



Description and User Guide for Farm-SAFE v3

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Farm-SAFE

A model to determine the relative profitability of arable, forestry and silvoarable systems at a one-hectare and field scale

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Executive summary

Farm-SAFE (a Financial and Resource Use Model for Simulating Agroforestry in Europe) is a spreadsheet-based model to compare the profitability of arable, forestry and agroforestry systems over a period of up to 60 years at plot, “unit”, and farm scales. It has been designed to use annual yields of trees and crops derived from the biophysical Yield-SAFE model. A first version of the model was developed through the EU-funded “Silvoarable Agroforestry For Europe” project from 2001 to 2005 (Graves et al., 2011). During the EU funded AGFORWARD project (2014-2018), further developments were made to Farm-SAFE and a publicly available version of the model called “Farm-SAFE_Mar2017” is available online (Graves et al., 2017). However, this model has become too complicated for many users, and hence we have created a simpler version of the model called “Farm-SAFE v3” using through the BioForce project funded by the UK Department for Energy Security and Net Zero.

The second section of this document describes the two spatial scales and the financial analyses used in the Farm-SAFE v3 model. The third section describes the software requirements and the structure of the model. Section 4 describes the “Options and Results” worksheet, where the user can call in biophysical data from worksheets called “Arablesystem”, “Forestrysystem”, and “Agroforestrysystem”, and financial data from worksheets called “Arablefinance”, “Treecost”, “Treevalue”, and “Treegrant”. The “Options and Results” can also be used for sensitivity analysis and the financial results are also presented in a tabular and graphical form. Section 5 provides a general description of other worksheets. Lastly Section 6 works through an example of a financial comparison of an arable, tree-only, and a silvoarable system.

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1 Development of the Farm-SAFE model

Farm-SAFE (a Financial and Resource Use Model for Simulating Agroforestry in Europe) is one of the models originally developed within a European Commission project called ‘Silvoarable Agroforestry for Europe’ (SAFE) which ran from 2001 to 2005 (Dupraz et al., 2005). The aim of the SAFE project was to increase the understanding of temperate silvoarable agroforestry relative to conventional arable and forestry systems. Within the SAFE project, the biophysical Yield-SAFE model with a daily time-step was developed to predict timber and crop yields within arable, forestry and agroforestry systems across Europe (Graves et al., 2007). These biophysical results were then used within the original Farm-SAFE model to compare the profitability of arable, forestry and agroforestry systems at a plot, “unit”, and farm scale (Graves et al., 2007). The original Farm-SAFE model was developed using some of the functions from earlier bio-economic agroforestry models such as POPMOD (Thomas, 1991; Burgess et al., 2000) and ARBUSTRA (Liagre, 1997), which are described in part by Graves et al. (2005). During the SAFE project, Farm-SAFE was also developed to allow financial comparisons between four “units” of a farm or region each potentially comprising an area of arable enterprises, forestry, and silvoarable agroforestry. These four land units could then be aggregated together to provide farm scale results. Using financial support from Switzerland, a “Quick User Guide” (Graves et al., 2006a) and a “User-Guide” (Graves et al., 2006b) to describe the use of Farm-SAFE was produced.

During the EU funded AGFORWARD project (2014-2018), further developments were made to Farm-SAFE to include assessment of net carbon sequestration. A publicly available version of the updated model called “Farm-SAFE_Mar2017” was made available online (Graves et al., 2017). Using this model it was possible to use the Farm-SAFE model for both financial and economic analyses. Subsequently, this second version of Farm-SAFE model was used to compare the financial and economic aspects of an arable, poplar, and poplar agroforestry systems at a single site in the UK (García de Jalón et al., 2018; Kaske et al., 2021), and agricultural, tree-only, and agroforestry systems at sites in Spain, Switzerland, and the UK (Giannitsopoulos et al., 2020).

However, the process of developing the “Farm-SAFE_Mar2017” model meant that the model became increasingly large and difficult to use for simpler plot-scale financial analyses of arable, tree-only and agroforestry systems. Hence using support in 2023 from the UK Department for Energy Security and Net Zero, a simpler version of the model called “Farm-SAFE v3” was developed. This report describes the key components of Farm-SAFE v3.

2 Financial spatial and temporal analysis

Farm-SAFE produces results at two spatial scales for the analysis of agricultural, tree-only, and silvoarable enterprises: ‘plot-scale’ (or one-hectare-scale) and ‘unit scale’ (aggregation of a number of ‘plots’ into a ‘land unit’). The ‘plot’ and ‘unit’ scale analysis support one arable, one tree-only, and one agroforestry system. The basic financial unit used in Farm-SAFE v3 has been specified as UK pound sterling, but this could be altered for use in other countries. The analysis assumes that a specific system (i.e. arable, tree-only, or agroforestry) is undertaken completely across the specified plots, but different areas of the three systems can be brought together to determine the revenues and costs for a “unit”.

Typically, when one arable enterprise is compared with another arable enterprise, the financial analysis is completed on a gross margin basis (i.e., revenue minus variable costs) where costs such as labour and machinery are assumed to be constant. By contrast, because the financial analyses of tree-based systems need to consider numerous years and are heavily dependent on intermittent labour and machinery costs, in comparisons of arable and agroforestry and tree-only systems, it is necessary to include the costs of machinery and labour. Hence, Farm-SAFE includes “assignable fixed costs” such as labour and machinery to derive a net margin per hectare for each enterprise (Willis et al., 1993).

People generally have a time preference for having money now rather than in the future. To account for this, Farm-SAFE allows the value of future revenues and costs to be discounted over time, using a specified discount rate i . The net benefit of each enterprise over a specified period of time is therefore expressed as a net present value (NPV) (Equation 1).

$$NPV = \sum_{t=0}^n \left(\frac{R_t - VC_t - AFC_t}{(1+i)^t} \right) \quad \text{Equation 1}$$

where R_t , VC_t , and AFC_t are respectively revenue, variable costs, and assignable fixed costs in year t (£ ha⁻¹), i is the discount rate, and n is the time horizon for the analysis.

The equivalent annual income from each system is calculated in terms of a financial equivalent annual value (EAV: £ ha⁻¹ y⁻¹) using Equation 2.

$$EAV = NPV \left(\frac{(1+i)^n}{(1+i)^n - 1} \right) i \quad \text{Equation 2}$$

At the plot-scale, the model assumes that the tree-only and agroforestry enterprises are planted only once in the first year of a project (i.e., year 1). However, a unit-scale analysis might include tree establishment in a range of years. Within a specified land unit, a farmer might choose to plant varying areas of forestry or agroforestry over a range of years. In Farm-SAFE, it is possible to plant forestry and agroforestry system over a user-defined area in as many as five different years. This option can be combined with the “phased planting” option if required, where a farmer might introduce forestry or agroforestry in a regular planting pattern. For a phased planting pattern, a specified area of a particular forestry or silvoarable system can be planted periodically, using an interval defined by the user in years, and a specified start and end date, also defined by the user in years.

3 Description of the Farm-SAFE model

3.1 Software requirements

Farm-SAFE v3 was developed to run within Microsoft® Excel® for Microsoft 365. This was done to facilitate widespread use of the model by using a modelling platform that is widely available. The model comprises a series of worksheets held within a workbook and has been developed to ensure that it can be loaded into different language versions of Excel.

3.2 Structure

Farm-SAFE is a Microsoft Excel workbook that has a number of worksheets, however, only those sheets that are required for data input and manipulation of scenarios are visible to the user. The worksheets are described below. Throughout the remainder of the report, the names of individual worksheets are written in blue print, bold and italics.

Options and results: the principal worksheet. In the options section, the user can select the arable, forestry and agroforestry systems within three plots, which can be combined to make up a “unit”. The user can also specify the planting programme and economic options. In the results section, the effects of these choices are described in terms of profitability, production and labour requirements at a plot and a unit scale.

Arablesystem, ***Forestrysystem***, and ***Agroforestrysystem*** contain the primary biophysical data.

Arablefinance, ***Treecost***, ***Treevalue***, and ***Treegrant*** are the four worksheets that contain the primary economic data for the model.

A schematic representation of the relationships between these worksheets is shown in Figure 1, and a description is provided in Table 1. A detailed description of the ***Options and results*** worksheet is provided in Section 4, and the other principal worksheets are described in Section 5.

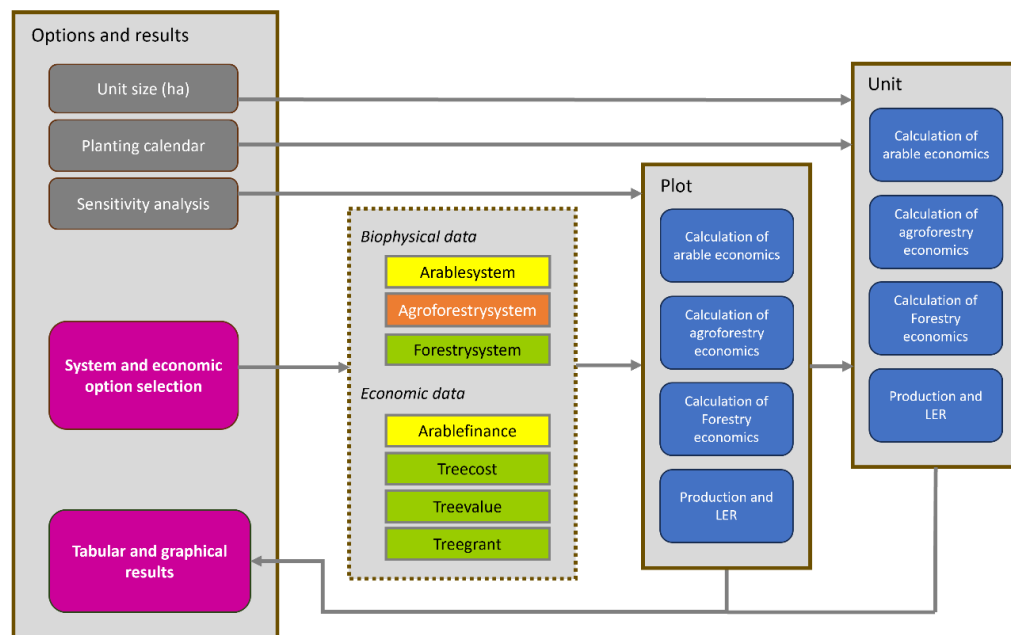


Figure 1. Schematic representation of Farm-SAFE economic model, showing the principal worksheets

Table 1. Principal worksheets in the Farm-SAFE and a brief description of their function

Worksheet name	Worksheet function
Data manipulation and results	
Options and results	Allows selection of data stored in 'Arablesystem', 'Arablefinance', 'Agroforestrysystem', 'Treesystem', 'Treecost', 'Treevalue' and 'Treegrant'. Allows selection of analytical criteria (e.g., discount rate). Displays production and economic one-hectare- and unit-scale results, as tabular and graphical data.
Tabular results	Summary tables of production and economic one-hectare- and unit-scale results
Data storage	
Arablesystem	Stores production data for arable systems
Forestrysystem	Stores production data for forestry systems
Agroforestrysystem	Stores production data for agroforestry systems
Arablefinance	Stores data on the prices, grants and costs associated with arable systems and the crop component of agroforestry systems
Treevalue	Stores data on the prices of tree products
Treegrant	Stores data on the grant systems associated with trees
Treecost	Stores data on the costs associated with forestry systems and the tree component of agroforestry systems
Data modelling	
Plot	Models one-hectare-scale economics and labour requirements of arable, forestry and agroforestry systems. This worksheet can be useful for extracting data to present results

Within the workbook there are three hidden worksheets (Table 2). These worksheets can be unhidden by right-clicking on a worksheet tab and selecting the "Unhide" function.

Table 2. Hidden worksheets in the Farm-SAFE and a brief description of their function

Worksheet name	Worksheet function
Data modelling	
Systemlist	A summary of the selectable arable, forestry and agroforestry systems
Unit	Models unit-scale economics, labour, and land use requirements of arable, forestry and silvoarable systems.
Optimisation	For 'Plot', calculates the optimal rotation of the crop component of the silvoarable system

4 Description of the ‘Options and results’ worksheet

The principal worksheet in the Farm-SAFE model is entitled *Options and results*. The worksheet is divided into nine sections. Each of these sections is described in turn.

4.1 Selection of arable data

The first section of the *Options and results* allows the selection of arable system and financial data. The user can select the biophysical data for the arable enterprise. The systems available are stored in *Arablesystem*. The user must also select an appropriate source of financial data from *Arablefinance*. The appearance of the input selection box for arable system and financial data from the *Options and results* worksheet is shown in Figure 2.

The screenshot shows a worksheet titled "1. Arable system" with the following inputs:

- Select system:** A dropdown menu showing "1" (range 1-30, "None" for no system). Below it, a text box shows "UK England standard Cereals".
- Crop rotation length:** A text box showing "30" years.
- Select arable financial data:** A dropdown menu showing "1" (range 1+). Below it, a text box shows "UK - Agriculture (BPS: from 2015)".
- Minimum area to maintain in arable:** A text box showing "0" ha.
- Labour cost:** A text box showing "14.6" £ hr⁻¹.

Figure 2. Appearance of input selection box for arable system and financial data from the ‘Options and results’

Within this section, by entering the appropriate number in the cells shaded yellow, the user can select:

1. The appropriate biophysical data for the arable enterprise
2. The appropriate financial data for the arable enterprise
3. The minimum area to maintain in arable production. If the combined area of the systems planted on a land unit exceeds the amount of land that is available in the land unit, a warning such as this: **Note: Excessive area planted** is given by Farm-SAFE in cells K48-N48 and cells K74-N74. The user should adjust the forestry or agroforestry planting schemes or reduce the minimum area to be retained in arable production until no warning appears.
4. the cost of labour per hour for crop operations (£ h⁻¹).

4.2 Selection of forestry data

The second section of the *Options and results* which deals with the tree-only or forestry data is split into three sub-sections allowing the selection of:

1. Forestry system and financial data
2. Tree planting and management options for the forestry system
3. Tree labour costs

The appearance of the input selection boxes for forestry data from the *Options and results* worksheet is shown in Figure 3. The options are selected by entering the appropriate number in cells shaded green.

The screenshot displays the 'Options and results' worksheet with various input selection boxes. The 'Tree' section includes options for system (1), rotation length (30 years), costs (2), values (1), and grants (1). The 'Discrete planting' section includes options for lot (1), year (35.5), and pruning (1). The 'Beating-up' section includes options for beating-up (10%), period of beating-up (1 year), minimum prune height of bole (1.0 m), bole height increment at each prune (1 m), max. bole height (70% of tree height), and pruning undertaken (1). The 'Labour costs' section includes options for establishment (16.0 £/ha), maintenance (16.0 £/ha), and clear felling (16.0 £/ha).

Figure 3. Appearance of input selection boxes for forestry system, financial data, tree planting and management options and labour costs from the 'Options and results' worksheet

4.2.1 Forestry system and financial data

The appearance of the input selection box for the forestry data from the *Options and results* worksheet is shown in Figure 4. The options are selected by entering the appropriate number in cells shaded green.

The screenshot displays the 'Options and results' worksheet with input selection boxes for forestry system and financial data. The 'Tree' section includes options for system (1), rotation length (30 years), costs (2), values (1), and grants (1). The 'Establishment grant' section includes options for area (Area), years (years), % of total cost for planting grant (% of total cost for planting grant), and % of total cost for planting grant supplement (% of total cost for planting grant supplement). The 'Compensation payment' section includes options for full (full) or manual override (% per ha forest). The 'Maintenance payment - Period 1' and 'Period 2' sections include options for full (full) or manual override (% per ha forest).

Figure 4. Appearance of input selection boxes for forestry system and financial data from the 'Options and results' worksheet

The user can select or define:

1. Biophysical data for the forestry enterprise from *Forestrysystem*
2. Tree costs from *Treecost*.
3. Timber price-size data from *Treevalue*
4. The tree grant system from *Treegrant*. Since grant schemes vary between nations, three options (“area”, “cost”, and user defined %) are provided to modify the grant data selected from *Treegrant*. Using “area” applies the grant to the proportion of trees in the system. Since in a forestry system, trees cover 100% of the system, 100% of the grant defined in *Treegrant* is applied. Using the “%” option, applies the selected value as a proportion of the grant defined in *Treegrant*. If the “cost” option is selected, the establishment grants are defined by the cost of establishment of the forestry system. For this option, the number of years and the proportion of the establishment cost paid as grant must be specified. Compensation and maintenance payments are commonly made on forestry systems. These may be applied as “full” in which case the full value defined by the record selected from the *Treegrant* database is used, or may also be applied as a percentage of that value.
5. A compensation payment. The options are “full” or a manual override of a percentage (%) per hectare of forest.
6. A maintenance payment for period 1. The options are “full” or a manual override of a percentage (%) per hectare of forest.
7. A maintenance payment – period 2. The options are “full” or a manual override of a percentage (%) per hectare of forest.

4.2.2 Planting and tree management options

The *Options and results* spreadsheet also allows the user to phase the tree planting within the forestry system. The appearance of the input selection box for forestry planting and tree management options in the *Options and results* worksheet is shown in Figure 5. The options are selected by entering the appropriate number in cells shaded green.

Discrete planting				Beating-up			
Lot 1	1	year		Beating-up	10%	%	
	33.3	ha		Period of beating-up	1	years	
Lot 2		year		Pruning			
		ha		Minimum prune height of bole	1.0	m	
Lot 3		year		Bole height increment at each prune	1	m	
		ha		Max. bole height	70%	% of tree height	
Lot 4		year		Autoprune?	no	yes/no	
		ha		Prunes undertaken	biophysically defined		
Lot 5		year					
		ha					
Continuous planting							
Start		year					
End		year					
Interval		year					
Area planted each year		ha					

Figure 5. Appearance of the planting and tree management options in the ‘Options and results’ worksheet

The user can specify up to five planting lots of different areas in different years. The user can also specify a planting pattern where fixed-size lots are planted for a specified area at a fixed interval

between a start year and end year for the planting. This option can be used either with or without the single lot planting option.

Table 3. Planting and management options in the 'Options and results' worksheet

Input category	Inputs
Either discrete plantings (lots 1 to 5)	Year of planting Area of lot (ha)
And/or regular plantings	Start year; End year Interval of planting (years); area of lots (ha)
Beating-up	Beating up (%); beating up period (years)
Pruning	Bole height at planting; Bole height increment Maximum bole height (%); Autoprune

Beating-up: the beating-up percentage represents the annual mortality of planted trees. The user may include a beating-up percentage and a period for beating-up to occur. It is assumed that the farmer will replace the dead trees with new planting stock.

Pruning options: Pruning of trees in forestry systems can be based on the biophysical records stored in *Forestrysystem* or the user can instruct the model to calculate the pruning automatically. If the biophysical record is used, the user must enter “No” in the “autoprune” option. This will then use the biophysical data from *Forestrysystem* to calculate the timing and costs of pruning. If the user would like to use the “autoprune” facility, the “autoprune” value should be set to “Yes”. The minimum prune height, bole height increment at each prune, the percentage of the total height of the tree to maintain in bole should also be defined. The “prunes undertaken” tells the user how many prunes are undertaken using the autoprune facility, and the cost of pruning will be calculated for those pruning events.

4.2.3 The labour costs (tree operations)

The *Options and results* spreadsheet also allows the user to specify costs for tree operations (€ h⁻¹). The appearance of the input specification box for tree operation costs in the *Options and results* worksheet is shown in Figure 6. The options are selected by entering the appropriate number in cells shaded green.

The user can set costs for the following tree operations (€ h⁻¹):

- For establishment:
 - Ground preparation
 - Full weeding
 - Marking-out
 - Planting
 - Protection
- For maintenance:
 - Localised weeding
 - Weeding
 - Pruning
 - Removal of prunings
 - Sward establishment
 - Sward maintenance

- Trimming epicormics
- Marking-up and thinning labour
- For clear felling:
 - Removal of thinned trees
 - Labour
 - Removal of clear-felled trees

Labour costs			
Establishment			
	Ground preparation	14.6	£ h ⁻¹
	Full weeding	14.6	£ h ⁻¹
	Marking out	14.6	£ h ⁻¹
	Planting	14.6	£ h ⁻¹
	Protection	14.6	£ h ⁻¹
Maintenance			
	Localised weeding	14.6	£ h ⁻¹
	Weeding	14.6	£ h ⁻¹
	Pruning	14.6	£ h ⁻¹
	Removal of prunings	14.6	£ h ⁻¹
	Sward establishment	14.6	£ h ⁻¹
	Sward maintenance	14.6	£ h ⁻¹
	Epicormics	14.6	£ h ⁻¹
	Marking-up and thinning	14.6	£ h ⁻¹
Clear felling			
	Removal of thinned trees	14.6	£ h ⁻¹
	Labour	30.0	£ h ⁻¹
	Removal of clear felled trees	14.6	£ h ⁻¹

Figure 6. Appearance of the input specification box for tree operation costs in the 'Options and results' worksheet

4.3 Selection of agroforestry data

The third section of the [Options and results](#) is split into two sub-sections allowing the selection of:

1. agroforestry system and financial data
2. tree planting and management options for the agroforestry system

The appearance of the input selection box for agroforestry data in the [Options and results](#) worksheet is shown in Figure 7. The options are selected by entering the appropriate number in cells shaded yellow or green.

3. Agroforestry system

Select system (1-20) ("None" for no system): 2
UK Siloe Siloe_02 Poplar 100 trees/ha wvbo 14yr 99% WWBO

Arable

Arable crop rotation length: 30 years

Select arable financial data: 1 (1+)
UK - Agriculture (BPS: from 2015)

Intercrop: 100% "area", % per ha or % canopy area per ha

Tree

Tree component rotation length: 30 years

Select costs: 1
UK Poplar Agroforestry England standard EU

Select values: 1
UK poplar

Select grants: 2
UK poplar agroforestry

Establishment grant (if cost based grant, period of payment and percentage of total): Area "area", "cost" or % defined grant

Period of payment: 1 years

% of total cost for planting grant: 100% % of total cost

% of total cost for planting grant supplement: "area" or % per ha

Tree-area based compensation payment: "area" or % per ha

Tree-area based maintenance payment - Period 1: "area" or % per ha

Period 2: "area" or % per ha

Planting scheme

Select crop code for manual override of specified crop rotation or automated optimisation: None "None" for no override

Year of manual override: None year ("None" for no manual override)

Discrete planting

Lot 1: 1 year Beating-up: 10% %
33.3 ha Period of beating-up: 1 years

Lot 2: 1 year

Lot 3: 1 year

Lot 4: 1 year Pruning: 1.0 m
Minimum prune height of bole: 1 m

Lot 5: 1 year Bole height increment at each prune: 70% % of tree height

Autoprune? no yes/no

Prunes undertaken: biophysically defined

Continuous planting

Start: 1 year

End: 1 year

Interval: 1 year

Area planted each year: 1 ha

Figure 7. Appearance of input selection box for the agroforestry system, financial data and tree planting and management options from the 'Options and results' worksheet

4.3.1 Agroforestry system and financial data

The first sub-section allows the selection of the biophysical data and the financial data for the arable and tree components of the agroforestry system. The user can select and store the biophysical data for the agroforestry systems, which include the arable and tree growth data, from [Agroforestrysystem](#).

The appearance of the input selection box for the agroforestry system and financial data in the [Options and results](#) worksheet is shown in Figure 8. The options are selected by entering the appropriate numbers in cells shaded yellow and green.

The user can select the agroforestry system to be modelled from [Agroforestrysystem](#) using the same procedure as for the arable and forestry systems. The financial data for the crop component of the agroforestry system are selected from [Arablefinance](#). In most cases it is likely to be the same as that selected for the arable system. Farm-SAFE applies the data on a pro-rata basis depending on the area of land in the agroforestry system occupied by the crop component. This is specified in the biophysical data from [Agroforestrysystem](#). The data selected from [Treegrant](#), [Treevalue](#) and [Treecost](#) are selected in the same way as for the forestry system.

Farm-SAFE provides a variety of means of applying the crop and tree component grants in agroforestry systems. If the "area" option is used, the annual grant defined in [Arablefinance](#) is applied on a pro-rata basis depending on the area of the crop. If the per hectare area of the crop is 80% of the agroforestry system, 80% of the value of the defined grants are applied. If the area of crop is reduced over time, for example because the trees are growing into the crop area, the grant is also proportionally reduced. If a percentage option is used, this percentage is applied over the whole

duration of the rotation irrespective of the area of the crop within the agroforestry system. For example, some grant scenarios may provide 100% of the crop grant per hectare of agroforestry system even though the crop only occupies 80% of the agroforestry system. A third option involves reducing the payment as a function of the tree canopy area in the agroforestry system. In this case the user defines how great the reduction in the payment will be as a proportion of the total canopy area in the system. For example, the reduction may be proportional or 100% of the canopy area. The value of the grant therefore reaches 0 £ ha⁻¹ when the tree canopy is deemed to cover 100% of the agroforestry system. The canopy area must be defined in [Agroforestry system](#) for this option to work.

3. Agroforestry system		
Select system (1-20) ("None" for no system)	2	UK Silsoe Silsoe_02 Poplar 100 trees/ha wwbo 14yr 99% WWBO
Arable		
Arable crop rotation length	30	years
Select arable financial data	1	(1+)
		UK - Agriculture (BPS: from 2015)
Intercrop	100%	"area", % per ha or % canopy area per ha
Tree		
Tree component rotation length	30	years
Select costs	1	
		UK Poplar Agroforestry England standard EU
Select values	1	
		UK poplar
Select grants	2	
		UK poplar agroforestry
Establishment grant (If cost based grant, period of payment and percentage of total)	Area	"area", "cost" or % defined grant
Period of payment		years
% of total cost for planting grant	100%	% of total cost
% of total cost for planting grant supplement		% of total cost
Tree-area based compensation payment		"area" or % per ha
Tree-area based maintenance payment - Period 1		"area" or % per ha
Period 2		"area" or % per ha

Figure 8. Appearance of the input selection box for the agroforestry system and the arable and tree financial data from the 'Options and results'

The way that the tree component of the agroforestry system receives grants can also be modified. These options are similar to those for the forestry system. For example, if "area" is specified as the basis for the establishment grant, the value of the selected record is applied depending on the area of the tree component in the silvoarable system. For example, if the tree component is 20% of the per hectare area of the agroforestry system, only 20% of the value of the selected grant will apply. However, if a percentage (%) input is selected, the value of the establishment payment is a percentage of the value defined in the record selected from [Treegrant](#). The cost-based option operates in a manner similar to the forestry system and the grant is calculated according to the cost of the

establishment of the tree component of the agroforestry system. The compensation and maintenance payments also operate in a similar way to the forestry system. If the “area” option is used, the grant is calculated according to the area of the tree component within the agroforestry system. Alternatively, a user-defined percentage of the value of these payments in the record selected from *Treegrant* may be applied.

The labour rates used for crop and tree management of the agroforestry system are based on the arable labour rate for the crop-related operations (Cell C27) and the forestry labour rates for tree-related operations (Cells S32:S43). For this reason, there is no separate input box for these values for the agroforestry system, as Farm-SAFE assumes the same labour rates for the crop and tree component of the agroforestry system that are specified for the arable and forestry system.

4.3.2 Planting and tree management options

The *Options and results* spreadsheet also allows the user to phase the tree planting within the agroforestry system. The appearance of the input box for selection of the agroforestry planting and tree management options from the *Options and results* worksheet is shown in Figure 9. The options are selected by entering the appropriate number in cells shaded green.

Planting scheme
Select crop code for manual override of specified crop rotation or automated optimisation

None "None" for no override

No override crop

Year of manual override

None year ("None" for no manual override)

Discrete planting

Lot	Year	ha	Beating-up	Beating-up	Period of beating-up	Pruning	Minimum prune height of bole	Bole height increment at each prune	Max. bole height	Autoprune?	Prunes undertaken
Lot 1	1	year		10%	1		1.0	1	70%	no	biophysically defined
	33.3	ha		%	years		m	m	% of tree height	yes/no	
Lot 2		year									
		ha									
Lot 3		year									
		ha									
Lot 4		year									
		ha									
Lot 5		year									
		ha									

Continuous planting

Start	End	Interval	Area planted each year

Area planted each year

Figure 9. Appearance of the input selection box for planting and tree management options in the 'Options and results' worksheet

Optimisation of agroforestry crop: The user can choose to manually override the agroforestry crop rotation with another crop (for example: fallow or pasture), for example, if the original crop becomes unprofitable because tree yield is being reduced. The option here provides a manual override capacity. The user can select the crop that they wish to use to override the existing crop rotation and the year in which this should commence. The crop selected for the override is shown in the white box below the selection box for the override crop. If the user wishes no override, then the user should type “none” instead of typing a commencement year for the replacement crop.

Tree planting: The user can specify up to five planting lots of different areas in different years. The user can also specify a regular planting pattern with a regular interval and lots of equal area. A start year and an end year can be specified for the continuous planting pattern. This option can be used either with or without the single lot planting option.

Beating-up: the beating-up percentage represents the annual mortality of planted trees. The user may include a beating-up percentage and a period for beating-up to occur. It is assumed that the farmer will replace the dead trees with new planting stock.

Pruning options: Pruning of trees in agroforestry systems can be based on the biophysical records stored in [Agroforestrysystem](#) or the user can instruct the model to calculate the pruning automatically. If the biophysical record is used, the user must enter “No” in the “autoprune” option. This will then use the biophysical data from [Forestrysystem](#) to calculate the timing and costs of pruning. If the user would like to use the “autoprune” facility, the “autoprune” value should be set to “Yes”. The minimum prune height, bole height increment at each prune, the percentage of the total height of the tree to maintain in bole should also be defined. The “prunes undertaken” tells the user how many prunes are undertaken using the autoprune facility, and the cost of pruning will be calculated for those pruning events.

4.4 Sensitivity analysis

In the fourth section of *Options and results*, the user can modify the relative levels of the production, prices, costs and labour values which are used to determine the net margins of each enterprise (Table 4; Figure 10). The options are selected by entering the appropriate number in cells shaded yellow. Entering “100%” assumes that the value is 100% of the original value. Entering “200%” assumes that the value is 200% of the original value, so that the value has doubled. Entering “50%” would assume that the value is 50%, or half of the original value. The user can enter a start year for these changes to take place and these will then be applied to the end of the rotation. Generally, it is most common to assess what effect a change has from year 1 of the rotation. But users may, for example, wish to simulate a future price shock that takes place at a specified year in the future.

Table 4. Options for sensitivity analysis in ‘Options and results’ worksheet for the arable, forestry, and the tree and crop components of the agroforestry system

Input category	Inputs
Production	Relative production (%) and start year
Non-grant revenue	Relative non-grant revenue (%) and start year
Grant revenue	Relative grant revenue (%) and start year
Labour hours	Relative labour input (%) and start year
Costs	Relative costs (%) and start year

4. Sensitivity analysis and one-off changes					
	Agroforestry				
	Arable	Forestry	Crop	Tree	
Production	100%	100%	100%	100%	%
	1	1	1	1	from year
Non-grant revenue	100%	100%	100%	100%	%
	1	1	1	1	from year
Grants	0%	0%	0%	0%	%
	1	1	1	1	from year
Labour hours	100%	100%	100%	100%	%
	1	1	1	1	from year
All costs	100%	100%	100%	100%	%
	1	1	1	1	from year

Figure 10. Appearance of the input box for one-off sensitivity analysis choices in the ‘Options and results’ worksheet

Production: the user can increase or decrease the relative production of the arable and forestry enterprises and the crop and tree component of the agroforestry enterprise. This can be done for the entire rotation or from a specified year.

Non-grant revenue: the user can increase or decrease the relative level of revenue (excluding grants) associated with the arable and forestry enterprises and the crop and tree component of the agroforestry enterprise. This can be done for the entire rotation or from a specified year.

Grant revenue: the user can increase or decrease the relative level of grants associated with the arable and forestry enterprises and the crop and tree component of the agroforestry enterprise. This can be done for the entire rotation or from a specified year.

Labour hours: the user can increase or decrease the relative level of labour inputs associated with the arable and forestry enterprises and the crop and tree component of the agroforestry enterprise. This can be done for the entire rotation or from a specified year.

Costs: the user can increase or decrease the relative level of costs associated with the arable enterprise, the forestry enterprise, or the crop and tree components of the agroforestry enterprise. This can be done for the entire rotation or from a specified year.

4.5 Price and cost trends

In a fifth section of *Options and results*, the user can provide linear trends in the values of crop and timber prices, labour, other costs and grants (Table 5). The appearance of selection of agroforestry planting and tree management options from the *Options and results* worksheet is shown in Figure 11. The options are selected by entering the appropriate number in the cells shaded yellow.

For example, it may be evident from historic data that the cost of labour is increasing at an annual rate of 3%, this could be modelled with Farm-SAFE. These prices and cost trends can also be input as negative trends. For example, for grants, it may be considered that these are likely to decrease by 2% a year. For grants, there is also an additional option for reducing the level of grant revenue to a specified proportion of its current value.

Table 5. Options for price and cost trends in 'Options and results' worksheet for the crop and tree-related components

Input category	Inputs
Crop and timber prices	Relative annual change (%)
Labour costs for crop and tree components	Relative labour cost (%)
Other costs for crop and tree components	Relative other costs (%)
Grant revenue for crop and tree components	Relative grant revenue (%)

5. Price and cost trends

	Crop	Timber
Prices	0%	0%
Labour costs	0%	0%
Other costs	0%	0%
Grant revenue	0%	0%

If reducing due to grant reform, percentage to reduce to: 0%

Figure 11. Appearance of the input box for price and cost trends in the 'Options and results' worksheet

4.6 Economic analysis results table

The sixth section of *Options and results* contains the unit scale results and the financial analysis results at a one hectare-scale. The unit area (ha), the maximum length of the simulation, the time period for analysis, and the base discount rate are provided as options in this results section so that the user can directly see the effect of changes on the results. The appearance of the results table from the *Options and results* worksheet is shown in Figure 12. The options are selected by entering the appropriate number in the cells shaded yellow.

Maximum simulation period: in the plot results, the user can set the maximum length of the financial simulation. The maximum length of the rotation should not be less than the time periods for analysis selected for Plots 1 - 4.

Time period for analysis: the time period for financial analysis can be specified. Using these values, the worksheet calculates the cumulative actual value of each enterprise (including and excluding standing trees).

Base discount rate: the discount rates are used to calculate the cumulative net present value for the arable, forestry and agroforestry enterprises. The selection of the base discount rate can be particularly important.

6. Results per unit and per hectare					
			Arable	Forestry	Silvoarable
					Crop Tree Combined
Unit area	100 ha				
Maximum simulation period	30 (years)				
Net present value (NPV)	£ unit ⁻¹		177494	39846	49633 66931 116624
Crop production	t unit ⁻¹		7075		2950
Tree production	m ³ unit ⁻¹			7234	7212
Labour	h unit ⁻¹		10493	2704	4877 1808 6686
Economic analysis results (per hectare)					
Time period for analysis	30				
Undiscounted net margin	£ ha ⁻¹		7800	6455	1475 8100 9574
Undiscounted product revenue	£ ha ⁻¹		44354	8698	18418 9604 28022
Undiscounted grant revenue	£ ha ⁻¹		0	0	0 0 0
Undiscounted costs	£ ha ⁻¹		36554	2243	16943 1504 18448
Base discount rate	4.0%				
Discounted net margin	£ ha ⁻¹		5314	1197	1492 2010 3502
Discounted revenue (excluding grants)	£ ha ⁻¹		27230	2789	14787 3080 17867
Discounted grant revenue	£ ha ⁻¹		0	0	0 0 0
Discounted costs	£ ha ⁻¹		21916	1592	13295 1070 14365
Equivalent annual value of net margin	£ ha ⁻¹ a ⁻¹		307	69	86 116 203
Equivalent annual value of revenue (ex	£ ha ⁻¹ a ⁻¹		1575	161	855 178 1033
Equivalent annual value of grant reven	£ ha ⁻¹ a ⁻¹		0	0	0 0 0
Equivalent annual value of costs	£ ha ⁻¹ a ⁻¹		1267	92	769 62 831
Production and labour					
Crop main product	t ha ⁻¹		212		89
Crop by-products	t ha ⁻¹		97		40
Timber	m ³ ha ⁻¹			8	0
Firewood	m ³ ha ⁻¹			177	100
Tree by-products	t ha ⁻¹			2201	0
Labour	h ha ⁻¹		314	0	30 15 44

Figure 12. Appearance of the unit scale results and the economic analysis results at a one hectare-scale from the 'Options and results' worksheet

Results include:

Unit scale (Arable, forestry and agroforestry systems)

- Net present value (NPV) (£ unit⁻¹)

- Crop and tree production (t unit⁻¹)
- Labour (h unit⁻¹)

Hectare-scale (Arable, forestry and agroforestry systems)

- NPV (£ ha⁻¹)
- Discounted product revenue (£ ha⁻¹), discounted grant revenue (£ ha⁻¹), and discounted costs (£ ha⁻¹)
- Equivalent annual value of the net margin (£ ha⁻¹), the product revenue (£ ha⁻¹), the grant revenue (£ ha⁻¹), and the costs (£ ha⁻¹)
- Production
 - Crop main product (£ ha⁻¹)
 - Crop by-products (£ ha⁻¹)
 - Timber (m³ ha⁻¹)
 - Firewood (m³ ha⁻¹)
 - Tree by-products (£ ha⁻¹)
- Labour (h ha⁻¹)

4.6.1 Summary of crop and tree yield

The final section of the results table provides a summary of the yields of the crop and tree components from the chosen arable, forestry and agroforestry systems (from *Arablesystem*, *Forestrysystem* and *Agroforestrysystem* respectively). The appearance of the results table from the *Options and results* worksheet is shown in Figure 13.

Yields				
	Arable	Forestry	Silvoarable	
			Crop	Tree
Standing timber (m ³ ha ⁻¹)		219		217
Standing firewood (m ³ ha ⁻¹)		104		103
Average crop yield (t ha ⁻¹)				
Wheat	8.8		7.8	
Barley	6.7		6.0	
Oilseed	3.5		3.2	
			Agroforestry fallow	0.0
Average crop by-product yield (t ha ⁻¹)				
Wheat	3.5		3.1	
Barley	4.0		3.7	
Oilseed	1.7		1.6	
			Agroforestry fallow	0.0

Figure 13. Appearance of the crop and tree yields from the 'Options and results' worksheet.

4.7 Graphs of results

The seventh section of *Options and results* provides graphical representations of the results. This section of the worksheet allows the user to define the default plotting period (Figure 14). The initial results include the non-discounted and the discounted cashflows for the three systems (Figure 15).

Graphical results

Default plotting period 30 years

Manual override years

Plotting period 30 years

Figure 14. The user can specify the period of time for the graphical outputs

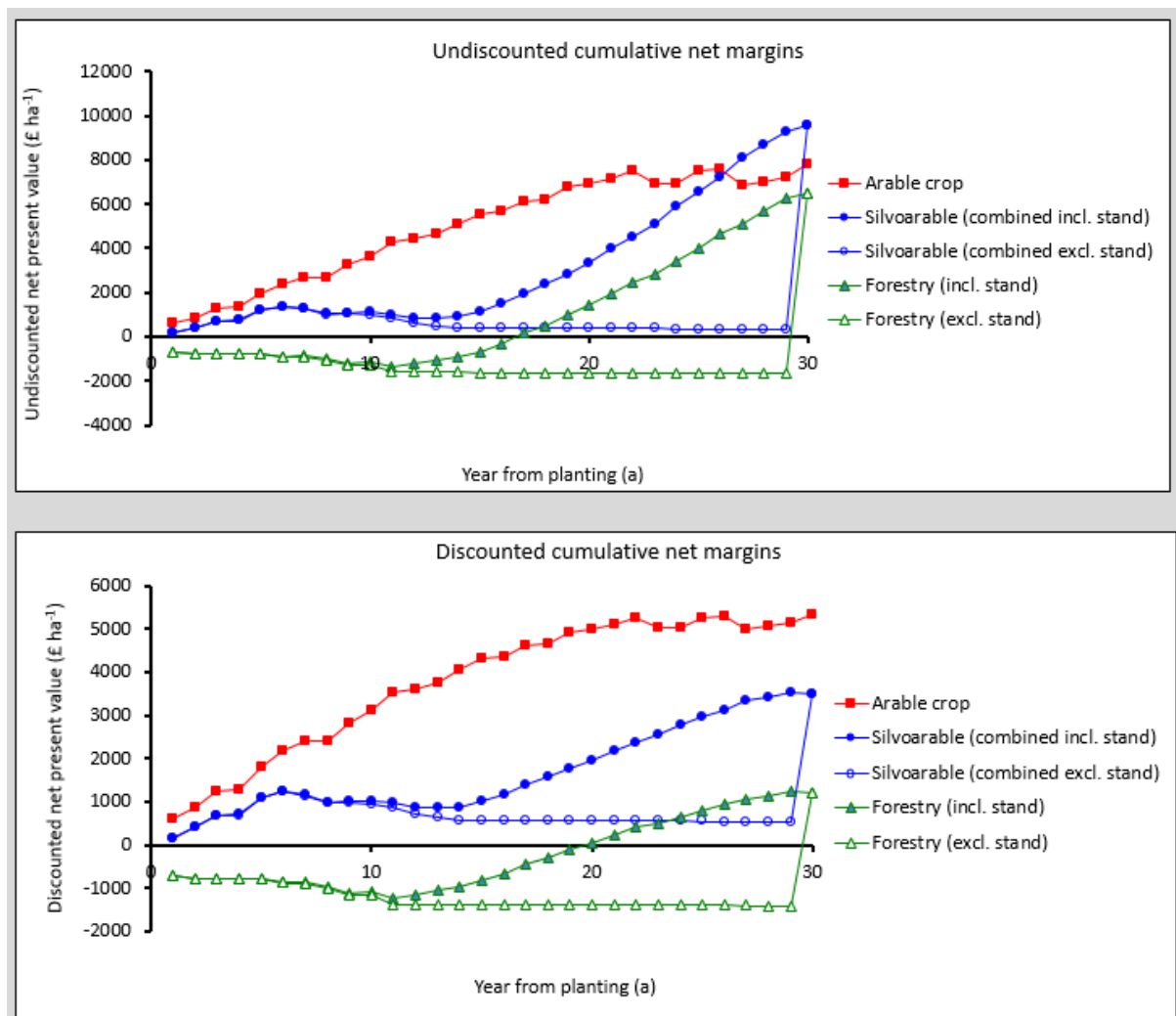


Figure 15. Graphical representation of the cumulative net present value of the arable, forestry and silvoarable systems assuming no discount rate and a specified discount rate of 4%

There are also graphs of the crop and timber volumes in the three systems (Figure 16), the harvested timber volumes and the labour requirements per hectare (Figure 17). The same results assuming a specified area of each system is also presented at the unit level (Figure 18). Lastly some additional results for each of the three systems is presented at a per hectare scale (Figure 19).

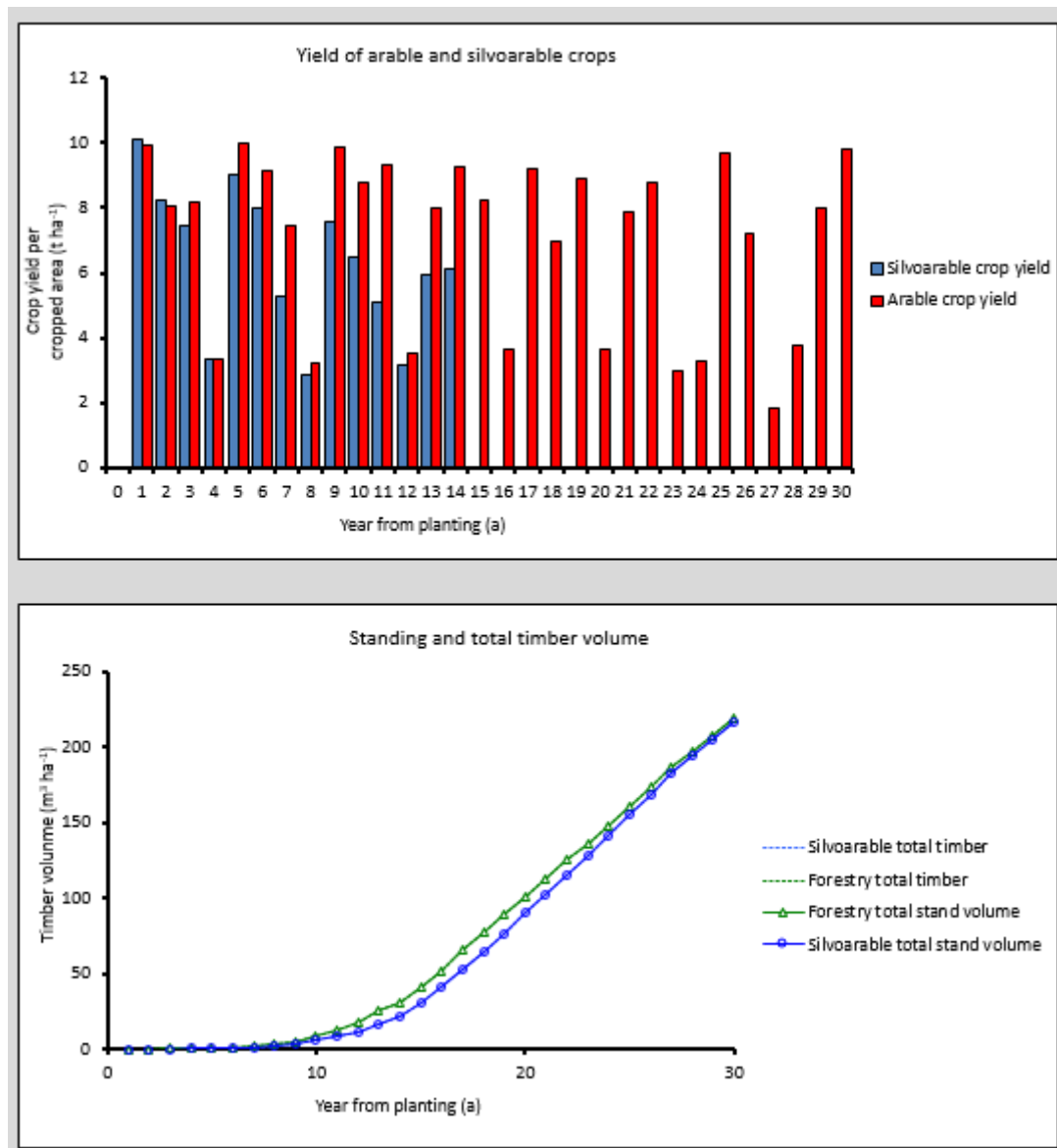


Figure 16. Graphical representation of the crop yields in the arable and the silvoarable system and the timber volume in the forestry and silvoarable system

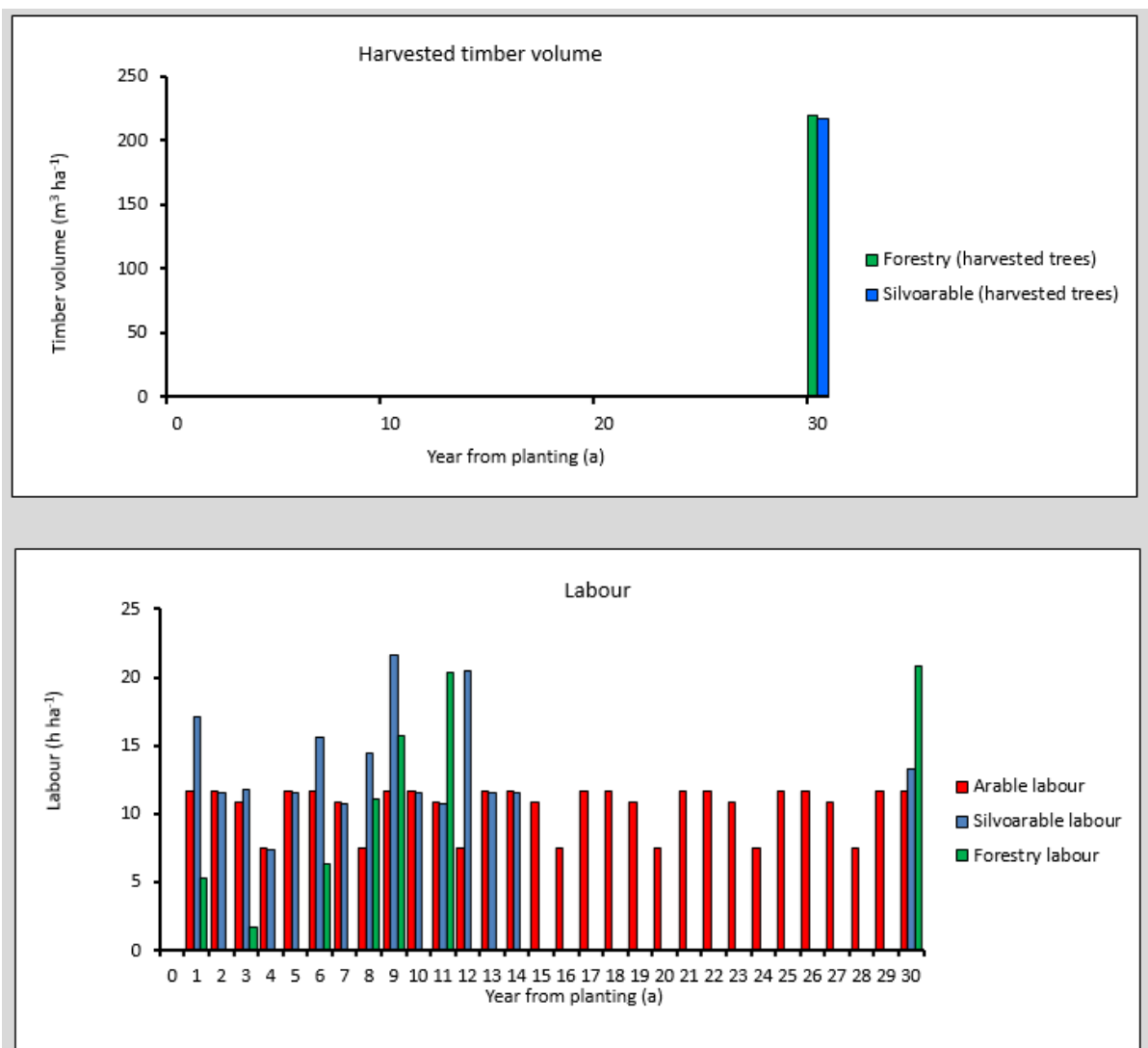


Figure 17. Graphical representation of the harvested timber volume and the labour requirements per hectare for the three systems

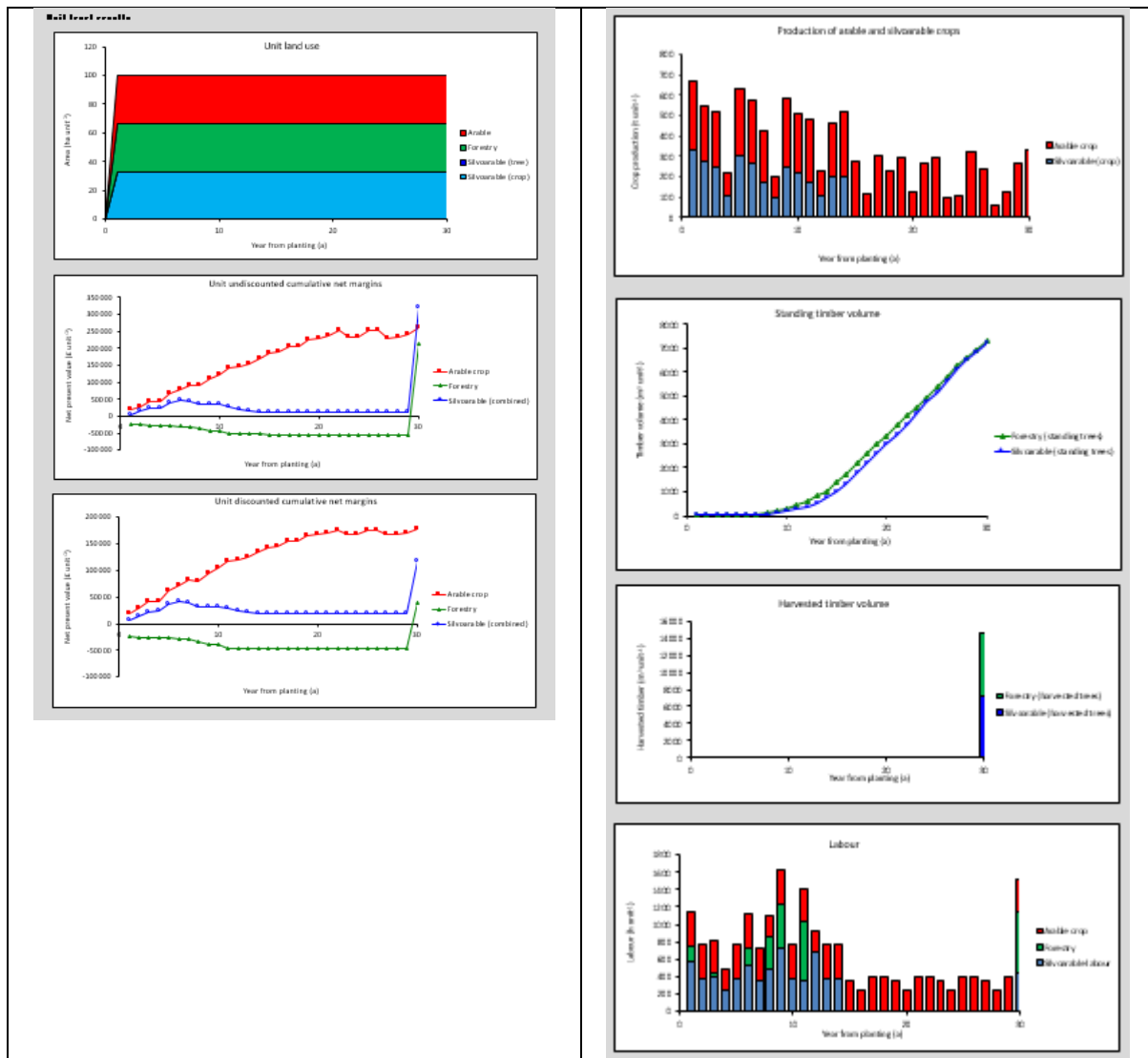


Figure 18. Graphical representation of the results at a unit level assuming a specified planting system

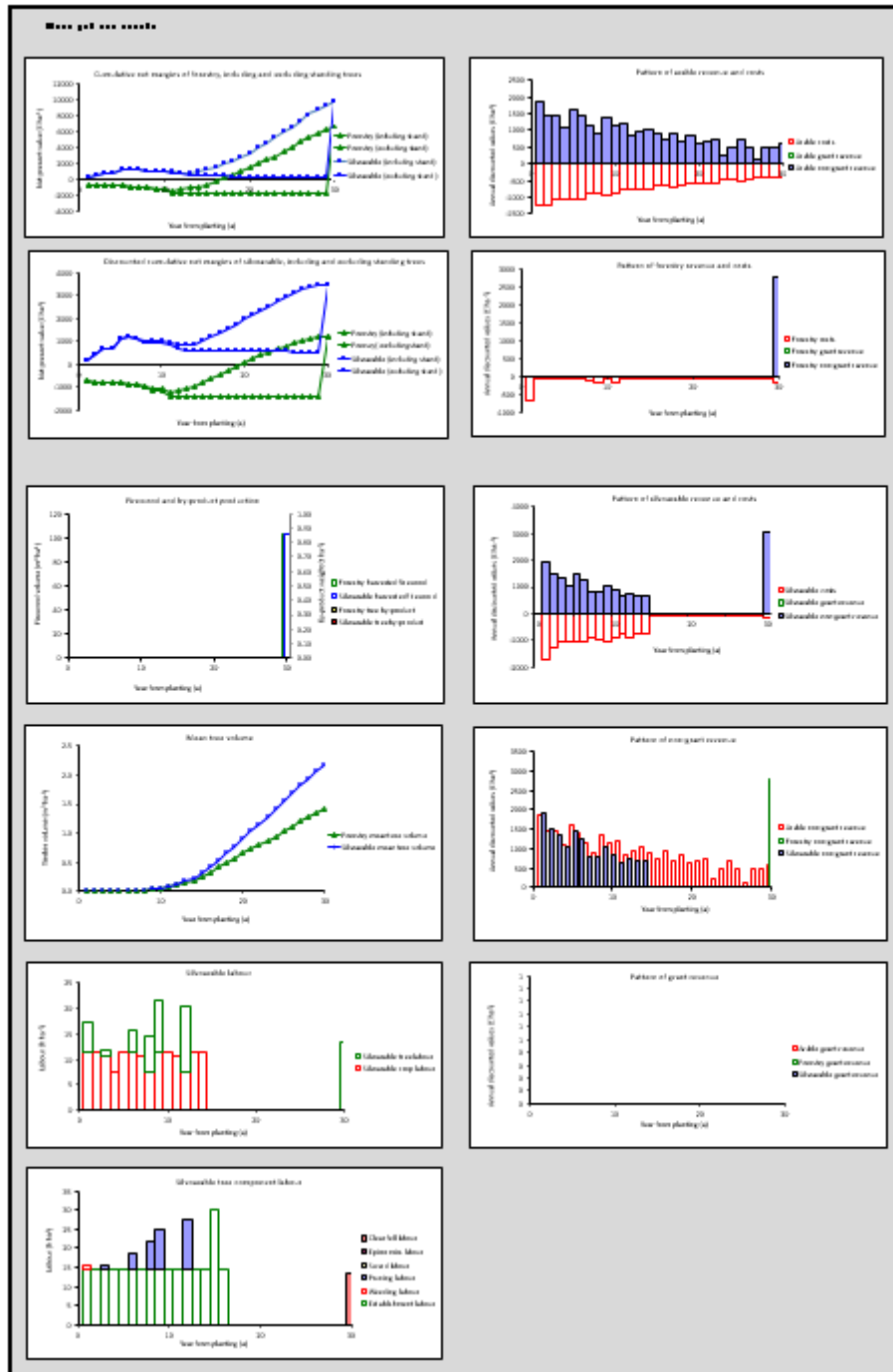


Figure 19. Graphical representation of additional results at a per hectare level

5 Description of the other worksheets

5.1 The 'Arablesystem' worksheet

The *Arablesystem* worksheet acts as a 'database' of possible arable rotations, each with a maximum period of 60 years. In Farm-SAFE, a maximum of 27 different records can be stored. Only the coloured cells should be changed by the user. The grey cells are derived cells and should not be altered. The inputs required are shown in Table 6 and Figure 14.

Table 6. Inputs required in the "Arablesystem" worksheet

Input function	Input names	Input values
Metadata (records 1-30)	Country; Region; Farm	(text)
	System	(text)
	Crop	(text)
Production data (years 1-60)	Name of crop	(text)
	Livestock	
	Area	(% ha ⁻¹ system)
	Crop yield	(t ha ⁻¹ crop)
	By-product yield	(t ha ⁻¹ crop)

Metadata: these describe the source of the production data. The user can provide information on the country, region, farm, system and a general description of the rotation. In describing silvoarable systems, it is important to specify the assumed tree density (e.g., poplar 113 trees ha⁻¹).

Production data: the second section is used for yield data. Any crop can be specified in any order for any number of years in the name column. The relative area planted (as a proportion of one hectare) should also be included. This will be 1 in conventional arable systems. However, the relative area will be less than 1 in agroforestry systems, and it may decline during the rotation. Lastly, the user should provide the yield for the corresponding crop (on a per hectare cropped area basis) and by-products if appropriate.

Note: it is important that the crop names correspond with the financial data in *Arablefinance*. For example, if "Wheat2" is accidentally typed with a space before (" Wheat2"), the worksheet will be unable to match the production and financial information.

	A	B	C	D	E	F
1	Table B. Rotation and yield data for arable systems					
2	B1. Metadata	1				
3	Country	UK				
4	Region	England standard				
5	Farm					
6	System					
7	Crop	Cereals				
8	Multicrop?	no				
9	Simultaneous ?	no				
	Search code	1 crop species	1 livestock	1 area	1 crop yield	1 by-product 1
10						
11	B2. Production data	crop species	livestock	area	crop yield	by-product 1
12	year	(name)	(T)	(%)	(t ha ⁻¹)	(t ha ⁻¹)
13	1	Wheat		1.00	9.92	3.97
14	2	Wheat		1.00	8.08	3.23
15	3	Barley		1.00	8.20	4.92
16	4	Oilseed		1.00	3.37	1.68
17	5	Wheat		1.00	10.02	4.01
18	6	Wheat		1.00	9.13	3.65
19	7	Barley		1.00	7.43	4.46
20	8	Oilseed		1.00	3.20	1.60
21	9	Wheat		1.00	9.85	3.94
22	10	Wheat		1.00	8.79	3.52
23	11	Barley		1.00	9.31	5.59
24	12	Oilseed		1.00	3.55	1.77
25	13	Wheat		1.00	7.98	3.19
26	14	Wheat		1.00	9.29	3.72
27	15	Barley		1.00	8.21	4.92

Figure 20. The appearance of a part of the 'Arablesystem' worksheet

5.2 The 'Forestrysystem' worksheet

The **Forestrysystem** worksheet is the forestry equivalent of the **Arablesystem** worksheet. It is a 'database' of the production data for forestry systems (Table 7; Figure 15). In a similar way as the **Arablesystem** worksheet, the worksheet requires both metadata and yield data. The user should only enter data in the green cells.

Table 7. Inputs required in the 'Forestrysystem' worksheet

Input function	Input names	Input values
Metadata (records 1-30)	System; Species (including tree density)	(text)
	Yield class	(YC)
	Maximum bole	(m)
Production data (years 0-60)	Trees planted; Trees harvested	(ha ⁻¹)
	Mean tree height	(m)
	Prune height	(m)
	Standing timber	(m ³ ha ⁻¹)
	Standing firewood	(m ³ ha ⁻¹)
	Harvested firewood	(m ³ ha ⁻¹)
	By-product yield	(t ha ⁻¹)

Metadata: the metadata is used to identify the production data. This helps the user to recognize within **Options and results**.

Production data: for each year of the rotation, the user can specify the number of trees planted and harvested, the tree height and the stand volume. Space is also available to enter the production of firewood and by-products if appropriate. These data can be provided by the separate Yield-SAFE model (Burgess et al., 2023).

Table C. Physical data for tree systems								
C1. Metadata								
System	UK					Fine		
Species	Poplar 156 trees/ha					1500		
Yield class								
maximum bole	8							
Search code	1 trees planted	1 trees harvested	1 tree height	1 prune height	1 standing timber	1 standing firewood	1 harvested firewood	1 by-product 1
C2. Production data								
	trees planted	trees harvested	tree height	prune height	standing timber	standing firewood	harvested firewood	by-product 1
year	(trees ha ⁻¹)	(trees ha ⁻¹)	(m)	(m)	(m ³ ha ⁻¹)	(m ³ ha ⁻¹)	(m ³ ha ⁻¹)	(t ha ⁻¹)
0	156							
1		0	1.46	0.00	0.03	0.01	0.00	0.00
2		0	1.83	0.00	0.06	0.02	0.00	0.00
3		0	2.34	1.50	0.12	0.05	0.00	0.00
4		0	2.96	1.50	0.23	0.10	0.00	0.00
5		0	3.69	1.50	0.46	0.20	0.00	0.00
6		0	4.71	3.00	0.95	0.42	0.00	0.00
7		0	5.83	3.00	1.80	0.79	0.00	0.00
8		0	6.89	4.50	2.97	1.31	0.00	0.00
9		0	8.27	6.00	5.14	2.27	0.00	0.00
10		0	9.67	6.00	8.23	3.63	0.00	0.00
11		0	11.12	7.50	12.49	5.51	0.00	0.00
12		0	12.49	7.50	17.72	7.81	0.00	0.00
13		0	14.03	7.50	25.14	11.09	0.00	0.00
14		0	14.96	7.50	30.45	13.43	0.00	0.00

Figure 21. The appearance of a part of the 'Forestrysystem' worksheet

5.3 The 'Agroforestrysystem' worksheet

The *Agroforestrysystem* worksheet is a 'database' of the production data for agroforestry systems (Table 8 and Figure 16). The worksheet requires both metadata and yield data.

Table 8. Inputs required in the 'Agroforestrysystem' worksheet

Input function	Input names	Input values
Metadata (records 1 – 17)	Country; Region; Farm	(text)
	Tree component	(text)
	Crop component	(text)
	Maximum bole	(m)
Production data (years 1 – 60)	(Crop component)	(text)
	Name of crop	(text)
	Livestock	
	Area	(% ha ⁻¹ system)
	Crop yield	(t ha ⁻¹ crop)
	By-product yield	(t ha ⁻¹ crop)
Production data (years 0 – 60)	(Tree component)	
	Trees planted	(ha ⁻¹)
	Trees harvested	(ha ⁻¹)
	Mean tree height	(m)
	Canopy area	(%)
	Prune height	(m)
	Standing timber	(m ³ ha ⁻¹)
	Standing firewood	(m ³ ha ⁻¹)
	Harvested firewood	(m ³ ha ⁻¹)
	By-product yield	(t ha ⁻¹)

Metadata: the metadata is used to identify the production data. This helps the user to recognize within *Options and results*.

Production data: for each year of the rotation, the user can specify the number of trees planted, the number of trees harvested, the tree height and the stand volume. Space is also available to enter the production of firewood and by-products if appropriate.

Table B. Rotation and yield data for agroforestry systems						Note: For LTS put records for 50 trees in LU1-4									
D1. Metadata		1													
Country	UK							Fine							
Region	Silsoe					1500									
Farm	Silsoe_02														
Tree compone	Poplar 100 trees/ha wwbo 30yr 80%														
Crop compone	WWBO														
Multicrop?	no														
Simultaneous	no														
Max. bole	8														
Search code	1 crop species	1 livestock	1 area	1 crop yield	1 crop by-product	1 trees planted	1 trees harvested	1 tree height	1 Canopy area	1 prune height	1 standing timber	1 standing firewood	1 harvested firewood	1 tree by-product	
D2. Production data	crop species	Livestock	area	crop yield	crop by-product	trees planted	trees harvested	tree height	Canopy area	prune height	standing timber	standing firewood	harvested firewood	tree by-product	
year	(name)	(T)	(%)	(t ha ⁻¹)	(t ha ⁻¹)	(trees ha ⁻¹)	(trees ha ⁻¹)	(m)	(%)	(m)	(m ³ ha ⁻¹)	(m ³ ha ⁻¹)	(m ³ ha ⁻¹)	(t ha ⁻¹)	
0						100									
1	Wheat		0.80	10.19	4.08		0	1.46	5.80	0.00	0.02	0.01	0.00	0.00	
2	Wheat		0.80	8.30	3.32		0	1.83	6.20	0.00	0.04	0.02	0.00	0.00	
3	Barley		0.80	7.50	4.75		0	2.34	15.40	1.50	0.07	0.03	0.00	0.00	
4	Oilseed		0.80	3.35	1.68		0	2.96	15.40	1.50	0.15	0.07	0.00	0.00	
5	Wheat		0.80	9.11	3.67		0	3.69	32.90	1.50	0.29	0.13	0.00	0.00	
6	Wheat		0.80	8.07	3.22		0	4.71	32.90	3.00	0.61	0.27	0.00	0.00	
7	Barley		0.80	5.34	3.20		0	5.84	45.10	3.00	1.16	0.51	0.00	0.00	
8	Oilseed		0.80	2.92	1.46		0	6.90	45.10	4.50	1.92	0.85	0.00	0.00	
9	Wheat		0.80	7.64	3.06		0	8.30	65.20	6.00	3.33	1.47	0.00	0.00	
10	Wheat		0.80	6.56	2.62		0	9.72	65.20	6.00	5.36	2.36	0.00	0.00	
11	Barley		0.80	5.13	3.08		0	11.19	68.80	6.00	8.18	3.61	0.00	0.00	
12	Oilseed		0.80	3.22	1.61		0	12.62	83.90	7.50	11.71	5.16	0.00	0.00	
13	Wheat		0.80	5.99	2.40		0	14.21	100.00	7.50	16.74	7.38	0.00	0.00	
14	Wheat		0.80	6.17	2.47		0	15.49	100.00	7.50	21.69	9.57	0.00	0.00	
15	Barley		0.80	3.12	1.87		0	17.31	100.00	7.50	30.23	13.33	0.00	0.00	
16	Oilseed		0.80	3.34	1.67		0	19.10	100.00	7.50	40.63	17.92	0.00	0.00	
17	Wheat		0.80	6.82	2.73		0	20.89	100.00	7.50	53.20	23.46	0.00	0.00	
18	Wheat		0.80	4.48	1.79		0	22.33	100.00	7.50	64.90	28.62	0.00	0.00	

Figure 22. The appearance of a part of the 'Agroforestrysystem' worksheet

5.4 The ‘Arablefinance’ worksheet

The *Arablefinance* worksheet is used to provide economic data for the arable systems (Table 9).

Table 9. Inputs required in the ‘Arablefinance’ worksheet

Input category	Inputs
Metadata (records 1 – 30)	Region number; Location; Crop name
Revenue	Grain price; By-product 1; Area payment
Variable costs	Seed price; Seed rate; Fertiliser price; Fertiliser rate; Spray price; Spray rate; Other price; Other rate; Aggregate variable cost if no breakdown
Fixed costs	Fuel and repairs Other 1; Other 2; Labour; Aggregate fixed cost if no breakdown (excluding labour)
Livestock data	LU annual energy requirement Crop energy; By-product energy; Livestock output; Headage payment; Livestock variable cost; Livestock fixed costs (excluding labour); Livestock labour costs; Subsidy by 1=area, 2 = headage

Metadata: this describes the source of the financial data. It is important that the metadata descriptors match those used in *Arablesystem*. Incompatibility is one possible cause of the error message “#N/A”, and the user should check to ensure that, for instance, no spaces have been put where they should not be.

Revenue: this comprises the income the farmer can obtain from the main crop product, the by-product and the area payment.

Variable costs: these include seed, fertilizer, and spray costs. Note that the inclusion of an aggregate value will override itemised values.

Fixed costs: the fixed costs include the “assignable” costs of machinery (fuel and depreciation) and the labour associated with each crop. The labour requirements need to be specified to allow the calculation of labour requirements per enterprise.

Livestock data: in the Farm-SAFE model, additional room was provided to include financial data for calculating potential livestock carrying capacity from crop biomass production. This was used in calculating the profitability of Dehesa systems in Spain.

5.5 The ‘Treecost’ worksheet

The data in the *Treecost* worksheet contains the costs related to specified tree production systems. The costs fall within seven broad groups (Table 10).

Table 10. Inputs required in the ‘Treecost’ worksheet

Input category	Inputs
Tree cost metadata	Country, system, species
Establishment costs	Cost of plant; Cost of individual tree protection; Labour for ground preparation; Labour for weeding; Labour for marking out; Labour for planting trees; Labour for tree protection
Maintenance costs	Year of first weeding; Year of last weeding; Annual labour for weeding; Annual cost of herbicide for weeding; Establishment of grass sward; Labour for grass sward establishment; Materials for grass sward establishment; Final year of grass sward; Labour for annual grass sward maintenance; Materials for annual grass sward maintenance; Year of first removal of epicormics; Year of last removal of epicormics; Labour for removal of epicormics
Pruning cost	Height at first prune; Minutes per tree at first prune; Height at last prune; Minutes per tree at last prune; Removal of prunings
Administration costs	Administrative cost of forestry; Insurance management
Thinning costs	Marking-up; Removal of tree
Clear-felling costs	Labour; Removal of tree
Other costs	First year of cost; Last year of cost; Amount

Metadata: this describes the source of the costs, and should include the country, the system (agroforestry or forestry) and the tree species (e.g. poplar or oak).

Establishment costs: these are one-off costs at the beginning of the rotation. ‘Marking out’ relates to the marking-out the positions where the trees will be planted.

Maintenance costs: this includes a start year and duration for weeding, the establishment and maintenance of a grass sward at the base of the trees (if appropriate), and the labour required for removing epicormics.

Pruning costs: the initial pruning height and the amount of time required for pruning each tree at this height should be provided. Similarly, the height of the final pruning and the labour required for pruning each tree at this height should be provided. It is assumed that the time required for pruning increases linearly between the two heights. In Farm-SAFE, the model maintains maximum bole height at a user defined proportion of the total tree height and only prunes the tree when the tree bole is less than the user defined height. The user can input a value for clearing prunings from the field.

Administration costs: these can include the cost of administration and insurance.

Thinning costs: these include time required for marking-up, felling and removing trees from the site.

Clear-felling costs: including time required for felling and removing the trees.

Other costs: provision for any other costs.

5.6 The 'Treevalue' worksheet

The *Treevalue* worksheet contains information on the potential value of the timber (Table 11). In Farm-SAFE, the data are entered as values for the timber (£/m³) for specific sizes of timber (m³). Currently 30 different records can be entered.

Table 11. Inputs required in 'Treevalue' worksheet

Input category	Inputs
Metadata (records 1 – 30)	Location
	Species
Prices	Firewood value
	By-product value
	Felling value

Metadata: the model requires information on the location and species.

Prices: prices can be entered for firewood and by-products. However, the timber value should be expressed on a price-size basis. In many countries, the value per cubic metre of wood increases as the size of the timber increases (Figure 23).

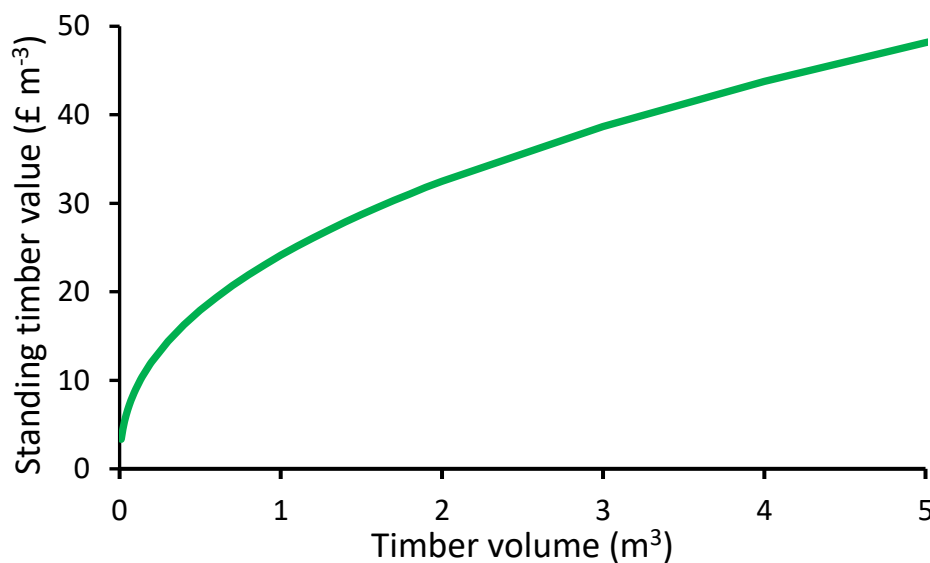


Figure 23. Example price-size curves for broadleaf timber in the UK derived from information quoted by Hart (1994)

5.7 The ‘Treegrant’ worksheet

The **Treegrant** worksheet contains information on possible grant systems for the forestry and agroforestry systems (Table 12).

Table 12. Inputs required in the ‘Treegrant’ worksheet

Input category	Inputs
Metadata	Grant system
Planting payment	Year of planting grant Value of planting grant Year of planting grant supplement Value of planting grant supplement Year of second planting grant Value of second planting grant
Compensation payment	Initial year of receipt Final year of receipt Amount
Maintenance payment 1	Initial year of receipt Final year of receipt Amount
Maintenance payment 2	Initial year of receipt Final year of receipt Amount

Metadata: this is needed so that the user can recognise the data in Options and results.

Planting payments: the current structure of the worksheet reflects the UK grant system. Three payments can be made for the establishment of trees in specified years.

Compensation and maintenance payments: recurring compensation and maintenance payments can be made with a specified start and an end year.

6 Example use of Farm-SAFE to compare an arable, forest and agroforestry system

6.1 Introduction

As part of the AGFORWARD project, Cranfield University staff used a version of the “Farm-SAFE_March17” model (Graves et al. 2017) to evaluate the profitability of arable, forestry, and agroforestry systems at Silsoe in Bedfordshire in the UK over a period of 30 years. The results are reported in a paper by Giannitsopoulos et al. (2020). The same inputs as far as possible have been incorporated into Farm-SAFE v3 to demonstrate the use of the model, with the assumption that the values in Euros reported by Giannitsopoulos et al. are converted directly to pounds sterling, i.e. the exchange rate is 1:1.

6.2 Method

6.2.1 Case study site and selection of land use systems

The selected systems (Table 13) were identified as typical enterprises that are or could be used at the case study site in Bedfordshire, England. A four-year arable crop rotation was compared with a poplar agroforestry system with an understorey arable crop for 14 years and then put to grass fallow for the remaining 16 years, and a plantation of poplar also planted in year 1 and harvested in year 30.

Table 13. Description of the arable, agroforestry and tree-only systems for case study site in Bedfordshire, UK

Length of rotation		30 years
Arable system	Crop rotation	Wheat, wheat, barley, oilseed rape
Forestry system	Tree	<i>Populus</i> spp. 156 trees ha ⁻¹
Agroforestry system	Crop rotation	Same arable rotation (however arable cropping did not continue after year 14)
	Tree	<i>Populus</i> spp. 100 trees ha ⁻¹

6.2.2 Biophysical data

Tree and arable crop growth and yields were derived from the Yield-SAFE biophysical model (van der Werf et al., 2007). Yield-SAFE uses seven state equations expressing the temporal dynamics of: (1) tree biomass; (2) tree leaf area; (3) number of shoots per tree; (4) crop biomass; (5) crop leaf area index; (6) heat sum; and (7) soil water content. The productivity of arable, tree-only and agroforestry systems at the Bedfordshire site (59 m a.s.l.) was assessed over an assumed tree rotation for fast-growing poplar (*Populus* spp.) of 30 years. Simulated climate data (daily temperature, solar radiation and rainfall) were obtained using the CliPick tool (Palma, 2017) and annual rainfall and temperature ranged from 410 to 867 mm and from 9.1 to 11.3°C respectively. In addition to the climate data, Yield-SAFE required tree planting density and the initial biomass of the tree and crops. Yield-SAFE was calibrated against measured yields from arable and tree-only systems before being used to predict the tree and crop growth in an agroforestry system.

The yield data for the arable system is presented in dataset 1 in the [Arablesystem](#) worksheet and is called “UK English standard Cereals”.

The yield data for the forestry system is presented in dataset 1 in the *Forestrysystem* worksheet and is called “UK Poplar 156 trees/ha”.

The tree yield and arable crop data for the agroforestry system, assuming continuous planting of an alley crops, is presented in dataset 1 in the *Agroforestrysystem* worksheet, and it assumes a cropping area of 99%. However, after about 10 years, the predicted arable yields are low. Hence for the financial analysis, it was assumed that arable cropping would occur for 14 years, and the understorey would then be fallow. These yields are presented in dataset 2 in the *Agroforestrysystem* worksheet, and in this analysis the cropping area was assumed to be 99%. The concatenated name of this second dataset is “UK Silsoe Silsoe_02 Poplar 100 trees/ha wwbo 14yr 99% WWBO”

6.2.3 Financial data for arable revenue and costs

The financial data for the arable system calls in the revenue and cost data for a rotation of wheat, wheat, barley, and oilseed rape crops that are described under the “UK – Agriculture (BPS: from 2015)” heading in *Arablefinance*. BPS refers to the basic payment scheme where a payment was made to farmers on an area basis. The assumed values for arable revenues and costs used in Farm-SAFE v3 are presented in Table 14.

Because the eventual financial analysis was completed assuming that there were no government grants (as the percentage grants is set to 0% in the Sensitivity settings in *Options and results*), the area payments were not used in the eventual calculations.

Table 14. Assumptions for selected arable revenue and costs

Crop	Grain price (£ t ⁻¹) ^a	Area payment (£ ha ⁻¹)	Seed rate (kg ha ⁻¹)	Fertiliser rate (kg N ha ⁻¹)	Variable costs ^{a b} (£ ha ⁻¹)	Labour costs (hr ha ⁻¹)	Other assignable fixed costs ^{a c} (£ ha ⁻¹)
Wheat 1	174*	235	150	175	653	11.63	444
Wheat 2	174*	235	170	175	722	10.44	444
Barley	160*	235	155	145	535	10.83	444
Oilseed	361*	235	5	200	634	7.46	444

^aData reported by Giannitsopoulos et al. (2020) in Euros are presented in £ assuming a 1:1 Euro: Pounds Sterling exchange rate to allow comparison with Farm-SAFE v3.

^bIncludes seed, fertiliser, spray and other costs.

^cIncludes costs relating to fuel and repairs, machinery, interest on working capital, installation, rent and other fixed costs.

*Nix (2017).

6.2.4 Financial data for forestry and tree-related agroforestry costs

The assumptions regarding forestry-related costs were derived from dataset 2 in *Treecost* which has the name “UK Poplar Forestry England standard EU”. A summary of the principal costs are provided in column three in Table 15. The assumptions regarding the agroforestry costs related to trees were derived from dataset 1 in *Treecost* which has the name “UK Poplar Agroforestry England standard EU”, and are summarised in column 4 in Table 15.

Table 15. Assumption for forestry related and tree-related agroforestry costs

Tree operation	Unit	Forestry	Agroforestry
Tree density	trees ha ⁻¹	156	100
Labour rates (harvest)	£ hr ⁻¹	30.0	30.0
Labour rates (other activities)	£ hr ⁻¹	14.6	14.6
Costs of individual plants	£ tree ⁻¹	2	2
Costs of individual tree protection	£ tree ⁻¹	2	2
Labour for ground preparation	hr ha ⁻¹	3.3	3.3
Labour for initial weeding	hr ha ⁻¹	1.4	1.4
Establishment cost ^a	£ ha ⁻¹	693	469
Weeding period	Year	1	1
Labour for weeding	min tree ⁻¹	0.20	0.53
Cost of herbicide	£ tree ⁻¹	0.02	0.02
Maintenance cost	£ ha ⁻¹	11	15
Height first prune	m	1	1
Labour first prune	min tree ⁻¹	0.05	0.05
Height last prune	m	8	8
Labour last prune	min tree ⁻¹	8.00	8.00
Removal of prunings	min tree ⁻¹	4	4
Total cost of pruning	£ ha ⁻¹	805	516
Annual administrative cost	£ ha ⁻¹	3	3
Tree cutting	min tree ⁻¹	7	7
Removal of tree	min tree ⁻¹	1	1
Total cost of tree removal	£ ha ⁻¹	584	374

^aBeating up, i.e. replacement of a proportion of trees in year 2 is an additional cost

6.2.5 Financial data for tree-related revenue

The two sources of tree-related revenue were assumed to be the value of timber and the value of firewood, which are specified as dataset 1 in *Treevalue*. Giannitsopoulos et al. (2020) assumed that poplar branches had a firewood value equivalent to £25 m⁻³ (Table 16). The value of the poplar for timber was assumed to be related to the volume of the timber (Figure 24).

Table 16. Assumed value of the branchwood and timber of poplar

	Value (£ m ⁻³)
Branchwood	25.0
Timber	Determined from Figure 24

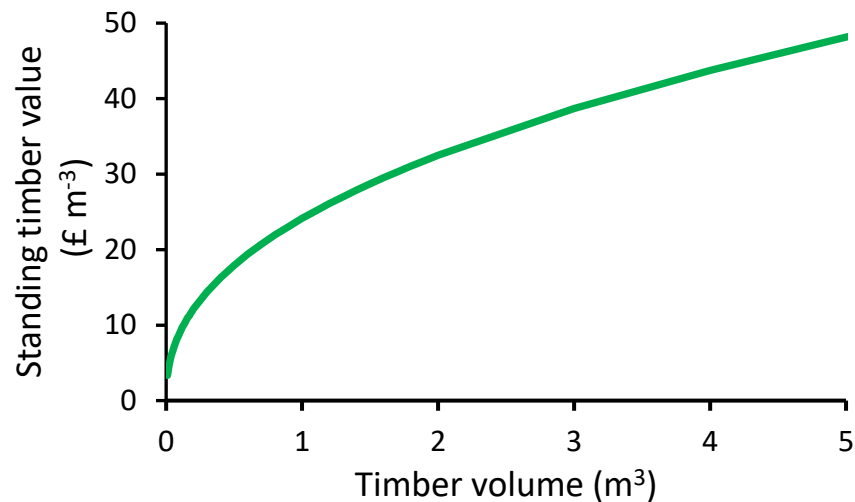


Figure 24. Assumed value of the poplar for timber was related to the timber volume

6.2.6 Financial data for tree-related grants

The value of tree-related grants is described in dataset 1 and 2 in [Treegrant](#) for the forestry and agroforestry system respectively. In Giannitsopoulos et al. (2020), it was assumed that there were no grants for tree planting at a density of 156 trees per hectare and below. This situation has now changed in England.

6.3 Results

6.3.1 Biophysical simulation of crop yields and timber biomass

Using the same input yield data as Giannitsopoulos et al. (2020), the Farm-SAFE v3 model calculated the similar mean yields in the arable system over 30 years of 8.7, 6.7 and 3.5 t ha⁻¹ respectively (Table 17). In a similar way, the calculated arable yields in the agroforestry system over 14 years for the wheat, barley and oilseed of 7.7, 6.0 and 3.1 t ha⁻¹ respectively were similar (Table 17). The volume of the standing timber for the tree-only poplar plantation (156 trees ha⁻¹) reached 219 m³ ha⁻¹ in year 30 in both models, compared to 216-217 m³ ha⁻¹ in year 30 for the poplar trees in the agroforestry system (100 trees ha⁻¹).

Table 17. Average annual crop yields of the arable and agroforestry systems and standing timber and firewood volume of the forestry and agroforestry for Silsoe as reported by Giannitsopoulos et al. (2020) and as calculated using Farm-SAFE v3

	Giannitsopoulos et al. (2020)			Farm-SAFE v3		
	Arable	Agroforestry	Forestry	Arable	Agroforestry	Forestry
Wheat (t ha ⁻¹ yr ⁻¹)	8.7	7.7 ^b		8.8	7.8 ^b	
Barley (t ha ⁻¹ yr ⁻¹)	6.7	6.0 ^b		6.7	6.0 ^b	
Oilseed (t ha ⁻¹ yr ⁻¹)	3.5	3.1 ^b		3.5	3.2 ^b	
Standing timber ^a (m ³ ha ⁻¹)		216	219		217	219
Standing firewood ^a (m ³ ha ⁻¹)					103	104

^a Populus spp. in year 30; firewood volumes not reported by Giannitsopoulos et al.

^b Agroforestry crop yields were for 14 years only

6.3.2 Financial analysis of arable system

Without grants, Farm-SAFE v3 indicated that the financial net margin of the arable system over 30 years at a discount rate of 4% was £5,314 ha⁻¹ (Table 18), compared to £5,444 ha⁻¹ calculated by Giannitsopoulos et al. (2020) with Farm-SAFE v3. Giannitsopoulos et al. (2020) calculated a slightly higher NPV as they assumed slightly lower arable labour requirement which were dependent on the arable crop yields. The labour rates assumed by Giannitsopoulos et al. are presented in

Table 19, and if these values are entered directly in the “Plot” worksheet in cells N8 to N37, then a similar net present value is achieved.

Table 18. Arable system: net margin (without grants) over 30 years and the equivalent annual values (EAV) at a discount rate of 4% as calculated by Giannitsopoulos et al. (2020), the default version of Farm-SAFE v3, and a version of Farm-SAFE v3 using the labour values described in Table 19.

	Net margin (£ ha ⁻¹)	EAV (£ ha ⁻¹ yr ⁻¹)
Farm-SAFE v3	5,314	307
Giannitsopoulos et al. (2020)	5,444	315
Farm-SAFE v3 with labour rates from Giannitsopoulos	5,446	315

Table 19. Default labour hours for the arable system in Farm-SAFE v3 (See ‘Plot’!N8:N37) and yield-dependent labour hours for the 30 year arable rotation from the study of Giannitsopoulos et al. (2020)

Year	Default labour values in Farm-SAFE v3 (hr ha ⁻¹)	Labour values assumed by Giannitsopoulos et al. (2020 (hr ha ⁻¹))	Year	Default labour values in Farm-SAFE v3 (hr ha ⁻¹)	Labour values assumed by Giannitsopoulos et al. (2020 (hr ha ⁻¹))
1	11.6	11.6	16	7.5	7.6
2	10.4	10.4	17	11.6	11.2
3	10.8	10.8	18	10.4	9.7
4	7.5	7.5	19	10.8	11.3
5	11.6	11.7	20	7.5	7.6
6	10.4	11.1	21	11.6	10.3
7	10.8	10.3	22	10.4	10.9
8	7.5	7.3	23	10.8	7.3
9	11.6	11.6	24	7.5	7.4
10	10.4	10.9	25	11.6	11.5
11	10.8	11.6	26	10.4	9.9
12	7.5	7.6	27	10.8	6.5
13	11.6	10.4	28	7.5	7.7
14	10.4	11.2	29	11.6	10.4
15	10.8	10.8	30	10.4	11.6

6.3.3 Financial analysis of forestry system

Without grants, Farm-SAFE v3 calculated that a net present value for the forest system of £1,197 ha⁻¹, which is the same as the value calculated by Giannitsopoulos et al. (2020) (Table 20).

Table 20. Forestry system: net margin (without grants) over 30 years and the equivalent annual values (EAV) at a discount rate of 4% as calculated by Farm-SAFE v3 and Giannitsopoulos et al. (2020)

	Net margin (£ ha ⁻¹)	EAV (£ ha ⁻¹ yr ⁻¹)
Farm-SAFE v3	1,197	69
Giannitsopoulos et al. (2020)	1,197	69

6.3.4 Financial analysis of agroforestry system

Without grants, Farm-SAFE v3 calculated a net present value of the agroforestry system at a discount rate of 4% of £3,502 ha⁻¹, which is similar to the value of £3,669 ha⁻¹ reported by Giannitsopoulos et al. (2020) (Table 21). Although, the 99% cropping area assumed in Farm-SAFE v3 and in Giannitsopoulos et al. (2020) is high, both methods resulted in a similar value.

Table 21. Agroforestry system: comparison of the net margin (without grants) over 30 years and the equivalent annual values (EAV) at a discount rate of 4% in Farm-SAFE v3 and as reported by Giannitsopoulos et al. (2020)

	Net margin (£ ha ⁻¹)	EAV (£ ha ⁻¹ yr ⁻¹)
Farm-SAFE v3	3,502	203
Giannitsopoulos et al. (2020)	3,669	212

The results from the financial analysis can also be viewed graphically (Figure 25). The results highlight that the cultivation of arable crops in the silvoarable system was no longer profitable after year 6, so from a financial perspective, the cropping could have stopped earlier than year 14.

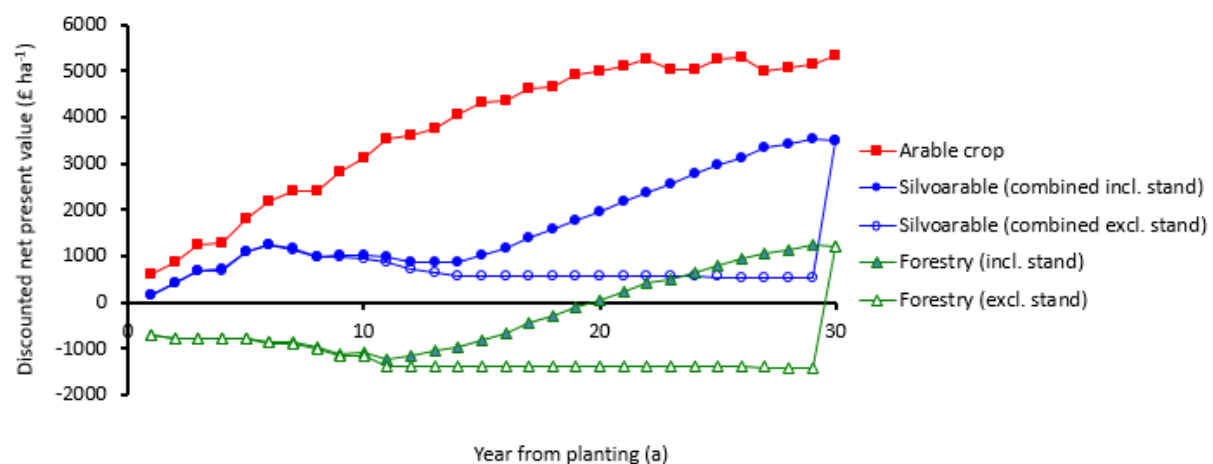


Figure 25. Graphical representation of the discounted (4%) cashflow of the arable, silvoarable, and forestry systems

7 Acknowledgements

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