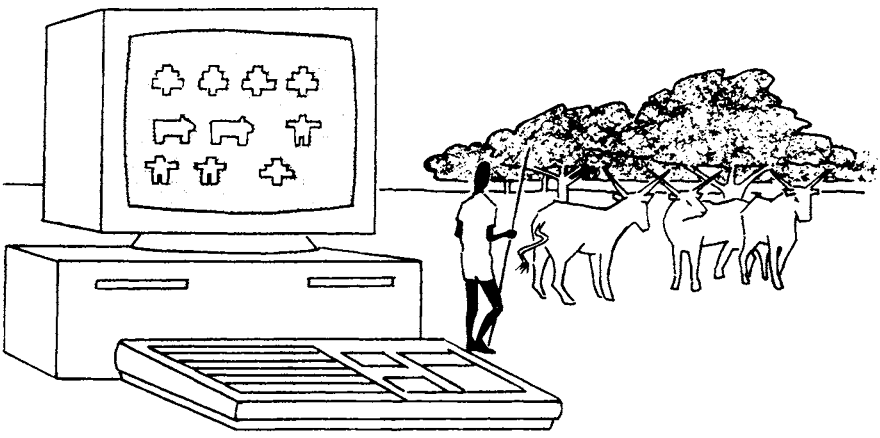
CHAPTER 3

ECONOMIC MODELLING FOR AGROFORESTRY SYSTEMS



A SPREADSHEET APPROACH TO THE ECONOMIC MODELLING OF AGROFORESTRY SYSTEMS

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CONTENTS

Introduction

This paper is divided into two parts. Section A is concerned with methodological aspects of the economic evaluation of a system of multiple land use in which agricultural and forestry enterprises are undertaken on the same area of land. It begins by describing the general approach and assumptions adopted and then proceeds to outline in detail key components of a computerised spread sheet model embodied within the VP - Planner package. This allows a large number of parameters, both technical and economic, to take on a range of possible values thus enabling an assessment of the sensitivity of profitability to changing technical and economic conditions. Section B presents the results of applying this methodology to a poplar, cereals and sheep agroforestry system, primarily to demonstrate its flexibility. Finally some conclusions are drawn as to the proper context within which a spreadsheet model such as this can operate.

SECTION A

1. The General Approach

The approach adopted here has been for both forestry and agricultural components to:

a. Identify relevant inputs.

b. Quantify their levels for assumed output levels consistent with specified site conditions.

c. To simulate 1) The growth of physical timber volume
2) The decrease in physical agricultural output consistent with this growth.

d. To calculate costs and revenues associated with both activities on an annual basis using input and output prices applying in a specified year.

e. To use Discounted Cash Flow Analysis for the purpose of calculating the Net Present Value (NPV) from:

(i) All Forestry
(ii) All Agriculture
(iii) Agroforestry on equivalent areas of land.

2. Assumptions relating to the approach adopted

(i) This analysis is confined to 1 ha 'cells' of land apportioned to varying fractions between agriculture and forestry. The fractional area occupied by agriculture is determined at the outset by assumed tree planting and inter row widths.

(ii) The analysis is conducted for a specific rotation length, though this of course can be varied to determine optimum rotations.

(iii) It is assumed the actual area of agroforestry within the farm is not of a sufficiently large extent to justify an alteration in fixed costs. Practical experience on farms in New Zealand stresses the importance of never planting at any one time an area of trees whose silvicultural needs in terms of thinning and pruning cannot be adequately coped with by the farm staff. By establising uneven age stands to a maximum of round 15% of the farm area this criterion can be met.

(iv) For certain specific operations relating for example to timber felling, cross cutting and extraction, additional capital items may well be required. In order to avoid difficulties associated with depreciating farm and forestry mixes of equipment, much of which may well already exist on farms, the approach adopted here is to use contractors for these operations.

(v) In the example illustrated in Section B the analysis is conducted throughout 1987, costs and prices at an assumed real interest rate of 3%. Inflation is assumed to affect both components equally in terms of costs and output. Sensitivity analysis enables scenarios which postulate changes in relative product prices and costs to be explored.

3. The Model

A schematic representation of its components is presented in Figure 1. Some additional comments relating to certain components are presented below.

a) Grower

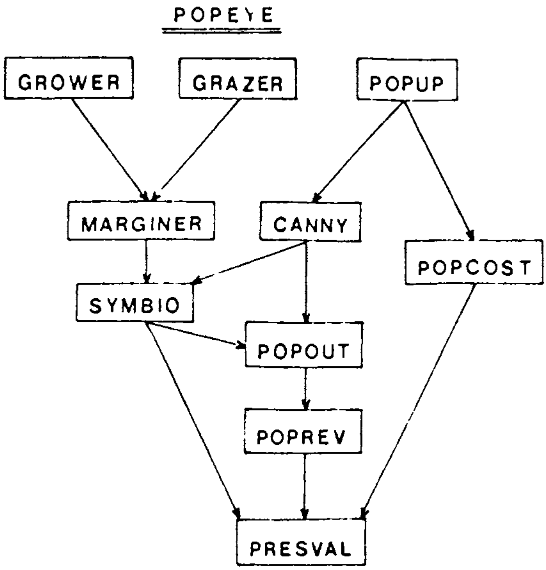
At present this is a user estimate of physical yield based on a visual inspection of the site in conjunction with data relating to soils, geology, topography and bioclimatic data. Input levels are assumed to be consistent with output levels. Eventually 'grower' will comprise a range of response curves which will be selected by the user and reflect differences in production levels according to site capability.

b) Grazer

Similarly what exists at present is a visual inspection of sward type. Dry matter production per ha, consistent with climatic and soil conditions, is assessed, as is its Metabolisable Energy (ME) value per ha. Stocking Density is then calculated on the basis of animal requirements consistent with an assumed level of livestock performance. It should be apparent therefore that site capability is an important element in the sensitivity analysis afforded by the spread sheet.

c) Popup

This is a timber yield model which describes the volumes of timber per ha. as a function of (i) the number of stems per ha.(ii) the diameter, height and form of individual trees. Tree diameter (D.B.H) varies with spacing at a given age and tree height varies with age but is largely invariant with spacing. Using widespread Poplar as an example, it is possible using stand tables to provide a range of values for spacing, age and tree diameter when which analysed by Multiple Regression Analysis can be used to predict both DBH and Tree height as a function of age.



GROWER. Estimates yield on the basis of site characteristics
GRAZER. Identifies sward.Calculates D.M. per ha. Estimates ME values of swards. Calculates stocking rate.Estimates performance level.
POPUP. Estimates Stem Diameter and height from spacing and age.
POPCOST.Details inputs and factor prices required for all planting. Silvicultural and harvesting operations. Calculates timber costs per ha. per year for any specified planting regime.
MARGINER. Converts Grower and Grazer to equivalent Gross Margins (£/ha).
CANNY. Estimates crown diameter from stem diameter and crown depth from POPUP for any specified pruning regime
SYMBIO. Reduces agricultural gross margins per ha. with increasing crown development. Alters annual basal area increment as required.
POPOUT. Estimates timber volume on the basis of Buttlog Volume and Toplog volume per ha.
POPREV. Includes grants, all product prices and calculates revenues per ha. per year of rotation for any specified planting regime.
PRESVAL.Calculates net cash flows per annum and uses these to give Net Present Values (NPV) per ha. for a range of real discount rates 'All Agricultural', All Forestry and Agroforestry' options are compared.

Notes All input and outputs are included as variables in both physical and financial forms. Thus changes in technical input/output coefficients, factor and product prices can be examined in terms of their impact on NPV.

Figure 1 Popeye: A Schematic Representation

This yields equations of the general form

$$D = a + b \ln (A.S) \qquad (1)$$

where

D = diameter at breast length (1.3m)
A = age of tree in years
$a\&b$ = constants
$\ln$ = natural logarithm
S = tree spacing in metres

and

$$H = a + b(A) + C(A^2) \qquad (2)$$

where

H = Dominant Tree height in metres
a,b&c are constants
A = Age of Tree in years.

d) **Popout**

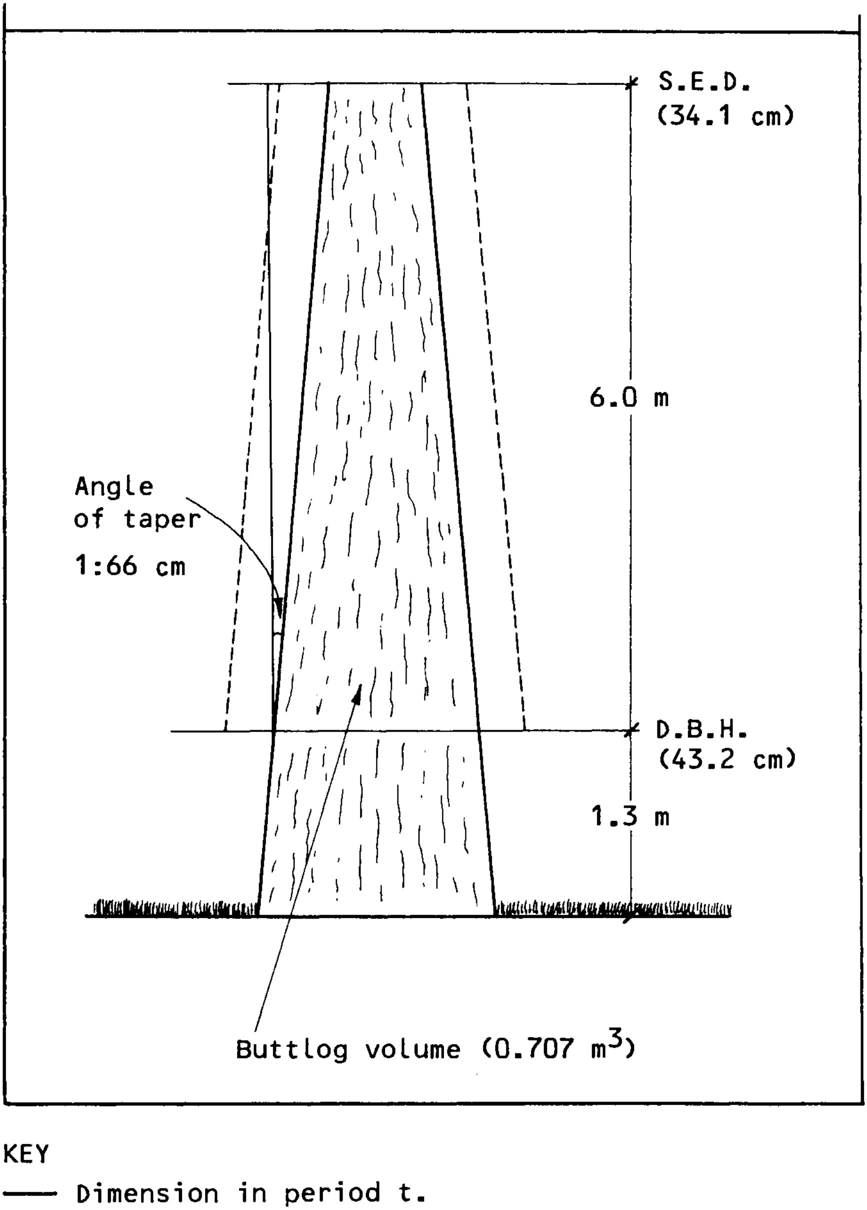
This component adjusts individual tree volume by a) introducing a range of 'taper' functions, b) calculating ' small end diameter' (SED) at any specified pruned height, and c) distinguishing between 'buttlog' and 'top log' volume. These features are illustrated in Figure 2.

'Butt log' volume is considered to be represented by the 'frustram of a cone' whose volume is given by

$$B = \frac{\pi}{12} (D^2 + Dd + d^2)\ h. \qquad (3)$$

where

B = butt log volume measured in cubic meters
D = diameter at Breast Height (1.3m)
d = 'small end' at 'top' diameter at a given height
h = dominant tree height in metres



KEY

—— Dimension in period t.

--- Dimension in period t+1.

Figure 2 The Form Characteristics Predicted by the Model Poplar (22 Years)

Top Log Volume is assumed to be represented by a 'cone' whose volume is given by:

$$T = \frac{\pi d^2 h}{12} \qquad (4)$$

where

T = Top log volume measured in cubic metres
D = diameter measured in metres
h = dominant tree height measured in metres

Form characteristics are an important aspect of open grown trees since these tend to produce greater taper and thus a loss in volume with increasing tree height. Pruning can reduce this effect by effectively pushing the cylindrical component further up the stem. It is obviously essential to achieve as high a volume of timber production from the buttlog as possible since pruned timber carries a much higher price premium. This can also be achieved by breeding. Certainly the latest Belgian poplar clones can have form factors as high as 0.5 (Van Slycken pers. com. 1989) when compared with a 'conical' form factor of 0.33. The Spreadsheet allows tree form to be altered across a range of taper functions.

Finally, top log and bottom log volumes are multiplied by their appropriate prices depending on their final end use. Within a market economy, price quotations for sawlogs based in larger diameter classes are obtainable, though precision in terms of a price size relationship varies enormously from country to country. It is particularly poor in the UK, better in Europe and much better in Australia, Chile and New Zealand where greater emphasis is placed on larger diameter logs (Thomas et al 1989). However, a subsistence economy presents greater problems in terms of product valuation.

e) **Canny**

This component uses an acknowledged relationship between crown diameter and stem diameter to simulate the dynamics of canopy development. The theoretical basis for this relationship can be found in the 'stove pipe' theory of plant growth (Franco 1987). Dawkins (1963) distinguished between a range of tropical species in terms of their ability to tolerate competition from other crowns whilst still maintaining diameter growth. More recently Kalibala (1988), Pryor (1985), Garson (1988) and Saville (1988) have determined crown diameter:stem diameter equations for a range of common British species following the general form:

$$D = A + B(DK) \qquad (5)$$

where

D = diameter at breast height measured in centimetres
DK = crown diameter measured in centimetres
a&b = constants

In this spreadsheet model the causal relationship is reversed so as to predict tree crown diameter from tree stem diameter in (1). However the nature of 'fit' is normally so good between these two variables this is not statistically a problem.

Crown diameter, and indeed crown depth are important information. Crown depth is predicted from tree height less any adjustment for pruning as and when it occurs.

f) **Symbio**

This component deals with positive and negative interactions between tree and agricultural activities. Dealing with negative interactions first, agricultural output declines as a result of tree growth and its associated increase in shading. This can be coupled with underground effects concerned with reduction in soil nutrients and water availability through increased root competition, for example Castellani and Prevosto (1967), (Atkinson 1988). Additional negative interactions may be concerned with bark stripping, browsing of young trees and increased parasitic infestation in animals.

Secondly, considering complementary effects, these may be manifested in an increased tree basal area increment of up to some 40% due to fertilising effects of grazing animals and reduced understorey competition (Knowles and West, 1987). Agricultural livestock productivity may be increased by up to 20% as a result of shelter or shade effects as reflected in higher lambing percentages or increased stocking rates (Reid and Wilson 1985). Similarly, trees may actually prolong pasture productivity within a season due to an amelioration of land drying by wind or direct sunlight. Variations undoubtedly exist between tree, grass, and animal types in terms of the nature of these interactions. For example not all trees are damaged by livestock and neither do all livestock damage trees. Similarly not all trees benefit from livestock grazing, indeed for poplar for example some evidence suggests the opposite (Anon 1986). By contrast, for the same genus light cultivations can significantly enhance the mean annual increment of timber volume (Anon 1977). Trees vary in terms of their ability to withstand heavy pruning regimes and maintain diameter growth. Evidence suggests however that price premia for clear wood (Price 1989) at least match in total revenue terms the reduction in volume which can arise, and grazing revenues are maintained.

Other differences in tree species with respect to the seasonal timing of their leaf development when compared with understorey development will significantly effect reduction in pasture production. Moreover seasonality of pasture production is itself likely to be site specific, at least in regional terms. In Wales for example, leaves tend to emerge when grass production is already well underway. The duration of the canopy is short and opacity of the canopy much lighter than when compared with, let us say, sycamore.

All of these aspects suggest a complex mix of positive and negative interactions which ultimately may result in a positive net effect on the side of agroforestry in terms of total production.

This very brief review of the real world 'black box' of interactions which is conceptually encompassed by SYMBIO serves to illustrate the likely complexity of interactions. There are also many gaps in the information available and many compartments needed to accommodate known and potential effects on output levels. As time progresses and information becomes available the relative importance of these various interactions under a range of topographic and climatic conditions will be better understood and estimates of technical parameters will be improved. Once a spreadsheet exists, however, it becomes easier to accommodate such progress within it.

This spreadsheet currently encompasses two broad types of interaction. Firstly negative interactions caused by shading out of the understorey with increased canopy development through time. Secondly, complementarity, or competition as reflected in the rate of annual change in timber volume per ha.

Taking the latter first the effect on timber volume can be accommodated by adjusting equation (3) as follows:

$$C_B \quad \sum_{t=1}^{r} \left[\frac{\pi}{12} \left(D^2 + Dd + d^2\right) h \right] c \qquad (6)$$

where

C_B = the total increase in timber volume per butt log

t = the start of the period over which the effect is assumed to occur

r = the end of the period over which the effect is assumed to occur

c = the complementarity or competition factor expressed as a decimal with appropriate sign attached

Such evidence as exists, for example (Knowles 1988) suggests that complementarity of this type occurs in the period prior to canopy closure though the effects of cropping and grazing may be quite different. The above equation effectively allows for a partitioning of the rotation into whatever periods are thought to be appropriate, with associated values for the complementarity or competition factor.

Considering now the matter of simulating the decline in agricultural production over time, a number of approaches have been used. In New Zealand for example, it has been observed that decreases in annual dry matter production appear to correlate well with green crown length and the number of crowns per ha This approach makes intuitive sense in that in higher latitudes, conical and columnar shapes cast longer shadows hence the importance of crown diameter and crown depth as variables. Alternatively, more fundamental approaches utilise light interception models. Some are forestry orientated in terms of planting designs, (eg Kauluvainen and Pukkala 1982). Others require information describing the opacity of the canopy as measured by leaf area index and crown dimensions at wide spacing (Jackson and Palmer 1979), (Slatterlund 1983). The latter in particular give rise to difficulties associated with spatial arrays of trees, a paucity of information existed until recently of the crown dimensions of trees and the horizontal distribution of shade associated with direct as opposed to diffuse sunlight.

Given these limitations, two approaches are currently available in this spreadsheet. The first can best be described as a sensitivity approach. The pasture component when viewed in general terms, follows a well developed pattern of declining productivity. There is an initial period of shade free years during which the level output is unaffected and can be characterised as a plateau, or may well increase. This is followed by a rapid decline in output, offset to varying degrees by thinning and pruning operations, before a lower plateau is reached as a result of canopy closure. The researcher effectively uses whatever sources of information are available to him to locate the upper plateau in horizontal space, ie. thereby defining the shade free period. The lower plateau has also to be located in vertical and horizontal space. These two plateaux are then linked by mathematical functions which best describe the rate of agricultural output decay through time. In Fig. 3 we see both plateaux located and representing an initial shade free period of two years and a lower plateau level of some 30% of open grazing. Both are connected with a combination of cereal and pasture decay functions derived by fixing equations to data pertaining to a poplar, cereals and sheep system found in the West Midlands of England (Beaton 1987).

The grazing decay function fits the data well and is represented by an equation of the form:

$$Y = A+Be^{-Kt} \qquad (7)$$

where

Y = a coefficient of decay expressed as a decimal
A,B and K are constants
t = time

The crop decay function also fits the data well and is represented by an equation of the general form

$$Y = \left(A \frac{100}{P(T+T^2)}\right) \qquad (8)$$

Where

Y = a coefficient of decay expressed as a decimal
A and P are constants
T = time

In Equation (7) and Fig. 3 the initial (shade free) plateau is represented by A+B, the final plateau by A and the proportional rate of decline by K. Provided A and B can be defined, it is possible to estimate how changes in the value of K influence yield at chosen times in the period of change. Moreover different scenarios relating to the difference between the temporal position of the upper plateau and horizontal position of the lower plateau can be examined in terms of their impact on agricultural output for a given tree species and planting regime.

There may of course be no secondary sources of data available since the system may have never been operated. Some form of biological modelling must then be necessary. Current work on light interception under ash trees in Southern England (Newman pers. comm.) suggests that a diffuse light situation falling vertically on opaque tree crowns is likely to approximate conditions prevailing there for over sixty percent of the time and particularly so in the period in which understorey growth is most pronounced. A similar situation might conceivably exist in the tropics. Provided that crown diameter can be predicted from stem diameter, the proportion of unshaded area at any point in time in any tree planting grid can be calculated and agricultural production adjusted accordingly. The logic of this approach is presented in Fig. 4 which illustrates canopy development with triangular planting designs. The spreadsheet enables the user to vary the spacing of trees thus increasing or decreasing the proportion of unshaded area.

The user may of course wish to crosscheck the results of both approaches. Indeed, using the sensitivity approach in the Poplar example discussed earlier, the lower plateau represented some 30% of open pasture grazing productivity, a fact confirmed by short term grazing rentals under trees being approximately one third of those of open pasture. By contrast, applying Newman's diffuse light model to the same planting configuration puts the lower plateau at approximately 10 percent higher. Immediately the researcher is looking for factors which have been omitted and here the answer very probably lies in the area of underground effects, whatever these may eventually prove to be. The important thing we as economists are doing is setting upper and lower boundaries to the position of the lower plateau and assessing their significance in terms of economic effects.

g) **Pop cost**

This component is basically an inventory of all input requirements for planting, protecting, weeding, silvicultural operations and harvesting. All inputs are expressed in physical terms and multiplied by factor prices to give cost per unit area. Estimates can be readily made, for example, of labour requirements for pruning by observation. Less easy to determine would be an appropriate labour wage rate. Such calculations are important however in agroforestry systems which are relatively labour intensive and farm based due to the potentially very high value productivity of farm labour in agricultural operations at

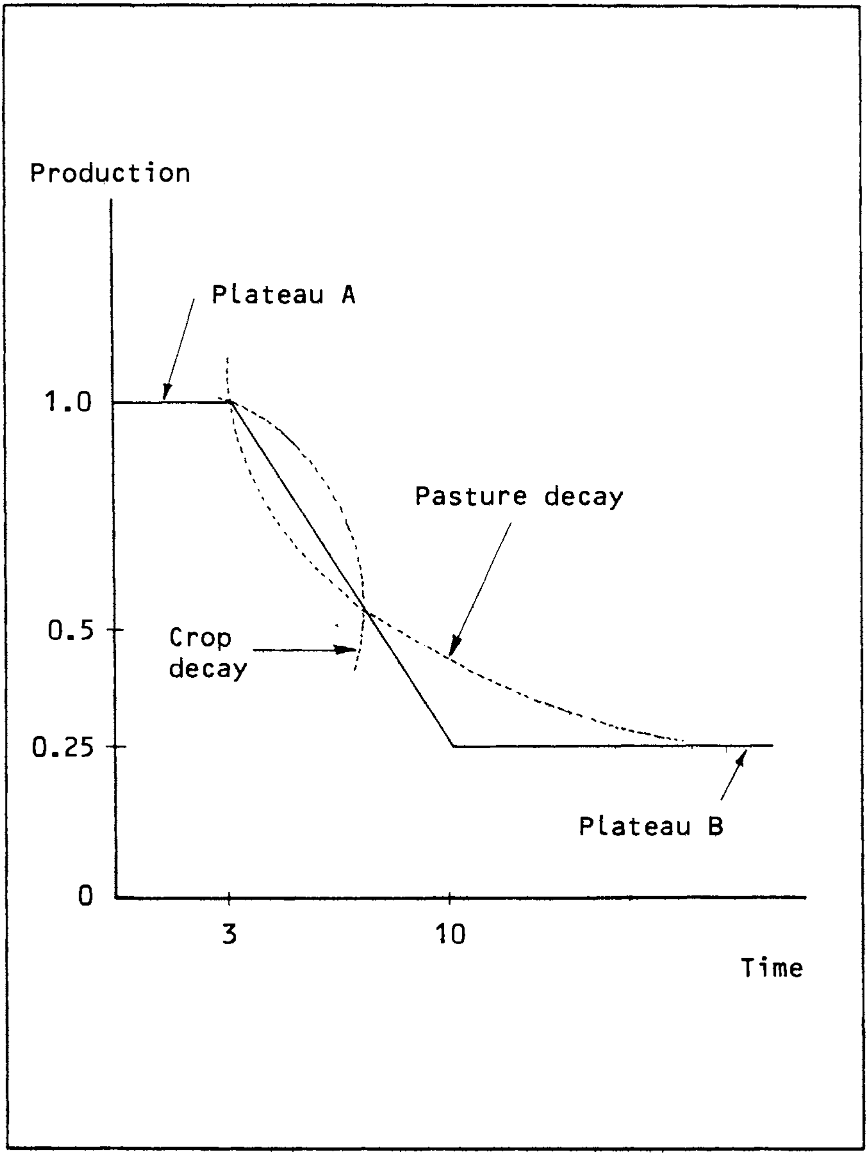
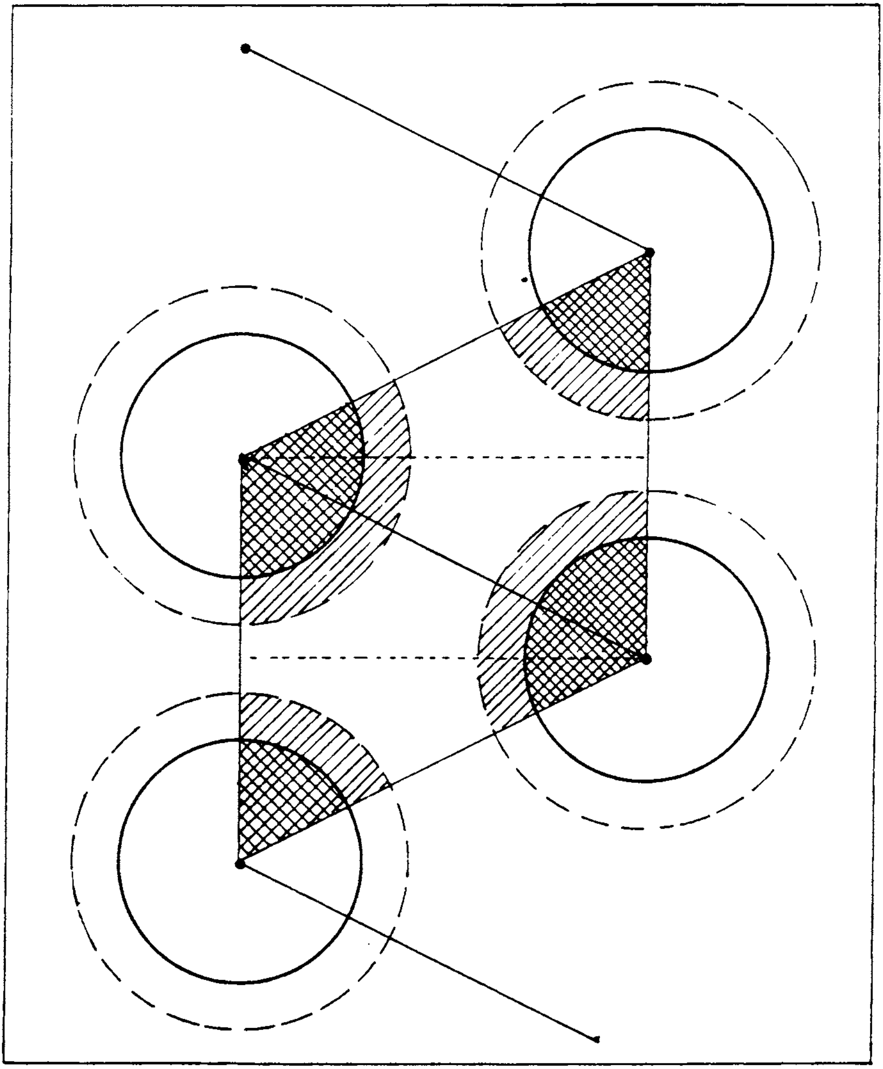


Figure 3 Agricultural Decay Functions used by the Model Poplar, Cereals (7 years) Sheep Grazing to 22 years



Key:

——— Measurement at t — Shaded pasture in t

– – – Measurement at t+1 — Shaded pasture in t+1

Figure 4 Shading Effect: Diffuse Light Model, Triangular Spacing

certain times of the year. The spreadsheet allows the researcher to employ a range of factor prices within this component.

h) **Presval**

Discounted Cash Flow Analysis is used to reduce future income flows from both components to a Net Present Value per ha. The user has the facility to use either a single real discount rate for both components which would imply that a given set of price changes for agriculture and forestry would be assumed to occur at the beginning and end of each rotation respectively. Alternatively the user has the facility to employ separate real rates of discount for each component which will simulate a gradual divergence of price trends through time.

SECTION B

An application of the model

The Site

This example relates to a site in the Midlands of England. Detailed information relating to soils, climate, geology and existing land use are presented in Table 1. A range of observed agricultural land uses are evident within the site : permanent pasture, grass leys, rough grazing for sheep and beef cattle; together with arable enterprises comprising spring barley, sugar beet and swede turnip. A number of agroforestry plantations using poplar can be found within the vicinity though all are now approaching the end of their first rotation and are generally of Yield Class 14.

Table 1 Site Characteristics

ITE LAND CLASS 15 SQUARE 436

Context

Farm type: Lowland livestock (cattle and sheep)

Soils	Group/sub-group	pH	Texture
Plots 1	Gley	6.2	
2	Gleyed brown earth	6.4	Loam
3	Gley	6.7	
4	Gleyed brown earth	6.2	Loamey silt
5	Gleyed brown earth	5.1	Loam

Climate

Mean daily max Jan	7°C
Mean daily max July	20.5°C
Mean daily min Jan	1.5°C
Mean daily min July	12°C
Average annual rainfall	700 mm
Average daily sunshine	5.5 hours

Geology

Ashgill and Caradoc; Pre-Cambrian; drift-glacial gravel

The System

This is one in which poplars are planted into cultivated land in rows at 8m triangular spacings giving an initial and final tree stocking density of 180 st. per ha. Two agricultural components are postulated. The first is one which crops cereals for a period of up to 7 years and is then undersown with a rye grass clover mixture to provide grazing for the remainder of the rotation. The second is a silvopastoral system using sheep from the outset with trees planted into permanent swards and protected by electric fencing.

System Parameters and Initial Values

Those relating to agriculture are presented in Table 2 and are self-explanatory. Input levels are consistent with output levels under these sorts of conditions when combined with factor prices, revenues, and flock investment requirements these data can be used to calculate gross margins for both cereal and livestock components, expressed per ha of agriculturally utilised land.

Those relating to forestry are presented in Table 3. The objective is to produce a 42cm DBH peeler buttlog in 22 years. All timber prices are 'ride side' so that net returns are very much a function of site location in relation to the harvest sawmill or peeling plant. All trees are assumed to be pruned to 6m, some 50% of which will be veneer quality. Some 10% of the stand volume is considered as wastage and allocated to the pulping market.

Results

Forestry and Agricultural Production

The forestry stand model and its components are shown for information in Table 4. Computed values relating to final volumes, revenues, silvicultural, harvesting and transport costs are presented in Table 5. The reduction through time in both agricultural components is illustrated in Table 6.

A Sensitivity Analysis

The sensitivity analysis concentrates on 5 key areas of interest. These are:

* Changes in prices and price trends of agricultural and forest products.

* Changes in factor prices, particularly that of labour.

* Changes in location in relation to sawmills.

* Changes in complementarity and competition assumptions.

* Changes in land types.

Table 6 presents a 'best scenario' analysis for this system on better quality land within the site. A comprehensive coverage of their scenarios can be found elsewhere (Thomas 1988). It is fairly obvious that a rather unlikely combination of factors would be needed to make this form of land use an attractive option when compared with monocultural agriculture. The picture changes significantly however when lower productivity land within the site is evaluated. This land is unable to produce cereals has a lower productivity in terms of Dry Matter production and therefore can support lower stocking at the same level of animal performance. These factors are reflected in Table 7 when compared with Table 2. A best scenario analysis for this land quality is presented in Table 8.

Finally, a scenario of opposing price trends in agricultural and timber products over the period of the next 22 years is evaluated in Table 9. This is achieved by using separate discount rates for the agricultural and forest component. In our case in the UK, the general concensus is that food prices are likely to fall in real terms whilst timber prices are likely to rise. The degree of divergence can be seen to significantly effect the viability of agroforestry when compared with monocultural land use systems.

Table 2 Agriculture - System parameters and initial values (Good Quality Lowlevel Grazing land)

int rate	3								
(real)									
seed	175kg/ha	wheat yld	5.9 t/ha	shade	2	DM yld	4100 kg/ha	lmb price	40.5
seed price	220 £/t	wheat prc	100 4/t	free yrs		ME val	10 mj/kg	wool val	3.2
fert rate	200 kg/ha	straw yld	2.5 t/ha	tree	8 m	lambing %	135	ram pchse	190
fert price	120 £/t	straw prc	20 £/t	spacing		ME req	4824 mj/ewe	cull ram	40
pest cost	70 £			tree				cull ewe	30
twine cost	9 £			strip width	2 m	concs	15 kg/ewe	repl rate	
				forest		con prc	140 £/t	ewes	22
		yrs of	7	rotation	22 yrs	vet & med	2.3 £/ewe	rams	33.3
		cereals				mktg cost	.9 £/ewe	ewes/ram	40
		% usable	.7113164			misc	.8 £/ewe	mortality	
		for ag				fert/ewe	10 £/ewe	ewes	3
		cereals		rotation in absence				lambs	9
		var csts	141.5	of forestry:		forage			
		revenue	640	cereals %	25	seed	21 £/ha		
		(unadjusted)				sprays	24 £/ha	stocking	8.499171
								rate (unadjusted)	
								livestock	16.1
								costs (unadjusted)	
								rev unadj	45.86694

Table 3 Forestry Inputs, Factor Prices and Product Prices

planting		strnr gap	25 m		
grant	£560 /ha	activator	£62	% fenced	50
		row lngth	100 m	wastage %	10
price/plt	£ 1	wire prce	£.03/m	pricescubic metre	
pltg lab	16 hrs	post prce	£.6	pulp	£ 15
lab cost	£3 /hr	strnr prc	£.04	firewood	£ 10
sprays	4 litres	year of thinning		veneer	£ 30
spray prc	£15 /ltr	first	99	sawlogs	£ 25
spray lab	2 hrs	second	99	taper	66
thinning lab	0 hrs	third	99	butt lgth	600 cm
Harvesting		year of pruning		veneer %	50
logging cost		first	3	thinnings	0
buttlog	£4 /cu.m	second	5		
toplogs	£6 /cu.m	third	7	COMPLEMENTARITY % + or -	
mill mles	30	fourth	9	cereals	0 %
cost/mile		year of spraying		livestock	0 %
buttlogs	£.2 /cu.m	first	1		
toplogs	£.3 /cu.m	second	2		
pruning hours/ha		third	99		
first	15 hrs	fourth	99		
second	18 hrs	fifth	99		
third	20 hrs				
fourth	23 hrs				

Table 4 Timber Yield Model Popup

Butt length (cm)	600	Pruning years		thinning years	
rotation (yrs)	22	first	3	first	99
taper	66	second	5	second	99
veneer proportions	5	third	7	third	99
tree spacing (m)	8	fourth	9	fourth	99
stems/ha	180,4273 (calculation)				

Tree Age	D.B.H	Top Height	Basal Area	Basal Area/ha	Crown Diam	Crown Height	MCL/ha	Top Diam	Buttlog Vol/tree	Toplog Vol/tree	Buttlog Vol/ha	Wastage Vol/ha	Toplog Vol/ha	Volume Thinns
							.00							
0	.00	.000	.0000	.00	.00	.000	452.48	.00	.0000	.0000	.00	.00	.00	.00
1	.00	2.508	.0000	.00	2.25	2.508	724.63	00	.0000	.0000	.00	.00	.00	.00
2	3.65	4.016	.0005	.08	2.83	4.016	724.63	00	.0021	.0000	.38	.04	.04	.00
3	10.35	5.490	.0038	.68	4.14	4.016	984.37	1.25	.0910	.0000	3.44	.34	.34	.00
4	15.08	6.930	.0080	1.44	4.99	5.456	984.37	5.99	.0556	.0009	10.03	1.00	1.16	.00
5	18.77	8.335	.0123	2.23	5.59	5.456	1231.70	9.68	.0985	.0057	17.78	1.78	2.81	.00
6	21.77	9.706	.0167	3.01	6.04	6.827	1231.70	12.68	1431	.0156	25.83	2.58	5.40	.09
7	24.32	11.042	.0208	3.75	6.39	6.827	1466.62	15.23	.1875	.306	33.83	3.38	8.91	.00
8	26.52	12.344	.0247	4.46	6.66	8.129	1466.62	17.43	.2308	.0505	41.65	4.16	13.27	.00
9	28.46	13.612	.0285	5.14	6.87	8.129	1689.12	19.37	.2729	.0748	49.23	4.92	18.42	.00
10	30.20	14.845	.0321	5.78	7.05	9.362	1905.42	21.11	.3135	.1032	56.56	5.66	24.28	.00
11	31.78	16.044	.0355	6.40	7.19	10.561	2115.51	22.69	.3527	.1353	63.63	6.36	30.78	.00
12	33.21	17.208	.0388	6.99	7.31	11.725	2319.39	24.12	.3905	.1707	70.45	7.05	37.85	.00
13	34.75	18.338	.0419	7.56	7.40	12.855	2517.07	25.44	.4270	.2091	77.04	7.70	45.43	.00
14	35.75	19.434	.0449	8.11	7.48	13.951	2708.54	26.66	.4623	.2501	83.40	8.34	53.46	.00
15	36.89	20.495	.0478	8.63	7.54	15.012	2893.80	27.80	.4964	.2933	89.56	8.96	61.88	.00
16	37.96	21.522	.0506	9.14	7.60	16.039	3072.86	28.87	.5294	.3386	95.51	9.55	70.65	.00
17	38.96	22.514	.0533	9.62	7.64	17.031	3245.71	29.87	.5613	.3857	101.28	10.13	79.72	.00
18	39.90	23.472	.0559	10.09	7.68	17.989	3412.35	30.81	.5923	.4342	106.87	10.69	89.04	.00
19	40.79	24.396	.0585	10.55	7.72	18.913	3572.78	31.70	.6224	.4841	112.30	11.23	98.57	.00
20	41.64	25.285	.0609	10.99	7.75	19.802	3727.01	32.55	.6517	.5349	117.58	11.76	108.27	.00
21	42.45	26.140	.0633	11.42	7.77	20.657	3875.04	33.35	.6801	.5866	122.72	12.27	118.11	.00
22	43.21	26.960	.0656	11.84		21.477		34.12	.7078	.6389	127.71	12.77	128.05	.00

Table 5 Computed Values for the Forestry Component (Status Quo)

Complementarity						
cereals	0%	dbh	43.21299	cm		
livestock	0%	cls dbh	24.31830	cm		
		net comp	0 x 100	%	rows	15,43418
planting costs	228,4273 £/ha	stems/ha	180.4273		canopy closure	
thinning costs	0 £/ha	values in end year			occurs yr	30
		adj dbh	43.21299	cm	wire mtrs	1507,852
spraying costs	66 £/ha	top ht	26.9602	m	figs if all forestry	
logging costs		basl area	.0656200	sqm	basl area	.0656200
buttlogs	10 £/cum	sed	34.12208	cm	sed	34,12208
toplogs	15 £/cum	volumes/ha			volumes/ha	
		buttlogs	127.7121	cu.m	buttlogs	127,7121
tot.logging & transport costs		toplogs	115.2755	cu.m	toplogs	155,2755
buttlogs	1149,409 £/ha	revenue/ha			revenue/ha	
toplogs	1920,701 £/ha	pulp	£1920.701		pulp	1920,701
		sawlogs	£1436.761		sawlogs	1436,761
		peelers	£1724.113		peelers	1724,113
fencing cost	142,0207 £/ha	thinnings	£0		thinnings	0
			5081.575			5081575

Table 6 The Viability of a Poplar, Cereals and Livestock Agro Forestry System. A Best Scenario Analysis on Good Land

	Net Present Value (£/ha)		
	Agro Forestry	Forestry	Agriculture
Best Scenario:			
Distance from mill - 10 miles Wood prices + 50% Labour £0 per hour Cereals complementarity + 10% Livestock " + 5% Fencing cost 0 Agricultural prices unchanged	5024.86	3434.43	4741.16
As above with fencing 50%	4886.98	3434.43	4741.16
As above with cereal prices -50%	4230.04	3434.43	4741.16

Table 7 Agriculture - System Parameters and Initial Values (Medium Quality Lowland Grazing Land)

Int rate 3							
(real)							
seed	175 kg/ha						
seed prc	220 £/t						
fert rate	220kg/ha						
fert prc	120 £/t						
pest cost	70 £						
twine cst	9£						
wheat yld	5.9 t/ha	shade	2	DM yld	2100kg/ha	lmb price	40.5
wheat prc	100 £/t	free yrs tree	8m	ME val	10 mj/kg	wool val	3.2
straw yld	2.5 t/ha	spacing tree		lambing %	135	ram pchse190	
straw prc	20 $/t	strip wdth	2m	Me req	4824 mj/ewe	cull ram	40
		forest rotation	22yrs	cocs	15 kg/ewe	cull ewe	30
				conc prc	140 £/t	repl rate ewes	22
yrs of cereals	0			vet & med	2.3 £/ewe	rams	33.3
% usable	.7113164			mktg cost	.9 £/ewe	ewes/ram	40
for ag cereals				misc	.8 £/ewe	mortality(%)	
var csts	141.5			fert/ewe	10 £/ewe	ewes	3
revenue	640	rotation in absence				lambs	9
(unadjusted)		of forestry:		Forage:			
		cereals %	0	seed	21 £/ha		
				sprays	24 £/ha	stocking rate	4.8
						(unadjusted)	
						livestock csts	16.1
						(unadjusted)	
						rev unadj	45.86694

Table 8 The Viability of a Poplar, Cereals and Livestock Agroforestry System. A best Scenario Analysis on Medium Quality Land (No Cereals)

	Net Present Value £ (ha)		
Best Scenarios	Agro Forestry	Forestry	Agriculture
1. Timber price +50% Everything else as status quo	2149	1680	2065.14
2. Timber price +25% Lamb price -25% Labour cost £0/hr Everything else as status quo	2164.66	1876.55	1319.22
3. Timber price +10% Lamb price -25% Labour cost £0/hr	1661.81	1373.70	1319.22
4. Timber price +10% Lamb price -25% Labour cost £3.0/hr	1420.15	1132.04	1319.22
5. Timber price unchanged Lamb price -25% Everything else as status quo	1167.73	880.86	1319.22
6. Timber price unchanged Lamb price -25% Labour cost 0 Complementarity +5% Everything else as status quo	1466.16	1178.05	1319.22
7. Timber price unchanged Lamb price -25% Labour cost £0/hr Complementarity 5% Distance from mill 10 miles	2125.80	1837.69	1319.22
8. As above with 20 miles distance from mill	1795.98	1507.87	1319.22

Table 9 The Viability of a Poplar, Cereals and Livestock Agroforestry System. Sensitively to Opposing Term Prices for Agricultural and Forest Components

(i) Better Quality Grazing land

	Net Present Value (£)/ha		
Price trend scenario	Agro Forestry	Forestry	Agriculture
Status Quo	2471.29	880.86	4741.16
Agro price rise 2% < inflation Forest price rise 2% > inflation	2844.09	1422.27	3915.94
Agro price rise 5% < inflation Forest price rise 5% > inflation	4207.80	2982.96	3034.68

(ii) Medium quality Grazing land

Status quo	1348.20	880.86	2065.14
Agro price rise 2% < inflation Forest price rise 2% > inflation	1825.02	1422.27	1705.69
Agro price rise 5% < inflation Forest price rise 5% > inflation	3312.41	2982.96	1321.84

Conclusions

The spreadsheet provides a framework within which the various components listed in Figure 1 can be linked together. So far the components themselves reflect requirements for the sort of system currently envisaged under Northern European conditions.

Popup and Popout for example simulate the production of pruned timber buttlogs. Similarly, the agricultural components and site conditions described here are Western European in character.

It should be apparent however that the incorporation of, for example, fruiting components, or coppice for biomass or fuel can be achieved without undue difficulty. Moreover the constant stream of income from this sort of tree component would significantly affect Net Present Values.

Similarly, beause the model works from initial conditions which reflect site productivity (provided relevant bioclimatic and topographical information is available, and key parameters relating to the performance of whatever components are being considered are known with reasonable accuracy), it should be possible to adopt the approach presented here for a range of site conditions and systems. Moreover, if changes in site productivity are envisaged to occur through time these can be reflected in the initial values of system parameters or built in to the respective decay functions.

The quality of information is obviously important to the reliability of the results. Some of the information, for example land capability and bioclimatic data may well exist for potential sites, as will data relating to input requirements and site productivity to serve as initial values and system parameters. Less easy questions may well relate to the valuation of inputs and outputs, the dynamics of tree and crown development at wide spacing and the effects of interactions in terms of increased or decreased output levels of the various components.

None of these aspects need necessarily be a problem when the analytical framework is incorporated within a spreadsheet. Indeed, not only can the spreadsheet indicate the sensitivity of a solution to a change in factor or product prices but it can also demonstrate the likely financial magnitudes of impact on the system as a whole of for example particular pruning regimes, improving the form characteristics of trees or perhaps a supplementary forage establishment programme using legumes late on in the course of a rotation. Using a model in this context can actually point the researcher in the direction in which greatest potential source of economic benefit from further research is likely to be.

Experimental Research need not be the only source of technical information employed. Delphi sessions should be able to establish ranges of estimates of key parameters which could be cross checked with the results of rapid rural appraisal techniques in the field. Farmers can be interviewed and their existing husbandry practices examined. Economic values such as for example grazing rentals under trees can provide suitable proxies for the purposes of assessing stocking capacities until experimentation based on light interception and root competition research yields better data. In an economic context the current situation is tending more towards one of assessment rather than optimisation. The resolution required of data should reflect this.

Finally, this model is currently based on a unit of area, rather than a farm. It avoids difficulties such as cash flow problems and capital items. It nevertheless provides a unit which can be aggregated upwards to both farm and regional level. At these higher levels of aggregation new and additional sets of issues emerge. The availability of labour and capital to farmers, their training and education, the provision of suitable infrastructures for transport, harvesting and processing, together with the communality of ownership in respect of system components are all important "grey areas". The establishment and management of uneven aged stands, the determination of farmers' needs, and their attitudes to agroforestry in relation to regional and national objectives also need to be determined.

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