood value will be based on the number of labor hours necessary to collect an equivalent amount of fuelwood from existing native forests (equivalent to 30 US/m^3). Other 'indirect' benefits which will not be valued but should be considered include rehabilitation of the native forest, lowering risk of crop failure through crop diversity and reducing erosion.

Costs in this case are based on material costs (seeds, seedlings, fertilizer, hand tools, etc.) and labor (planting, weeding and harvesting).

Discounting, PNV, B/C

The benefits and costs occur at different times over the three-year rotation period. Thus we need to apply discounting to properly evaluate the investments. In order to apply discounting we need a time preference rate. In this case, the fact that farmers are fairly well fed now but perceive future crop and fuelwood supply problems points to using a lower time preference rate. In addition, the villagers are now making long term investments in cattle production. This indicates lower rates are acceptable. Therefore, in this instance we chose 6%/annum as an initial rate to use to calculate PNV and B/C values.

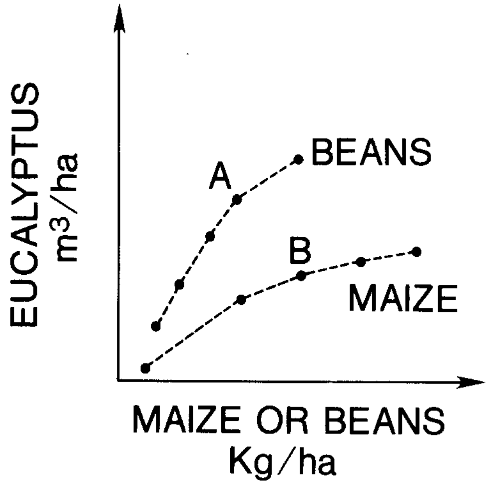

Fig. 2. Expansion paths (---) for two AF practices. The expansion path denotes the best (maximum PNV) joint production combination for each cost outlay. Point A represents the "best of the best" or best overall joint production combination for Eucalyptus and beans. Point B is the best overall for Eucalyptus and maize.

Joint production

Each AF management option, Eucalyptus-beans and Eucalyptus-maize, may have varying densities of Eucalyptus and thus different yields of both the food crop and Eucalyptus over the three years. These different combinations could exist given the same total cost. As costs are expanded, in this case by applying fertilizer, a whole new set of production possibilities can occur.

Figure 2 illustrates the two AF practices joint production possibilities showing variations in Eucalyptus densities and food crop yields. Each point represents a different cost outlay. Costs and Eucalyptus/food crop yields increase with the application of fertilizer. Within each practice there is one "best" combination for each cost outlay and one best overall when costs are varied. Determining which AF practice is best involves comparing the PNV, B/C and IRR for each combination. Table 2 gives figures for an economic analysis of one joint production possibility for each practice (labeled points A and B on Figure 2). The figures in Table 2 illustrate how economic analysis may indicate one practice is better given a certain economic criterion while another is better when using a different criterion. For example, here Eucalyptus-beans has the largest PNV whereas Eucalyptus-maize has the largest B/C ratio. Choosing one over the other depends on the situation. If there is limited dollars available one might choose Eucalyptus-maize because this AF's total costs are less and the dollar return per dollar

Table 2. Joint production yield information and economic analysis of one production possibility for each AF practice.[a] (Points A and B in Figure 2)

	AF practice					
	Eucalyptus-beans (Point A)			Eucalyptus-maize (Point B)		
Production Costs & Returns	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
Food crop (Kg/ha)	550	400	0	1200	800	0
Eucalyptus (m^3/ha)	0	0	15	0	0	10
Costs/ha ($)	100	80	100	75	60	90
Returns/ha ($)	275	200	450	300	200	300
PNV/ha ($)	551			501		
B/C	3.1			3.4		
IRR (%)	17.5			29.0		

[a] Costs are assumed to occur at the beginning of the year, returns at the end. A single payment discounting formula is used $\left(\frac{1}{1 + i}\right)^n$ where n is the number of years in the future and i is the time preference rate.

invested (B/C) is greater (even though the PNV is less compared to Eucalyptus-beans).

If we analyzed all the possibilities for a given cost outlay as well as those for greater cost outlays we could develop an 'expansion path' for each AF practice. This expansion path depicts the best production combination for each cost outlay. There is one combination along this path that is best overall (highest PNV). This represents the 'best of the best' of the joint production possibilities from a PNV standpoint, (see Fig.2). In this case, the best combination along the expansion path are those shown in Table 2.

Linear programming

The economic analysis tools used to this point have defined the best joint production combinations for specific agroforestry practices. However, in this analysis we did not explicitly consider the additional constraints or requirements as stated in the scenario. These might affect our AF practice selection. Using LP we now add these constraints and requirements to the problem while using the 'best of the best' of the AF practices as alternatives or decision variables.

Table 3 shows the amounts of resources available and product requirements for this case. In addition, the amounts of resources used and AF products produced are given for each AF practice (on a per ha basis).

The LP formulation of this problem is:

x_1 = ha of Eucalyptus-beans

x_2 = ha of Eucalyptus-maize

maximize PNV = $551x_1 + 501x_2$

subject to: $150x_1 + 125x_2 \leqslant 900$ labor hours

$280x_1 + 225x_2 \leqslant 1200$ budget dollars

$15x_1 + 10x_2 \geqslant 60$ fuelwood m^3

$250x_1 + 200x_2 \geqslant 900$ protein Kg

$x_1 + x_2 \leqslant 5$ land ha

Using LP we can now determine what is best given the objective of maximizing PNV but now allowing for a mix of the two 'best of the best' AF practices while considering constraints and requirements as specified by the villager.[4] Although this simple problem may be solved graphically, a computerized package LINDO was used to solve the problem.[5]

The LP results below show the solution that is best given the objective and constraints/requirements:

Objective function

Total PNV $2483

Optimal production

Eucalyptus-beans 2.6 ha

Eucalyptus-maize 2.1 ha

Resource constraints

	Amount used	*Amount unused*	*PNV Value of one more unit of resource*
land (ha)	4.7	.3	0
labor (hrs)	652	248	0
budget ($)	1200	0	3.48

Production requirements

	Amount produced	*Amount produced over requirement*	*PNV value for relaxing requirement by 1 unit*
fuelwood (m^3)	60	0	28.4
protein (kg)	1070	170	0

PNV/ha

	Allowable change in PNV/A	
	Increase	*Decrease*
551 (Eucalyptus-beans)	72	∞
501 (Eucalyptus-maize)	∞	58

The LP solution indicates applying a mix of two practices is optimal. Beyond this the LP provides other information important to analyzing the problem. For example, everything else being the same, land and labor are not constraining the solution (there is some amount unused), thus the farmer might consider the unused amounts for use elsewhere. On the other hand, all the budget is used, and one more dollar of budget is worth \$3.48 in terms of PNV. This is a fairly substantial return per dollar invested and the farmer might consider a loan, if possible, to increase production. The fuelwood requirement (of producing at least 60 m^3) is reducing the ability to make more in terms of PNV. The farmer might consider buying fuelwood (if a market exists). In this case, he could afford to pay up to \$28.35/m^3 and be better off. The protein requirement was met, in fact 170 more Kg of protein was produced over that needed. Thus the farmer could consider selling some of the food crops. Finally the LP provides a sensitivity analysis showing the ranges of values for objective function coefficients and constraint right-hand side values such that the solution (basis) stays the same. All the sensitivity analysis is not shown here but the sensitivity analysis for PNV values indicates a \$72 increase in the PNV/ha for Eucalyptus-beans and a \$58 decrease in the PNV/ha for Eucalyptus-maize might change the solution. These are fairly small changes so if the time preference rate, or any other economic or production figure we used here is not considered accurate the LP sensitivity analysis indicates we had better reanalyze the problem with other estimates as the optimal production solution may change.

Table 3. Constraints and requirements[a]

Constraints	Amount of resources used or Product produced (per ha) Eucalyptus-beans	Eucalyptus-maize	Total amt. required/ available
Land (ha)	1	1	5
Family labor (hrs)	150	125	900
Budget (\$)	280	225	1200
Fuelwood (m^3)	15	10	60
Nutritional protein (Kg)	250	200	900

[a] All figures are the total for the three-year production cycle

Conclusions

Proper specification of optimal AF systems requires the application of a land use planning process. Within this process economic analysis techniques can help to determine the best AF approach to use. Production economics concepts coupled with using discounting, valuation and benefit cost analysis can be used to provide estimates of the best production combinations. In turn, these best combinations can be used as decision variables or alternatives in a linear programming model that considers additional constraints and requirements. The LP analysis then specifies what is best in the broader context of the problem. Coupled together as a package these economic analysis techniques provide guidelines for developing optimal AF strategies. The analysis does require substantial data and time and effort. However, if performed properly, a rigorous analysis such as that described here can aid in determining what AF practices ought to be applied given a particular set of circumstances.

Notes

1. This paper is based on presentations given by the author in 'Economical Analysis of Agroforestry Systems' at the International Short Course in Agroforestry, 1986, held at Colorado State University.
2. It should be noted that the first two phases in this process are similar to the 'diagnosis' procedures discussed by Huxley and Wood in ICRAF Working Paper No. 26. The last phase is similar to what is mentioned as 'design' in their work.
3. MULBUD is a computer program to analyze AF production and economic options. It should be noted that one particular combination (single point on each production curve) might be one option in a MULBUD run. Thus it is clear that a complete analysis such as described above could require substantial data and analysis.
4. We could also use different objectives in the LP such as maximizing B/C or maximizing protein production. Further, the LP analysis could be expanded to include the other lands classified for singular production of either foodcrops or forests.
5. LINDO – Linear, Interactive Discrete Optimizer; Schrage L. 1982, Scientific Press, 670 Gilman Street, Palo Alto, CA 94301, USA; available for personal computers.

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