Predicting the Effect of Climate Change and Increased Carbon Dioxide Concentrations on the Silvoarable and Silvopastoral Experiments at Loughgall

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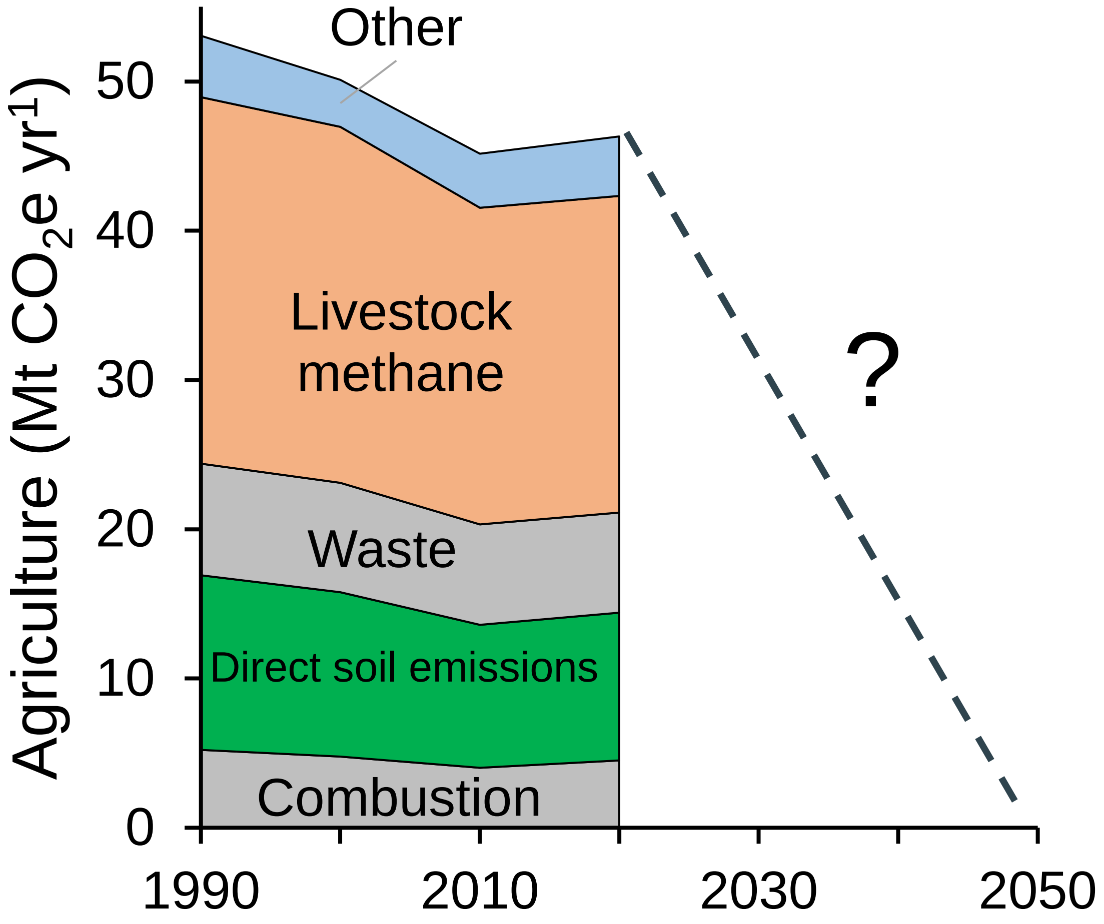
Farm Woodland Forum Meeting 2023
Greenmount College, Northern Ireland
16 June 2023

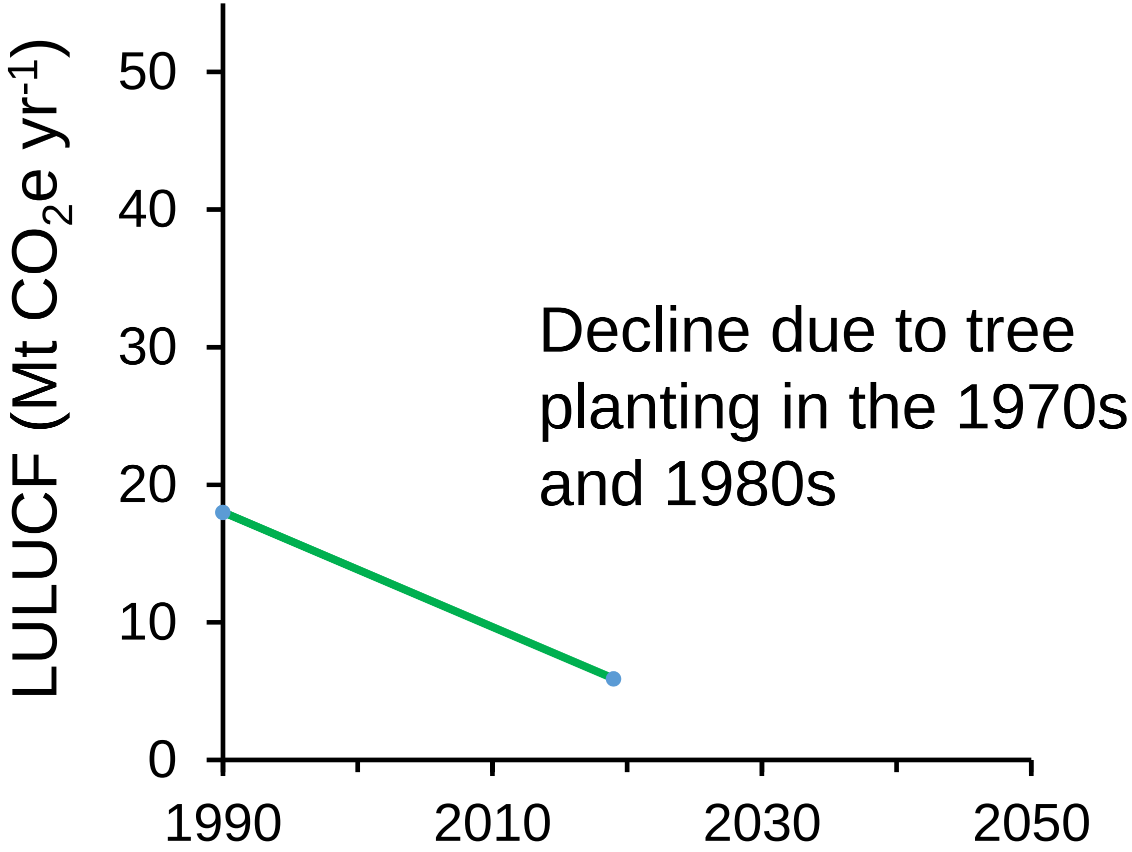
Contents

UK agriculture, land use and climate change

UK **agriculture** GHG emissions of 46 Mt CO_2e, in 2019 (~10% of UK total)



Land use and land use change and forestry emissions of 6 Mt CO_2e in 2019



Burgess and Graves (2022)

Indicative baseline emissions per hectare

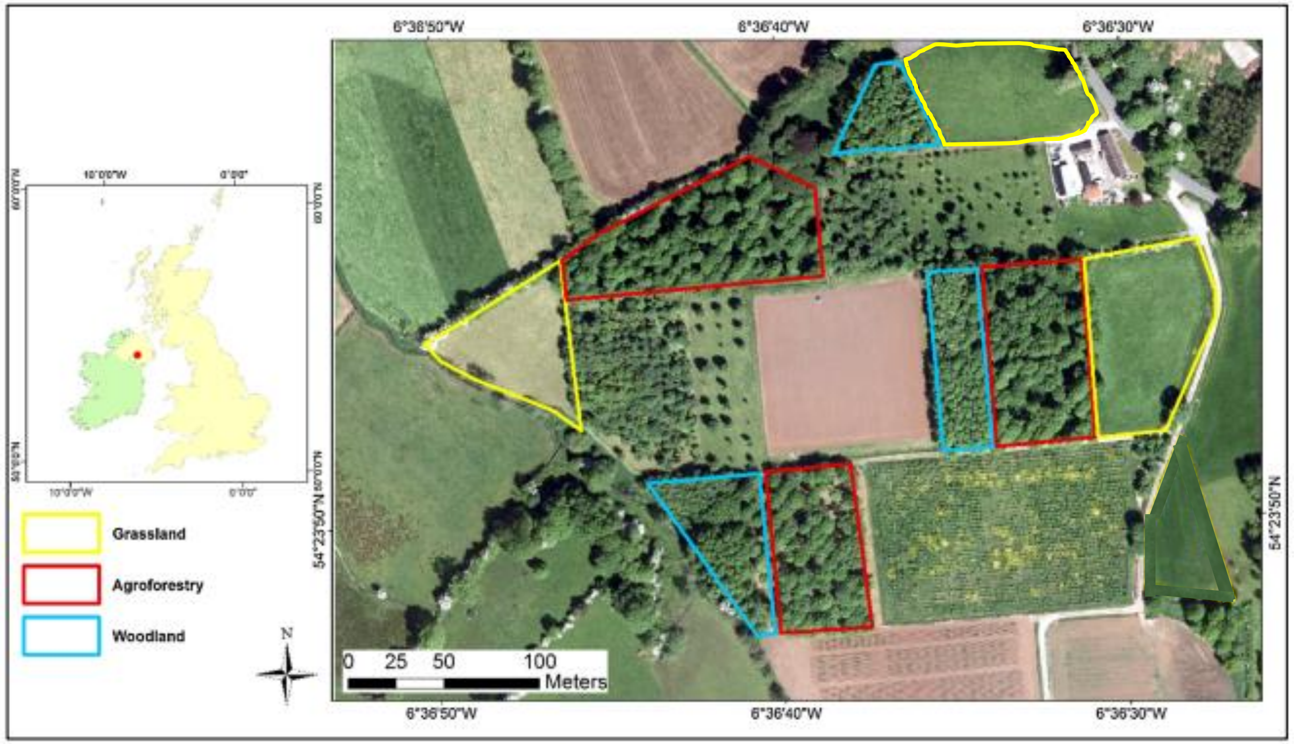
Land use	UK area (million ha)	Emissions ($t\ CO_2e\ ha^{-1}\ yr^{-1}$)			
		Combustion	Fertiliser	Livestock and other	Total
Arable land	4.8	0.9	0.9		**~2.0**
Grassland[a]	11.2		0.4	3.0	**~4.0**

[a]: Temporary grassland and permanent pasture

Silvopastoral experiment at Loughgall

Established in 1989 comprising:
three silvopastoral plots with ash trees (*Fraxinus excelsior* L.),
three woodland plots planted with ash trees, and
three permanent grassland plots.

Plot size ranges approximately from 0.12 to 0.56 ha.



Permanent Grassland	Agroforestry - Silvopastoral trees	Woodland
		
Pasture with perennial ryegrass (*Lolium perenne* L.)	Silvopastoral system planted with ash trees (400 stems ha^{-1})	Woodland planted with ash trees (2500 stems ha^{-1})

	Grassland	Silvopastoral (trees ha^{-1})	Woodland (trees ha^{-1})
1989		400	2500
2004		265	
2009		170	1100

Silvopasture system with ash at Loughgall

Modelling: Yield-SAFE

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

Yield-SAFE

A daily time-step model describing biomass accumulation of trees, crops and grass as a function of their capacity to intercept and use solar radiation and soil water

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Worksheet D: Biophysical calculations

D1-D2 Date and climate							D3 Tree				
Date	Day	Day of year	Year	Temp (°C)	Rad (MJ m^{-2})	Precipitation (mm)	Tree density (tree m-2)	Trees present	Leaf development per shoot (m2)	Leaf area per tree (m^2 $tree^{-1}$)	Leaf area index (m^2 m^{-2})
01/01/92				3.9	2.7						
02/01/92	1	1		3.9	2.8						
03/01/92	2	2		9.8	2.1	2.6	0.1089	1			
04/01/92	3	3		7.4	2.6	4.0	0.1089	1			
05/01/92	4	4		8.6	2.8		0.1089	1			
06/01/92	5	5		9.8	1.8		0.1089	1			

Spreadsheet model requires daily data on the mean air temperature (°C), the daily solar radiation (MJ m^{-2}) and precipitation (mm)

Modelling Yield-SAFE - microclimate effects

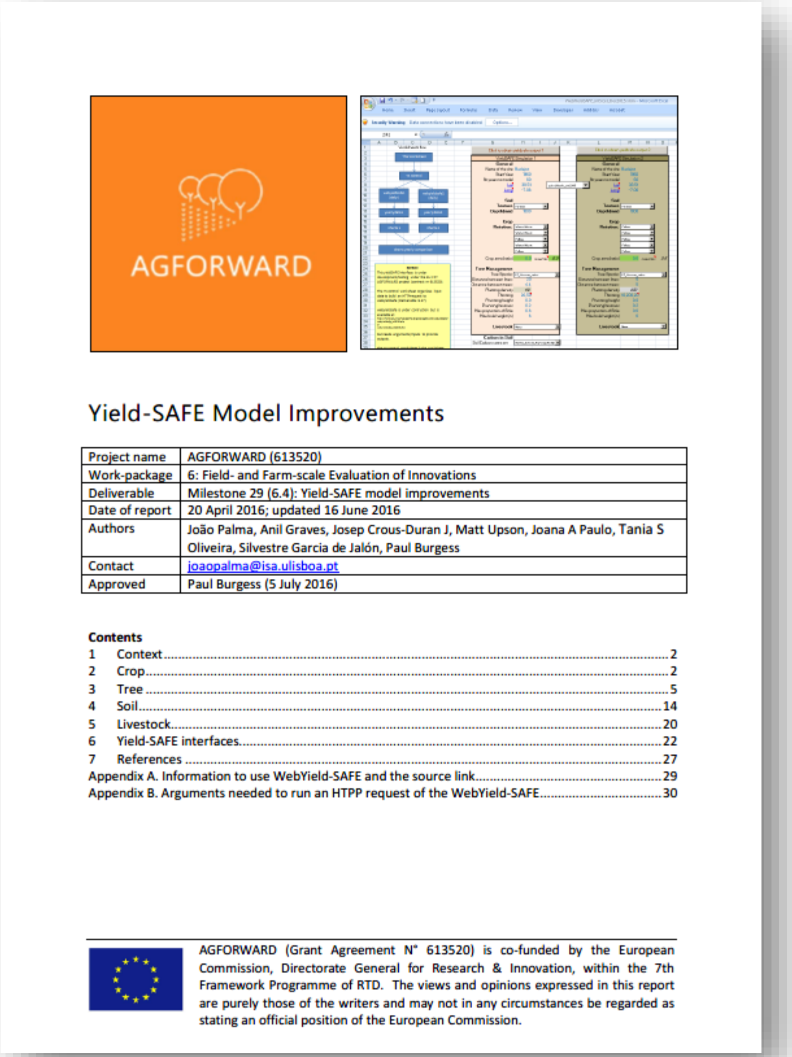
Maintenance respiration of grass crops

Water use responds to daily vapour pressure deficits

Effects of trees on temperature and wind speed

Routines to predict the turnover of soil organic carbon and leaching of nitrate

Shade effect on livestock metabolizable energy requirements


AGFORWARD

Yield-SAFE Model Improvements

Project name	AGFORWARD (613520)
Work-package	6: Field- and Farm-scale Evaluation of Innovations
Deliverable	Milestone 29 (6.4): Yield-SAFE model improvements
Date of report	20 April 2016; updated 16 June 2016
Authors	João Palma, Anil Graves, Josep Crous-Duran J, Matt Upson, Joana A Paulo, Tania S Oliveira, Silvestre Garcia de Jalón, Paul Burgess
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Approved	Paul Burgess (5 July 2016)

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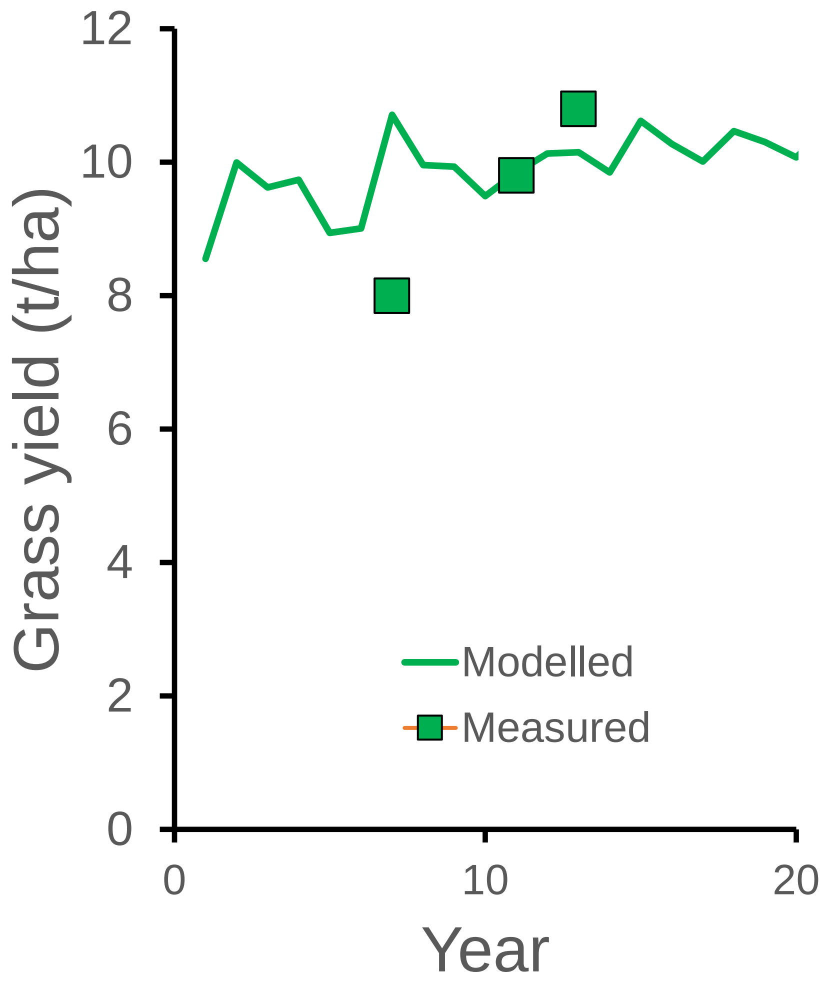
AGFORWARD (Grant Agreement N° 613520) is co-funded by the European Commission, Directorate General for Research & Innovation, within the 7th Framework Programme of RTD. The views and opinions expressed in this report are purely those of the writers and may not in any circumstances be regarded as stating an official position of the European Commission.

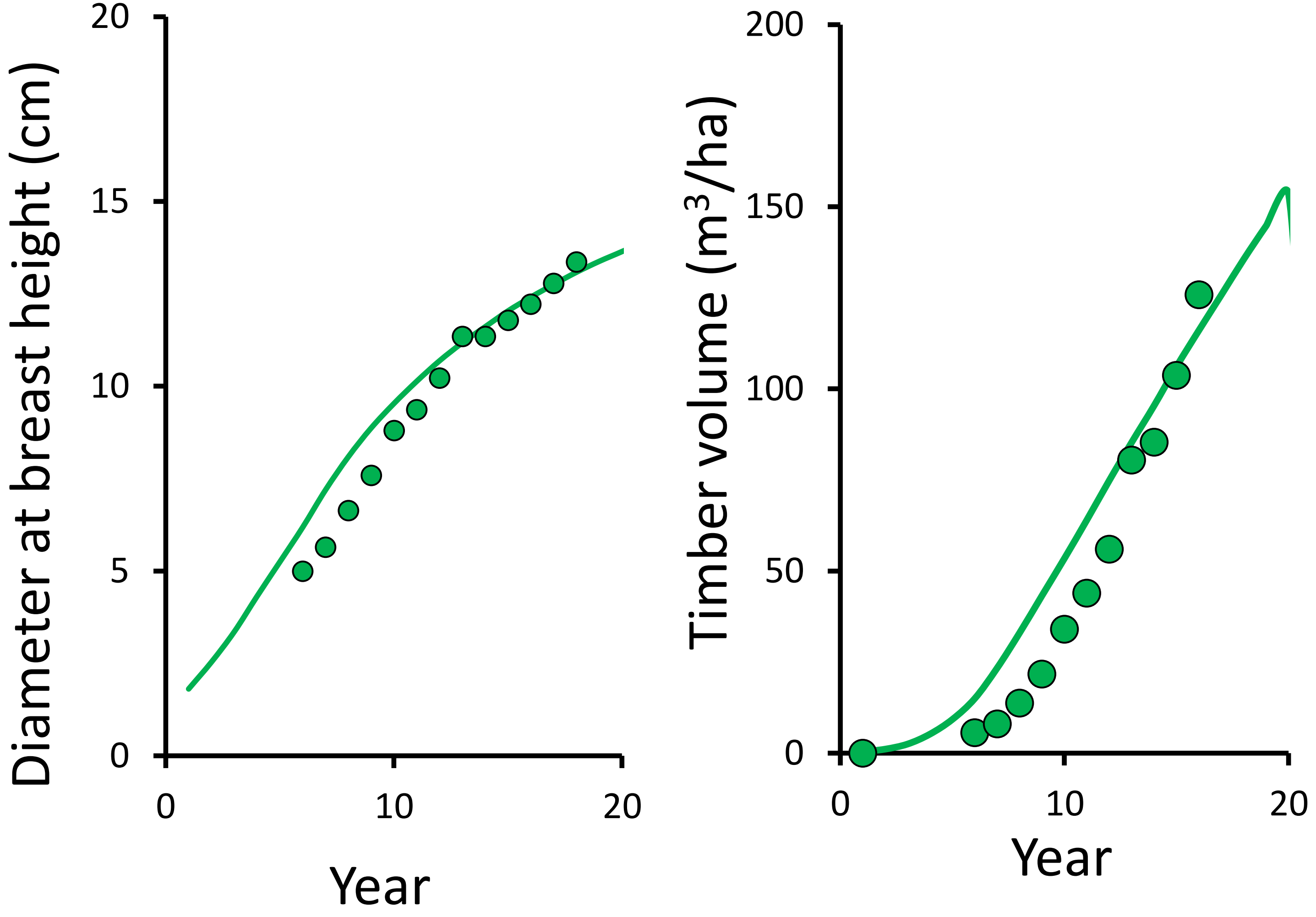
Palma et al. (2016)

Modelling Loughgall grass and ash woodland systems with Yield-SAFE

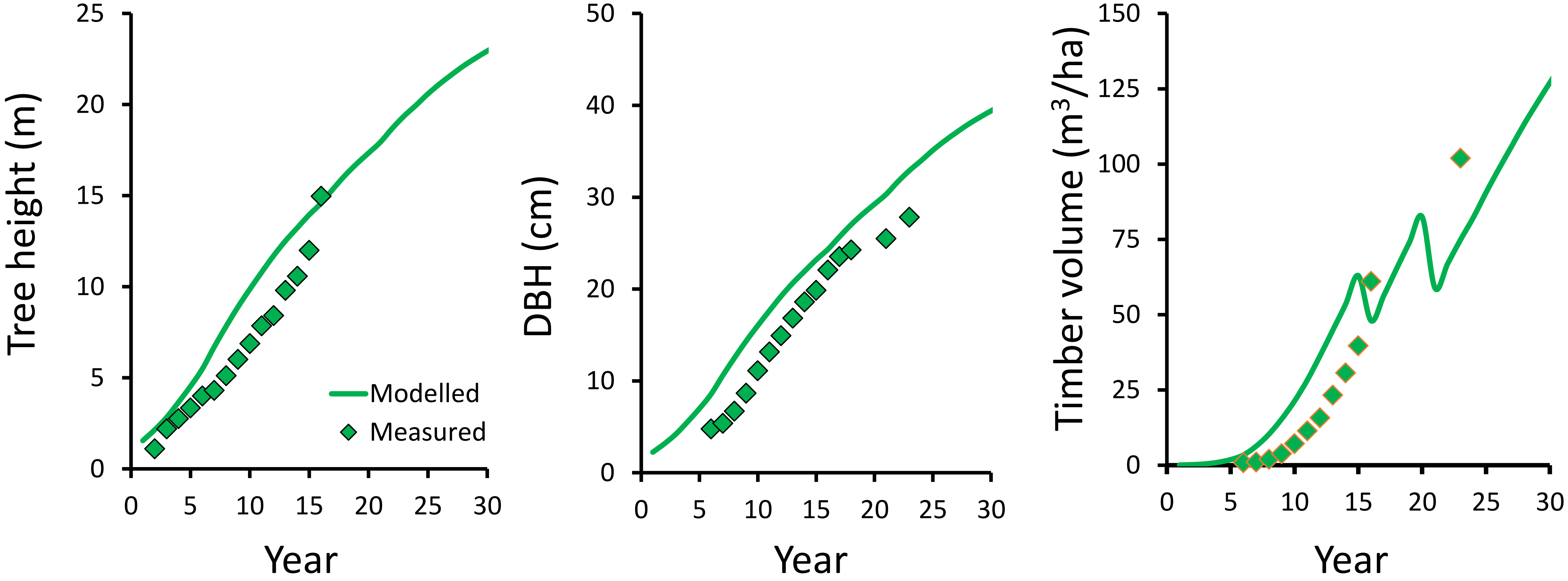
Grass



Ash woodland



Modelling silvopastoral ash growth with Yield-SAFE



Ash height, diameter at breast height (DBH) and timber volume at a tree density of 400 trees ha^{-1}, as measured at Loughgall silvopastoral trial and as predicted by Yield-SAFE

What could be the effect of climate change?

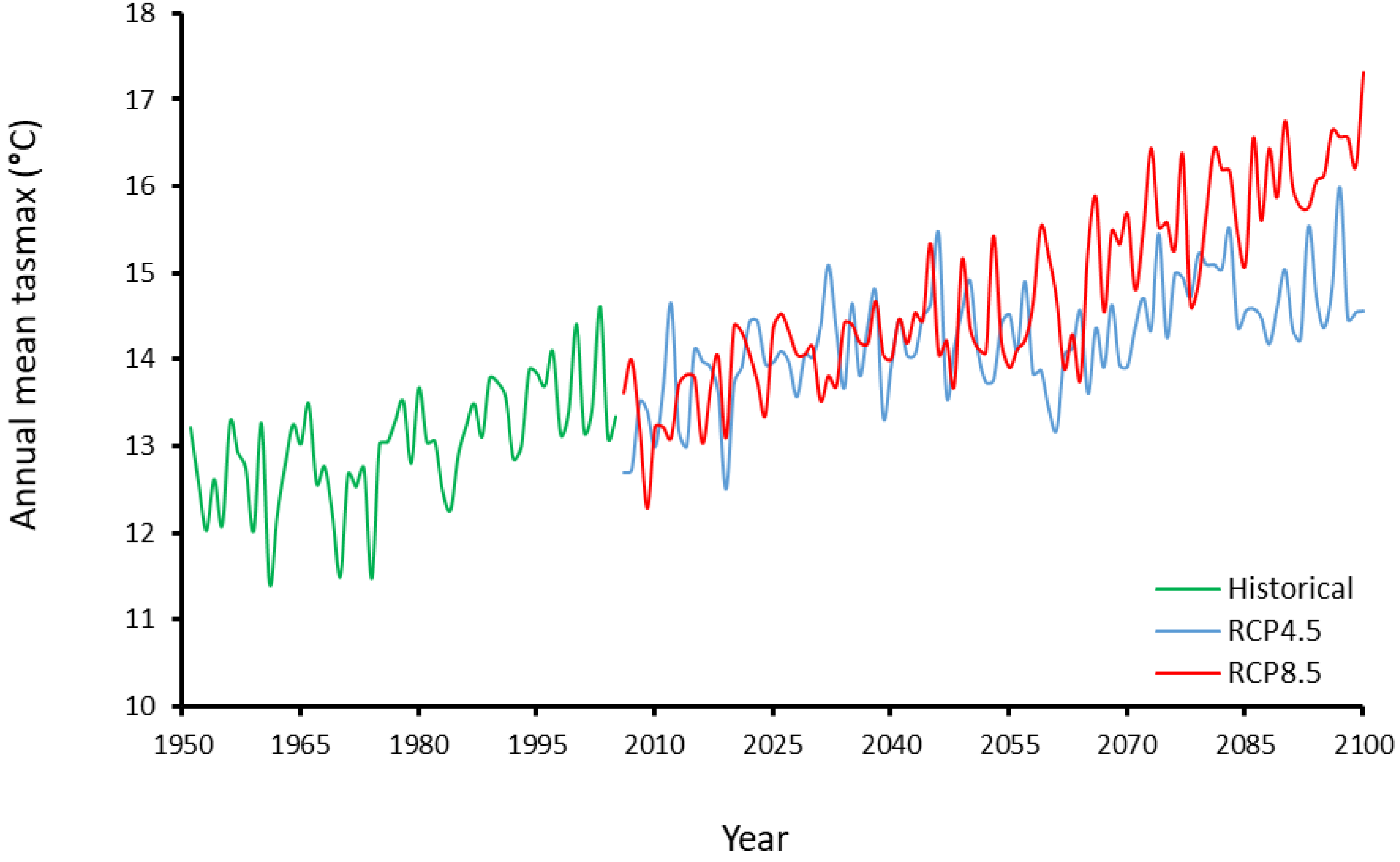
Future climate situations are simulated by emission scenarios called representative concentration pathways (RCPs) (Moss et al., 2010).

These scenarios have four pathways: RCP2.6, RCP4.5, RCP6 and RCP8.5, which are named according to their radiative forcing in W m^{-2} in 2100 (van Vuuren et al., 2011).

RCP	Change in temperature (°C) by 2081-2100
RCP2.6	1.6 (0.9-2.3)
RCP4.5	2.4 (1.7-3.2)
RCP6.0	2.8 (2.0-3.7)
RCP8.5	4.3 (3.2-5.4)

Original measured weather data for the period 2003-2015 were provided by AFBI.

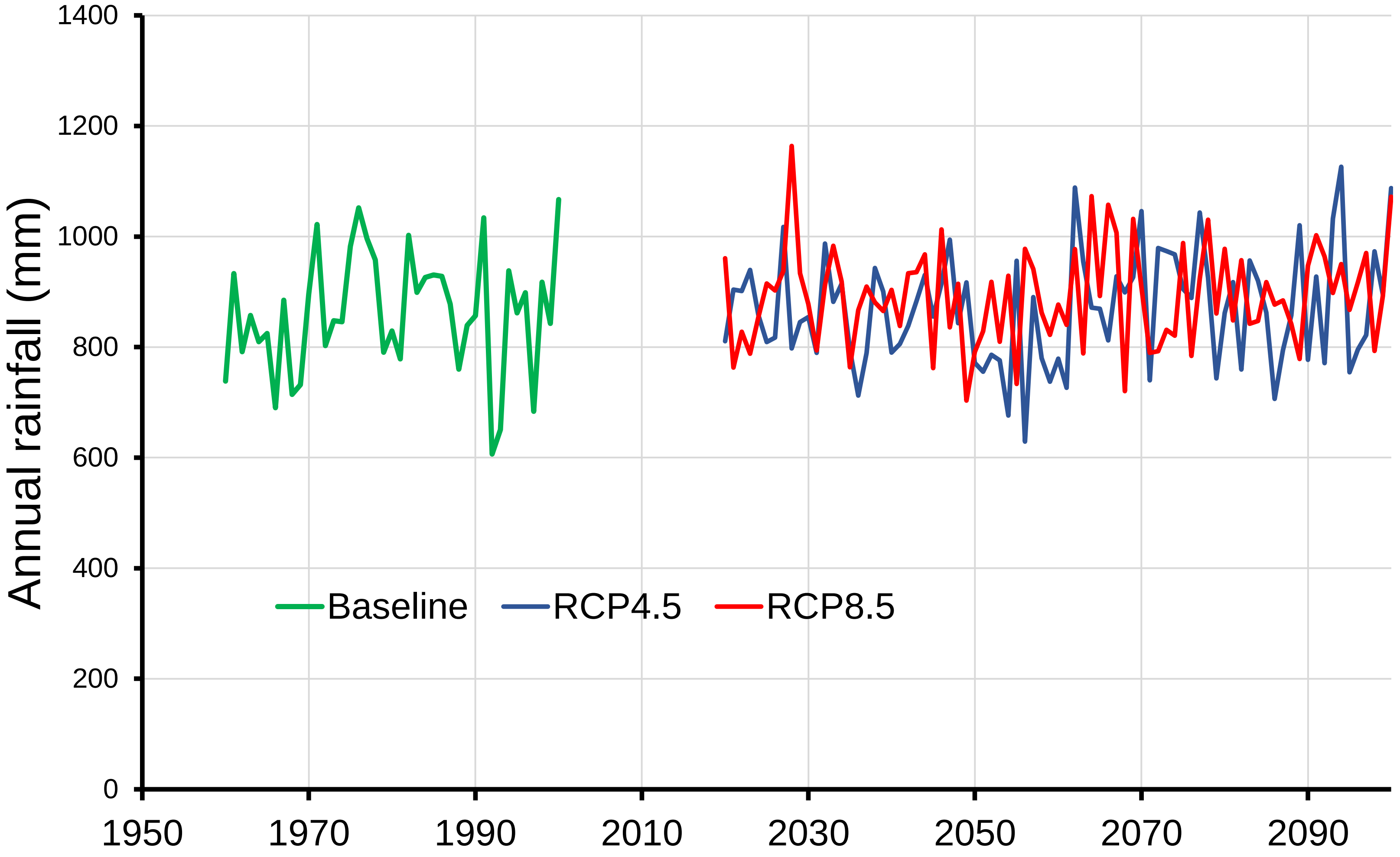
Temperature measurements and predictions



Scenario	Mean max. temp (°C)	Mean min. temp (°C)
Baseline (1950-2000)	13.0	5.1
RCP 4.5 (2020-2060)	13.9	7.1
(2060-2100)	14.2	7.5
RCP 8.5 (2020-2060)	14.0	7.4
(2060-2100)	15.2	8.8

Figure 1. Mean annual maximum temperature (tasmax) for the historical and the projected RCP4.5 and RCP8.5 weather data at Loughgall.

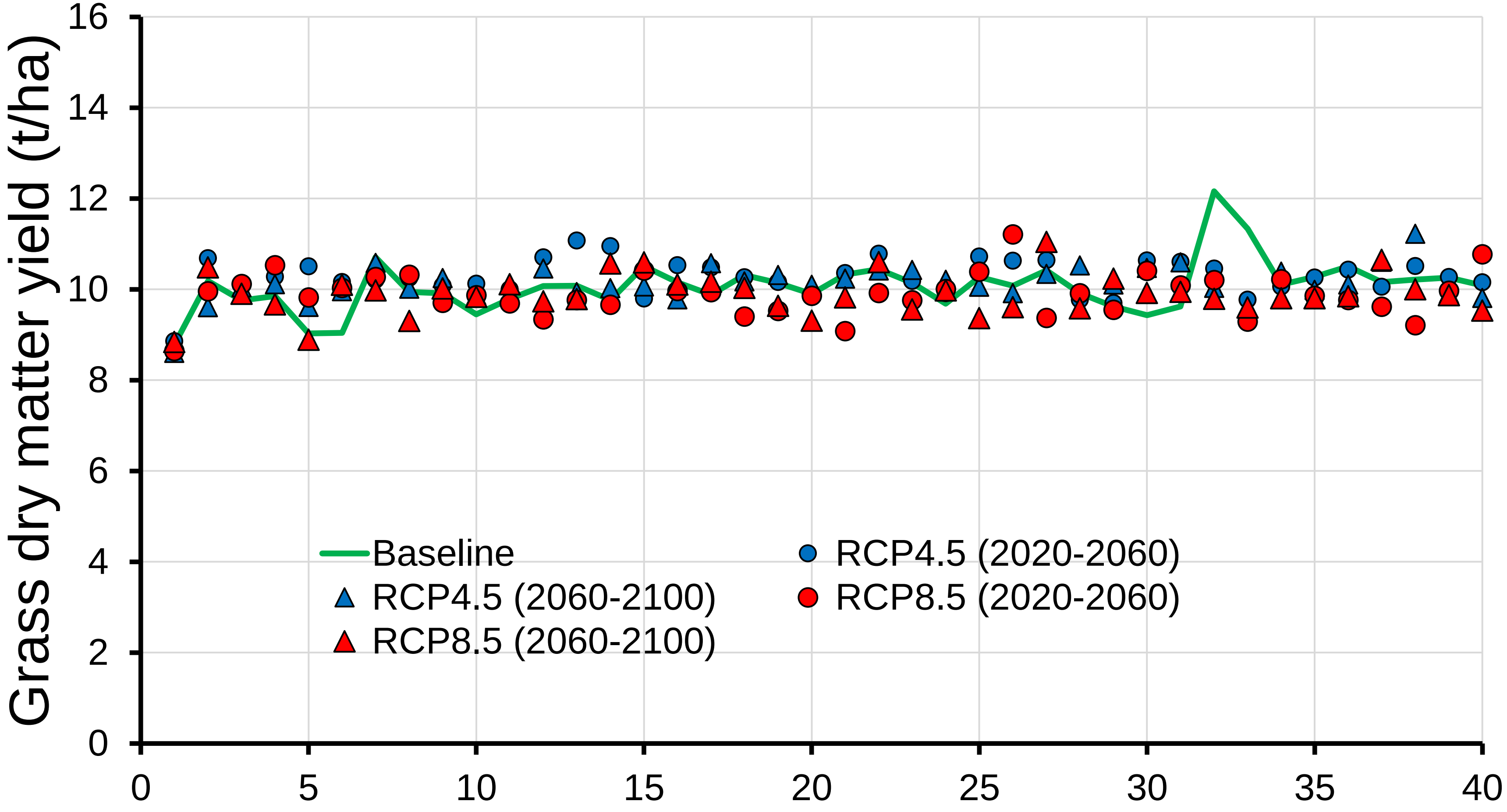
Rainfall measurements and predictions



Scenario	Annual Rainfall (mm)
Baseline (1950-2000)	861
RCP 4.5 (2020-2060)	843
(2060-2100)	895
RCP 8.5 (2020-2060)	881
(2060-2100)	903

Annual rainfall for the historical and the projected RCP4.5 and RCP8.5 weather data at Loughgall

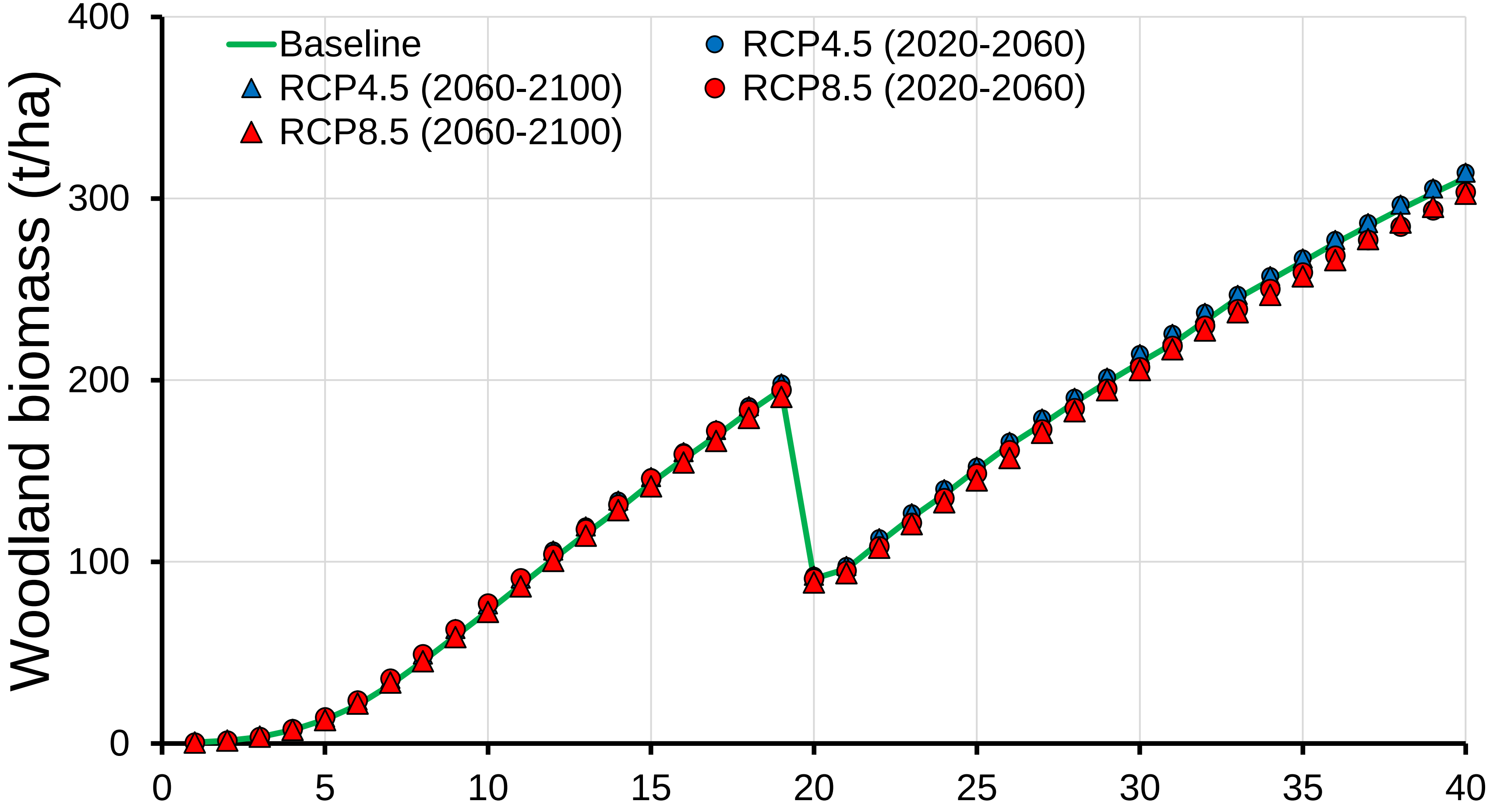
Grass: predicted effect of temperature and rainfall change



Scenario	Mean grass yield (t/ha)
Baseline (1989-2029)	10.1
RCP 4.5 (2020-2060)	10.3
(2060-2100)	10.1
RCP 8.5 (2020-2060)	9.9
(2060-2100)	9.9

Minimal predicted effect on grass yields

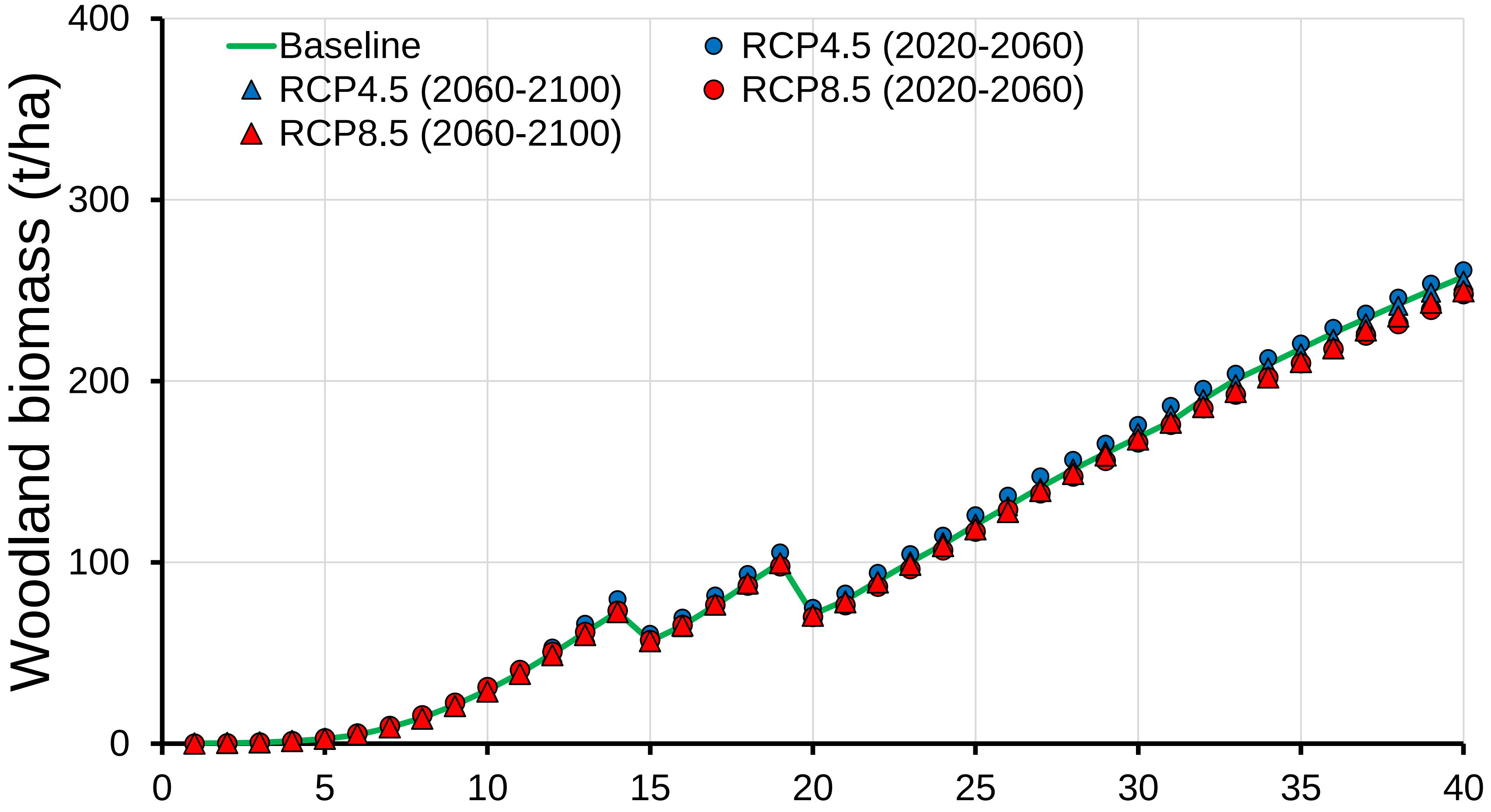
Ash woodland: predicted effect of temperature and rainfall change



Scenario	Stand biomass at 40 years (t/ha)
Baseline (1989-2029)	311
RCP 4.5	
(2020-2060)	314
(2060-2100)	314
RCP 8.5	
(2020-2060)	303
(2060-2100)	303

Minimal predicted effect on woody biomass

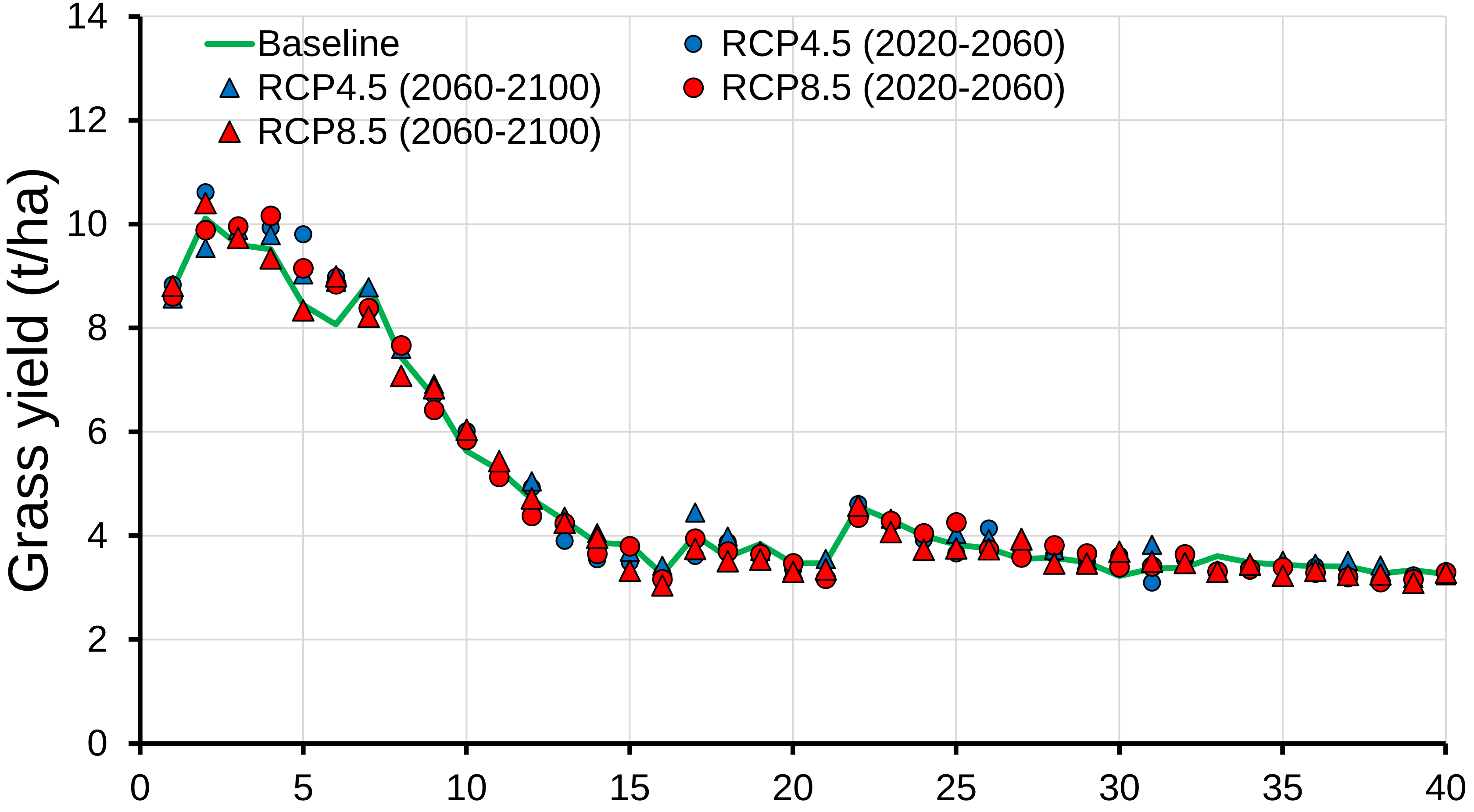
Ash silvopastoral: predicted effect of temperature and rainfall change



Scenario	Stand biomass at 40 years (t/ha)
Baseline (1989-2029)	258
RCP 4.5 (2020-2060)	261
(2060-2100)	255
RCP 8.5 (2020-2060)	248
(2060-2100)	250

Minimal predicted effect on woody biomass

Ash silvopastoral: predicted effect of temperature and rainfall change

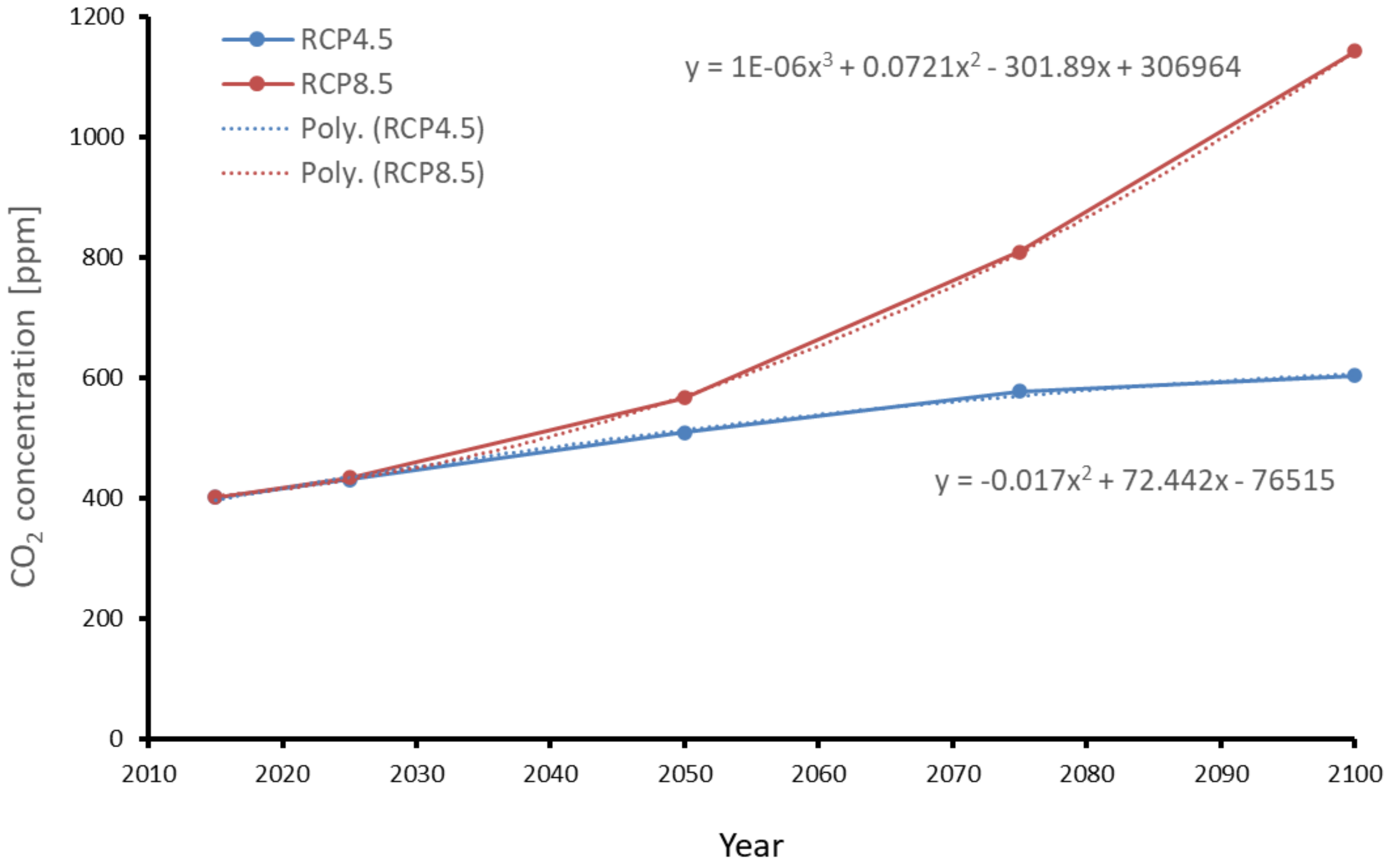


Scenario	Mean grass yield over 40 years (t/ha/yr)
Baseline (1989-2029)	4.9
RCP 4.5 (2020-2060)	4.9
(2060-2100)	5.0
RCP 8.5 (2020-2060)	4.9
(2060-2100)	4.8

Minimal predicted effect on grass yield

Modelling increased carbon dioxide concentrations

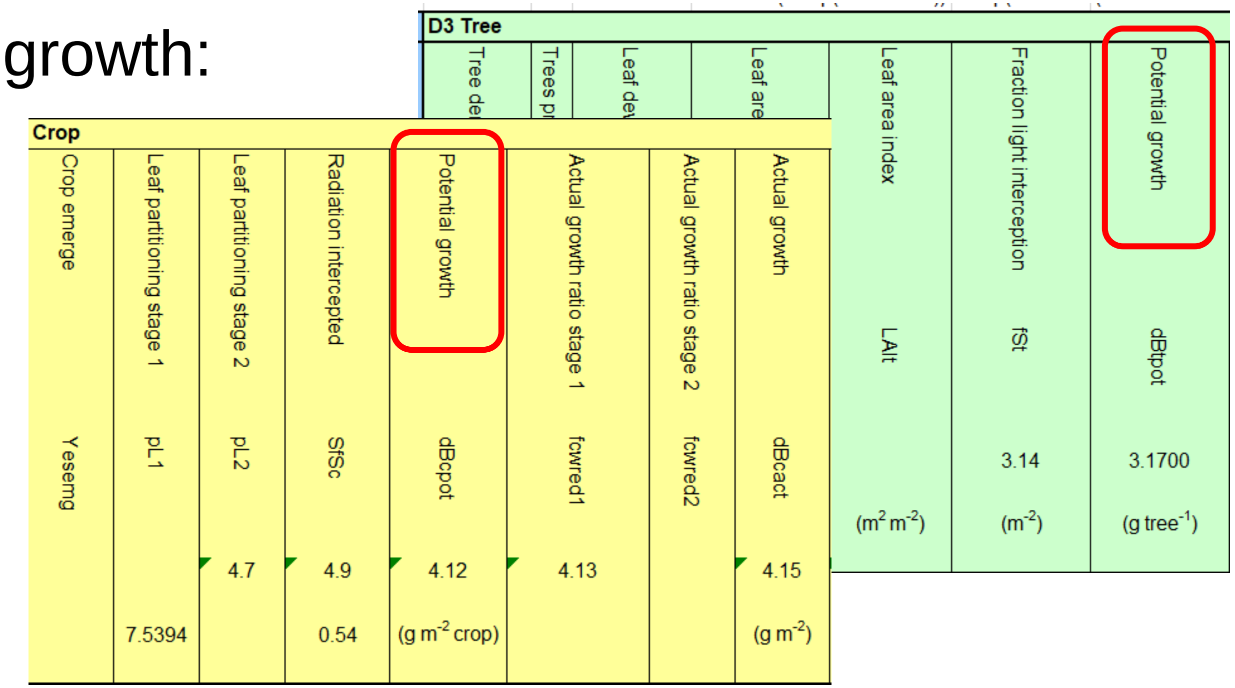
Scenario	Year	CO_2 (ppm)
RCP 4.5	2015	402
	2025	431
	2050	509
	2075	577
	2100	604
RCP 8.5	2015	402
	2025	434
	2050	567
	2075	809
	2100	1142



Reported future atmospheric CO_2 concentrations up to 2100 for RCP4.5 and RCP8.5 (Meinhausen et al., 2020)

Modelling the effect of increased CO2 concentration on photosynthesis

In Yield-SAFE, CO_2 effect on crop and tree growth:
Apply a multiplier to potential growth

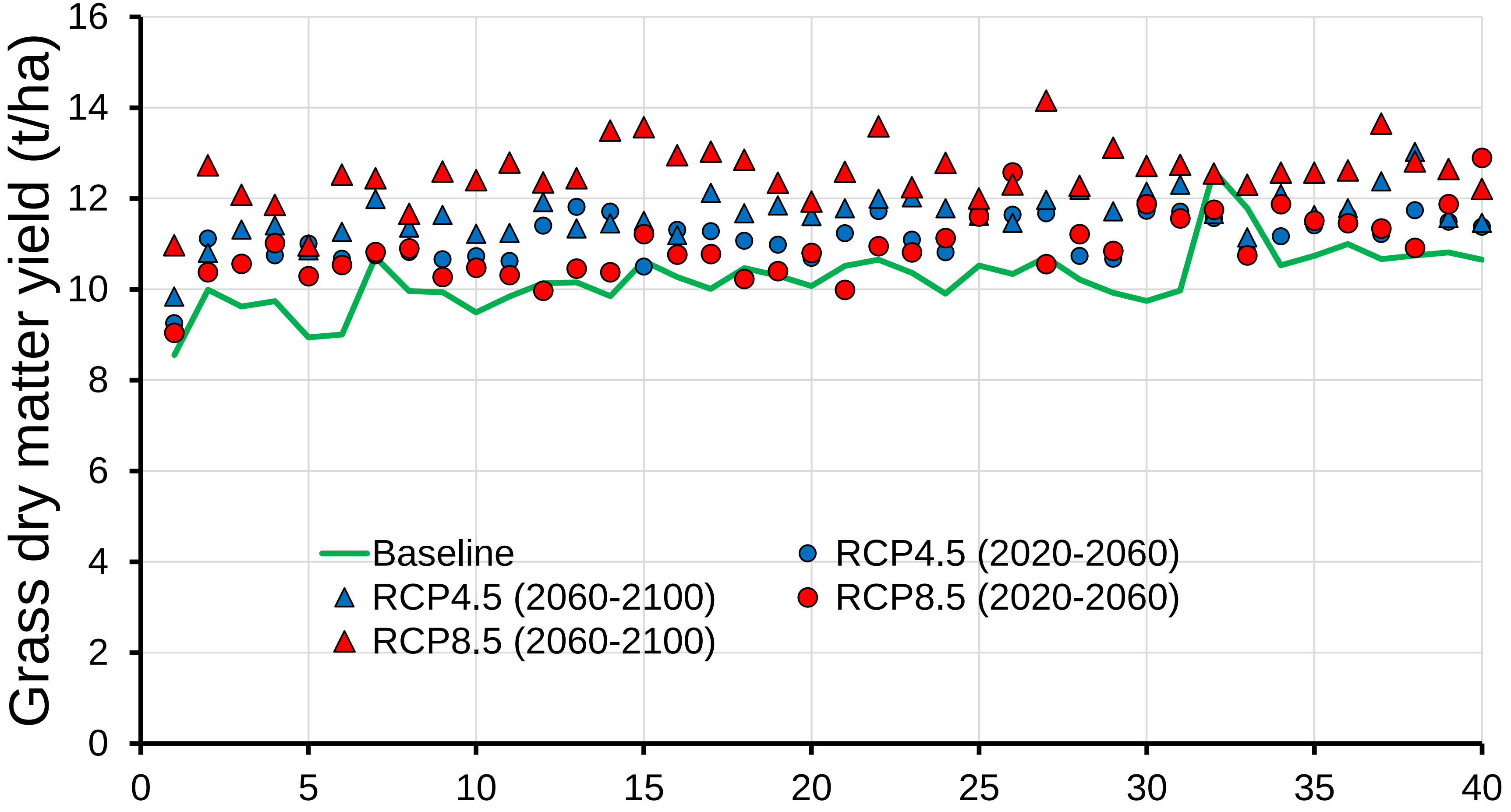


Response to 700 ppm (Ainsworth et al. 2003) or 915 ppm (Zheng et al. 2018)

Atm. CO_2 (ppm)	Correction actor
40	0.00
360	1.00
720	1.25
800	1.35
2000	1.35

In Yield-SAFE a maximum of 35% benefit up to a CO_2 concentration of **800** ppm was assumed, above which no additional change in potential growth has been considered
(Prooter et al., 2022; Rodriguez et al., 1999).

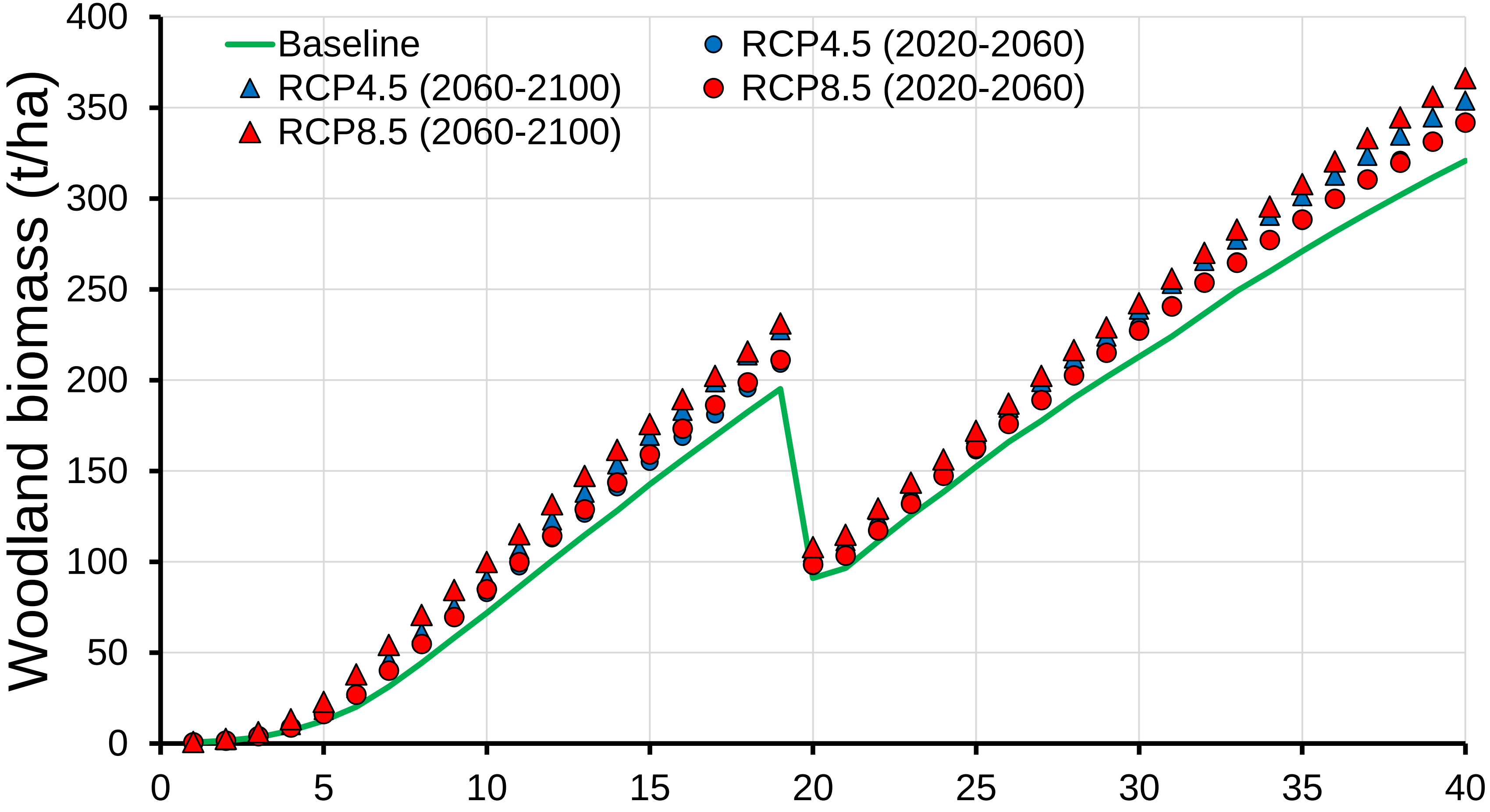
Grass: predicted effect of temperature, rainfall, and CO_2 change



Scenario	Mean grass yield (t/ha)
Baseline (1989-2029)	10.3
RCP 4.5 (2020-2060)	11.1
(2060-2100)	11.6
RCP 8.5 (2020-2060)	10.9
(2060-2100)	12.6

Increased CO_2 concentration increasing grass yields

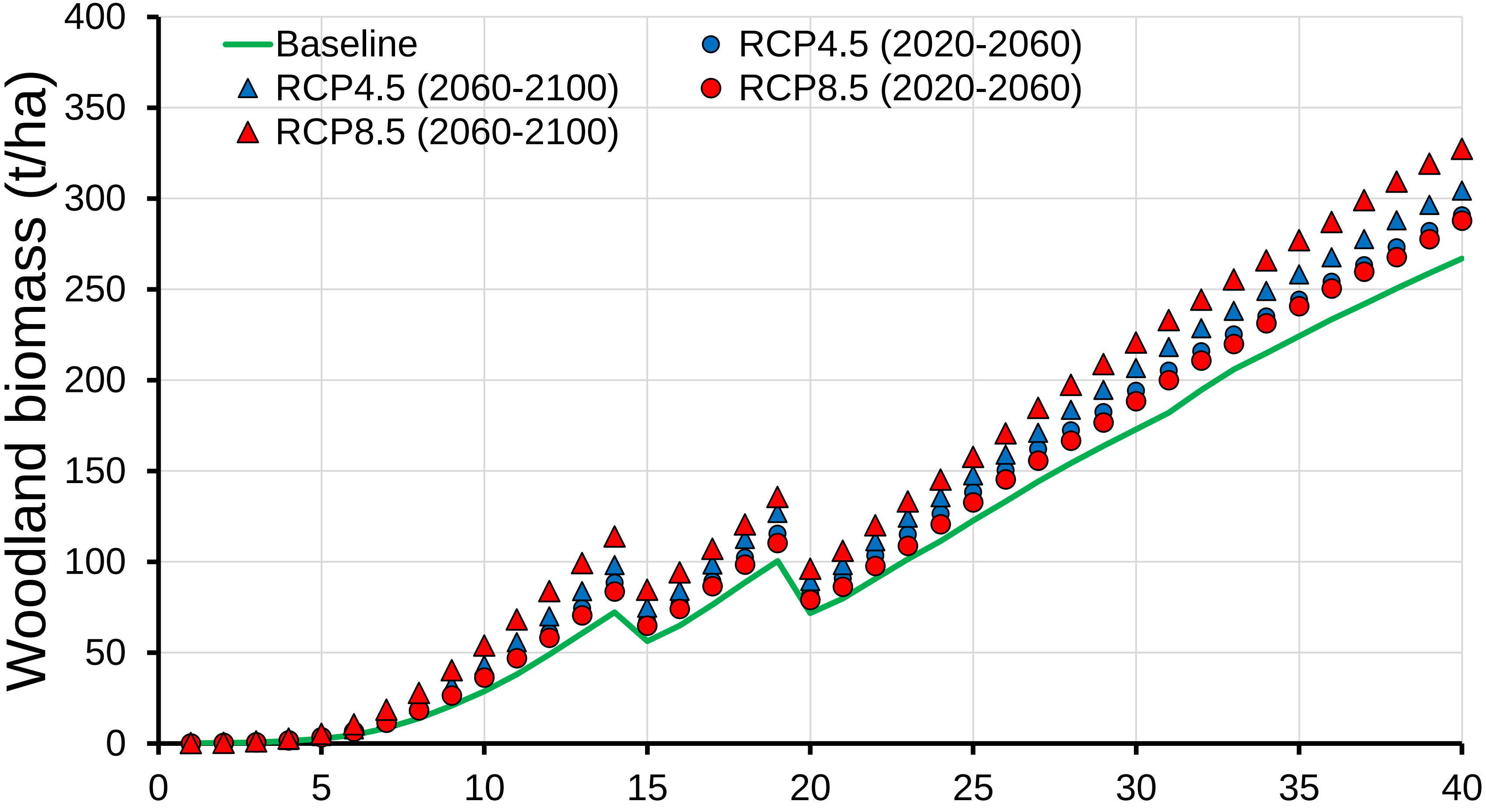
Ash woodland: predicted effect of temperature, rainfall and CO_2 change



Scenario	Stand biomass at 40 years (t/ha)
Baseline (1989-2029)	320
RCP 4.5 (2020-2060)	342
(2060-2100)	353
RCP 8.5 (2020-2060)	342
(2060-2100)	366

Elevated CO_2 predicted to increase tree biomass

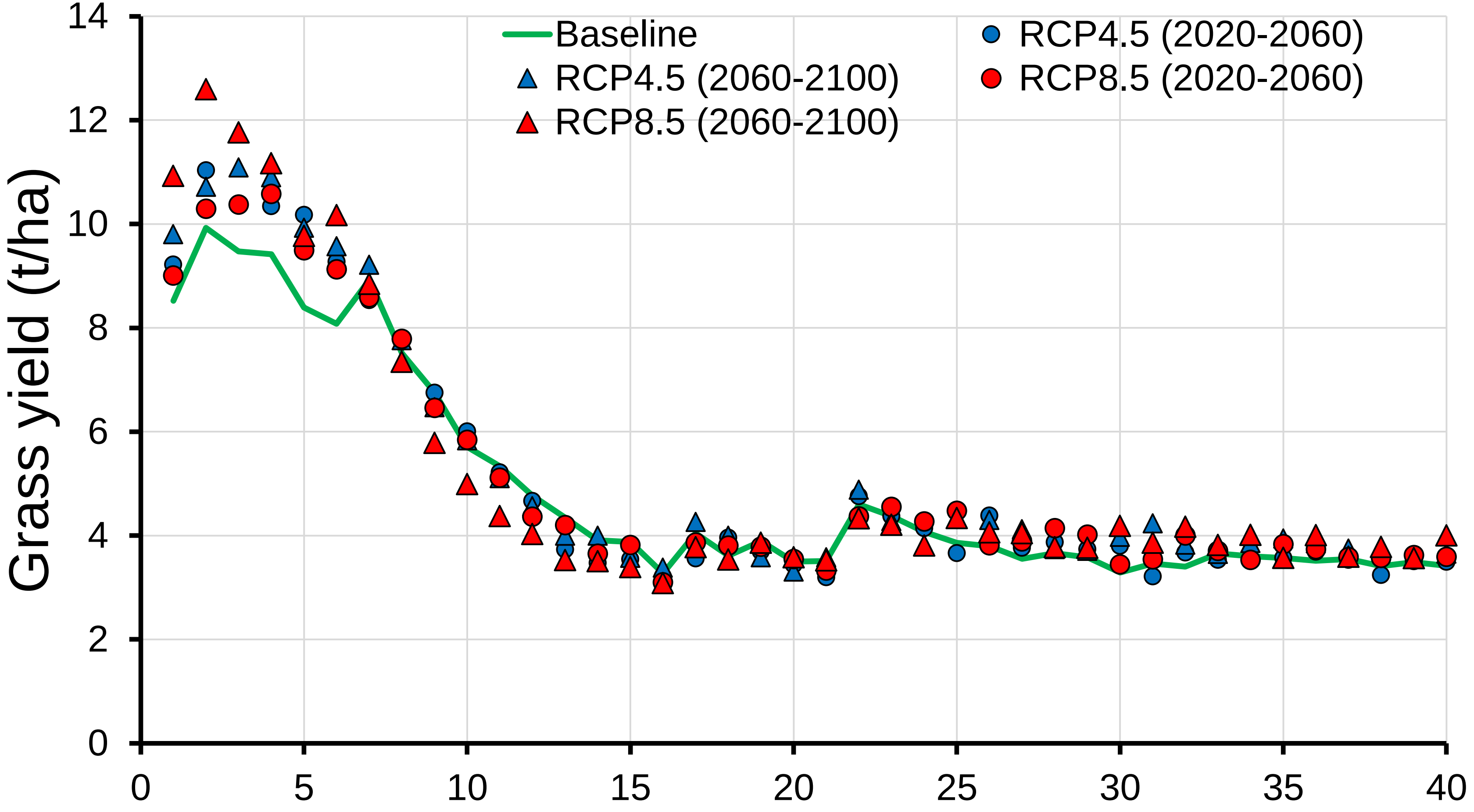
Ash silvopastoral: predicted effect of temperature, rainfall and CO_2 change



Scenario	Stand biomass at 40 years (t/ha)
Baseline (1989-2029)	267
RCP 4.5 (2020-2060)	291
(2060-2100)	304
RCP 8.5 (2020-2060)	288
(2060-2100)	327

Minimal predicted effect on woody biomass

Ash silvopastoral: predicted effect of temperature, rainfall and CO_2 change



Scenario	Mean grass yield over 40 years (t/ha/yr)
Baseline (1989-2029)	4.9
RCP 4.5 (2020-2060)	5.1
(2060-2100)	5.2
RCP 8.5 (2020-2060)	5.1
(2060-2100)	5.2

Minimal predicted effect on woody biomass

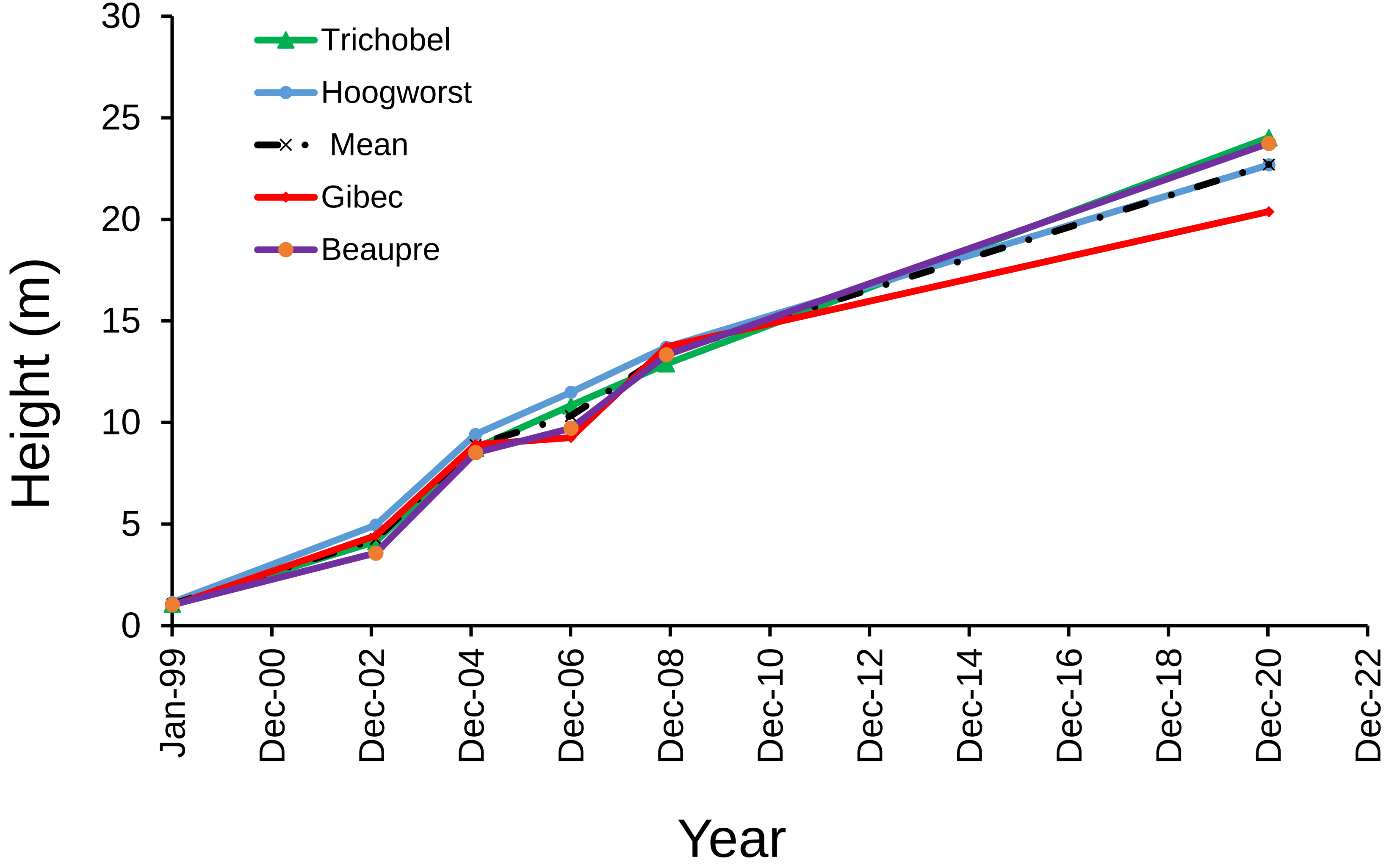
Effect on the Land Equivalent Ratio

Scenario	Monoculture grass yield over 40 yr (t/ha/yr)	Woodland biomass at 40 years (t/ha)	Silvopastoral grass yield over 40 yr (t/ha/yr)	Silvopastoral biomass at 40 years (t/ha)	Predicted Land Equivalent Ratio
Baseline (1989-2029)	10.3	320	4.9	267	1.31
RCP 4.5 (2020-2060)	11.1	342	5.1	291	1.31
(2060-2100)	11.6	353	5.2	304	1.31
RCP 8.5 (2020-2060)	10.9	342	5.1	288	1.31
(2060-2100)	12.6	366	5.2	327	1.31

Silvoarable experiment at Loughgall

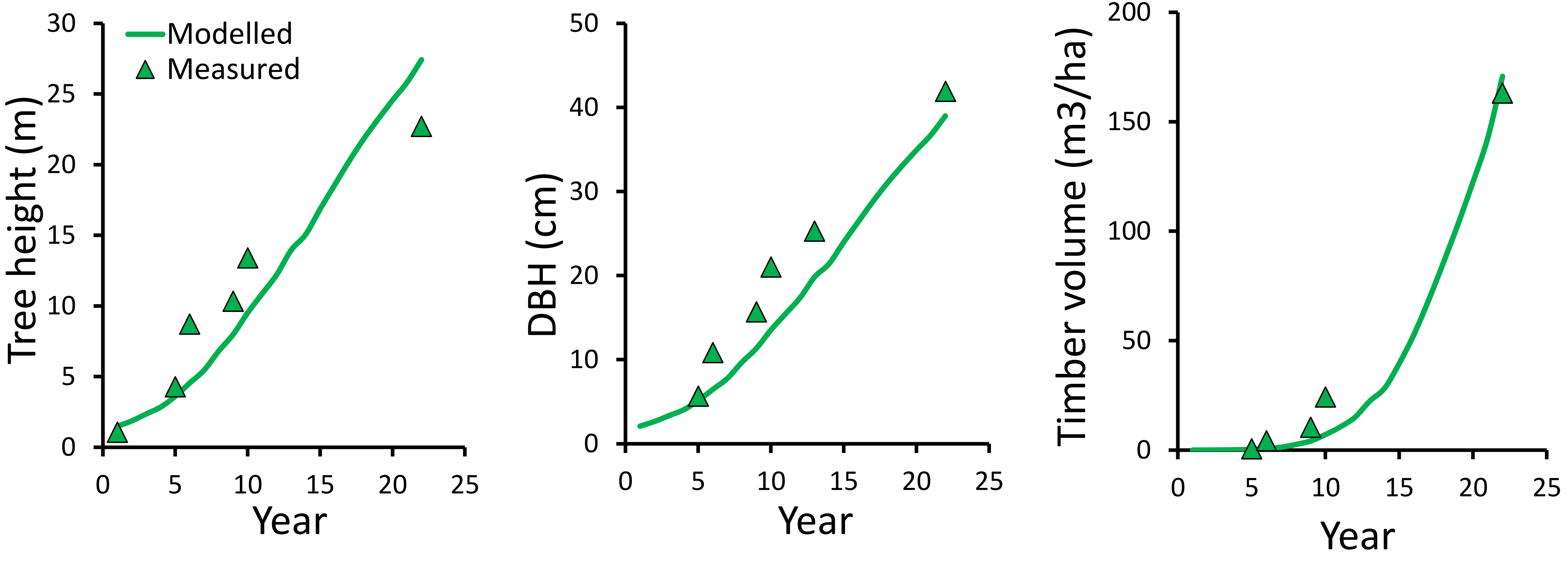
The poplar silvoarable system was planted in 1999 at a 5 m x 12 m spacing
(Photo from June 2007)

Measurements of tree height and diameter



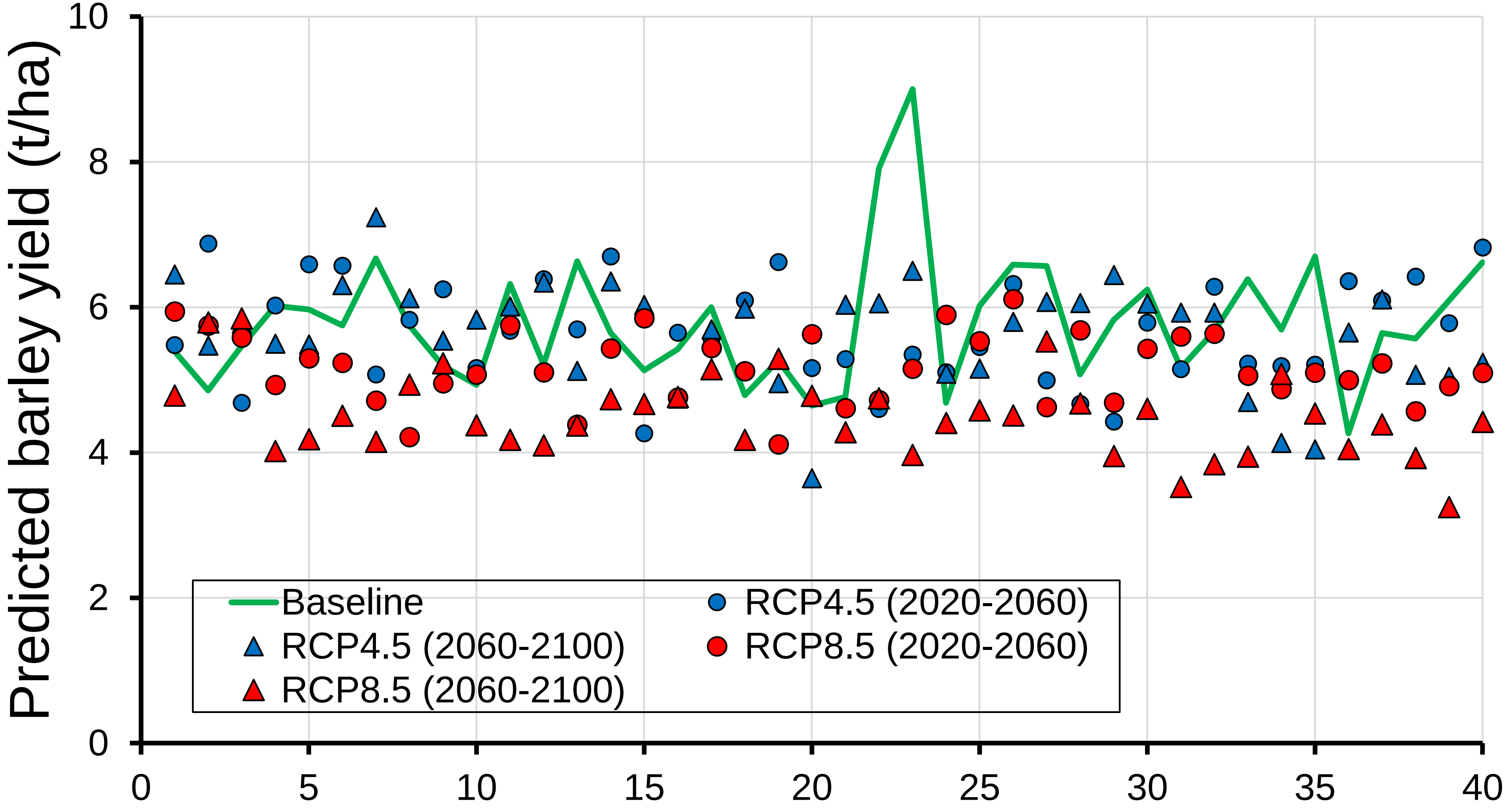
The heights of the poplars increased to a mean of 22.7 m in Jan 2021

Modelling silvoarable poplar growth with Yield-SAFE



Poplar height, diameter at breast height (DBH) and timber volume for a 22-years period following planting, as measured cultivars at Loughgall and as predicted by Yield-SAFE

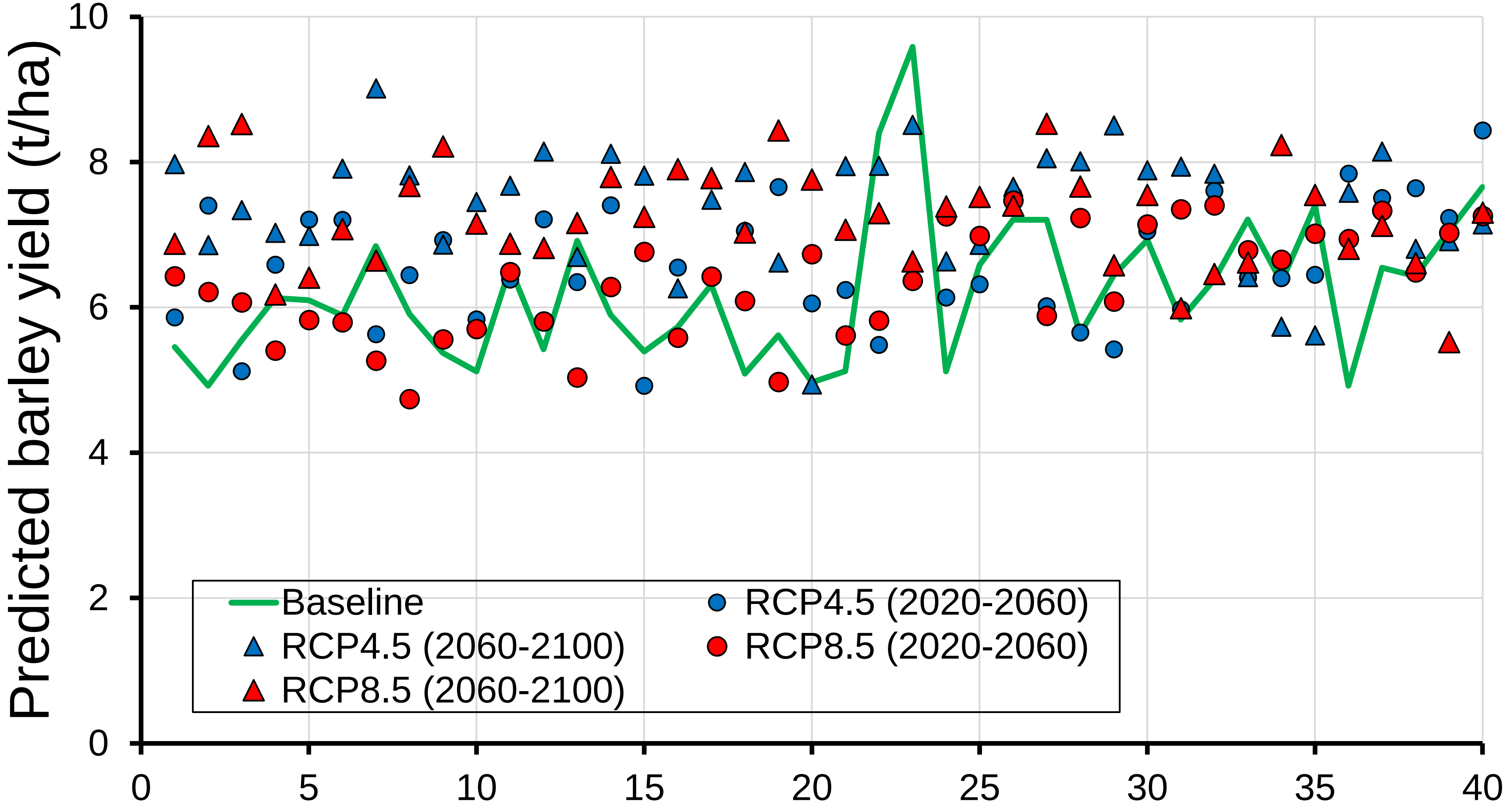
Barley: predicted effect of temperature and rainfall change



Scenario	Mean barley yield (t/ha)
Baseline (1999-2039)	5.8
RCP 4.5 (2020-2060)	5.7
(2060-2100)	5.6
RCP 8.5 (2020-2060)	5.2
(2060-2100)	4.5

Increased temperatures reducing barley yields

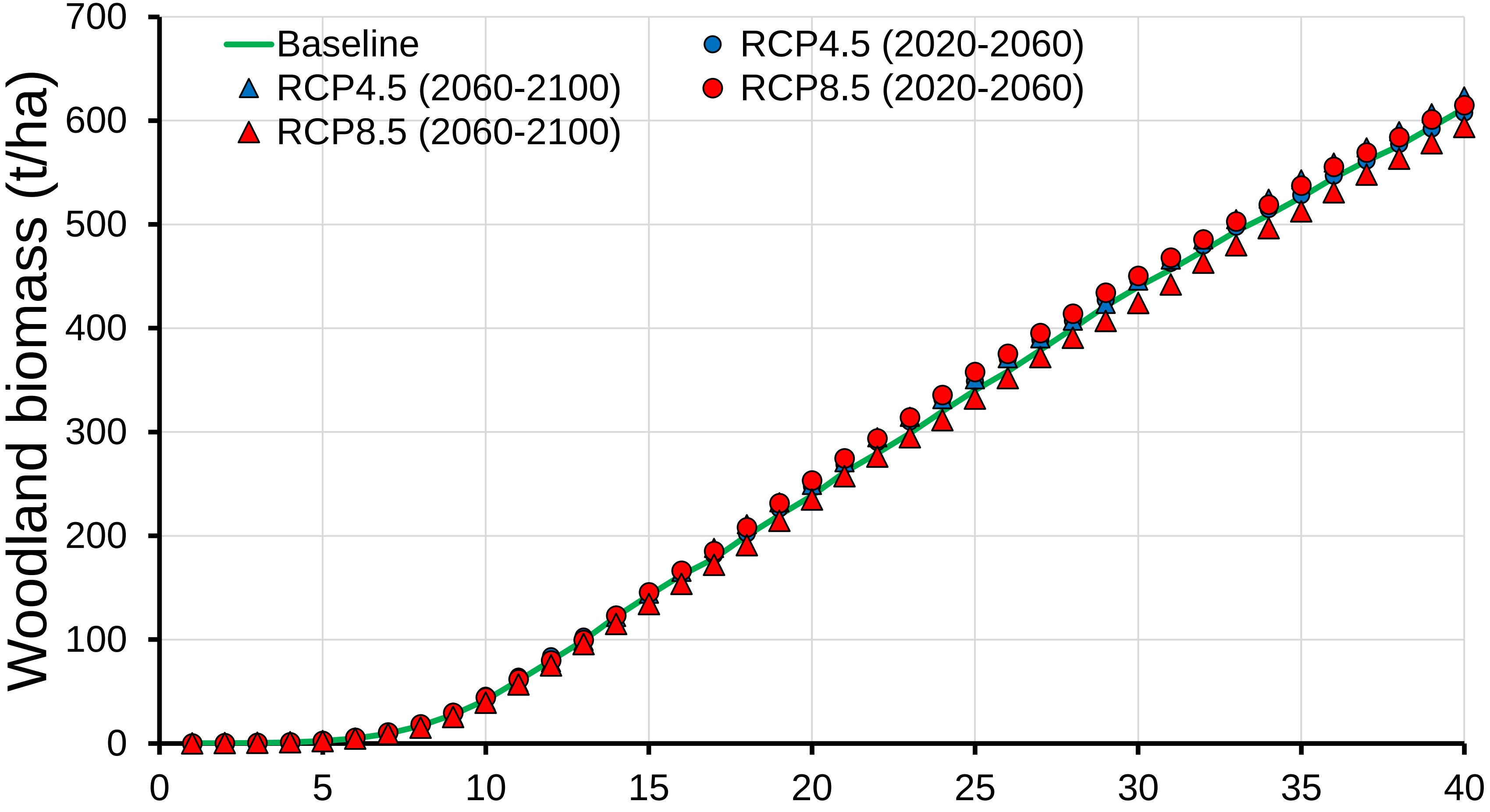
Barley: predicted effect of temperature, rainfall and CO_2 change



Scenario	Mean barley yield (t/ha)
Baseline (1999-2039)	6.2
RCP 4.5 (2020-2060)	6.6
(2060-2100)	7.4
RCP 8.5 (2020-2060)	6.3
(2060-2100)	7.2

Increased CO_2 predicted to more than offset the effect of temperature rise

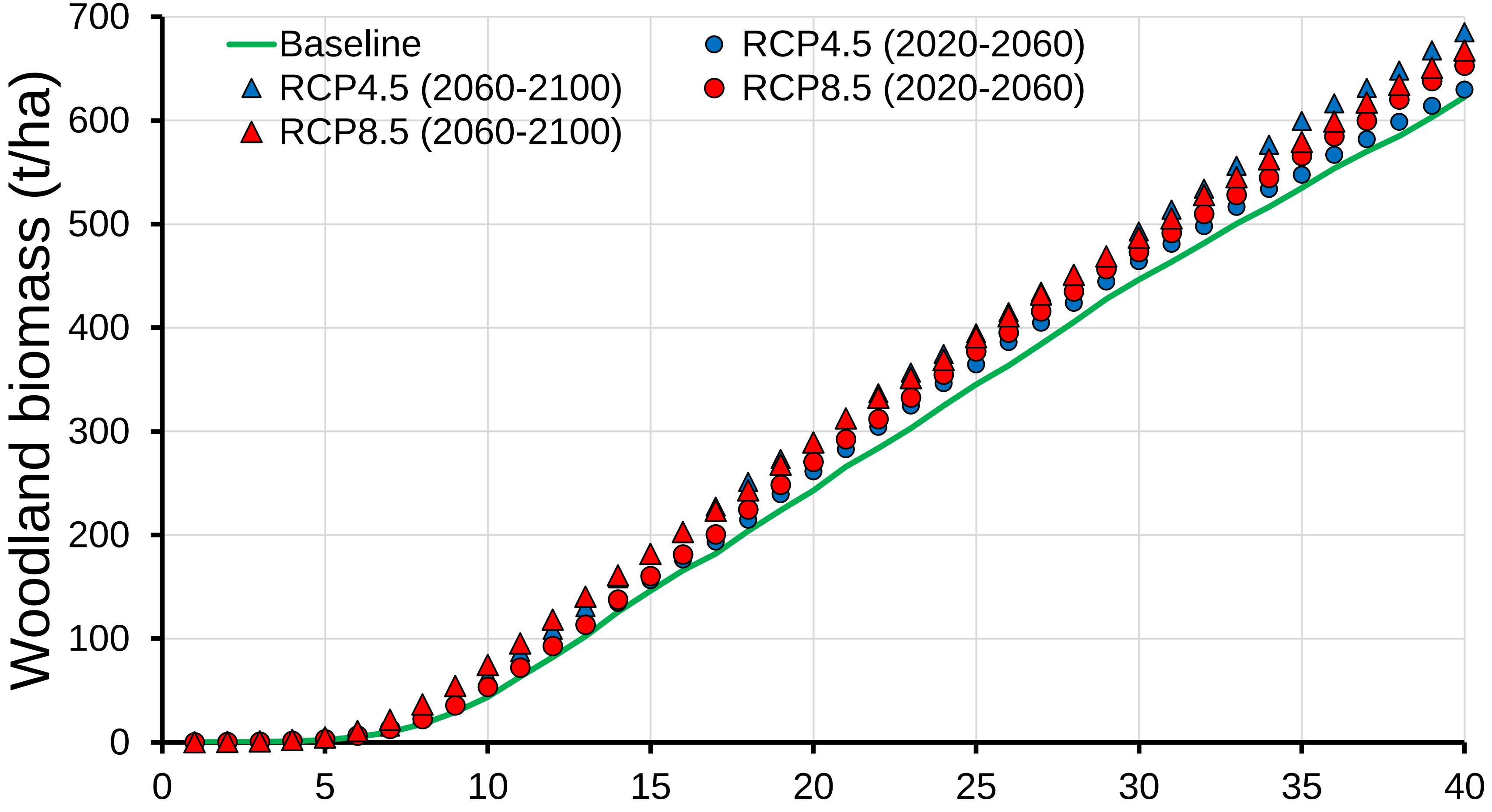
Poplar woodland: predicted effect of temperature and rainfall change



Scenario	Stand biomass at 40 years (t/ha)
Baseline (1989-2029)	612
RCP 4.5 (2020-2060)	608
(2060-2100)	623
RCP 8.5 (2020-2060)	615
(2060-2100)	594

Minimal predicted effect on woody biomass

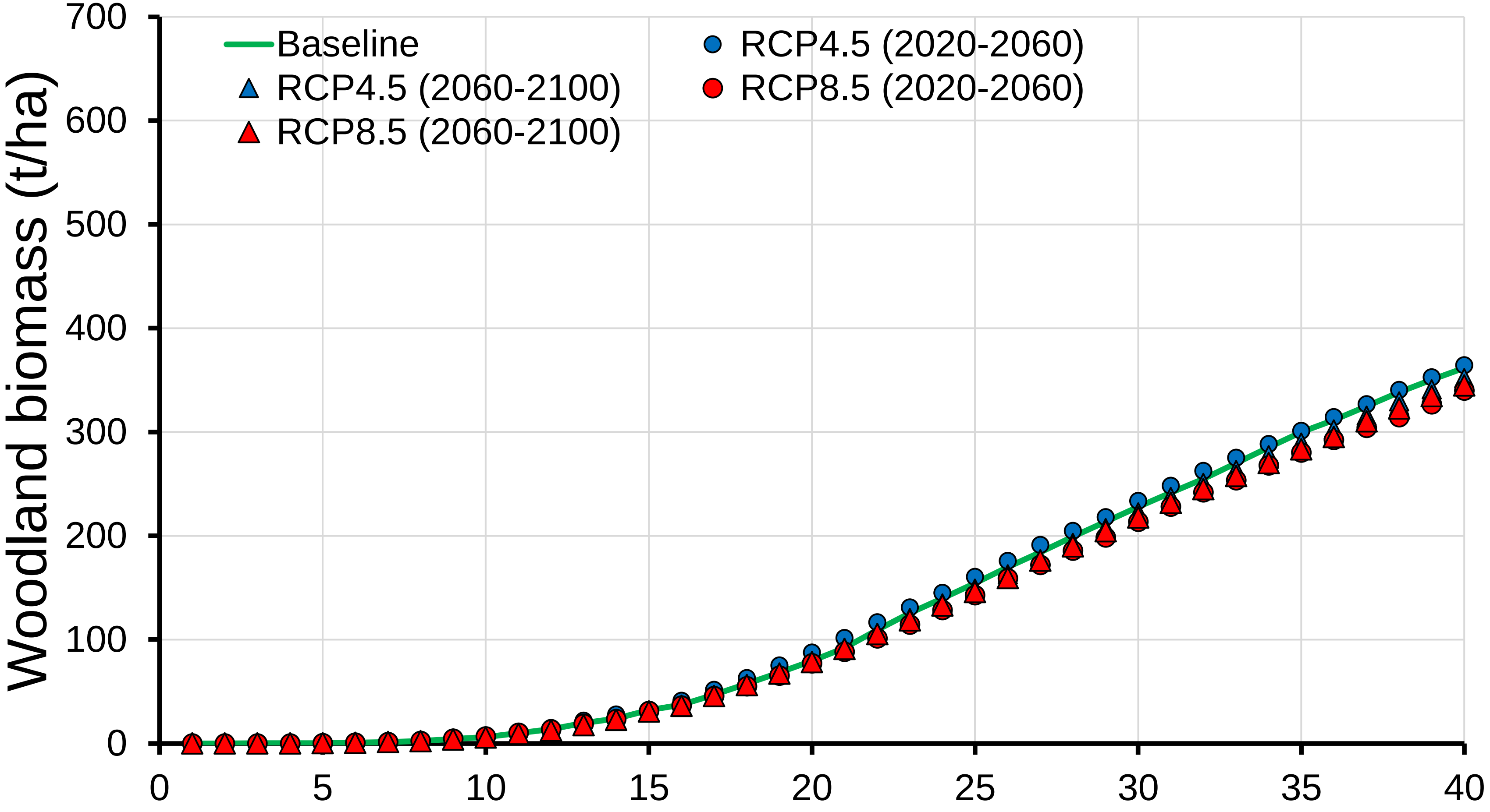
Poplar woodland: predicted effect of temperature, rainfall and CO_2 change



Scenario	Stand biomass at 40 years (t/ha)
Baseline (1999-2039)	622
RCP 4.5 (2020-2060)	630
(2060-2100)	685
RCP 8.5 (2020-2060)	653
(2060-2100)	668

Increased CO_2 elevated tree biomass accumulation

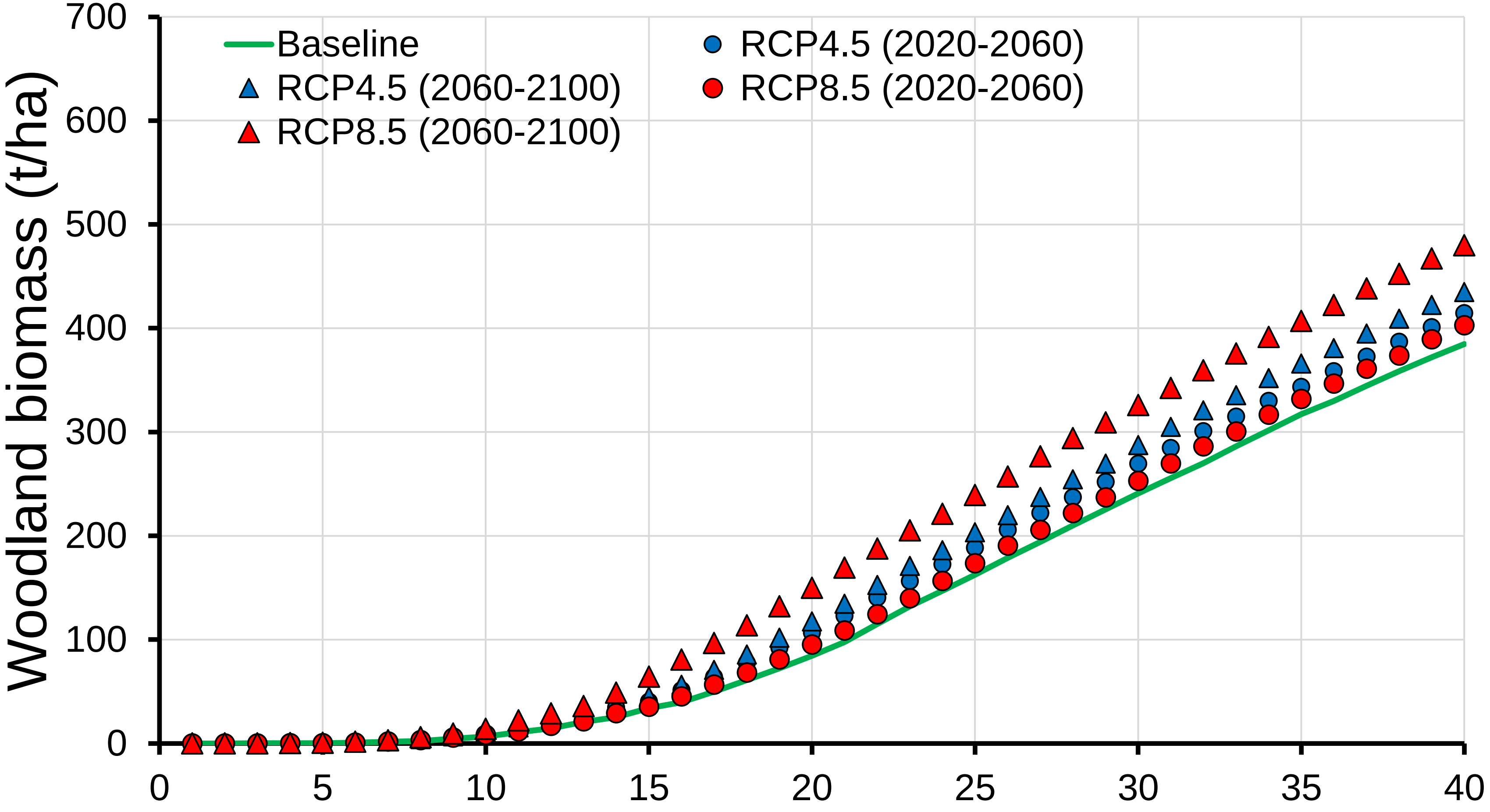
Poplar silvoarable: no CO_2 fertilization effect



Scenario		Stand biomass at 40 years (t/ha)
Baseline	**(1999-2039)**	362
RCP 4.5	**(2020-2060)**	365
	(2060-2100)	352
RCP 8.5	**(2020-2060)**	340
	(2060-2100)	345

Minimal predicted effect on woody biomass

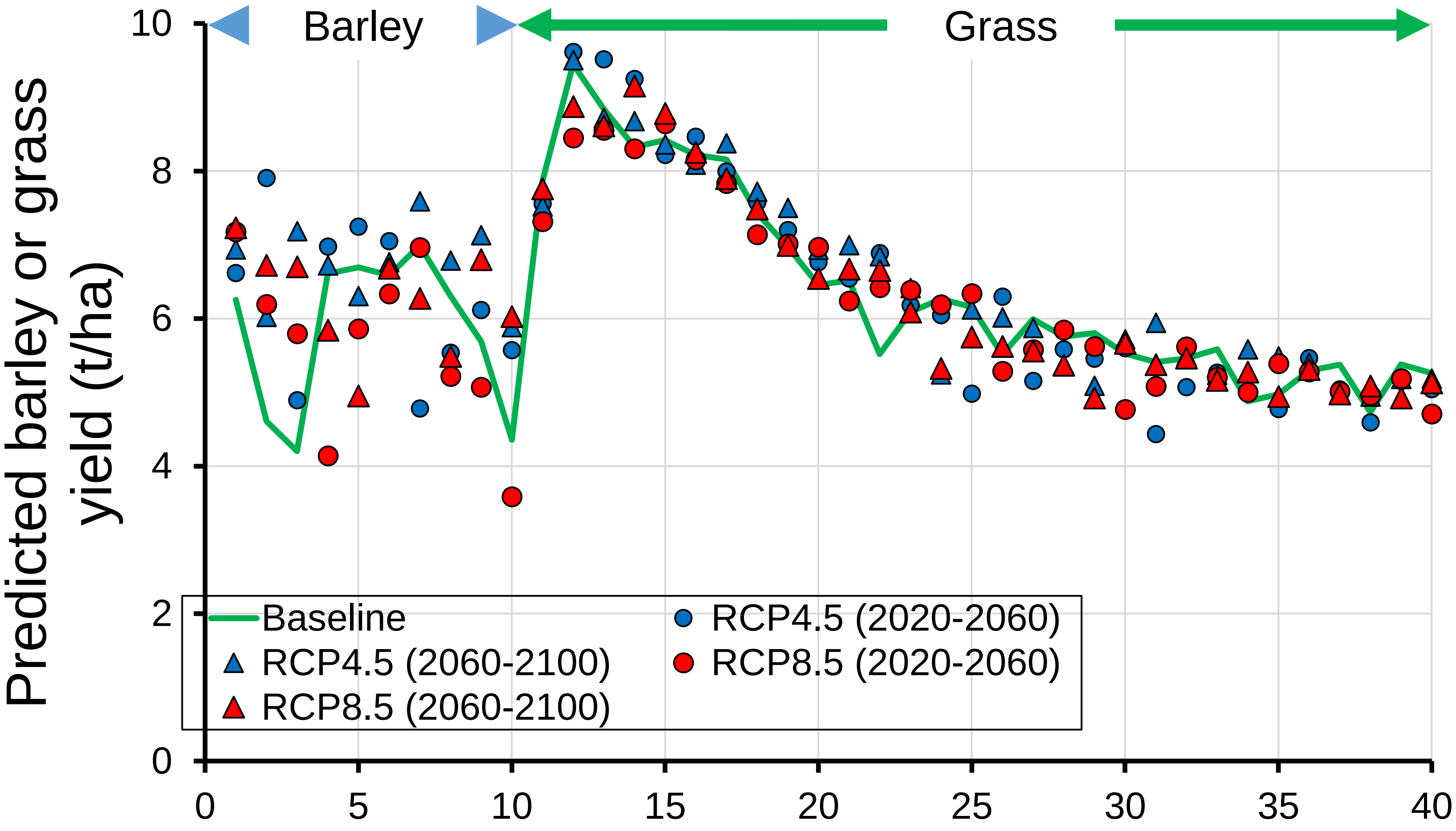
Poplar silvoarable: effect of temperature, rainfall and CO_2 change



Scenario	Stand biomass at 40 years (t/ha)
Baseline (1999-2039)	384
RCP 4.5 (2020-2060)	414
(2060-2100)	435
RCP 8.5 (2020-2060)	403
(2060-2100)	480

Large increase in woody biomass

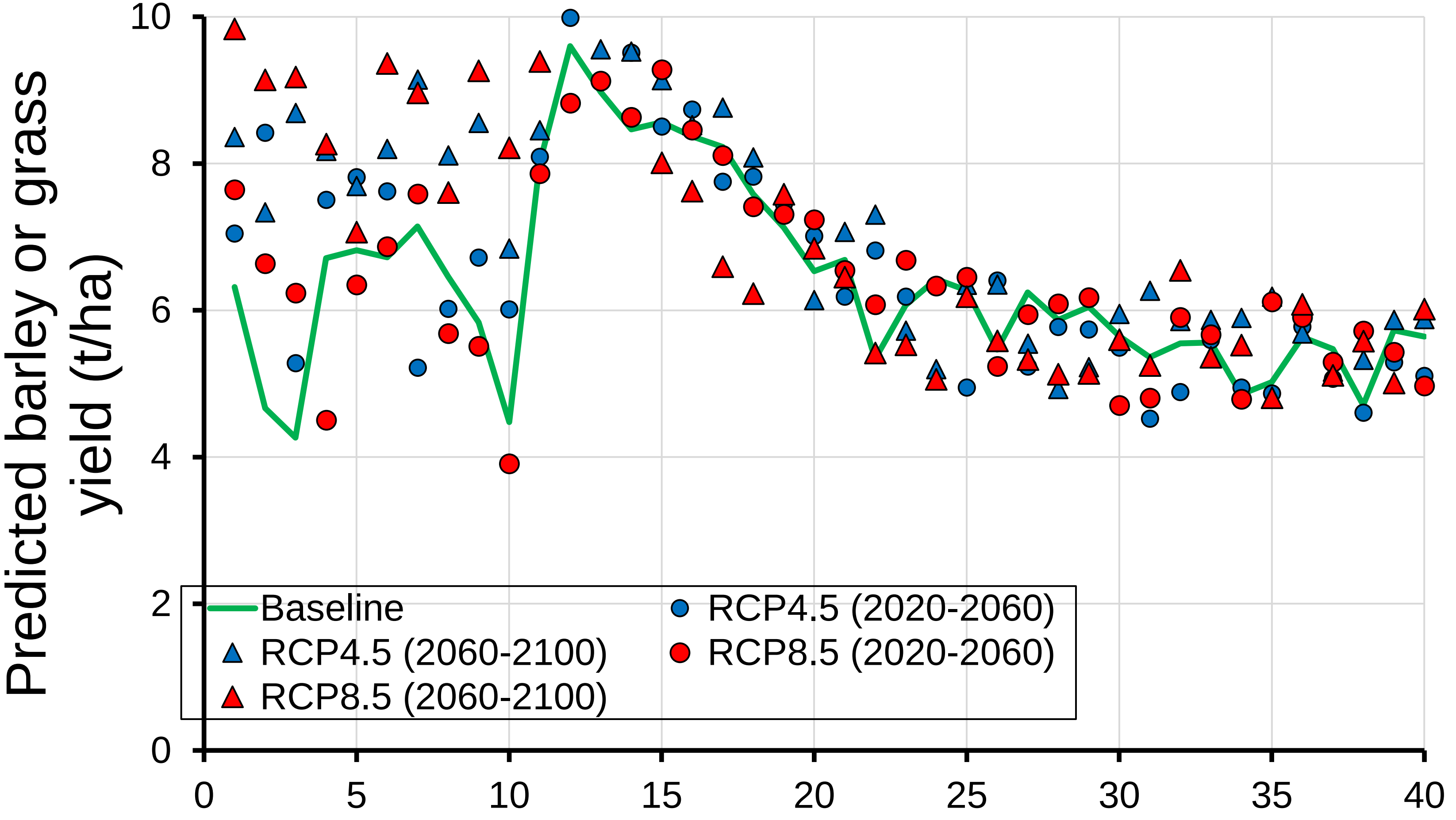
Silvoarable barley and grass: predicted effect of temperature and rainfall change



Scenario	Mean barley yield (t/ha)	Mean grass yield (t/ha)
Baseline (1999-2039)	5.8	6.4
RCP 4.5 (2020-2060)	6.3	6.4
(2060-2100)	6.7	6.5
RCP 8.5 (2020-2060)	5.6	6.3
(2060-2100)	6.3	6.3

Increased temperatures reducing barley yields

Silvoarable barley and grass: predicted effect of temperature, rainfall and CO_2 change



Scenario	Mean barley yield (t/ha)	Mean grass yield (t/ha)
Baseline (1999-2039)	5.9	6.5
RCP 4.5 (2020-2060)	6.8	6.5
(2060-2100)	8.1	6.8
RCP 8.5 (2020-2060)	6.1	6.6
(2060-2100)	8.7	6.5

Increased CO_2 increasing initial barley yields (year 1-10), but minimal effect on grass yields

Conclusions

- Measurements from mature field experiments at Loughgall allowed the calibration of an agroforestry model.
- Daily weather predictions for four climate scenarios were developed (up to +3°C and +4% annual rainfall)
- Predicted effect of higher temperatures and 4% additional rainfall on grass, tree, silvopastoral and silvoarable yields were minimal; higher temperatures were predicted to reduce barley yields (-2 to -23%).

Conclusions

- We also included the fertilising effect of increased carbon dioxide concentrations up to 800 ppm
- In the silvopastoral experiment, this was predicted to lead to increased grass production (+6-22%), woodland growth (+7-14%), silvopastoral tree growth (7-22%), and silvopastoral grass yields (+4-6%).
- The different climate assumptions did not affect the predicted land equivalent ratio of the silvopastoral system.
- In the silvoarable system, adding the CO_2 effect led to a predicted increase in monocrop barley yield (2-19%), poplar woodland growth (1-10%), poplar silvoarable growth (5-25%), but limited effect on grass understorey growth (1-5%).

Acknowledgements

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement 862993.

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