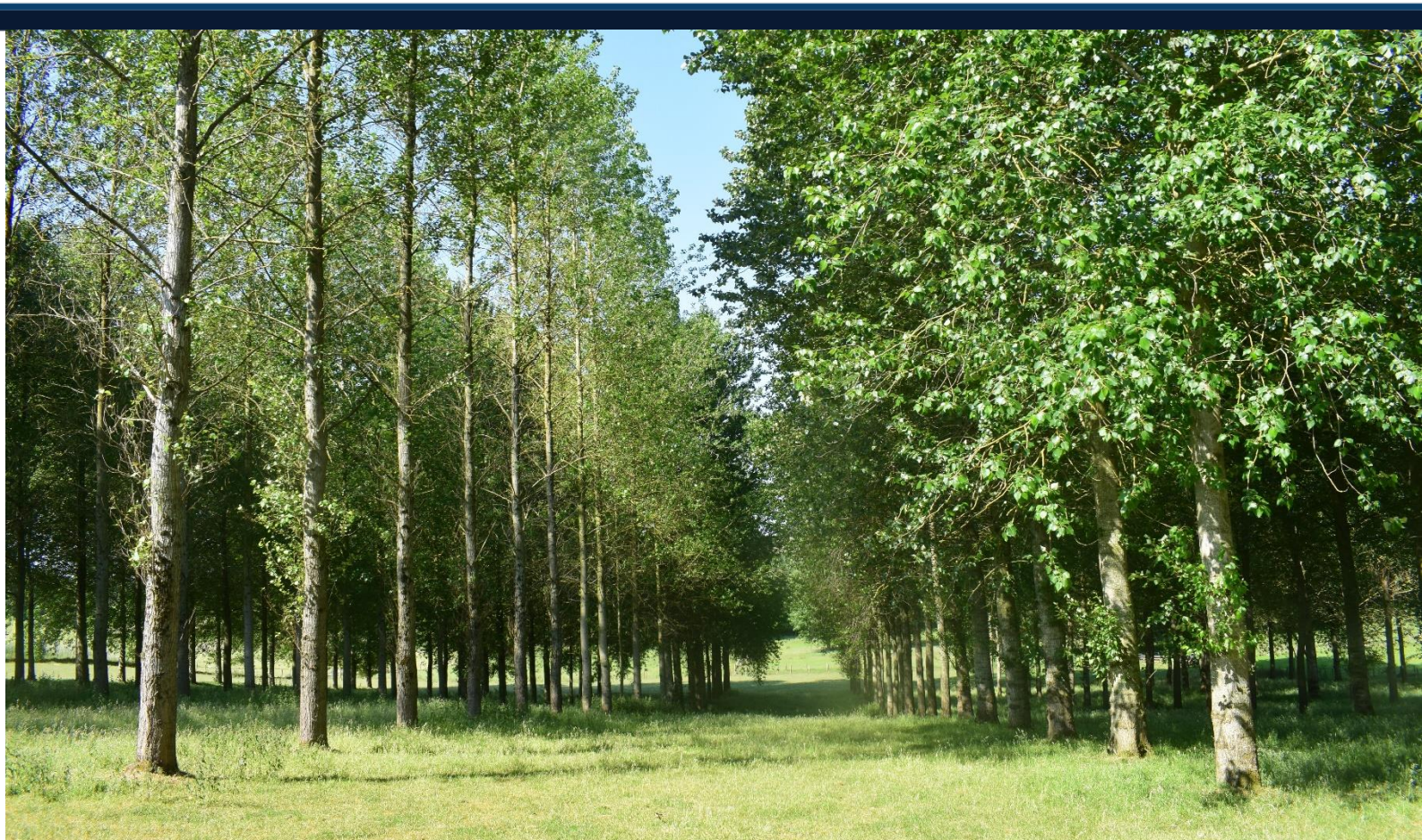




Description of the biophysical EcoYield-SAFE v2 model as implemented in Microsoft® Excel®

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Photo on the front page is the silvoarable poplar experimental area at Loughgall in Northern Ireland in June 2023 (Photo: Paul Burgess).

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1 Overview

Agroforestry can be defined as the integration of trees with grass and/or arable crops on the same parcel of land. Because of the long time between the planting trees and their maturity, it is useful to develop simulation models to compare the effect of agricultural, horticultural, forestry, and agroforestry systems on tree and crop growth. For example, in agroforestry, as the trees increase in size, the grass and/or arable yields will tend to decline due to light and water competition with the trees. The form of the tree-crop yield relationship will vary with the level of solar radiation, rainfall, the species being grown, management actions such as choice of planting date and pruning, the soil type, and the time from tree planting.

Within the EU sponsored project “Silvoarable Agroforestry for Europe (SAFE)”, we created the biophysical Yield-SAFE model (van der Werf et al., 2007). The model enables the prediction of tree and crop growth in crop-only, tree-only, and agroforestry systems. In 2023, a Microsoft Excel version of the model called “Yield-SAFE v2” was made available online, together with a description of the model and a description of the calibration process (Burgess and Graves, 2023).

Versions of Yield-SAFE have been used to inform both financial and economic assessments of agroforestry systems (García de Jalón et al., 2018; Giannitsopoulos et al., 2020). A version of Yield-SAFE v2 is available through the online repository at Cranfield University (Burgess et al. 2023).

This guide describes the EcoYield-SAFE v2 model which was used to generate results as part of a paper submitted in 2025 (Giannitsopoulos et al., 2025). It is based on an earlier version of EcoYield-SAFE, where some of the main additional algorithms are described by Palma et al. (2016, 2018). The EcoYield-SAFE model is a development of Yield-SAFE because it includes:

- 1) The inclusion of vapour pressure deficit to modify water use efficiency.
- 2) The respiration of grass crops.
- 3) Inclusion of the RothC model of soil carbon dynamics (Coleman and Jenkinson, 2014). This includes an assessment of tree and crop additions of carbon to the soil in the form of leaves and root turnover, and the decomposition of organic inputs.
- 4) The capacity to model fruit trees and cork oak.
- 5) The limitation of tree water uptake related to tree root density (Upson, 2014).
- 6) The effect of the trees on microclimate, specifically temperature and wind.
- 7) The inclusion of a nitrogen dynamics worksheet to estimate nitrogen leaching.
- 8) An estimate of the carrying capacity of grassland and silvopastoral systems for livestock.

EcoYield-SAFE v2 also includes a modification in the radiation use efficiency of trees and crops in response to changes in carbon dioxide concentrations (Giannitsopoulos et al., 2025).

2 Model requirements

2.1 Software

EcoYield-SAFE v2 is a spreadsheet-based biophysical model which was last used in Microsoft® Excel® for Microsoft 365 MSO (Version 2412 Build 18324.20240). The memory requirement for storing Yield-SAFE depends on the number of days of tree and crop growth that are simulated. For example, 14973 days of analysis (40 years) requires around 146 MB.

EcoYield-SAFE v2 is recommended to be run with a computer using Windows 7 (or a more recent version: Windows 10, etc.) and Excel® 2010 or a more recent version (Excel® 2013 or Excel® 2016). The worksheets of EcoYield-SAFE have been developed at a screen resolution of 1920 x 1080.

3 Model description

EcoYield-SAFE assumes that a specific system (i.e., arable, grassland, tree-only system, or silvoarable/silvopastoral system) is undertaken completely across a specified area. The model describes the dynamics of competitive capture of solar radiation and water and the associated growth of the tree, grass or crop components in a chosen system allowing the user to compare the effects of agroforestry with those of an arable, grassland or tree-only enterprises.

EcoYield-SAFE v2 is provided on-line on the Cranfield University repository. It is a cleaned version of the spreadsheet used to prepare a paper published by Giannitsopoulos et al. (2025).

To provide the best chance that robust parameter values can be identified for use in the model, Yield-SAFE was developed with as few parameters and equations as possible (van der Werf et al., 2007). The model assumes that the competition between the trees and crop is solely determined by light and water competition. In the default version, there is assumed to be no competition for nutrients and no nutrient stress. The state variables within the model include:

- Biomass of the tree component
- Biomass of the crop component
- Leaf area of the tree component
- Leaf area of the crop component
- Number of shoots of tree

The leaf areas govern radiation capture, and consequently the capacity for dry matter production and the associated water loss through transpiration. The number of tree shoots governs the potential leaf area within a given year.

- Heat sum for the tree component
- Heat sum for the crop component

The development of the tree and crop are determined by the accumulation of “degree days” above a specified base temperature.

- Available soil water

The available water in the soil determines the level of water limitation, and is dependent on precipitation, soil depth and the soil water holding properties.

3.1 Structure

The EcoYield-SAFE model has been constructed as ten worksheets (Figure 1, Table 1). There are two information worksheets, three data input worksheets, three calculation worksheets, and two output worksheets.

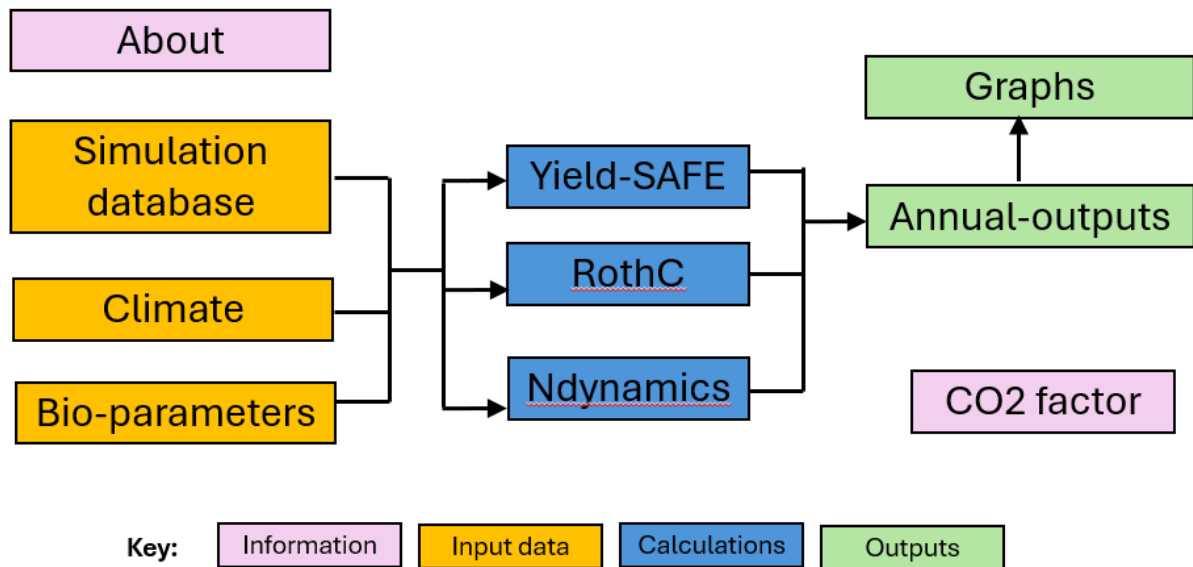


Figure 1. Schematic representation of the EcoYield-SAFE model, showing two information worksheets, three input worksheets, three calculation worksheets, and two output worksheets.

Table 1. The ten worksheets in EcoYield-SAFE and a brief description of their function.

Worksheet type	Worksheet name	Worksheet function
Information	About	A description about the authors and source of the model
	CO2 factor	An explanation of the assumed effect of changes in carbon dioxide concentration on radiation use efficiency
Input data	Simulations database	Selection and description of 56 agriculture, agroforestry, tree-only and climate combinations used in an analysis of the systems at Loughgall.
	Climate	Selection and description of 12 climate scenarios
	Bio-parameters	List of tree, crop, soil, irrigation, environment, and livestock parameters for the biophysical model.
Calculation	Yield-SAFE	Calculates on a daily basis the tree and crop yields and associated environmental and livestock-related outputs for the system specified in the Simulations database
	RothC	Calculates on a daily basis the changes in soil organic carbon
	Ndynamics	Calculates on a daily basis the changes in soil nitrogen
Outputs	Annual-outputs	Maintains a yearly summary of EcoYield-SAFE output
	Graphs	Graphical presentation of the biophysical outputs

3.2 Information worksheets

3.2.1 About

The “About” worksheet includes a disclaimer regarding the use of the model, details about the copyright, and acknowledgements of the supporters of projects which have allowed the development of the EcoYield-SAFE model (Figure 2).

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	EcoYield-SAFE v2																	
2	Everyone is welcome to use this biophysical model of crop, tree and agroforestry yields, however by using EcoYield-SAFE, the user agrees to the disclaimer and copyright below.																	
3																		
4	Disclaimer: use of EcoYield-SAFE is entirely at the risk of the user. No responsibility is taken by the developers, authors or funders for errors remaining within EcoYield-SAFE, or for actions or consequences of actions arising from use of EcoYield-SAFE.																	
5	Copyright: The authors are happy for the model to be used and modified for research and education purposes. However, persons seeking to use the model for commercial gain should contact the authors.																	
6	Acknowledgements: Yield-SAFE was originally developed in the SAFE project funded by the EU (2001-2005) contract number QLFS-CT-2001-00560 (van der Werf et al. 2007). This version of the model is called EcoYield-SAFE and was further developed during the EU-funded AGFORWARD FP7 research project (2014-2017; AGroFOREstry that Will Advance Rural Development; Contract No. 613520).																	
7	Additional developments were implemented in the EU-funded AGROMIX research project (2020-2024; AGROforestry and MIXed farming systems; grant agreement 862993).																	
8	This particular version of EcoYield-SAFE v2 was used to examine the silvopastoral and silvoarable system at Loughgall in Northern Ireland																	
9	Suggested reference for model: Burgess, P.J., Graves, A., Giannitsopoulos, M., Upson, M., Palma, J.H.N. (2025) EcoYield-SAFE v 2 model in Excel. Bedfordshire: Cranfield University. 1 March 2025																	
10	Background references: Palma, J.H.N., Crous-Duran, J., Graves, A.R., Garcia de Jalon, S., Upson, M., Oliveira, T.S., Paulo, J.A., Ferreira-Dominguez, N., Moreno, G., Burgess, P.J. (2018). Integrating belowground carbon dynamics into Yield-SAFE, a parameter sparse agroforestry model. <i>Agroforestry Systems</i> 92, 1047–1057. https://doi.org/10.1007/s10457-017-0123-4																	
11	Contact details for authors: p.burgess@cranfield.ac.uk; a.graves@cranfield.ac.uk																	

Figure 2. Screenshot of the contents of the “About” worksheet.

3.2.2 CO₂ factor

This worksheet provides the data that was used to derive the equations to determine the effect of climate change on tree and crop yields. In EcoYield-SAFE, the effect of increases in atmospheric carbon dioxide concentration (CO₂) result in an assumed modification of the potential radiation use efficiency of the trees, grass, and crops. Hence the multiplier to the radiation use efficiency increased from 1 at a concentration of 360 ppm, to 1.25 at 720 ppm, and 1.28 at 800 ppm (Poorter et al., 2022; Jägermeyr et al., 2021; Wolf 2012; Rodriguez et al., 1999).

3.3 Input worksheets

3.3.1 Simulations datasheet

The simulations datasheet allows the user to select one of 56 tree-crop-climate combinations (Table 2). The selected tree-crop-climate combination is selected by altering the number in **cell D4** (Table 2). The soil depths and textures are the same in each combination. The tree species includes species 39 (woodland ash), 40 (silvoarable poplar), 41 (densely planted poplar), and 42 (silvopastoral ash). The crop species include species 9 (fallow), 47 (spring barley), and 48 (permanent grass).

Table 2. The content of “Simulation datasheet” which allows the user to select a specific tree-crop-climate combination.

	A	B	C	D	E	F	G	H
3								
4		Selected set in simulation		1				
5								
6						Nr of years	10	30
7			Soil depth (mm)	Soil texture	Tree species	Tree density	Crop1	Crop2
8	1	NI Loughgall_SA_Calibration	1000	3	40	142	47	48
9	2	NI Loughgall_SA_Baseline	1000	3	40	142	47	48
10	3	NI Loughgall_SA_RCP4.5 (2020-2060)	1000	3	40	142	47	48
11	4	NI Loughgall_SA_RCP4.5 (2060-2100)	1000	3	40	142	47	48
12	5	NI Loughgall_SA_RCP8.5 (2020-2060)	1000	3	40	142	47	48
13	6	NI Loughgall_SA_RCP8.5 (2060-2100)	1000	3	40	142	47	48
14	7	NI Loughgall_SP_Calibration	1000	3	42	400	48	48
19	12	NI Loughgall_SP_RCP8.5 (2060-2100)	1000	3	42	400	48	48
20	13	NI Loughgall_WD_Calibration	1000	3	39	2500	9	
25	18	NI Loughgall_WD_RCP8.5 (2060-2100)	1000	3	39	2500	9	
26	19	Barley only_Calibration	1000	3	40	0	47	
31	24	Barley only_RCP8.5 (2060-2100)	1000	3	40	0	47	
32	25	Poplar only densed_Calibration	1000	3	41	900	9	
37	30	Poplar only densed_RCP8.5 (2060-2100)	1000	3	41	900	9	
38	31	Grass only_Calibration	1000	3	42	0	48	
43	36	Grass only_RCP8.5 (2060-2100)	1000	3	42	0	48	
44	37	Crop_SA_Calibration	1000	3	40	0	47	48
49	42	Crop_SA_RCP8.5 (2060-2100)	1000	3	40	0	47	48
50	43	NI Loughgall_SP_RCP8.5 (2060-2100)	1000	3	42	50	48	
56	49	NI Loughgall_SP_RCP8.5 (2060-2100)	1000	3	42	600	48	
57	50	NI Loughgall_SA_RCP8.5 (2060-2100)	1000	3	40	50	47	48
63	56	NI Loughgall_SA_RCP8.5 (2060-2100)	1000	3	40	600	47	48

3.3.2 Climate worksheet

The climate worksheet stores 12 sets of climate data which can be called in by selecting the appropriate number in **cell C5** (Table 3). Each dataset includes the day, month, and year. The weather data includes the maximum air temperature (*tasmax*; °C), the minimum air temperature (*tasmin*; °C), the mean relative humidity (*hurs*; %), the evaporation rate (*evpsbl*; mm d⁻¹), the shortwave radiation (*rsds*; MJ m⁻² d⁻¹), precipitation (*pr*; mm d⁻¹), and windspeed (*sfcWind*; m s⁻¹). The evaporation rate is not used in the calculations, but reference evapotranspiration is calculated from the temperatures, the solar radiation, the humidity, and the windspeed.

Table 3. Screenshot of the “Climate” worksheet which includes a climate database. which allows the user to select a specific tree-crop-climate combination.

Worksheet C: Climate database										Left to update: 1, 2, 4 and 11									
Climate data from database										1	2	3	4	5	6	7	8	9	10
Select	4									41	42	43	44	45	46	47	48	49	410
from simulation database										Climate being used by YieldSAFE									
										Baseline									
										Day	Month	Year	<i>tasmax</i>	<i>tasmin</i>	<i>hurs</i>	<i>evpsbl</i>	<i>rsds</i>	<i>pr</i>	<i>sfcWind</i>
										SA									SP
										1999									1989
										2039									2029
										Bar-only									
										1999									1989
										2039									2029
										PP									
										1999									1989
										2039									2029
										WD									
										1999									1989
										2039									2029

The time periods covered by the weather data range from 22 to 94 years (Table 4). Weather records 1 and 2 are only for 22 years. Hence if weather data 1 to 2 are selected, the tree and crop modelling only cover 22 years.

Table 4. Description of the twelve weather datasets that can be selected in the model.

No	Site	Description and time period	Period (years)	Purpose of weather data
1	Loughgall	1999-2021	22	For calibration of silvoarable
2	Loughgall	1989-2021	22	For calibration of silvopastoral system (used RCP4.5 for 2022-2024)
3	Loughgall	1951-2005	54	Historical baseline
4	Loughgall	Calibration data (1989-2021) and RCP4.5 (2022-2028)	40	Baseline for grassland, silvopastoral and ash woodland systems
5	Loughgall	RCP4.5 (2006-2100)	94	
6	Loughgall	RCP4.5 (2020-2060)	40	
7	Loughgall	RCP4.5 (2060-2100)	40	
8	Loughgall	RCP8.5 (2006-2100)	94	
9	Loughgall	RCP8.5 (2020-2060)	40	
10	Loughgall	RCP8.5 (2060-2100)	40	
11	Loughgall	Calibration data (1999-2021) and RCP4.5 (2022-2038)	40	Used for calibration of arable, silvoarable, and dense poplar system
12	Unspecified	(1992-2010, and then 1981-1993)	40	

3.3.3 Bio-parameters

The bio-parameters worksheet includes sets of parameters for the trees, crops, and soil selected in the simulation database (Table 5).

Table 5. The nine parameter sections within the Bio-parameters worksheet.

Section	Rows
D1: Tree parameters	2 to 84
D2: Crop parameters	85 to 124
D3: Soil parameters	125 to 148
D4: Irrigation schedule	149 to 160
D5: Environmental parameters (Nitrogen leaching)	161 to 202
D5: Environmental parameters (Effects of evapotranspiration)	203 to 218
D6: Crop harvesting calendar	219 to 322
D7: Livestock parameters	323 to 382
D8: RothC parameters	383 to 430
D9: Cork specific parameters (to be implemented)	431 to 440

3.4 Calculation worksheets

3.4.1 Yield-SAFE

The Yield-SAFE worksheet includes a separate row for each day considered. The columns address the date and climate, tree growth, crop growth, soil dynamics and irrigation, environmental assessments for RothC, fruit production, microclimate effects, cork, provisioning services, and carbon dioxide calculations (Table 6).

Table 6. Description of the 12 sections of the Yield-SAFE worksheet in EcoYield-SAFE.

Section	Columns
E1-E2 Date and climate	A to G
E3: Tree	H to AH
E4: Crop	AI to BO
E5: Soil dynamics and irrigation	BP to CB
E6: Environmental assessment including tree leaf fall and fine root turnover and crop carbon for RothC, and root water uptake	CC to DE
E7: Unused section	DF to ED
E8: Fruit production and pruning	EE to GC
E9: Microclimate effects	GD to HD
E10: Cork	HE to HM
E11: Provisioning services	HV to IH
E12: Carbon dioxide calculations	IJ to IQ

3.4.2 RothC

The RothC worksheet calculates the predicted changes in soil organic carbon based on carbon inputs (derived from the Yield-SAFE worksheet) and assumed decomposition rates (determined from rows 383 to 422 in the Bio-parameters worksheet) (Table 7).

Table 7. Screenshot of the RothC worksheet predicts the changes in soil organic carbon based on the level of carbon inputs and decomposition rates.

[illegible]

3.4.3 Nitrogen dynamics

The N dynamics worksheet has been designed to predict the nitrogen dynamics within the system. In the Bio-parameters worksheet it is possible to indicate levels of nitrogen fertiliser application in the system. In the default EcoYield-SAFE v2 model, no nitrogen fertiliser applications are assumed. Based on the assumed application and tree and crop nitrogen uptake and leaching, a nitrogen balance is calculated (Table 8).

Table 8. Screenshot of the N dynamics worksheet which can be used to predict the nitrogen balance within the system.

Worksheet G: Nitrogen dynamics		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																												
		Year	Crop code	Crop species	Crop yield	Yield	Yield	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Months	Month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3.5.2 Graphs

The Graphs worksheet provides a graphical representation of some of the annual outputs (up to 40 years) described in the Annual-outputs worksheet.

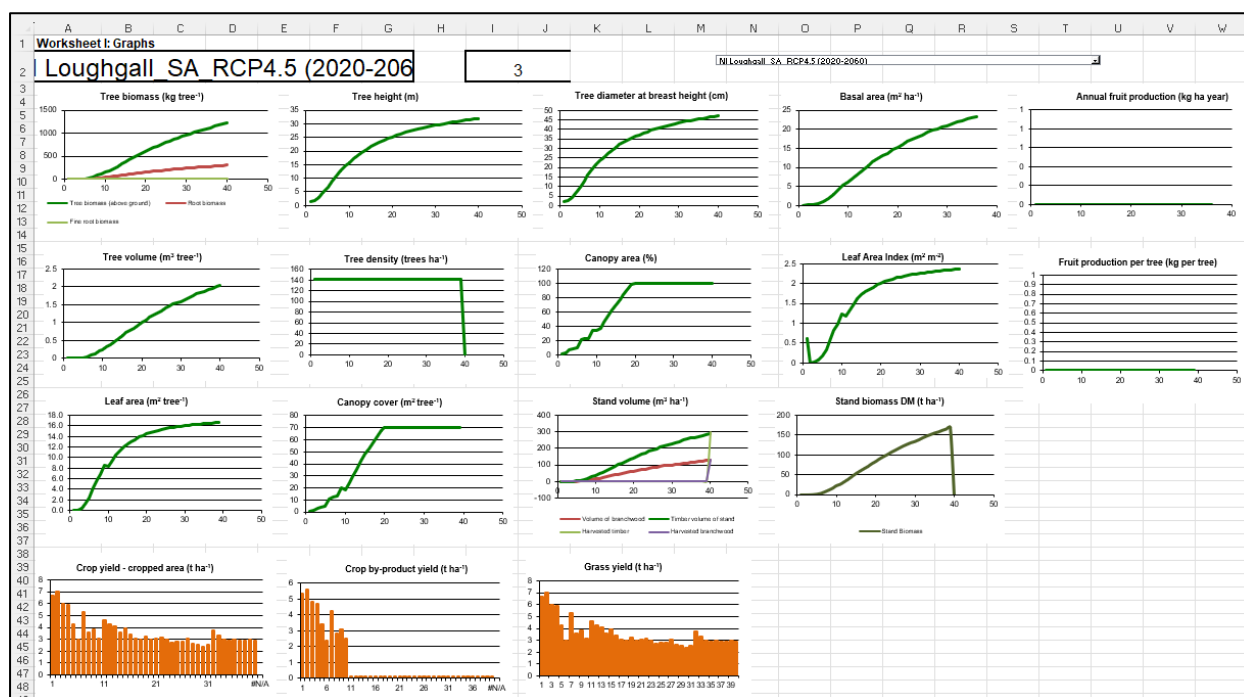


Figure 3. Example appearance of Graph worksheet.

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