Research and Development Protocol for the Grazed Orchards in England and Wales Group

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Milestone	Milestone MS10 (3.3) Part of Experimental Protocol for WP3
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1 Context

The AGFORWARD research project (January 2014-December 2017), funded by the European Commission, is promoting agroforestry practices in Europe that will advance sustainable rural development. The project has four objectives:

1. to understand the context and extent of agroforestry in Europe,
2. to identify, develop and field-test innovations (through participatory research) to improve the benefits and viability of agroforestry systems in Europe,
3. to evaluate innovative agroforestry designs and practices at a field-, farm- and landscape scale, and
4. to promote the wider adoption of appropriate agroforestry systems in Europe through policy development and dissemination.

This report contributes to the second objective. It contributes to the initial research and development protocol (Milestone 3.3 (MS3.10)) for the participative research and development network focused on the use of agroforestry in high value tree systems.

2 Background

It is estimated from censuses that there are 25,350 ha of traditional orchards in the UK (Robertson et al., 2010), of which 24,600 ha are thought to be in England. Other estimates based on remote sensing suggest a figure for England of closer to 16,992 ha (Burrough et al. 2010), whilst a recent survey of commercial orchards (from census data – and including modern style orchards) indicated a total area of just 17,625 for England and Wales (DEFRA 2013).

Despite the lack of clarity on the total area, there is a consensus that the majority of systems occur in Western England, the South West, and the South East. The principal crop is apple (*Malus domestica*), although pears (*Pyrus communis*), plums, cherries and other fruit and nuts are also grown (Burrough et al. 2010; DEFRA 2013).

Whilst grazing of traditional orchards has long been a common practice in England (Hoare 1928), and continues to be practised in a considerable percentage of extant traditional orchards (Burrough et al. 2010), it is not common for more commercial cider 'bush' orchards to be grazed. Bush orchards are the dominant system used for cider apple production in the UK, with stocking density of about 650-750 trees ha^{-1}, inter-row spacing of about 3.5-4.5 m, and intra-row spacing of 2-2.5 m (Vylupek 2010; Durrant & Durrant 2009).(Corroyer 2014; Mcadam 2014)

Livestock incur costs and add additional complexity to the system, and an administrative burden, which is generally at odds with commercial scale cider production (Burgess 2014; Durrant and Durrant 2009; Corroyer 2014). However, these orchards can be mown about eight times a year, and may require herbicide application or plastic or organic mulches to control weeds, which have an additional expense, environmental impact, amongst other disadvantages (Durrant and Durrant 2009). Therefore, if the complexity and additional administrative burden can be overcome, there exist opportunities for using grazing as a tool to manage the grass understorey whilst providing grazing for sheep, and potentially other beneficial synergies. For example, it has been postulated by farmers that better control of apple scab might be achieved by grazing, since sheep will eat apple

leaves immediately as they fall to the ground, and help to decompose old leaves by trampling, thus reducing harbourage for the organism responsible (Corroyer 2014; McAdam 2014).

This trial is being conducted in association with a Soil Association Field Lab. Field labs aim to put farmers at the heart of agricultural research, by helping farmers to develop their own field trials on issues which they consider to be of interest. In the present case, researchers from the Soil Association and Cranfield University are providing technical support to a farmer-led trial.

Meetings of the 'Grazed Orchards in England and Wales' stakeholder group were held on 9 June 2014 and 17 September 2014, at which it was decided that a key area of interest was the use of the Shropshire sheep breed to graze orchards, as they are considered to be 'tree-safe' .

At the September meeting, one of the participants agreed to conduct a trial on an orchard which he has access to in Peterstow in Herefordshire. A field visit was made to the site on 13 October 2014, and measurement variables and an experimental procedure agreed upon.

3 Objective of trial

The aim of the trial is to produce quantitative information about the use of Shropshire sheep to graze bush orchards (as opposed to traditional orchards where grazing is more routine) in comparison to normal management and mechanical mowing.

Key questions include:

- What are the financial and labour impacts of grazing?
- Is there any damage to trees caused either by mechanical mowing or grazing?
- What is the impact of grazing on the bottom of tree canopies?
- What is the impact of grazing in the orchard on weight and condition of sheep?
- Develop a better understanding of the constraints imposed in normal orchard operations, such as spraying, of grazing with sheep.
- Is grazing a problem for the fruit quality, do the animals or competition with weeds impact fruit yield?
- Is it better to graze for a short period with lots of animals, or for a longer period with fewer animals?

Alongside these questions, a number of hypotheses can be developed:

- Savings will be made on the cost of mowing as a result of the introduction of sheep into the orchards, although these may be offset by the additional labour related costs associated with handling the sheep.
- The sheep will browse the lower branches of the trees, thereby raising the lower limit of the canopy. This damage will be light.
- Sheep live weight gain will be similar to the live weight gain expected on a similar area of pure pasture for a similar time period.

4 System description

The trial will take place in a 3.9 ha bush orchard located at Broome Farm, Peterstow in Herefordshire (Figures 1 and 2). The orchard is composed of rows of 'Harry Master' variety apples (*Malus domestica*) orientated predominantly NW to SE (highlighted green in Figure 3).

Trees in the orchard are at least 10 years old and approximately 4.5-6.0 m in height. At present the bottom of the canopy is about 0.6 cm from the ground, but the intention is to raise the canopy of trees to about 1.2 m prior to commencing the trial (if so, this may be out of reach of the sheep). The field is well fenced to the north, east, and south, while fencing to the west will need to be installed for the duration of the trial. The grass sward is an old 'reseed' suitable for sheep, whilst a water trough will be accessible to the sheep. Further details are given in Table 1.

Figure 1. Looking South-East along the tree rows (13 October 2014).

Figure 2. Windfalls being harvesting mechanically (13 October 2014).

Table 1. Description of the site, with soil, tree, understorey, livestock, and climate characteristics.

Site characteristics	
Area (ha):	3.9
Co-ordinates (lon./lat.):	51°55'16.8'' N 2°37'32.3''W (51.921343, -2.625647)
Site contact:	Tobias Lovell
Site contact email address	lovelltobias@gmail.com

Soil characteristics	
Soil type (WRB classification)	Eutric Chromic Endoleptic Cambisol
Soil depth	>120 cm
Soil texture (sand%, silt%, clay%)	Loamy (TBC)
Additional soil characteristics	Soils are of the Eardiston 1 (541c) series (NSRI 2015), described as: 'Well drained reddish coarse loamy soils over sandstone, shallow in places especially on brows'.
Aspect	South-East

Tree characteristics		
System	Agroforestry system	Reference system*
Tree species	Apple (*Malus domestica*)	Apple (*Malus domestica*)
Variety/rootstock	'Harry Master'	'Harry Master'
Tree density (spacing)	TBC	TBC
Tree protection	None	None
Additional details		

Understorey characteristics		
System	Agroforestry system	Reference system*
Species	Grass	Grass
Coverage	Complete	Complete
Additional details	Grass managed by grazing with Shropshire sheep.	Grass managed by mowing and herbicide application.

Livestock characteristics		
System	Agroforestry system	Reference system*
Species	Shropshire sheep	none
Stocking density	20 ewes (5 ha^{-1})	

Climate data	
Mean monthly temperature	10.22 (± 4.51 SD) °C
Mean annual precipitation	629 (± 181 SD) mm
Additional details (e.g. spring frost risk)	TBC
Details of weather station (and data)	Data from 01/01/1960-31/12/1989) from a number of UK Meteorological Office MIDAS (2015) stations: see Appendix B.
**Agreement with Ensembles data?	Sources: KNMI_A1B and A1B_Had Hadley predictions have a better fit. See appendix B.

* To which the agroforestry system is compared

** Does the ENSEMBLES climate data (http://www.ensembles-eu.org/) look to be a good fit for actual data? Accessible as csv here.

Trial design

4.1 Conceptual design

The design involves two treatments (Table 2), and the measurements are described in Section 5.

Table 2. Description of the two treatments

Treatment A	Treatment B
Conventional orchard management with the usual mixture of mowing and herbicide spraying to keep down the grass understory	Grazed with Shropshire sheep

4.2 Description of design

A map of the Broome farm site is shown in Figure 3. The 3.9 ha block will be divided into roughly equal plots of c. 2 ha each with electric fencing. The division will be made along the line of the trees (i.e. NW to SE). A different treatment will be applied to each of the plots; the first treatment will follow conventional orchard management with the usual mixture of mowing and herbicide spraying to keep down the grass understory. The second treatment will be grazed with Shropshire sheep. This is likely to be with up to 20 ewes or replacement ewe lambs over winter. A second possible period would be in early summer following any spraying until 56 days before the predicted harvest. This would likely be with ewes and lambs.

Figure 3. Distribution of traditional orchards in England (inset, Burrough et al., 2010) with current site marked with red crosshair. Map of the Broome Farm site. Red lines indicate rows of apple trees in bush orchards, green dots represent individual apple trees in traditional orchards. The orchard on which experimental measurements are based has been highlighted in green. © Crown Copyright and Database Right 2014. Ordnance Survey.

5 Measurements

The planned measurements to be taken in the two treatments are described in Table 3.

5.1 Measuring bottom height of tree canopy

- 30 sample trees selected on a 'W' walk through each experimental plot.
- The distance from the lowest point of the branch to the bottom of the grass sward is measured for each tree in cm.
- Five measurements are to be taken per tree, and these values averaged.
- Sampling to be completed before and after sheep are introduced in treatment 2, and at the start of the trial in treatment 1.

5.2 Recording tree damage by sheep

- Photographs of any damage to be taken.
- The extent of any damage recorded on a 1-5 scale:
  1. Leaf and bud browsing
  2. Light branch grazing
  3. Small end branches broken
  4. Small areas of trunk grazed (<30 mm radius)
  5. Large areas of trunk grazing (>30 mm radius and torn branches).
- The sward condition at the location of any tree damage should also be recorded, preferably with a photo.

Example recording sheets are included as an appendix to this document.

Table 3. List of measurements to be taken in the two treatments

Treatment	Sheep grazing	No sheep
Measurements	Bottom height of tree canopy. Date of sheep introduction and removal, and numbers. Weight and condition of sheep on entry and exit from the orchard. Photographic record of grass sward on entry and leaving the orchard. A record of dates, quantity, and type of minerals. Labour time spent on fencing and sheep work. Tree damage caused by sheep with photographs of damage.	Bottom height of tree canopy. Dates of any field operations, e.g. topping, spraying, mowing, etc. Photographic record of grass sward at same time as entry and leaving the grazing orchard. A record of dates, quantity, and type of minerals. Cost of sprays used, cost of pruning Tree damage from machinery operations.

6 Biophysical modelling

The second part of this protocol describes attempts to model the system using the YieldSAFE biophysical model. The YieldSAFE model has been parameterised for cider orchards previously during an MSc thesis by Oldrich Vylupek (Vylupek 2010). Tree data from nine orchards owned by Heineken UK were collected, and used to parameterise the model which could be used to predict apple yield.

Whilst Vylupek (2010) was successful in modelling apple tree yield, no attempt was made to parameterise growth in a grass understorey. Hence the present modelling component will have two objectives:

- Validation of the existing apple growth model (Vylupek 2010) and additional calibration as required.
- Parameterisation/calibration of the understorey component.

In the former case, it may be necessary to collect additional measurements of tree height, diameter, crown dimensions, and apple yield as only four of the nine sites sampled by Vylupek were planted at the necessary density to be considered true 'Bush' orchards as defined by Durrant and Durrant (2009). In addition, the data collected by Vylupek was predominantly from orchards younger than ten years, or older than twenty five years. No information was recorded for trees in between these ages, hence it would be worthwhile to collect additional data to fill this gap.

Some of this information may be available from records or new measurements taken at the Loughall experimental orchards in Northern Ireland, in association with the Grazed Orchards in Northern Ireland Group. The table below summarises measurements which may be required/could be used to improve the current parameterisation/calibration of YieldSAFE.

Table 4. Possible measurements to improve current parameterisation of the YieldSAFE model.

Measurement	Method
Height Diameter at breast height (D_{bh}), diameter above graft (D_{40}) Crown dimensions	Physical measurement of trees 10 < years < 25 at field sites in Herefordshire and/or Northern Ireland, and at appropriate planting density: 650-750 trees ha^{-1}, inter-row spacing of about 3.5-4.5 m, and intra-row spacing of 2-2.5 m (Vylupek 2010; Durrant & Durrant 2009).
Apple yield	Physical counts, calculation based on total yield and tree density.
Aboveground biomass	Destructive sampling, and moisture content of a subsample of different tissues.
Maximum leaf area	Destructive sampling/defoliation: determination of total wet leaf mass, and leaf area, and moisture content of a sub-sample.
Wood density	Destructive sampling or measurements of prunings. This is not a priority as the existing measurments are derived from a number of sources, but is simple to measure if destructive sampling is completed.
Proportion of shoots removed per prune	Currently this was estimated, but the value may be better informed by expert judgement/measurement from prunings.

In the latter case, it is recognised that the present treatment of perennial grass is simplistic, as YieldSAFE essentially considers it to be an annual crop with a long rotation; hence growth broadly follows patterns of annual solar radiation receipt. In reality, due to winter storage of carbohydrate in roots, grass growth exhibits a strong early flush and follows a pattern closer to Figure 4 (Corrall et al. 1990).

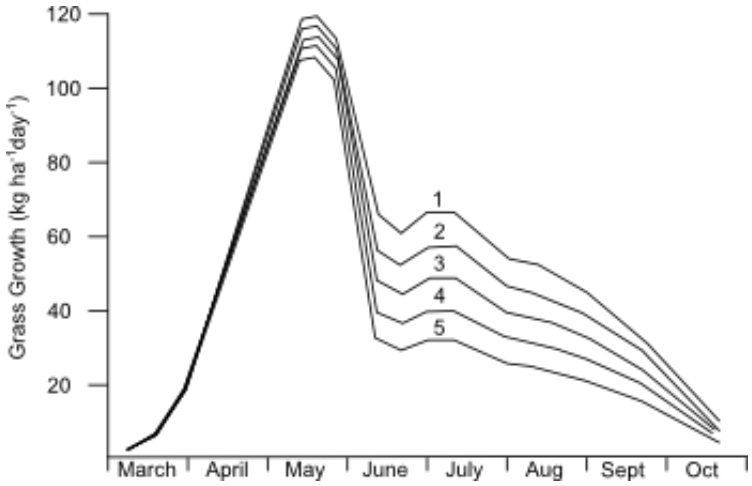

Figure 4. Seasonal pattern of dry matter production from a perennial ryegrass sward at five site class, reproduced from Corrall et al. (1990).

Since this bimodal pattern of grass growth may have interesting interactions with tree growth, and implications for grazing, the YieldSAFE model may be improved by taking it into account. Therefore, data (probably from existing sources) will be required to define additional parameters (if required) and to calibrate the grass model.

7 Acknowledgements

The AGFORWARD project (Grant Agreement N° 613520) is co-funded by the European Commission, Directorate General for Research & Innovation, within the 7th Framework Programme of RTD, Theme 2 - Biotechnologies, Agriculture & Food. 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. We acknowledge the support of the Soil Association and the Bulmer Foundation in organising the meetings.

8 References

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Appendix A. Example recording sheets

Table A.1. Tree canopy recording

	Bottom heights in centimetres					
Tree number	1	2	3	4	5	Average
1.						
2.						
3. etc						

Table A.2 Sheep weight

Date in	Number of sheep	Sheep type*	Average weight	Average condition score	Date Out	Number of sheep	Sheep type	Av weight	Av condition score

*ewe, lamb, ewe lamb, in-lamb ewe, ewes with lambs at foot

Table A.3. Field operations

Date	Type of operation*	Inputs used~	Cost of inputs	Time taken

*Topping, spraying, etc ~sprays, lime, etc

Table A.4. Minerals

Mineral type/description	Date	Quantity

Table A.5. Labour

Date	Job description	Time taken

Table A.6. Tree damage

Date	Treatment 1 or 2	Short Description	Damage scale 1-5

Appendix B. Climatic data

Obtaining appropriate climatic data from comparison with the ENSEMBLES predictions was somewhat challenging since the many local weather stations tend to have incomplete or spurious records. All Climatic data were obtained from UK Meteorological Office (2014). The available local climatic data are presented in Figure B1, B2, and B3.

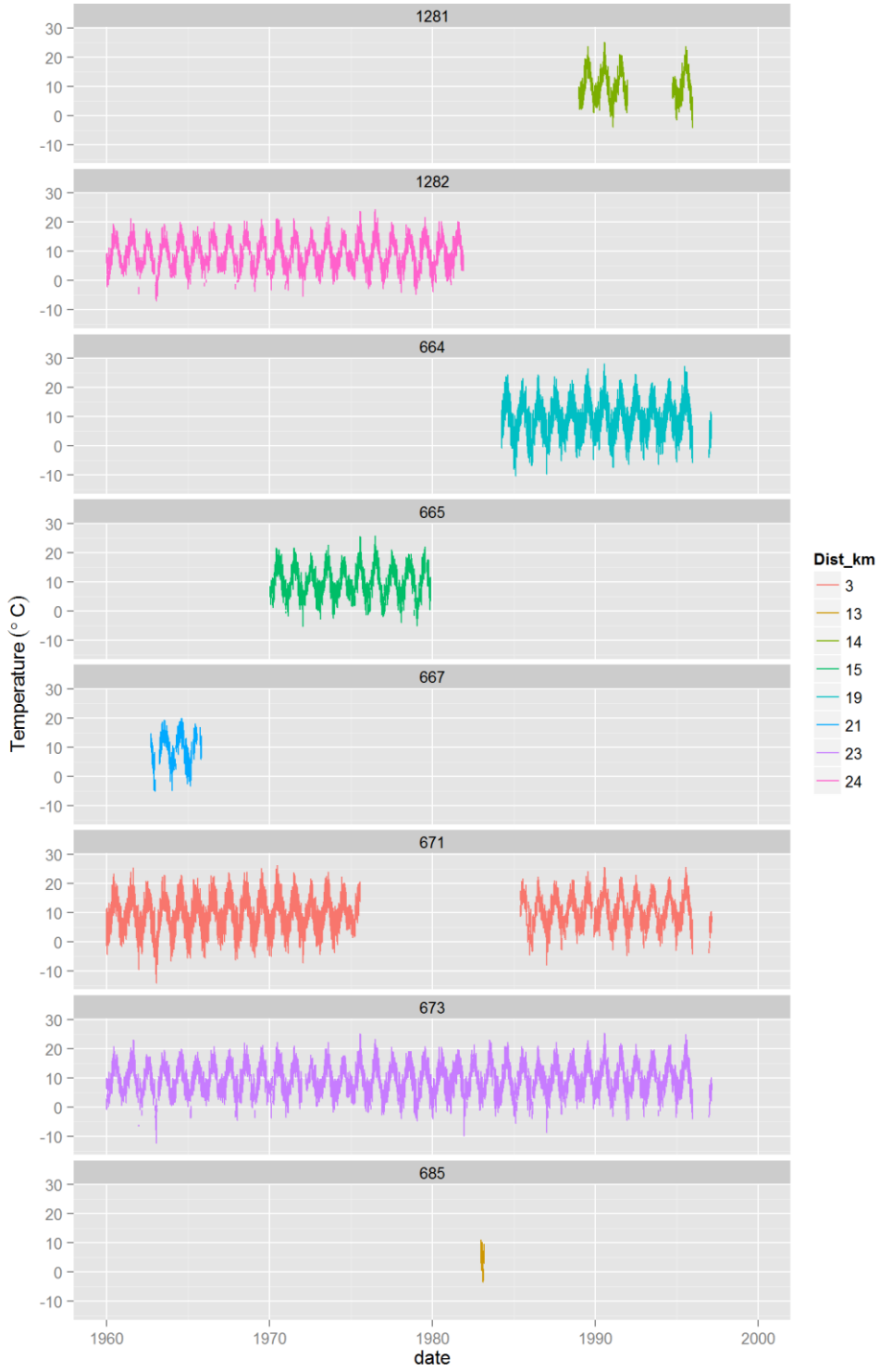

Figure B1. Temperature data from MIDAS stations within a 30 km radius of the trial site (UK Meteorological Office, 2015).

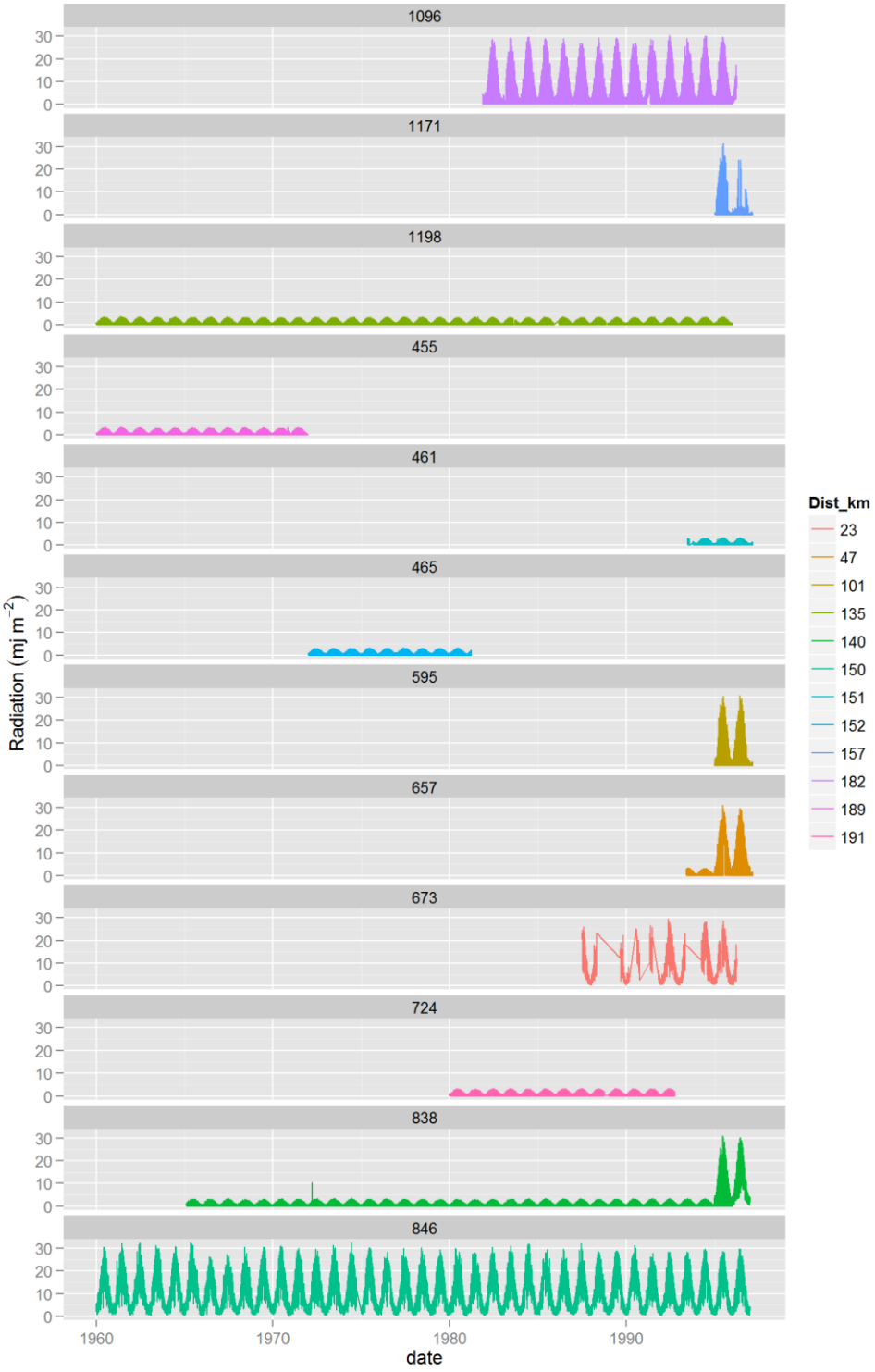

Figure B2. Solar radiation receipt data from MIDAS weather stations within a 200 km radius of the trial site (UK Meteorological Office, 2015).

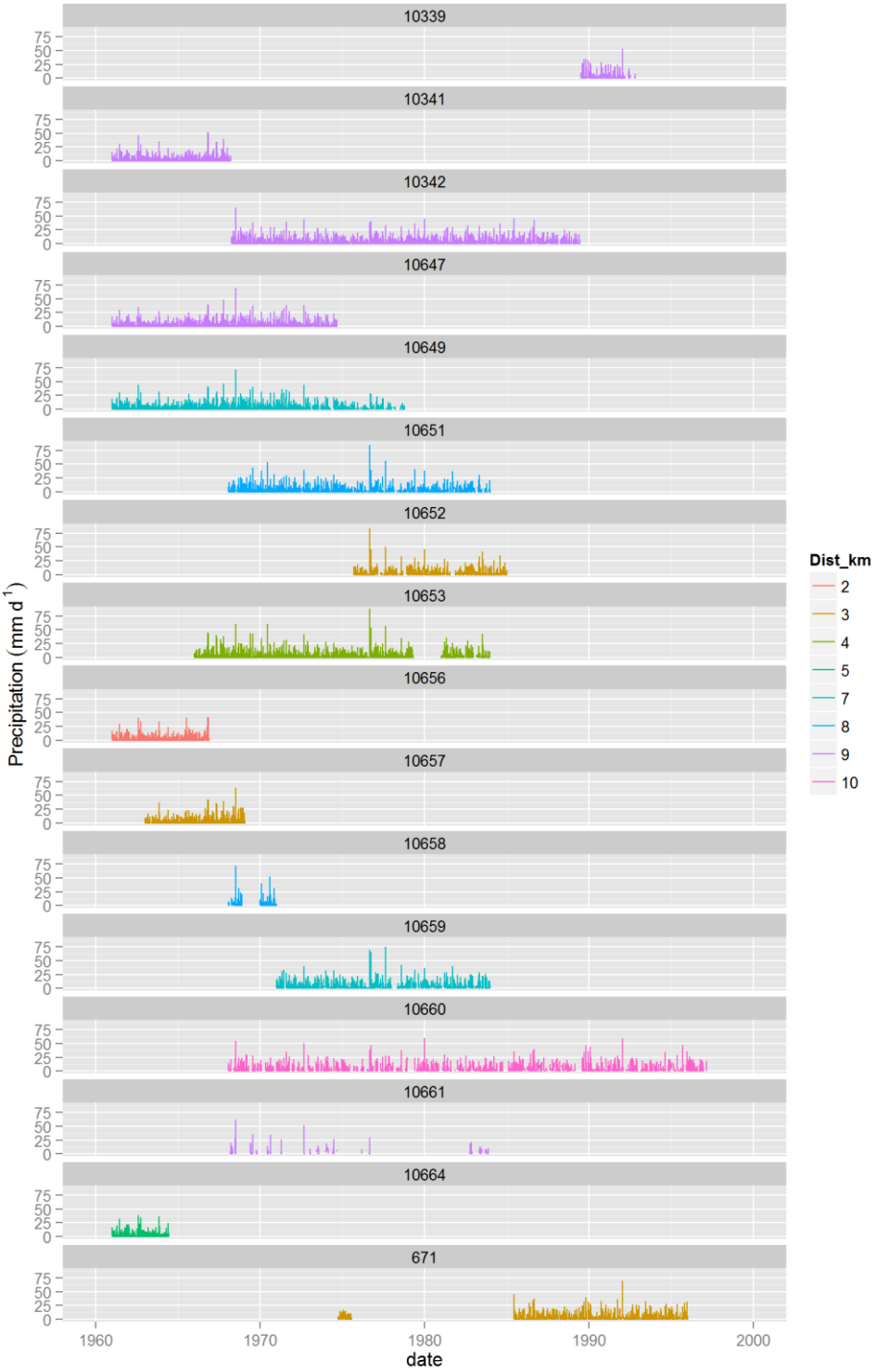

Figure B3: Precipitation data from MIDAS stations within a 10 km radius of the trial site (UK Meteorological Office 2015).

Finally, measurements were chosen from the longest contiguous records for temperature: station 673, solar radiation: station 846, and rainfall: station 10660. Note that station 846 was 140 km distant from the field site, hence any comparisons should be considered carefully. This was however the nearest continuous solar radiation measurement that was available across the UK (Table B1).

Table B1. Summary of the weather stations

	Precipitation	Temperature	Solar Radiation
src id	10660	673	846
Name	Carwendy: Tomlinsfield Farm	Preston Wynne	Everton
Area	Hereford & Worcester	Hereford and Worcester	Hampshire
Area type	County	County	County
start date	01/01/1967	01/01/1950	01/01/1953
end date	01/10/2000	21/08/2008	01/10/2003
Latitude	51.9197	52.1242	50.7416
Longitude	-2.76491	-2.63674	-1.57365
Postcode	HR2 8	HR1 3	SO41 0
Dist km	9.58	22.51	149.62

Comparisons between the actual weather data and predicted weather data for the periods 1960-1990 (1970-1990) for rainfall are presented in Figures B4-B6.

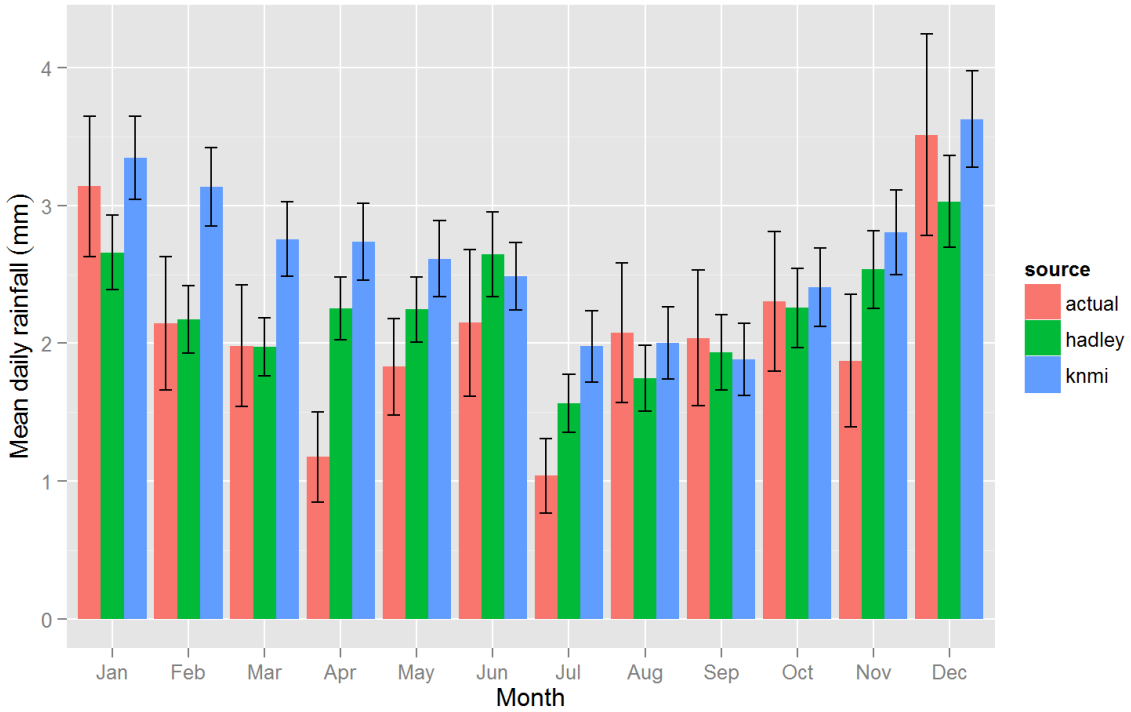

Figure B.4. Comparison of mean daily rainfall (1970-1990) by month from the Tomlinsfield Farm weather station, and the "had" and "knmi" predictions from the ENSEMBLES project. Note that mean daily rainfall was used in this instance due to the large number of missing values which would prejudice a monthly sum. Error bars represent 95% confidence intervals, and show the variation between the years 1970-1990.

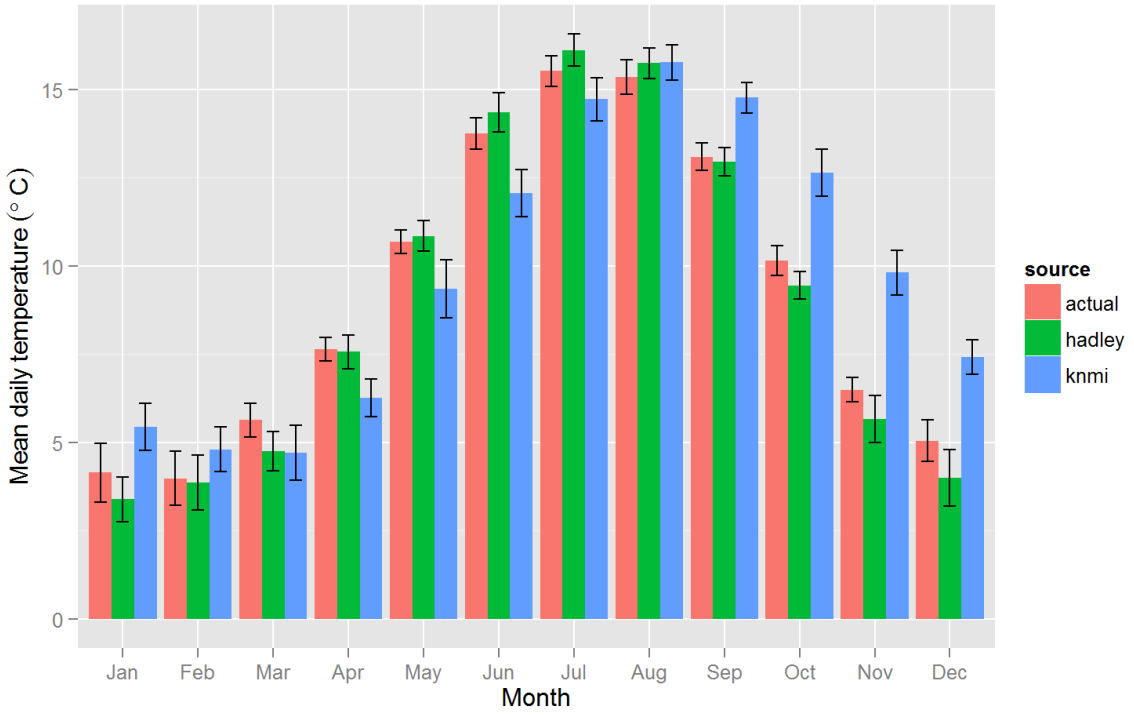

Figure B.5. Comparison of mean monthly rainfall for the period (1960-1990) from the Preston Wynne weather station, and the "had" and "knmi" predictions from the ENSEMBLES project. Error bars represent 95% confidence intervals, and show the variation between the years 1960-1990.

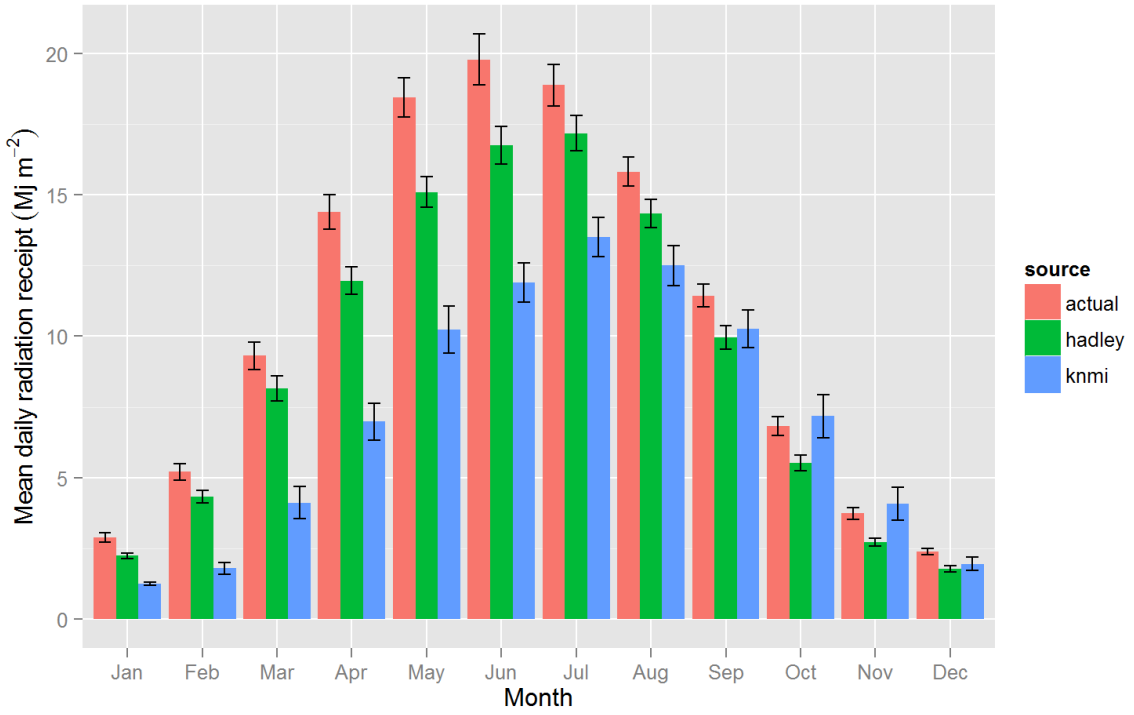

Figure B.6. Comparison of mean daily radiation receipt for the period (1960-1990) from the Everton weather station, and the "had" and "knmi" predictions from the ENSEMBLES project. Error bars represent 95% confidence intervals, and show the variation between the years 1960-1990.

Finally the estimated daily data were compared with the actual data (having removed all missing values) using the Root-mean-square-error (RMSE) cost function (Equation B1) on daily values of temperature and precipitation for the dates: 1 January 1960 to 31 December 1989 (1 January 1970 to 31 December 1989 for rainfall). This gives a measure of the average deviation from the observed, hence a lower value represents a better with between the observed and the predicted. Results from this function are given in Table B2.

Equation B1

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(\hat{y} - y)^2}{n}}$$

Where:

n = number of training examples.
ŷ = Actual value recorded from weather data.
y = Predicted value in ENSEMBLEs data.

Table B2. Comparison between actual data and two predictions from the ENSEMBLE project for climatic data for the Broome Farm trial site.

	RMSE for ENSEMBLE Prediction	
Measurement	**Had**	**KNMI**
Temperature	4.18	4.49
Precipitation	6.34	6.63
Solar radiation	6.44	7.39