AGFORWARD
Agroforestry for Europe

Lessons learnt – Grazed orchards in England and Wales

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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 Objective 2, Deliverable 3.8 which is to describe the lessons learnt from innovations within agroforestry with high value tree systems. Within the project, there were ten stakeholder groups focused on such systems (e.g. grazed orchards, intercropped and grazed olive groves and citrus orchards, and high-value walnut and chestnut plantations). This report focuses on a stakeholder group which focussed on grazed orchards in England and Wales. This can be read alongside a report focused on grazed bush orchards in Northern Ireland (McAdam and Ward 2015) and standard orchards in Normandie in France (Corroyer 2016).

2 Background

In 2012, the total area of apple orchards England and Wales was recorded as 14,470 ha, with 7,180 ha identified as cider orchards (DEFRA, 2013). Including pears, plums, and cherries the total orchard area was 17,620 ha. Other estimates based on remote sensing indicate 16,992 ha for England (Burrough et al. 2010).

In June 2014, an initial stakeholder meeting focusing on grazed standard orchards in the UK was held in Herefordshire which includes about 16% of the orchard area in England (Natural England, 2012). Eleven people attended the meeting of whom ten were involved in orchard or sheep management. The area of their orchards ranged from 0.2 to 24 hectares and four of the attendees were already practising grazed orchard management.

The participants, who included a member of the Shropshire Sheep Breeders' Association (SSBA), identified that sheep from the Shropshire breed were "tree-friendly". For example SSBA (2008) cites the work of Graham Allan who used sheep to manage weeds within conifer plantations in Denmark. In comparison with other UK sheep breeds valued for meat production (including Leicester, Dorset, Suffolk, and Oxford Down), Shropshire sheep "proved consistently to be the most reliable" in terms of minimising tree damage. As a result of such work, Shropshire sheep are being imported in Austria and Switzerland, and 250 British Shropshire sheep were imported by French fruit producers between 2008 and 2009 (Geddes and Kohl, 2009).

At the initial stakeholder meeting, the key positive benefits from integrating sheep into traditional apple orchards included a potential reduction in costs because there was a reduced need to use a tractor and mower to cut the grass below the trees. Other positive benefits, from a sheep owner's perspective, were an increased access to pasture and thereby increased animal production. One participant considered that there were animal health and welfare benefits and one was attracted by the originality of the system (Burgess 2014). From a negative perspective the key concerns were the complexity of work, the management costs associated with the need to inspect the sheep, and the administrative burden (Burgess 2014).

There are three main growth forms for apple trees. The traditional form of growing apple trees is as a ”standard” or a ”half-standard”, but increasingly the trees are being grown as bushes. A standard tree has a trunk of more than 2 m high, a half-standard has a trunk of 1-2 m high, and a bush has a trunk of less than 1 m high (Robertson et al. 2012 page 47). The total height of the trees in a ’bush’ or ’hedgerow’ orchard can be as low as 2-3 m in height (Durrant and Durrant, 2009). The original aim of the research protocol for this stakeholder group (Upson et al. 2015) was to produce quantitative information about the use of Shropshire sheep within a bush orchard. However following the initial field visits it was eventually decided to focus on the socio-economic effects of grazing on an apple orchard with standard trees. The effect of grazing on bush orchard apple yields has been studied separately in Northern Ireland (McAdam and Ward 2015). Other questions raised were related to the financial and labour impacts of grazing, potential damage to trees, and a better understanding of the constraints imposed in normal orchard operations, such as spraying, on grazing with sheep.

Following a site visit in December 2015, Burgess et al. (2016) provided a description of the grazed orchard trial and details on the initial parameterisation of the Yield-SAFE model to model apple tree development and yields. This report provides a summary of lessons learnt, summarising some of the results of the initial modelling work (Section 3). It then includes the trial site description (Section 4), a financial analysis of orchard grazing (Section 5), and a consideration of the impact on ecosystem services (Section 6). Section 7 considers some issues related to management of a complex system and some conclusions are provided in Section 8.

3 Initial modelling of orchard and grass growth

Many of the agroforestry systems considered within the AGFORWARD project have been modelled using the daily time-step Yield-SAFE model of tree and crop growth which is available in a Microsoft Excel format (van der Werf et al. 2017). Burgess et al. (2016) described the development of a biophysical model for apple trees in Yield-SAFE, based on the field measurements taken by Oldrich Vylupek in Herefordshire in 2010. The parameterisation of the model is described in detail by Burgess et al. (2016) and the key points are summarised here for information.

3.1 Tree densities

Apple trees used for cider production typically include a semi-dwarfing clonal rootstock, such as MM106 and MM111, with a clonal scion which determines fruit quality. Such apple trees can produce trees 6-7 m high (Vylupek, 2010). The field trial described in Section 4 is a traditional cider orchard (planted in 2001 i.e. 16 years old) where the trees were planted at a spacing of 3 m x 6 m (about 555 trees ha^{-1}). There is a tendency for recently-planted apple trees to be planted at higher densities and the density of the 16 year trial site is typical for orchards of that age in Herefordshire (Figure 1).

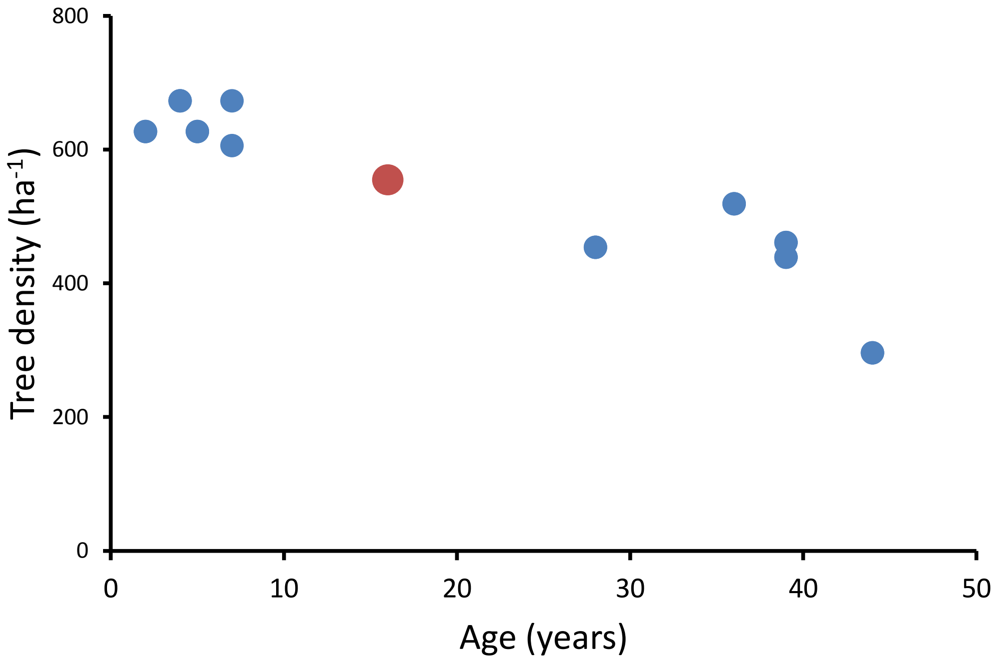

Figure 1. Density of cider apple trees in the study system (●) and as measured (●) in ten cider orchards by Vylupek (2010)

3.2 Describing apple yields using the Yield-SAFE model

Burgess et al. (2016) reported some parameters to be used in the Yield-SAFE model to describe the development and growth of apple trees over a 40-year period (Table 1). The model includes some parameters that are pertinent to the case study in Section 4 including the timing of pruning (December). It is noted that whereas in the case study annual pruning was assumed, in the model by Vylupek (2010), pruning was only assumed every fifth year.

Table 1. Some of the site management and tree data used to describe the growth of an apple trees within the Yield-SAFE (Vylupek, 2010)

Feature	Average value
Distance between rows (inter-row tree spacing)	599 cm
Tree distance within a row (intra-row tree spacing)	318 cm
Trees per hectare	525
Rotation	40 years
Thinning regime	None
Pruning regime	First six years annually then every fifth year
Planting date	January 2
Pruning date	December 16
Time of bud burst	May 15
Time of leaf fall	November 6
Maximum bole height	1.8 m

Burgess et al. (2016) also describe the extent to which the Yield-SAFE model, calibrated using the parameters described by Vylupek, could explain the first 16 years of apple yields of a bush orchard in Loughgall, Northern Ireland. It appeared that the model underestimated yields in the early years of growth and overestimated yields in later years (Figure 2).

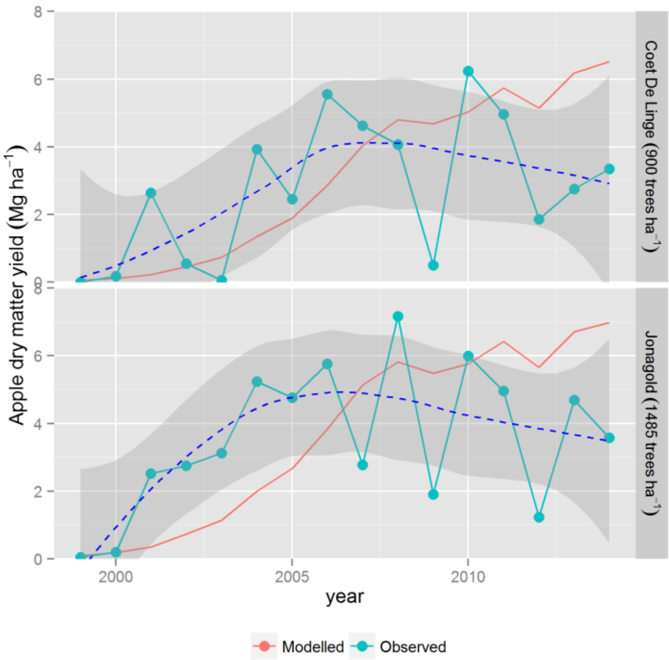

Figure 2. Comparison of the modelled apple yields (using Yield-SAFE) with the observed yields for two orchards at Loughgall, Northern Ireland. Observed yields have been overlaid with a local polynomial regression with associated standard error shown as the shaded region.

The report also described how the Yield-SAFE model could be used to predict the response of apple tree mortality on apple yields per hectare. In one example, the model predicted that, assuming that tree mortality was evenly distributed, then a reduction from a density of 525 trees to 210 trees per hectare would only cause at 5% loss in apple yield. It appears that assuming that the tree loss was uniform, the model assumed that the remaining trees would compensate by producing a larger canopy.

3.3 Describing grass growth with the Yield-SAFE model

Burgess et al. (2016) also reported how the understorey crop component of the Yield-SAFE model can be used to model the seasonal growth of grass. The initial analysis suggested that whilst early grass growth may be similar to that in an open paddock, shading by the trees (as the leaf area of the trees increases) will restrict grass growth later in the season. Unfortunately this aspect of research was not followed up and it remains a pertinent area for study.

4 Field trial to compare ungrazed and grazed orchards

4.1 Site description

The unreplicated trial took place in a 3.9 ha traditional orchard located at Broome Farm, Peterstow in Herefordshire (51°55'16.8'' N 2°37'32.3''W) in England (Figure 3). The mean annual rainfall is estimated at 629 mm and the soil type is loam (Table 2). The 3.9 ha block was divided into roughly equal plots of about 2 ha each with electric fencing (Figure 3 and Figure 4). The ungrazed section followed conventional orchard practices such as the use of mowing to control the grass understory. The other section was grazed with Shropshire sheep for part of the year. The apple orchard belongs to a relation of the owner of the sheep.

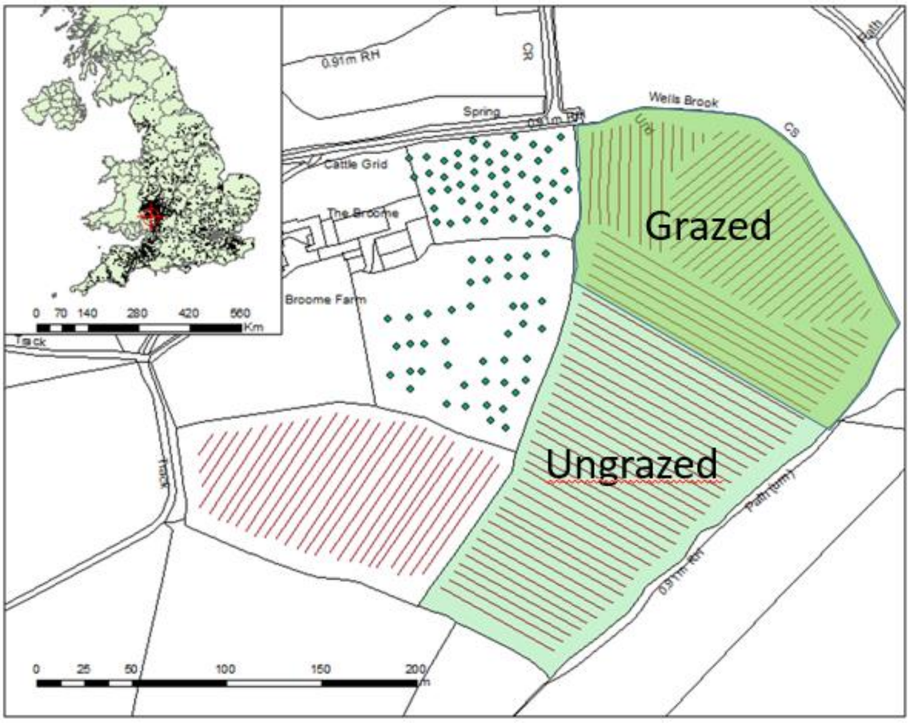

Figure 3. Red lines indicate rows of apple trees and green dots represent individual apple trees in traditional orchards. The trial is based in the area highlighted in green which has been split into a grazed and ungrazed area. © Crown Copyright and Database Right 2014. Ordnance Survey.

Table 2. Climate and soil type at the study site

Climate characteristics	
Mean monthly temperature	10.22 (± 4.51 SD) °C
Mean annual precipitation	629 (± 181 SD) mm
Soil type	
Soil type	WRB classification: Eutric chromic endoleptic cambisol Eutric refers to a high level of base saturation; endoleptic means that the soil rests on continuous rock starting 50-100 cm from the soil surface, and cambisol are typically young soils.
Soil series	Eardiston 1 (541c) series (NSRI, 2015): "Well drained reddish coarse loamy soils over sandstone, shallow in places especially on brows".
Aspect	South-East

4.2 Tree management

The orchard is composed of rows of 'Harry Master' apple trees (*Malus domestica*) orientated predominantly north-west to south-east (Figure 4 and Table 3). "Harry Master" is a traditional English cider apple variety that tends to be harvested very late in the season (Lea 2015) and they produce a bittersweet juice (Orange Pippin Fruit Trees, 2015).

Figure 4. An electric fence (left hand side of photo) has been used to divide the orchard into a grazed and ungrazed area (December 2015)

Table 3. Tree and tree management characteristics

Tree characteristics	
Species and variety	Apple (*Malus domestica*) 'Harry Master'
Date of planting	2001
Spacing	3 m x 6 m
Tree density	About 555 trees ha^{-1}
Tree protection	Wire surrounding the tree trunk to a height of 50 cm to protect from rabbits
Pruning	The side branches of the apple trees have been pruned to a height of 1.3 m. Hence the orchard comprises "half-standard" trees
Crop/understorey characteristics	
Species	Grassland including perennial ryegrass (*Lolium perenne*)
Management	The grass in the ungrazed orchard was mown three times
Fertiliser, pesticide, machinery and labour management	
Fertiliser	Minimal fertiliser is applied; the field is limed every five years
Pesticides	The apple trees are not sprayed although a problem with Ermine moth (*Yponomeuta malinellus*) was reported
Machinery	Tractor access between trees to allow mowing and spraying if required

4.3 Sheep management

Bulmers is a cider producer in Herefordshire and the contracts between Bulmers and apple suppliers state that sheep should be removed 56 days before apple harvest. This helps to prevent faecal contamination. Although it could be argued that this restriction is unnecessary as the cider is pasteurised, the need to have alternative grazing areas is a key feature of orchard grazing. In mid-May 2015, 40 ewes with their lambs entered the site (i.e. 20 ewes ha^{-1}) for a ten-week period until 1 August 2015, when they were moved from the orchard to a separate grass field to fulfil the contractual obligations for the apple harvest. The apples were harvested in October. On 15 December, the flock was then divided so that 20 ewes (without their lambs which had been sold) were reintroduced to the grazed orchard plot (10 ewes ha^{-1}) with the rest remaining in the separate grass field. The sheep stayed in these locations until February prior to lambing in March.

Figure 5. Shropshire ewes within the apple orchard in December 2015

Livestock management	
Species and breed	Sheep; Shropshire breed reported to be "tree friendly" (Geddes 2012).
Description of livestock system	The area of the grazed component of the field is about 2.0 hectares. Typically 40 ewes will be kept with one ram. The ewes are impregnated in the autumn ("tupping"), with lambing occurring in the spring. It is assumed that, on average, each ewe will have 1.5 lambs. During the weeks immediately before lambing the sheep will be kept indoors, before being moved to a field. The lambs will typically be separated from the ewe in late spring. The typical aim is to fatten the lambs as soon as possible ready for market, and to maintain the weight of the ewes until "tupping".
Labour	Sheep need to be checked daily in terms of numbers, health and welfare.
Fencing	To stock-proof the field, the grazing area was fenced using electric fencing.
Animal health and welfare issues	Sheep need to be check daily to ensure health and welfare. During the summer, potential issues include flystrike caused by blowflies (ELANCO, 2015).
Supplementary feed	Sheep are given a mineral bolus

5 Financial comparison of a grazed and ungrazed traditional orchard

5.1 Objective

The objective of this section is to compare the profitability of separate management of apple and sheep production with an integrated agroforestry system. This is done from both the perspective of a single business which includes both apple and a sheep production and from the perspective of an agreement between an orchard owner without sheep, and a sheep farmer without an orchard. The analysis is based on the system described in Section 4 although in some instances, alternative assumptions were made.

5.2 Methodology

An initial financial comparison of the grazing of an unintegrated with an integrated system was undertaken during 2017 as a ten-week project by a team of four graduates at Cranfield University (Francesca Chinery, Georg Eriksson, Erica Pershagen, and Cristina Pérez-Casenave), supervised by Paul Burgess and Silvestre Garcia de Jalon. The team undertook a literature review and sites visits were made to Herefordshire to discuss the systems with two farmers who practice orchard grazing: Toby Lovell and Harvey Clay. A key stage in undertaking the financial analysis was to develop an annual model of sheep management in the orchard using a monthly-time step within Microsoft Excel. Graves et al. (2005) provides a useful framework to describe the objectives and nature of financial modelling (Table 4). The developed model describes the seasonal distribution of grass growth and the energy demands for the sheep and the associated lambs. The model then included values for the revenue and costs of production for sheep and apple production. In the final stages, a sub-model was also included to describe the financial benefits and costs of a separate grass field that could be used to produce a hay crop when the sheep are grazing the orchard.

Table 4. Criteria established for the financial model categorised using the framework based on Graves et al. (2005)

Characteristic		Criteria for the economic model. The model should be able:
1. Background	1.1	To operate as an “open” format model
2. Systems modelled	2.1	To model an “ungrazed” and a ”grazed” orchard
	2.2	To model a separate grass field either for grazing and for hay production
3. Objectives of economic analysis	3.1	To undertake a financial marginal cost benefit analysis within a single year
	3.2	To examine sensitivity to changes in input values
4. Viewpoint of analysis	4.1	To simulate a financial view-point from the perspective of i) a business that includes apple and sheep production and ii) separate apple and sheep production businesses
5. Spatial scale	5.1	To operate for blocks of one hectare each
6. Temporal scale	6.1	To use a monthly time-step for the description of the grazing model over one year
7. Platform	7.1	To be a spreadsheet “workbook” model
8. Inputs and outputs	8.1	To enter inputs directly into the spreadsheet
	8.2.	To produce both tabular and graphical output

The monthly output from the sheep management model was then integrated with the revenue and the costs of apple production and hay production, and the results were expressed as an annual value. The default ”baseline” orchard system was an ungrazed orchard comprising 555 apple trees per hectare (spacing of 3 m x 6 m). The financial analysis is based on a mature apple orchard of the same age as the case study of 16 years.

5.3 Technical assumptions

In order to undertake the financial analysis, a number of technical assumptions were needed in terms of both the apple and the grazing system.

5.3.1 Apple production and restrictions on sheep presence

Based on information from the owner, it was assumed that the mean annual cider apple yield was 22 t ha^{-1}. It was assumed that the apples were harvested all at the same time in the second half of October. Although the case study site did not use fertiliser or agrochemicals in the case study year, for the financial analysis a cost was included for fertiliser and pesticide application.

It was assumed, as in the case study, that both the ewes and the lambs were removed from the apple orchard on 1 August to ensure that 56 days had elapsed before apple harvest in October. After the apples have been harvested it was assumed that the sheep could return to the field on 1 November and remain there until late March when the sheep were housed indoors for one month for lambing. After lambing, the ewes and lambs are returned to the orchard, where they remain until 1 August (Table 5). It is assumed that the lambs were sold on 31 August.

Table 5. Assumed operations and location of sheep (indicated in green) between the orchard, a separate grass field, and the lambing shed. The sheep are removed from the orchard during the periods indicated in yellow.

Month	Apple orchard		Separate grass field	Lambing shed
	Apples	Understory grass in orchard		
Jan Feb		Separate ewes and rams		
Mar	Spray[a]	Sheep indoors for lambing		Sheep kept indoors
Apr May June Jul	Fertiliser	Sheep and lambs moved to orchard Separate lambs from ewes	Potential to use grassland area for hay production	
Aug Sep Oct	Spray[a] Harvest	Sheep removed prior to apple harvest	Lambs sold and ewes kept on alternative grassland area	
Nov Dec	Pruning	Return ewes and rams to orchard		

[a]Sprays to apply pesticide may occur at the times indicated

5.3.2 Sheep production and energy requirements

The analysis was based on one hectare and the default assumption was that this supported 10 ewes (Table 6). For the analysis it was assumed that a quarter of the ewes were replaced each year, similar to the 23% value quoted by Nix (2017) for lowland sheep. It was assumed that the ewes lambed on 1 March each year and that the mean lambing percentage was 150% i.e. there would be three lambs for every two ewes. It was assumed that the weight of the ewes remained constant over the course of the year. However the ewes have an energy requirement dependent on a baseline energy demand, a daily energy requirement, and energy needed for wool production. The energy requirement of the lambs was similar although it included also the energy needed for growth (Table 6).

Table 6. Assumptions for sheep energy requirement and sheep management

Parameter		Unit
Area of orchard	1	ha
Area of alternative grassland area	1	ha
Number of ewes	10	
Weight of ewe	60	kg
Baseline energy demand per sheep [1]	1.40	MJ d^{-1}
Energy requirement [1]	0.15	MJ kg^{-1} d^{-1}
Energy needed for wool production [1]	0.23	MJ d^{-1}
Energy needed for growth [1]	2.86	MJ d^{-1}
Date of lambing	1 March	
Lambing percentage	150	%
Weight gain per lamb per day	0.2	kg d^{-1}
Date of sale of lambs	31 Aug	

[1]: McDonald et al. 1984

5.3.3 Technical assumptions regarding grass production

The yield of grass is dependent on the temperature, the availability of water (i.e. absence of drought) and the availability of nitrogen. The nitrogen input from sheep (kg N ha^{-1}) can be calculated from the number of sheep (ha^{-1}), the proportion of the year when the sheep are in the field, and an annual nitrogen excretion factor of 10.2 kg N $head^{-1}$ (Robertson et al. 2002, page 55). Hence the presence of 10 sheep for 8 months per year and 15 lambs (assumed half the weight of a sheep) for four months implies a nitrogen application of about 94 kg ha^{-1}. Assuming that there was an additional fertiliser application of 66 kg ha^{-1}, then a total nitrogen application of 160 kg ha^{-1} should be sufficient to enable an annual grass dry matter yield (under conditions of no drought stress) of about 8 t ha^{-1} (Corrall et al. 1990). The default assumption, in the absence of other information, was that the grass yield in the orchard would be 6.4 t ha^{-1} (80% of the grass yield from a paddock of 8 t ha^{-1}). The energy content of the grass was assumed to be 12.10 MJ kg^{-1} (McDonald et al. 1984).

The seasonal distribution of grass production is also important in sheep production. It was assumed that the proportion of the grass growth in each month followed the pattern reported by Corrall et al. (1990). They assumed no grass growth between November and February (due to the low temperatures) and a peak in production in May (due to the re-partitioning of dry matter to above-ground growth in the spring) (Table 7).

Table 7. Assumptions regarding the seasonal distribution of grass production, derived from Corrall et al. (1990)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Proportion	0	0	0.010	0.144	0.272	0.168	0.161	0.124	0.084	0.037	0	0

On the basis of these assumptions, it was possible to construct a model of how the energy demanded by the sheep could be met from the grass in the orchard. The model highlights that the sheep owner needs to purchase additional feed during mid-October through to mid-March to meet the livestock energy demand. During the period April to September, the energy in the monthly grass production is sufficient to meet the demands of the sheep (Figure 6).

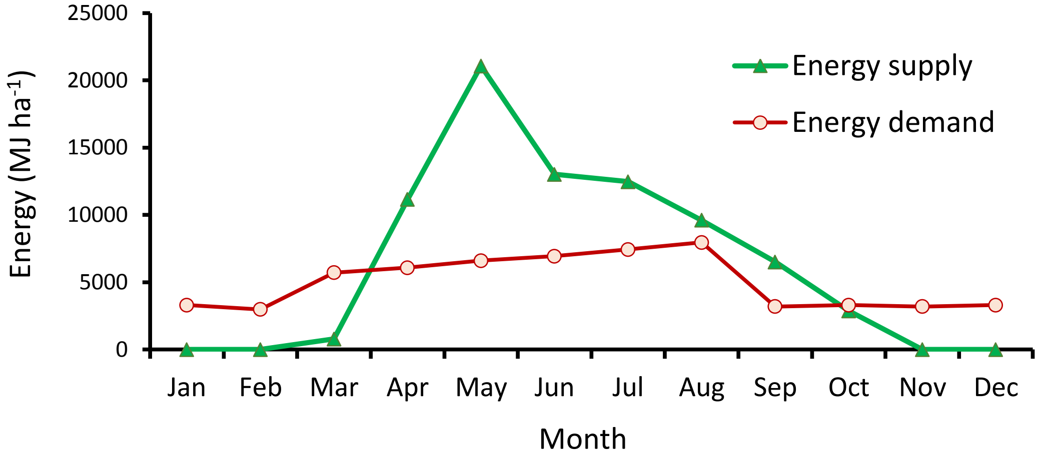

Figure 6. Feed/energy balance between the energy in the grass and the energy demand of the sheep and lambs for each month of the year

The impact of this seasonal distribution on the need to used either purchased or stored feed for use in January, February, March, November and December is demonstrated in Figure 7. The figure also demonstrates the cost associated with moving the sheep indoors in March, outdoors in April, and away from the orchard in August and back to the orchard in November.

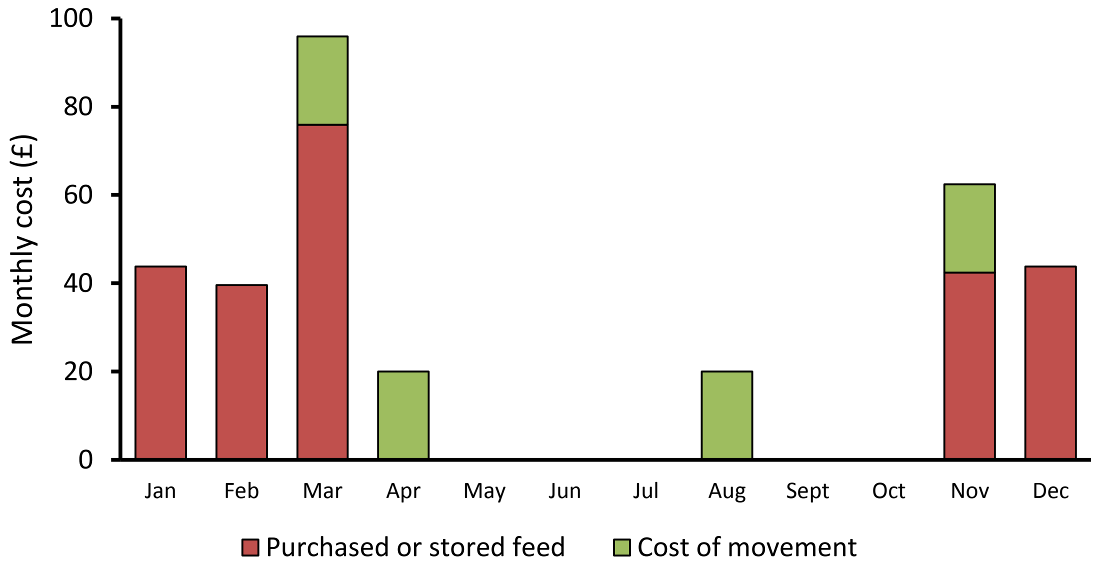

Figure 7. The sheep owner needs to provide purchased or stored feed for the sheep in January, February, March, November and December to overcome the energy shortfall. The sheep are moved in March, April, August, and October.

5.4 Financial assumptions

The financial assumptions were developed for two scenarios: the first where the apples and sheep are integrated in a single business, and the second where there is an apple orchard owner who has a business agreement with a sheep farmer.

Apple orchard costs: the assumed costs for the ungrazed cider apple orchard (Table 8) were largely derived on-site and from the low-range values presented by Nix (2017).

Table 8. Assumed value of the orchard costs. Note that the values are indicated in £ sterling. In August 2017, £0.91 was equivalent to €1.00.

	Prices/costs	Value for ungrazed orchard	Value for grazed orchard	Unit
Apple				
Apple revenue	Yield of cider apples [1]	22	22	t ha^{-1}
	Price [2]	120	120	£ t^{-1}
	Total revenue	**2640**	**2640**	**£ ha^{-1}**
Apple costs	Orchard depreciation [3]	415	415	£ ha^{-1}
	Fertiliser/sprays [4]	300	300	£ ha^{-1}
	Pruning [5]	300	300	£ ha^{-1}
	Grass topping [6]	72	24	£ ha^{-1}
	Crop sundries [7]	30	30	£ ha^{-1}
	Harvesting [8]	36	36	£ t^{-1}
		792	792	£ ha^{-1}
	Grading/packing [9]	30	30	£ ha^{-1}
	Transport [10]	242	242	£ ha^{-1}
	Total costs	**2181**	**2133**	**£ ha^{-1}**
Apple margin	**Gross margin**	**459**	**507**	**£ ha^{-1}**

[1] Yields were derived from personal communication during site visits

[2] Price for cider apples without deductions for transport or storage.

[3] Assumed establishment costs are written off over the current orchard lifetime.

[4] Although the case study site had no fertiliser or agrochemical application, for this financial analysis and annual cost of fertiliser and sprays amounting to £300 ha^{-1} is assumed.

[5] Based on values from Nix (2017)

[6] Cost of grass topping is £24 ha^{-1} (Nix 2017) and this is carried out three times per year (i.e. £72 ha^{-1}). With the inclusion of sheep, the amount of grass topping can be reduced to one topping.

[7] Includes depreciation, tree replacements, beehive hire, tree ties and stakes.

[8] Assumed mean including management supervision. In practice this might vary greatly due to variety, yield, fruit quality and size. Price based on dessert apples.

[9] Assumed mean but actual value will vary with varieties and apple quality

[10] Transport to the cider factory is assumed to be £6 per tonne of apples plus £110 ha^{-1}; hence for an apple yield of 22 t ha^{-1}, the transport cost is £242 ha^{-1} (Nix 2014)

Fencing and sheep production costs: the costs associated with sheep production were also largely derived from values established on site and from values in Nix (2017). The fencing costs were based on the use on electric fencing which was assumed to have a lifetime of five years.

Hay production: orchard grazing requires the use of an additional paddock area. For the purposes of the analysis, it is assumed that a key benefit of using a grazed orchard is that this area can be used to produce grass for the period when the sheep are in the orchard (Table 5). It is assumed that each tonne of hay has a marginal value of £44 t^{-1} (85% DM) (Table 9).

Table 9**.** Assumed value of sheep and fencing costs and hay production on an associated grassland area. Note that the values are indicated in £ sterling. In August 2017, £0.91 was equivalent to €1.00.

	Prices/costs	Value for grassland paddock	Value for grazed orchard	Unit
Sheep				
Revenue	Value of lamb [1]	1.80	1.80	£ kg^{-1}
Costs	Ewe replacement cost [2] Feed [3] Medicine and miscellaneous [4] Movement cost	17.5 0.0133 20.0 20	17.5 0.0133 20.0 20	£ ewe^{-1} £ MJ^{-1} £ ewe^{-1} £ per change
Fencing				
Fencing	Capital cost of fencing [5] Longevity of fencing		300 5	£ ha^{-1} Years
Hay				
Hay production	Sale value of hay [6] Production cost [6] Net margin on hay	117 73 44		£ per DM tonne £ per DM tonne £ per DM tonne

[1] Value of lambs based on values in Nix (2017). Assumption that 41 kg lamb is worth £74

[2] Replacement costs based on purchase cost of £145 and sale cost of £75 over four years (Nix 2017)

[3] The cost of feed is based on the assumption of a hay price of £117 per tonne dry weight and an energy value of 8.8 MJ per kg dry matter (Nix 2016)

[4] Value from Nix (2016)

[5] Based on an estimated cost for an electric fencer of £100 and an estimated cost for the electric fencing of £200 (Toby Lovell, personal communication 2016; Burgess et al. 2016). The longevity of the fencing is assumed to be 5 years.

[6] Cost of production of hay from Nix (2017), and assuming a sale value of £100 per tonne of hay at 85% dry matter (i.e. £117 per tonne dry matter).

Grants: although the landowner receives basic farm payments for the field, these are excluded from this model as it is assumed that they will be the same for the two systems.

Choice of discount rate: because the study was restricted to an analysis for only twelve months, the effect of a discount rate is likely to be minimal. The only major cost which involved an upfront capital expenditure was the fencing. However in order to simplify the analysis, the capital cost of the fencing was simply divided by the 5-year life time to derive an annual cost of £60.

Labour costs: note that the analysis does not include any shepherding costs. Including these would substantial reduce the gross margins associated with sheep production.

Contract arrangements and rent: in the analysis for a grazed orchard system involving an orchard owner and a sheep producer it was assumed that a contract (assumed cost: £100) would be needed, and that the sheep producer would pay an annual rent of £50 ha^{-1}.

5.5 Results for orchard grazing within one business

An analysis was carried out for an enterprise where an owner has both an apple orchard (1 ha) and a grass field (1 ha) used for sheep production. A comparison was made between keeping apple and sheep production separate, and allowing the sheep to graze the apple orchard (Table 10). The gross margin for the separated system across the two hectares (£792) is the sum of the gross margin from apple production (£459) and the gross margin from sheep production (£333). In the integrated system where the orchard is grazed, the gross margin of apple production is increased because of the reduced mowing costs. It is assumed that the level of sheep production in the orchard is similar to that in an open grass field. However this margin is reduced because of the need to transport the sheep two additional times (£40) and the need to provide electric fencing in the orchard (£60). A key benefit of grazing the orchard is that the removal of the sheep from the grass field from April to the end of July means that the grass field can be used to produce a hay crop, and it is calculated that this has a net benefit to the farmer of £262. Hence on the basis of these assumptions the gross margin across the two hectares increases from £792 for the separate systems to £1002 for the integrated grazed orchard system (Table 10).

Table 10**.** Comparison of gross margins between a) keeping apple and sheep production separate or b) allowing the sheep to graze the apple orchard, for a single business including an apple orchard (1 ha) and a grass field (1 ha). It is assumed that the farmer can produce a hay crop on the 1 ha of grassland when the sheep are grazing the orchard. Note that the values are indicated in £ sterling. In August 2017, £0.91 was equivalent to €1.00.

	a) Separate apple and sheep production (£)	b) Integrated production where the sheep are allowed to graze the apple orchard (£)	Difference (£)
Apple production gross margin	459	507	
Sheep production gross margin	333	333	
Additional movement of sheep		-40	
Fencing in orchard		-60	
Hay production gross margin		262	
Total for 2 ha	**792**	**1002**	**210**

Sensitivity: The profitability of integrated production orchard is particularly sensitive to the assumed effect on apple yields. On the basis of the stated assumptions, if the apple yield declined by 12% due to grazing then the integrated system would be no longer advantageous (Table 11). If the capital cost of the fencing increased to £1350 ha^{-1}, the benefit from hay production declined to less than £9 per tonne, or the grass yield in the orchard was less than 16% of that in the grass field, then it would be more profitable for the owner to keep apple and sheep production separate.

Table 11. Sensitivity of the break-even point (i.e. the point at which the profitability of the integrated system matches the separate system) selected variables. Note that the values are indicated in £ sterling. In August 2017, £0.91 was equivalent to €1.00.

Variable	Default value	Break-even value	Proportional change
Apple yield in grazed orchard	22 t ha^{-1}	19.4 t ha^{-1}	0.88
Cost of fencing	£300	£1350	4.50
Net benefit of hay	£44 t^{-1}	£8.71 t^{-1}	0.20
Grass yield in orchard	6.4 t ha^{-1}	1.0 t ha^{-1}	0.20

5.6 Results for orchard grazing involving two businesses

The second scenario considers the profitability of orchard grazing which brings together two businesses: an orchard owner and a sheep farmer with a grass field. It is assumed that a contract would be needed between the owner and the sheep farmer and a value of £100 was assumed, divided equally between the two parties. The gross margin for the two systems managed separately (£792) (Table 12) is the same as for the two systems managed separately by the same business (Table 10). However in the two business system, the overall margin of £902 is £100 less than for the single business system because of the £100 allowance for a contract. Even so, in the combined system with two businesses the orchard owner and the sheep farmer both secure a benefit from the combined system of £48 and £62 respectively, if the sheep farmer provides the orchard owner with a rent of £50 ha^{-1}.

Table 12**.** Comparison of the effect of orchard grazing where apple and sheep production are undertaken as an agreement between two separate businesses. Note that the values are indicated in £ sterling. In August 2017, £0.91 was equivalent to €1.00.

Perspective	Variable	Separate systems (£)	Grazed orchard system (£)	Difference (£)
Orchard owner (1 ha)	Apple production gross margin	459	507	
	Contract cost		-50	
	Rent from sheep farmer		50	
	Gross margin	**459**	**507**	**48**
Sheep farmer with 1 ha of grass	Sheep production gross margin	333	333	
	Additional sheep movement cost		-40	
	Contract cost		-50	
	Cost of rent		-50	
	Cost of fencing		-60	
	Hay production on paddock		262	
	Gross margin	**333**	**395**	**62**
	Total (for 2 ha)	**792**	**902**	**110**

Sensitivity: assuming that the rent is fixed, the individual profits from the two separate businesses are much more sensitive to price changes than the combined business (Table 13 v Table 11). For the default assumptions, orchard grazing would become unprofitable for the orchard owner if there was a 3% decrease in apple yield or if the sheep farmer paid no rent (Table 13). For the sheep farmer, the use of the orchard would become unprofitable if the capital cost of fencing equipment was more than £600 (i.e. £120 per hectare per year), the cost of moving the sheep on each occasion exceeded £50, or if the benefit of producing hay on the paddock was less than £33 per tonne. It would also be unprofitable for the sheep farmer if the grass yield was less than 34% of that under open grass field, i.e. grazing the orchard would result in the need to purchase or store additional feed.

It is also worth noting that a grazed orchard system between two organisations should not only be of benefit to both parties, but it should be also be more profitable than other options. In this study, the cost of using the orchard (including contract, fencing and rental costs) is £160 ha^{-1}. This is very similar to the value of £184 ha^{-1} (personal communication, Toby Lovell) to secure one hectare of grass keep in the Herefordshire area. As the cost of using the orchard increases, so the options of identifying other alternative fields increases.

Table 13. Sensitivity of the break-even point (i.e. the point at which the profitability of a dual agreement matches the gross margin of the separate systems) to selected variables. Note that the values are indicated in £ sterling. In August 2017, £0.91 was equivalent to €1.00.

Perspective	Variable	Default value	Break-even value	Proportion
Orchard Owner	Apple yield	22.0 t ha^{-1}	21.3 t ha^{-1}	0.97
	Contract cost	£50	£98	1.96
	Annual rent from sheep farmer	£50	£2	0.04
Sheep Farmer	Cost of fencing	£300	£609	2.03
	Contract cost	£50	£112	2.24
	Cost of moving sheep once	£20	£51	2.56
	Net benefit of the hay	£44 t^{-1}	£33 t^{-1}	0.76
	Grass yield in orchard	6.4 t ha^{-1}	2.2 t ha^{-1}	0.34

6 Impact on ecosystem services

The adoption of grazed orchards is not just determined on the basis of the financial profitability but it can include a consideration of the effect on wider ecosystem services which may provide wider societal benefits. These can be assessed using the ecosystem service framework used by de Groot et al. (2002) which categorises the wider societal benefits and costs of ecological systems in terms of production, regulation, information, and habitat services. In terms of provisioning services, it is assumed that the capacity of the orchard to produce apples is not significantly affected. However the inclusion of sheep provides an additional product: lambs for sale as meat (Table 14).

Table 14. Assumed effects of integrating sheep in an apple orchard on ecosystem services

Grouping	Category	Ungrazed orchard	Grazed orchard	Change	Reference
Provisioning	Apples	++	++	0?	
	Lamb	0	++	++	
	Biomass	+	+	0	
Regulating	C sequestration	+	+	0	Woodland Trust (2013)
	Flood control	+	+	0	Woodland Trust (2013)
	Air quality	+	+	0	Woodland Trust (2013)
	Water quality	0	+	+	Coffey & Mumma (2014)
Cultural	Recreation/tourism	+	+	0	Taplin (2008)
	Landscape	+	+	0	NSA (2016b)
	Education	+	+	0	NSA (2016a)
	Heritage	+	+	0	English Heritage (2014)
Carrier and habitat	Biodiversity	+	++	+	Woodland Trust (2013)
	Genetic resources	+	+	0	NSA (2016a)

Significant positive effect = ++, Positive effect = +, no effect = 0, negative effect = - and significant negative effect = --

It is assumed that the effect of integrating grazing in the apple orchard has minimal effect on regulating services such as carbon sequestration, flood control, and air quality. The impact of an ungrazed orchard on water quality is indicated as zero as it is assumed that the positive effect of the trees on water quality balances out the negative effect of fertiliser and pesticide applications. Coffrey and Mumma (2014), Buehrer and Grieshop (2014) and Corroyer (2016) argue that because sheep can eat unharvested apples and fallen leaves, they can reduce the pest and disease burden and hence the requirement for sprays. The sheep can also decrease the need for artificial fertiliser application, but the uneven spatial distribution of dung produced by the sheep may cause uneven leaching of nitrogen.

It is recognised that orchards can provide recreational, landscape, educational and heritage-based benefits (Taplin 2008; English Heritage 2014). The relative advantage or disadvantage of integrating sheep on these attributes is unclear.

Lastly orchards also provide a home for several habitats and species (Woodland Trust 2013). It could be argued that the inclusion of sheep will support a wider range of species because grazing benefits variation (National Sheep Association 2016a) and there is some empirical evidence suggesting that biodiversity is higher in orchards grazed by livestock (Seffan-Dewenter and Leschke, 2003; Bergmeier *et al.,* 2010; Defra, 2010). Robertson et al. (2002) also reported higher levels of lichen, fungi, bryophytes and mxyomycetes in orchards that were less intensively managed. However high grazing pressure can result in low species richness (Robertson et al. 2002, page 55).

7 Management of a complex system

The initial stakeholder workshop highlighted that the complexity of work was a key issue. This section considers three management issues: the need for an additional area of grassland, adaptive responsive management, and the options for co-operation.

7.1 Need for an additional area of grassland

A key lesson learnt is that the management of a grazed orchard needs additional grassland so that the sheep can be removed from the orchard effectively for about two to three months before the harvest of the apples. In this exercise, we assumed that this would be the period August to October. The analysis suggests that a key advantage of using an orchard between April to July is that a sheep producer can more effectively use his/her other grassland to produce, for example, a hay crop. It is assumed that it is not technically feasible to produce a hay crop from within the orchard as the shade provided by the orchard will prevent drying. As one of the stakeholders noted: ”grazing orchards are logical but you need additional grassland prior to harvest”

7.2 Responsive grazing management

A key determinant of successful orchard grazing is responsive grazing management. If stocking rates are too low, then the understorey grass can be wasted and the sheep do not gain the benefit of the additional grass. On the other hand, if stocking rates are too high, then lamb growth can be reduced and the sheep may be more inclined to damage the trees by debarking them (Houis 2007; SSBA 2008). Hence, regulated management of the orchard area is needed to minimise tree damage (SSBA 2008).

7.3 Grazed orchard agreements

The study compared two contrasting business approaches to grazing apple orchards: i) where an orchard owner produces sheep within a single business and ii) a contract between two parties: an orchard owner and a sheep farmer.

Combined business: on the basis of the assumptions made the use of sheep within a standard apple orchard can make financial sense where it allows the owner to make effective use of the additional grassland area. The benefit of £210 across two hectares could be significant. In the combined system, this relatively high benefit meant that a substantial decrease in apple yields (-12%) or increased fencing costs (+360%) would be needed for the change to be unprofitable.

Agreement between two businesses: the analysis demonstrates that a grazed orchard agreement between two businesses is feasible. The orchard owner can benefit from reduced mowing costs and a potential rental income; the sheep farmer can benefit from an additional source of grass from April through to July. The advantage of such an arrangement is that each party can continue to specialise in their own particular business. However successful collaboration between two businesses requires a good working relationship; things can proceed well if everything goes to plan but things can also go wrong. Hence it can be wise for a contract to be in place to highlight the particular responsibilities and liabilities of each partner. In the case study an assumed cost of £100 to develop a contract effectively halved the financial benefit to both the orchard owner and the sheep farmer. In reality, in the case study, the orchard owner was a relation of the sheep farmer and this could have helped reduced the contractual costs. This form of good ”social capital” between two businesses can reduce the costs of the agreement with benefits for both parties. However the absence of a clear contract can also mean that unforeseen circumstances (for example substantial damage to trees) can place that social capital, and for example family relationships, at risk.

8 Conclusions

The study demonstrates that a farmer who has an apple orchard and sheep can benefit financially from grazing the orchard with the key potential benefits being reduced mowing costs, reduced feed costs for sheep production, and the opportunity to use grassland elsewhere between April and July to produce, for example, a hay crop. The critical issue is that the grazing does not result in a reduction in apple yields. Whilst it is evident that sheep can substantially reduce apple yields in bush orchards (McAdam and Ward 2015), the feedback from the stakeholder group was that there was minimal effect on the apple yield from half-standard and standard apple trees that are already pruned above the browsing height of the sheep. Pruning the trees at this height can increase air movement through the orchard thereby reducing apple diseases and the inclusion of sheep can provide additional nitrogen to the apple crop.

The study also demonstrated that it can be feasible to develop working agreements for orchard grazing between an apple orchard owner and a sheep farmer to the financial benefit of both. In such an agreement, the financial advantage for the orchard owner is particularly sensitive to there being minimal effect on the apple yield. The benefit for the sheep owner (who must have access to an additional area of grassland for at least 60 days before apple harvest) is dependent on making effective use of the grassland that is released whilst the sheep are in the orchard and the minimisation of transport costs. In the case study, the inclusion of a contractual cost of £100 between two parties effectively halved the financial benefit for each party and hence minimising this cost is also important.

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