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A spreadsheet approach to the economic modelling of agroforestry systems

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ABSTRACT

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The ability to simulate the functioning of an agroforestry system in respect of its technical and economic components is important from a number of viewpoints. This paper outlines the components of a simulation model currently being developed at Bangor and discusses the potential of spreadsheet modelling in a number of contexts.

The paper is divided into two parts. The first part 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.

The second part illustrates, in an application of the model to a poplar, cereal and sheep agroforestry system, how such an approach can be used to good effect in three broad areas of investigation. These are firstly, the economic evaluation of changing technical variables associated with complementary interactions and declining agricultural productivity through time. Secondly, the consequences of alternative price scenarios under differing initial land productivity and agricultural decay functions are examined. Finally, the scope for use of the spreadsheet modelling approach is illustrated.

THE GENERAL APPROACH

For both forestry and agricultural components, the approach adopted here has been to:

(a) Identify relevant inputs.

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

(c) Simulate (1) the growth of physical timber volume, and (2) the decrease in physical agricultural output consistent with this growth.

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

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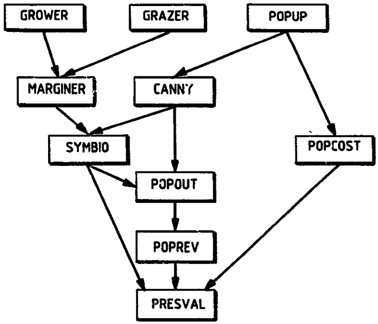
(e) Use discounted cash flow analysis for the purpose of calculating the net present value (NPV) from:
(i) all forestry;
(ii) all agriculture;
(iii) agroforestry on equivalent areas of land.

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, although this of course can be varied to determine optimum rotations.
(iii) It is assumed that 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 met by the farm staff. By establishing uneven age stands to a maximum of around 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 the section: 'An application of the model', the analysis is conducted throughout in 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.

THE MODEL

A schematic representation of its components is presented in Fig. 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 climate. 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 for arable production.
(b) *Grazer.* Similarly what exists at present is a visual inspection of sward



GROWER	Estimates yield on the basis of site characteristics.
GRAZER	Identifies sward. Calculates stocking rates. 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 rigime.
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.
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 . This changes in technical input/output coefficients, factor and product prices can be examined in terms of impact on NPV.

Fig. 1. A diagram to show the components of the model, POPEYE. Each component is described briefly in the text.

type. Dry matter production per hectare consistent with climatic and soil conditions is assessed, as is its metabolisable energy (ME) value. 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 spreadsheet.

(c) *Marginer.* This converts Grower and Grazer to equivalent gross margins (£/ha).

(d) *Popup.* This is a timber yield model which describes the volume of timber per hectare as a function of: (i) the number of stems per hectare, and (ii) the diameter, height and form of individual trees. Tree diameter at breast height (DBH) varies with spacing at a given age and tree height varies with age but is largely invariant with spacing. Using poplar as an example, it is possible using stand tables to provide a range of values for spacing, age and tree diameter which, when examined by multiple regression analysis, can be used to predict both DBH and tree height as a function of age.

This yields equations of the general form

$$D=a+b\ln(A\,S) \tag{1}$$

where D=diameter at breast length (i.e. 1.3 m) (cm), A=age of tree (year), S=tree spacing (m), and a and b are parameters; and

$$H=a'+b'A+c'A^2 \tag{2}$$

where H=dominant tree height (m), and a', b' and c' are additional parameters.

(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, 1985). 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 Pryor (1985), Garson (1988), Kalibala (1988) and Saville (1988) have determined crown diameter:stem diameter equations for a range of common British species following the general form:

$$D=a''+b''D_k \tag{3}$$

where D_k=crown diameter (cm), and a'' and b'' are parameters.

In this 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 that 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 (see, 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.

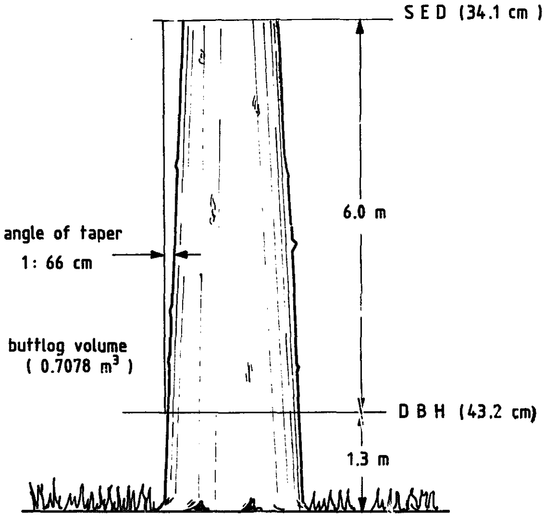
Secondly, complementary effects may be manifested in an increased tree basal area increment of up to 40% resulting from the fertilising effects of grazing animals and reduced understory competition (Knowles and West, 1987). Agricultural livestock productivity may be increased by up to 20% as a result 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 because of amelioration of 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 (Anonymous, 1979). By contrast, for the same genus light cultivation can significantly enhance the mean annual increment of timber volume (Anonymous, 1977). Trees vary in terms of their ability to withstand heavy pruning regimes and maintain diameter growth. Evidence suggests, however, that price premiums 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 understory development 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, ash 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 compared with sycamore, for example.

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 improved data within it.

(g) *Popout.* This component adjusts individual tree volume by: (i) intro-



Notes.

1. The model assumes the log behaves as if its three dimensional shape corresponds to that of a frustram of a cone.
2. Log dimensions are derived from equations within 'POPEYE' based on data extracted from Forestry Commission Yield Tables for Poplar planted at 8 metre triangular spaceing on sites capable of achieving Yield Class 14.

Fig. 2. A diagram to illustrate the use of taper functions to calculate small end diameter (SED) from diameter at breast height (DBH) and buttlog volume.

ducing a range of 'taper' functions, (ii) calculating 'small end diameter' (SED) at any specified pruned height, and (iii) distinguishing between 'buttlog' and 'top log' volume. These features are illustrated in Fig. 2.

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

$$B=\frac{\pi}{12}(D^2+Dd+d^2)H \tag{4}$$

where B=buttlog volume (m^3), and d='small end' at 'top' diameter at a given height (cm).

Top log volume is assumed to be represented by a 'cone' whose volume is given by

$$T=\frac{\pi D_b^2 H}{12} \tag{5}$$

where T=top log volume (m^3), and D_b=basal diameter (m). The spreadsheet allows tree form to be altered across a range of taper functions with consequent implications for buttlog volumes.

Finally, top log and buttlog volumes are multiplied by their appropriate prices depending on their final end use. Within a market economy price quotations for saw logs based on larger diameter classes are obtainable, although precision in terms of a price/size relationship varies enormously from country to country. This relationship is particularly poor in the U.K., 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).

(h) *Popcost.* 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 is an appropriate labour wage rate. Such calculations are important, however, in agroforestry systems which are relatively labour intensive and farm based because of the potentially very high value productivity of farm labour in agricultural operations at certain times of the year. The spreadsheet allows the researcher to employ a range of factor prices within this component.

(i) *Poprev.* This component includes grants and all product prices and calculates revenues per hectare and per year of rotation for any specified planting regime.

(j) *Presval.* Discounted cash flow analysis is used to reduce future income flows from both components to a net present value per hectare.

THE SPREADSHEET

In the present context, the spreadsheet approach is applied to take into account interactions within the poplar, cereal and sheep grazing regime that are included within the component Symbio.

This spreadsheet currently encompasses two broad types of interaction: firstly, negative interactions caused by shading out of the understory with increased canopy development through time; secondly, complementarity, or competition as reflected in the rate of annual change in timber volume per hectare.

Taking the latter first the effect on timber volume can be accommodated by adjusting equation (4) as follows:

$$C_B = \sum_{s=1}^{r} \frac{\pi}{12}[(D^2+Dd+d^2)H]c \tag{6}$$

where C_B = the total increase in timber volume per buttlog, s = 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, and 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 although 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 simulation of the decline in agricultural production over time, for which a number of approaches have been used. In New Zealand for example, it has been observed that decreases in annual pasture dry matter production appear to correlate well with green crown length and the number of crowns per hectare (Percival et al., 1984). This approach makes intuitive sense in that in high or low latitudes, conical and columnar shapes cast long shadows, leading to 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 (for example, 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 (for example, Jackson and Palmer, 1979; Slatterlund, 1983). The latter in particular gives rise to difficulties associated with spatial arrays of trees, because of paucity of information 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 an empirical 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 of output is unaffected, and can be characterised as a plateau, or may 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. Whatever sources of information are available may be used to locate the upper plateau in horizontal space, i.e. 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 equations which best describe the rate of decay of agricultural output through time, for whatever tree density is being considered.

The equations in the present case are based on data relating to a poplar, cereals and sheep system with a non-thinning regime at a stocking density of 180 stems/ha (Beaton, 1987), found in the West Midlands of England and shown schematically in Fig. 3.

The grazing decay function is determined by an equation of the form

$$Y_g = A + Be^{-Kt} \tag{7}$$

where Y_g = a coefficient of decay expressed as a decimal, t = time, and A, B and K are parameters.

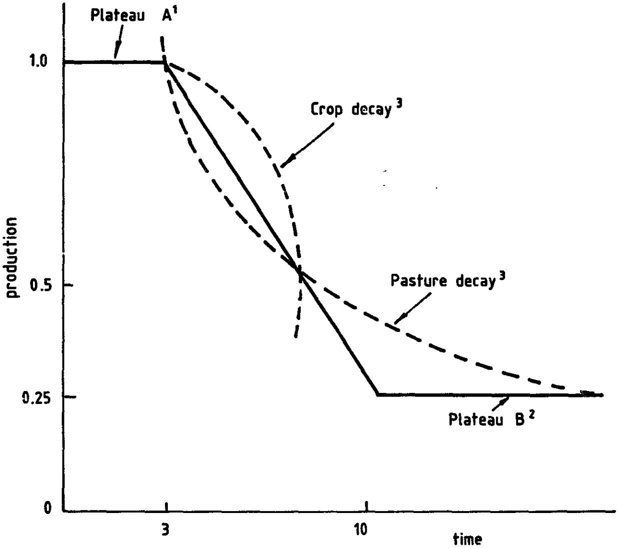
The crop decay function is determined by an equation of the general form

$$Y_c = \frac{100A}{P(t+t^2)} \tag{8}$$

where Y_c = a coefficient of decay expressed as a decimal, and A and P are parameters.

In equation (7) and Fig. 3 the initial (shade-free) plateau is represented by $A+B$, the final plateau by B 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 is then necessary. Current work on light interception under ash trees in southern England (Newman, 1989) suggests that a situation of diffuse light falling vertically on opaque tree crowns is likely to approximate conditions prevailing there for over 60% of the time and particularly so in the period in which understore growth is most pronounced. One assumption might be that agricultural production decreases on a pro rata basis with increase in the shaded area. Provided that the crown: stem diameter relationship is known, the pro-



Notes.

1. The height of Plateau A. represents the level of physical agricultural production which can be expected when no trees are present. The horizontal length of Plateau A describes the period in time during which no decline in output per ha is expected to occur.

2. The height of Plateau B represents the lower level to which agricultural production might be expected to gravitate . Its position in horizontal space corresponds to that point in time when all silvicultural operations might be expected to be complete and subsequent canopy closure takes place.

3. The crop and pasture decay functions linking both Plateaux are a schematic representation of the equations referred to in the text to describe cereal and grass productivity under a stand of Poplars harvested at 22 years of age. Any decay function can be 'projected' to correspond with a Plateau B which is of a specified height at any given point in time.

Fig. 3. Agricultural decay functions used in the poplar, cereal, sheep grazing model. Cereal crops are grown for 7 years, and grazing of pasture by sheep for 22 years.

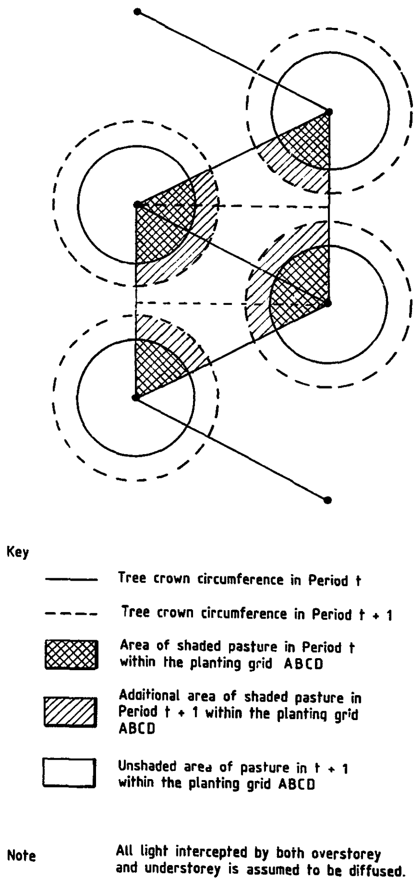


Fig. 4. A diffuse light model of shaded and unshaded areas in a triangular tree planting regime.

portion of unshaded area at any one time within a tree planting grid can be calculated and agricultural production adjusted accordingly. Although this may appear to be a major assumption, underground effects are as yet not incorporated within the model so that by applying what is a severe assumption, the economic implications of the worst 'competition scenario' possible are simulated. The logic of this approach is presented in Fig. 4 which illustrates development with a triangular planting configuration. The spreadsheet enables the user to vary the spacing of trees thus increasing or decreasing the proportion of unshaded area at any given point in time.

The user may, of course, wish to evaluate the economic implications of accepting either approach as a satisfactory indicator of the true decline in agricultural productivity through time. The model enables the user to compare agricultural decay functions and resulting NPVs with a view to establishing the best and worst tree and agriculture competition scenarios for any given planting regime.

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 although all are now approaching the end of their first rotation and are generally of Yield Class 14.

The system

Poplars have been planted into cultivated land in rows at 8 m triangular spacings giving an initial and final tree stocking density of 180 stems per hectare. Two agricultural components are postulated. In the first cereals are cropped for a period of up to seven years and are then undersown with a rye grass-clover mixture to provide grazing for the remainder of the rotation. The second is a silvopastoral system from the outset with trees planted into permanent grass swards and protected from grazing by the sheep by electric fencing.

TABLE 1

Site characteristics: site land class 15, square 436

Plots	Soils		
	Group/sub-group	pH	Texture
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 January		7°C	
Mean daily max July		20.5°C	
Mean daily min January		1.5°C	
Mean daily min July		12°C	
Average annual rainfall		700 mm	
Average daily sunshine		5.5 h	
Geology			
Ashgill and Caradoc; Pre-Cambrian; drift-glacial gravel			
Context			
Farm type: lowland livestock (cattle and sheep)			

System parameters and initial values

Those relating to agriculture are presented in Table 2. Input levels are consistent with output levels under these conditions and 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 hectare of agriculturally utilised land.

Parameters and initial values relating to forestry are presented in Table 3. The objective is to produce a 42 cm DBH peeler buttlog in 22 years. All timber prices are 'ride side' so that net returns are a function of site location in relation to the sawmill or peeling plant. All trees are assumed to be pruned to 6 m and 50% of the buttlogs will be of 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 in Table 4. Computed values relating to final volumes, revenues, silvicultural, harvesting and transport costs are presented in Table 5.

Agricultural revenues scheduled through time on the basis of empirically

TABLE 2

Agricultural system parameters

Cereals		Livestock	
Wheat yield	5.90 t/ha	D.M. yield	4100.00 kg/ha
Wheat price	£100.00/t	M.E. value	10.00 MJ/kg
Straw yield	2.50 t	Lambing %	135.00 no/yr
Straw price	£20.00/t	M.E. requirement	4824.00 MJ/ewe
Seed rate	175.00 kg/ha	Lamb price	£40.50/head
Seed price	£220.00/t	Wool value	£3.20/ewe
Fertiliser rate	200.00 kg/ha	Ram purchase	£190.00/ram
Fertiliser price	£120.00/t	Cull ram	£40.00/ram
Pesticide cost	£70.00/ha	Cull ewe	£30.00/ewe
Twine cost	£9.00/ha	Replacement rate	
		Ewes	22.00%
Unadj: Revenue	£640.00/ha	Rams	33.30%
Var. costs	£141.50/ha	Ewes/ram	40.00
Gross margin	£498.50/ha	Mortality: Lamb	3.00%
		Ewe	9.00%
		Concentrates	15.00 kg/ewe
		Concentrate price	£140.00/t
		Vet. and Med.	£2.30/ewe
		Marketing cost	£0.90/ewe
		Miscellaneous	£0.80/ewe
		Forage seed	£21.00/ha
		Forage spray	£24.00/ha
		Fertiliser	£10.00/ha
		Unadj: Stock rate	8.50 ewes/ha
		Revenue	£45.15/ewe
		Var. costs	£6.10/ewe
		Gross margin	£39.05/ha
Rotation without forestry-cereals %	25.00%		
Shade-free years	2.00 yr		
Newman's diffuse light model (dlm) (0), empirical equation (1)	1.00	Newman's dlm (0), empirical equation (1), projected equation (type shade coefficient % @ year 12)	1.00
Percentage of land usable for agriculture	0.71% (calc.)		

derived forms of equations (7) and (8) are indicated in Table 6, as is the aggregate net present value (NPV) for the system as a whole on the basis of assumed system parameters.

TABLE 3

Forestry inputs, factor prices and product prices

Planting grant	£560/ha	Strainer gap	25 m	% fenced	50%
Price/plant	£1	Activator	£62	Wastage %	10%
Planting lab	16 h	Row length	100 m	Price (per cubic metre)	
Lab cost	£3/h	Wire price	£0.03/m	Pulp	
Sprays	4 dm³	Post price	£0.6	Firewood	£15
Spray price	£15/dm³	Strainer price	£0.04	Veneer	£10
Spray lab	2 h	Year of thinning		Saw logs	£30
Thinning lab	0 h	First	99	Taper	£25
Harvesting		Second	99	Butt length	66
Logging cost		Third	99	Veneer %	600 cm
Buttlog	£4/m³	Year of pruning		Thinnings	50
Top logs	£6/m³	First	3	Complementarity	0
Miles to mill	30	Second	5	Cereals	% + or −
Transport cost per mile		Third	7	Livestock	0%
Buttlogs	£0.2/m³	Fourth	9		0%
Top logs	£0.3/m³	Year of spraying			
Pruning (hours/ha)		First	1		
First	15	Second	2		
Second	18	Third	99		
Third	20	Fourth	99		
Fourth	23	Fifth	99		

The real value of the spreadsheet approach rests in the flexibility it offers in assessing the sensitivity of such a result to changes in the parameters upon which it is based. The next section presents such a sensitivity analysis.

A sensitivity analysis

This analysis concentrates on two broad areas of interest. These are:

(a) Changes in technical parameters concerning, agricultural/tree complementarity and the nature of decline in agricultural productivity through time.

(b) Changes in prices and price trend scenarios for agricultural and forest products.

Additional analyses with respect to factor prices (particularly of labour), location in relation to sawmills and land quality can be found in Thomas (1988).

Dealing with technical aspects first, the analysis presented in Table 7 indicates the change in NPV arising from the complementary interaction of animal and tree components. It only reflects changes in timber volume that might be associated with the presence of animals through reduced understory competition and increased nutrient availability. In that respect it is of course incomplete (see the section on 'The model' (e) Canny). However, as new research takes place additional interactions can be incorporated and existing default values can be confirmed or discarded. Certainly, on the basis of this particular example it would appear that this form of complementarity is not a poten-

TABLE 4

Timber yield from model Popup

Year	Per tree									Per hectare		
	DBH (cm)	Adjusted DBH (cm)	Top height (m)	Basal area (m^2)	S.E.D.	Crown height (m)	Crown diameter (m)	Buttlog volume (m^3)	Top log volume (m^3)	Buttlog volume (m^3)	Top log volume (m^3)	Basal area (m^2)
1	0.00	0.00	2.51	0.0000	0.00	2.51	2.25	0.0000	0.0000	0.00	0.00	0.00
2	3.65	3.65	4.02	0.0005	0.00	4.02	2.83	0.0021	0.0000	0.38	0.00	0.08
3	10.34	10.34	5.49	0.0038	1.25	5.49	4.14	0.0191	0.0000	3.44	0.00	0.68
4	15.08	15.08	6.93	0.0080	5.99	5.49	4.99	0.0556	0.0009	10.03	0.16	1.44
5	18.77	18.77	8.34	0.0124	9.68	6.90	5.59	0.0985	0.0057	17.78	1.03	2.23
6	21.77	21.77	9.71	0.0167	12.68	6.90	6.04	0.1431	0.0156	25.83	2.82	3.01
7	24.32	24.32	11.04	0.0208	15.23	8.23	6.39	0.1875	0.0306	33.83	5.52	3.75
8	26.52	26.52	12.34	0.0247	17.43	8.23	6.66	0.2308	0.0505	41.65	9.10	4.46
9	28.46	28.46	13.61	0.0285	19.37	9.50	6.87	0.2729	0.0748	49.23	13.50	5.14
10	30.20	30.20	14.85	0.0321	21.11	9.50	7.05	0.3135	0.1032	56.56	18.62	5.78
11	31.78	31.78	16.04	0.0355	22.69	10.70	7.19	0.3527	0.1353	63.63	24.41	6.40
12	33.21	33.21	17.21	0.0388	24.12	11.86	7.31	0.3905	0.1707	70.45	30.80	6.99
13	34.53	34.53	18.34	0.0419	25.44	12.99	7.40	0.4270	0.2091	77.04	37.72	7.56
14	35.76	35.76	19.43	0.0449	26.66	14.09	7.48	0.4623	0.2501	83.40	45.12	8.11
15	36.89	36.89	20.50	0.0478	27.80	15.15	7.54	0.4964	0.2933	89.56	52.93	8.63
16	37.96	37.96	21.52	0.0506	28.87	16.18	7.60	0.5294	0.3386	95.51	61.10	9.14
17	38.96	38.96	22.51	0.0533	29.87	17.17	7.64	0.5613	0.3857	101.28	69.59	9.62
18	39.90	39.90	23.47	0.0559	30.81	18.13	7.68	0.5923	0.4342	106.87	78.35	10.09
19	40.79	40.79	24.40	0.0585	31.70	19.05	7.72	0.6224	0.4841	112.30	87.34	10.55
20	41.64	41.64	25.29	0.0609	32.55	19.94	7.75	0.6517	0.5349	117.58	96.51	10.99
21	42.45	42.45	26.14	0.0633	33.35	20.79	7.77	0.6801	0.5866	122.72	105.84	11.42
22	43.21	43.21	26.96	0.0656	34.12	21.61	7.79	0.7078	0.6389	127.71	115.28	11.84

TABLE 5

Forestry physical and economic parameters, computed revenues and costs

Plant price	£1.00/plant	Labour cost	£3.00/h	Planting grant	£560.00/ha
Sprays	4.00 dm^3	Labour requirement (per hectare)		Timber prices (£/m^3)	
Spray price	£15.00/dm^3	Planting	16.00 h	Pulp	15.00
Fencing		Spraying	2.00 h	Firewood	10.00
Percentage fenced	50.00%	Thinning	0.00 h	Veneer	30.00
Row length	100.00 m	Pruning: First	15.00 h	Saw logs	25.00
Strainer gap	4.00 m	Second	18.00 h		
Prices: Strainer	£0.50	Third	20.00 h	Veneer percentage	50.00%
Wire	£0.05/m	Fourth	23.00 h	Wastage	10.00%
Post	£0.05/m			Thinnings-volume per tree (m^3)	
Activator	£120.00			First	0.00
				Second	0.00
Logging cost				Third	0.00
Buttlog	£4.00/m^3				
Top logs	£6.00/m^3				
Miles to mill	30.00			Rows	15.43
Transport cost per mile				Total wire	1507.85 m
Buttlog	£0.20/m^3				
Top logs	£0.30/m^3				

TABLE 5 (continued)

Costs (£)								Revenue (£)					
Year	Planting	Fencing	Spraying	Pruning	Thinning	Logging	Total costs	Pulpwood	Saw logs	Peelers	Thinning	Total revenue	Net cash flow
0	228.43	358.39	0.00	0.00	0.00	0.00	586.82	0.00	0.00	0.00	0.00	0.00	−586.82
1	0.00	0.00	66.00	0.00	0.00	0.00	66.00	0.00	0.00	0.00	0.00	560.00	494.00
2	0.00	0.00	66.00	0.00	0.00	0.00	66.00	0.00	0.00	0.00	0.00	0.00	−66.00
3	0.00	0.00	0.00	45.00	0.00	0.00	45.00	0.00	0.00	0.00	0.00	0.00	−45.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	54.00	0.00	0.00	54.00	0.00	0.00	0.00	0.00	0.00	−54.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	60.00	0.00	0.00	60.00	0.00	0.00	0.00	0.00	0.00	−60.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	69.00	0.00	0.00	69.00	0.00	0.00	0.00	0.00	0.00	−69.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00	0.00	3070.11	3070.11	1920.70	1436.76	1724.11	0.00	5081.58	2011.47

Source: POPEYE Spreadsheet Model.

TABLE 6

Scheduled agricultural costs and revenues

Year	Cereals				Livestock						Total gross margin (£)
	Shade coeff.[1]	Total revenue (£)	Var. costs (£)	Gross margin (£)	Shade coeff.[1]	Stock rate (no/ha)	Total revenue (£)	Var. costs (£)	Forage costs (£)	Gross margin (£)	
0	1.000	0.00	0.00	0.00	1.000	0.00	0.00	0.00	0.00	0.00	0.00
1	1.000	455.24	100.65	354.59	1.000	0.00	0.00	0.00	0.00	0.00	354.59
2	1.000	455.24	100.65	354.59	1.000	0.00	0.00	0.00	0.00	0.00	354.59
3	0.948	431.61	100.65	330.96	0.638	0.00	0.00	0.00	0.00	0.00	330.96
4	0.852	193.98	50.33	143.66	0.454	0.00	0.00	0.00	0.00	0.00	143.66
5	0.726	165.32	50.33	114.99	0.352	0.00	0.00	0.00	0.00	0.00	114.99
6	0.587	133.57	50.33	83.25	0.294	0.00	0.00	0.00	0.00	0.00	83.25
7	0.450	102.32	50.33	52.00	0.258	0.00	0.00	0.00	32.01	−32.01	19.99
8	0.326	0.00	0.00	0.00	0.235	1.42	64.05	8.65	7.11	48.29	48.29
9	0.225	0.00	0.00	0.00	0.219	1.33	59.86	8.09	7.11	44.66	44.66
10	0.147	0.00	0.00	0.00	0.209	1.26	56.97	7.70	7.11	42.16	42.16
11	0.091	0.00	0.00	0.00	0.201	1.22	54.91	7.42	7.11	40.38	40.38
12	0.053	0.00	0.00	0.00	0.196	1.18	53.41	7.22	7.11	39.08	39.08
13	0.030	0.00	0.00	0.00	0.192	1.16	52.29	7.06	7.11	38.11	38.11
14	0.016	0.00	0.00	0.00	0.188	1.14	51.43	6.95	7.11	37.37	37.37
15	0.008	0.00	0.00	0.00	0.186	1.12	50.77	6.86	7.11	36.80	36.80
16	0.004	0.00	0.00	0.00	0.184	1.11	50.25	6.79	7.11	36.34	36.34
17	0.002	0.00	0.00	0.00	0.183	1.10	49.83	6.73	7.11	35.99	35.99
18	0.001	0.00	0.00	0.00	0.181	1.10	49.50	6.69	7.11	35.70	35.70
19	0.000	0.00	0.00	0.00	0.180	1.09	49.22	6.65	7.11	35.46	35.46
20	0.000	0.00	0.00	0.00	0.180	1.09	49.00	6.62	7.11	35.27	35.27
21	0.000	0.00	0.00	0.00	0.179	1.08	48.81	6.60	7.11	35.11	35.11
22	0.000	0.00	0.00	0.00	0.178	1.08	48.66	6.57	7.11	34.97	34.97

[1]Derived from empirical equations.

TABLE 7

The sensitivity of net present value (NPV) to assumptions relating to livestock/tree interaction

Complementarity assumption[1]		NPV (£/ha)	Index
Cereals	(no interaction)	2560.20	100
Livestock	(no interaction)		
Cereals	0%		
Livestock	−5%	2535.20	99
	+5%	2585.28	101
	+10%	2609.62	102
	+15%	2633.69	103
	+20%	2657.49	104

Source: POPEYE Spreadsheet Model.
[1]Negative complementarity implies competition.

tially large source of additional revenue in the system. A 5% increase in timber volume would appear to be reflected in a 1% increase in NPV for the system as a whole.

The nature of the decline in agricultural output through time is an important feature of the system about which relatively little is known for tree species and agricultural activities found under U.K. conditions. However, following the approaches discussed earlier (see the section on 'The spreadsheet'), Fig. 5 presents a range of agricultural decay functions derived variously from crown:stem diameter information, utilising equation (3) and the empirical equations (7) and (8), and offering a range of projected lower (B) plateaux heights. The NPV's associated with using each function on a poorer agricultural site are presented in Table 8. We do not know which one of these functions is 'correct' although the empirical plateau tends to be confirmed by the fact that grazing rentals under mature poplars in the Midlands are currently between 20% and 30% of open grazing capacity. Moreover, Newman's approach tends to overstate grazing capacity when compared with the empirical function, which is intuitively what should be expected, since no allowance is made for underground interactions. Once more, the true values for the coefficients will almost certainly lie somewhere between these extremes, to be determined by further research. However, because with broadleaves much more light may penetrate through tree crowns, the value of grazing later in the rotation may well be more significant than is found with pines under typical New Zealand conditions. The important thing for an economist is to set upper and lower boundaries to the true position and examine their significance in economic terms. The net present values consistent with each decay function are presented in Table 8.

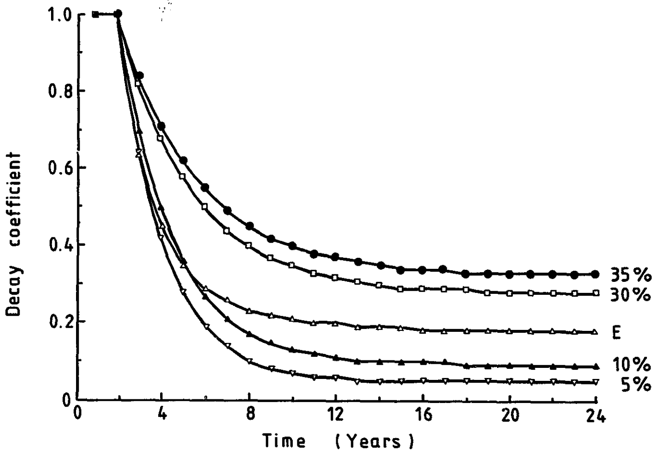


Fig. 5. A range of agricultural decay functions derived from empirical equations for livestock under poplar on poor land with various projected plateaux heights for the lower *B* plateau. Curve E uses the empirical equations (7) and (8).

TABLE 8

Sensitivity of agroforestry NPV to various agricultural decay functions – poplar and livestock[1]

Agricultural decay function		NPV (£/ha)	Index[3]
Newman dlm		1409.00	118
Empirical livestock:		1187.28	100
Projected plateau B	35%[2]	1492.40	125
	30%	1418.62	119
	10%	1101.19	92
	5%	1008.10	84

[1]On poorer permanent grassland with no cereal component.
[2]Assumes 180 stems/ha relative grazing capacity to open grazing from year 12 onwards.
[3]The empirical equation for livestock grazing capacity through time is used as a base value.

Thus far attention has been focussed on technical aspects. There are, of course, many other analyses which are possible, such as varying the assumptions relating to tree form, product classes, tree spacing, land allocations to each component and fencing regimes, but they will not be covered here. Similarly, a whole range of economic parameters can be examined, but a sum-

TABLE 9

The viability of a poplar, cereals and livestock agroforestry system. A best scenario analysis on medium quality land (no cereals)

Best scenarios		Net Present Value (£/ha)		
		Agroforestry	Forestry	Agriculture
(1)	Timber price +50% Everything else as status quo	2149.00	1680.00	2065.14
(2)	Timber price +25% Lamb price −25% Labour cost £0 /h Everything else as status quo	2164.66	1876.55	1319.22
(3)	Timber price +10% Lamb price −25% Labour cost £0 /h	1661.81	1373.70	1319.22
(4)	Timber price +10% Lamb price −25% Labour cost £3.0 /h	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 /h Complementarity +5% Everything else as status quo	1466.16	1178.05	1319.22
(7)	Timber price unchanged Lamb price −25% Labour cost £0 /h 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

mary analysis only for this system on medium quality grazing land typical of much of the Welsh hinterland is presented in Table 9.

Essentially the spreadsheet is being used, having examined each parameter in turn, to group those most significant parameters and assess their combined impact on the net present value of the system as a whole. Product prices and location in relation to sawmills are particularly significant in this respect. A more comprehensive discussion of these scenarios can be found in Thomas (1988).

Long-term price trends are likely to be very important to the economics of agroforestry in two contexts. Firstly, since the system has, in effect, two product components, changes in the relative prices of either will give rise to changes in the optimum combination of timber and food within the system per se. Secondly, price trends will alter the competitiveness of the system in compar-

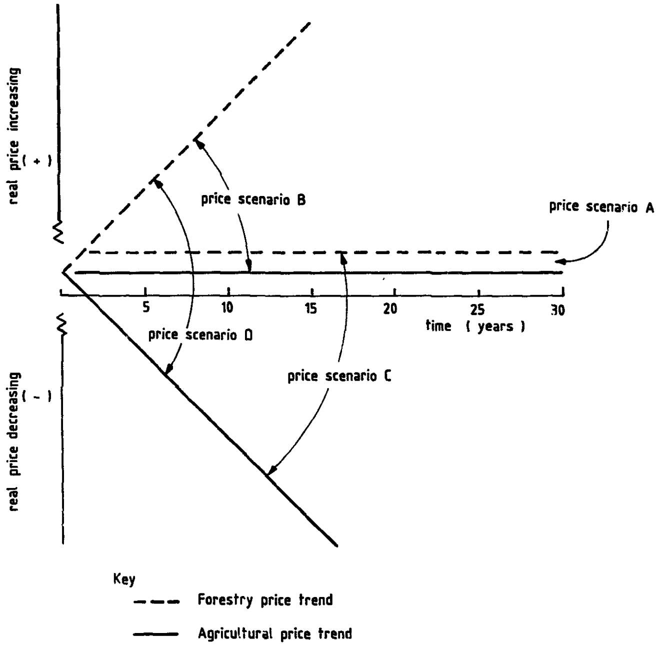


Fig. 6. A diagram to illustrate some potential future, real price trend scenarios for agriculture and forestry in the agroforestry system. These scenarios are evaluated quantitatively in Table 10.

ison to monocultures of either agriculture or forestry. With this in mind, Fig. 6 presents a schematic view of four price trend scenarios for the next 20 years. Scenario A represents a situation in which both components are maintained in real terms relative to each other. In scenario B, agricultural prices are maintained in real terms with an increase in forestry prices to a maximum of 4% per annum in real terms (CAS, 1980). Scenario C indicates a situation in which forestry prices are maintained in real terms and agricultural prices decline. Finally, scenario D describes a long run, divergent price trend with forestry and agricultural prices rising and falling, respectively, to varying degrees in real terms.

The results of simulating the scenarios within the spreadsheet are presented

TABLE 10

A comparison between net present value from agriculture and agroforestry under varying land type, price trends, and agricultural productivity decay scenarios, using POPEYE

Annual price changes in real terms	Net benefit agriculture: Agroforestry (£/ha)					
	Better land			Poorer land		
	Empirical decay function	Projected plateau *B* 35%	Projected plateau *B* 10%	Empirical decay function	Projected plateau *B* 35%	Projected plateau *B* 10%
Scenario A	3193	2823	3374	1259	953	1345
Scenario B						
Agricultural price constant						
Forestry price						
+1%	2948	2578	3129	1014	709	1100
+2%	2637	2266	2818	702	397	788
+3%	2239	1869	2420	305	0	391
+4%	1732	1361	1823	−202	−507	−116
Scenario C						
Forestry price constant						
Agricultural price						
−1%	2774	2453	2930	1063	790	1137
−2%	2414	2135	2548	895	649	957
−3%	2102	1859	2219	749	527	802
−4%	1832	1620	1933	622	420	668
Scenario D						
Agricultural price falling; forestry price rising						
Price divergence						
2%	2529	2209	2685	819	545	892
4%	1857	1578	1991	338	92	401
6%	1148	906	1265	−204	−426	−150
8%	371	159	472	−839	−1040	−793

in Table 10 in terms of the net advantage to agriculture over agroforestry. The results indicate the power of a spreadsheet in terms of its ability to scan the effect of varying a range of technical and economic parameters simultaneously. The four price trend scenarios have been evaluated under two different, initial site conditions with three possible agricultural decay functions. It is immediately obvious that falling agricultural prices do little for the viability of an agroforestry system. Moreover, increasing timber prices with agricultural prices held constant narrows the gap between forestry and agroforestry. The most favourable price scenario for this type of agroforestry would appear to be one of divergent prices, with the system gaining the benefit of higher agricultural prices earlier in the rotation when physical returns are in any event highest. Given such a scenario the ability to increase the physical value of later grazings would appear to be beneficial to agroforestry and, moreover, these effects are all the more pronounced on land of lower initial site productivity.

The spreadsheet is, in this case, being used primarily as a scanning device attempting to focus on those aspects of the system which could be significant in a policy and research context. Such findings might suggest for example that if price scenario D was most likely, attention should be focussed on lowlands of more marginal quality with a research emphasis on increasing the productivity of later grazing. These suggestions are in no way prescriptive, they are presented only to illustrate.

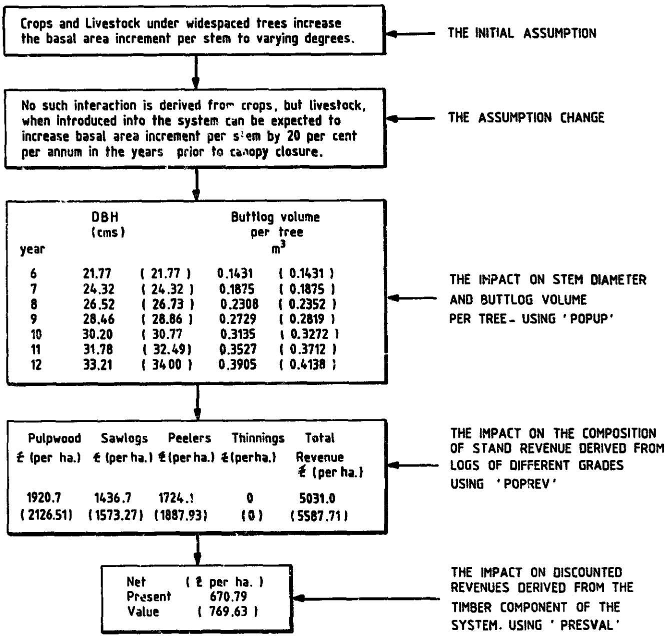


Fig. 7. An example of taking the POPEYE spreadsheet apart to examine parts of different components. The effects of a 20% complementarity effect on the trees from the livestock component is traced through to show its effect on net present value (NPV). The figures in brackets relate to the revised values resulting from the complementarity effect.

EDUCATIONAL VALUE

So far the spreadsheet has only been discussed in a research context. However, its transparent nature makes it an excellent tool for illustrating the interactions which take place in an agroforestry system to students. Its interactive tabular structure enables the user to trace through, in terms of cause and effect, the results of changing any of the technical or economic parameters on either the physical or economic performance of the system as a whole, or on its constituent parts.

Ideally this can only be really demonstrated in an interactive situation. However a simple example of a 'search mode' is presented in Fig. 7. It is assumed in this case that the effect of livestock is to increase basal area increment by some 20% from year 7 to the period of canopy closure. In Fig. 7 we are looking at small areas of different components 'torn' from the spreadsheet. Increased DBH is reflected in larger buttlog volume which is, in turn, distributed in revenue terms amongst the various product categories and ultimately in a higher NPV for the forestry component of the system. Using the spreadsheet in this way not only traces 'cause and effect' but also indicates the relative magnitudes where 'trade-offs' are involved. An additional pathway to follow would be to use the decay function in the diffuse light model, available within the spreadsheet, to determine the implications of complementarity in terms of larger volume, large diameter logs on agricultural revenues from the system. For brevity this is not undertaken here.

CONCLUSIONS

The spreadsheet provides a framework within which the various components listed in Fig. 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, because 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 required information, for example land capability and bioclimatic data, may well exist for potential sites, as may data relating to input requirements and site productivity that 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 impacts on the system as a whole of, for example, particular pruning regimes that improve the form characteristics of trees or perhaps a supplementary forage establishment programme that uses legumes late-on in the course of a rotation. Using a model in this context can actually point the direction in which the greatest potential source of economic benefit from further research is likely to result.

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 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. Nevertheless it provides a unit which can be aggregated upwards to both farm and regional level. Above all the spreadsheet must be viewed as a powerful and flexible tool. Its operational value as a scanning and planning device is only as good as its component parts. In this context it is seen as a framework within which preliminary analysis can be undertaken and which will continually be refined as improved functions are incorporated as a result of further research.

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