AHDB Beef & Lamb

Sustainable beef systems on arable units

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Final Report for AHDB

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1 EXECUTIVE SUMMARY

1.1 Background

The high costs and increasing competition for land can make starting or expanding beef enterprises challenging. One option for beef producers is to graze cattle on leys on predominantly arable units, either by renting land or by paying arable farmers to keep cattle. Introducing leys into arable systems has been identified as method of increasing soil organic matter which is key to maintaining and enhancing soil quality.

This project was set up to investigate the practical, economic, environmental and agronomic implications of integrating beef enterprises into arable systems. Measurements were carried out at two farm sites, one in Cambridgeshire (Thriplow Farm) and the other in Somerset (Norwood Farm).

As part of the project the AHDB Economics and Analysis team have created a simple Excel based tool to help farmers calculate potential costs and margins of integrating beef into arable rotations. The calculator is populated by utilising drop-down lists which provide a 'mix and match' of different infrastructure set-ups, ley establishments and cattle rearing systems.

AHDB has a specific webpage dedicated to "livestock within the arable rotation" with links to relevant reports and good practice guidance.

1.2 Agreement types for integrating beef into arable rotations

There are several different business models available to farmers considering introducing grazing cattle (or other livestock) into an arable rotation including:

Owner-occupier or tenant farming where the farmer manages the land and owns the livestock. This is the simplest model as the farmer has control of the land and livestock. There is increased interest in a return to mixed farming systems due to potential economic and environmental benefits, and various support payments available (via Entry Level Stewardship (ELS)/Higher Level Stewardship (HLS) and in the future via Environmental Land Management scheme (ELM). The owner-occupier model is the one adopted by Norwood Farm (section 4).

Rented grazing where the livestock farmer rents grazing land. This can include summer, annual or even short-term Farm Business Tenancy (FBT) agreements.

Contract grazing tends to be shorter term than rented grazing. Various contract grazing models exist including:

- Beef unit takes on the field on a per head per day deal.
- Beef unit provides a service to the arable farm grazing cattle within a larger business arrangement.
- Cattle supplied to the arable farmer for growing under contract with input (starting) and output (ending) prices agreed between the parties.

'Bed and breakfast' cattle grazing system is a joint venture between a beef producer and a landowner, where the landowner takes on the management of the cattle on a day-to-day basis, and is paid either on a per day basis, or on a per day and weight gain basis (where a bonus is paid for weight gain above a certain amount). The 'B&B' joint venture model is the one adopted by Thriplow Farm (section 3).

Some beef producers have been able to use rented grazing, contract grazing, and/or joint venture agreements to start and grow their businesses with minimal land base of their own.

1.3 Benefits of integrating beef into arable rotations

Integrating beef enterprises into arable rotations provides opportunities for both beef producers and arable farmers. For beef producers, this represents an opportunity for new entrants to the beef industry or for enterprise expansion. For arable farmers, beef cattle may be able to achieve the same or higher net margin per hectare compared to traditional arable rotations, with the potential additional benefits of better weed control and improved soil condition resulting from the establishment of grass or multispecies leys.

Continuous arable cropping with annual cultivations and little or no inputs of organic materials have led to reductions in soil organic matter content, which is central to the maintenance of soil quality and fertility. Temporary leys have the potential to increase soil organic matter levels by stopping annual cultivation and increasing the return of organic matter in the form of root and litter turnover. Increasing soil organic matter has the potential to increase soil moisture retention and nutrient turnover, improve soil structure and reduce erosion risk. The re-introduction of leys into arable rotations was identified in the Government's 25-year plan for the Environment as a key mechanism for improving soil health (Defra, 2018). However, prior to this project there have been very few long-term studies investigating the benefits of integrating grazed leys into arable rotations.

In this project, detailed assessments at Norwood Farm showed a significant improvement in soil properties after three years of grass and clover, and multispecies leys. Topsoil soil organic matter increased by an average of 0.3 percentage points (from 7.8% in 2017 to 8.1% in 2020), equivalent to an increase of 6 t/ha organic matter in the top 15 cm of soil. Earthworm numbers increased by 60% from 158 to 253 worms/m^2, and total earthworm biomass increased three-fold from 46 to 137 g/m^2.

These improvements to soil properties can be expected to benefit following arable crops in the rotation. Organic matter holds approximately 10 times its weight in water; therefore the 6 t/ha increase in organic matter content measured at Norwood can be expected to increase water holding capacity by approximately 60,000 litres per hectare in the top 15 cm, equivalent to 6 mm of rainfall. Spring barley yields were increased by 0.7 t/ha following the three-year grass and clover ley at Norwood Farm compared to continuous arable production.

The introduction of a ley into an arable rotation can also help with the cultural control of black-grass by allowing seed to decline in the weed seedbank, which also reduces the resistance pressure to current herbicides, maintaining their effectiveness for longer. Measurements at Norwood Farm showed a reduction in the number of black-grass heads after a three-year grass and clover ley indicating the potential of leys to help cultural control of black-grass.

This project has shown that there is potential for the arable farmer to make a positive margin from cattle grazing a ley in an arable rotation. A cost benefit analysis of integrating beef into arable systems at both Thriplow and Norwood Farms, showed a positive net margin of around £250/ha (before rent and finance). AHDB Farmbench results showed that whilst these margins cannot match the returns from a winter wheat crop, they are as good as if not better than some of the other common combinable crops, especially a traditional break crop of winter beans. Furthermore, margins can be improved by:

- Entering the land into a subsidy or stewardship agreement. For example, the Countryside Stewardship GS4 herb and legume rich sward option is worth £309/ha/year.
- Accounting for the increased yields from the following arable crop; the increase of 0.7 t/ha in spring barley yields at Norwood Farm is worth £112/ha with spring barley at £160/tonne.

- Depreciating the ley over a longer time period; increasing the length of the ley from 3 to 5 years at Norwood increased the net margin by *c*.£35/ha/yr.

1.4 Challenges to consider

Introducing beef into previously stockless arable rotations represents a significant systems change, and there are number of considerations that need to be addressed including:

- **Fencing, water, and electricity** – is there adequate existing infrastructure, or is investment needed? The AHDB 'mix and match' calculator can be used to help calculate the cost of different infrastructure set up options.
- **Cattle gathering and handling system** for stock during the grazing period. Cattle handling for management tasks such as fly prevention or TB testing should be planned, and investment made in suitable facilities. Portable handling systems that include gathering and drafting pens alongside handling and even weighing facilities are available and offer flexibility when different blocks of land are being utilised (for example Plate 4).
- **Farm and stock management** – the farming business integrating cattle and grazing leys needs to recognise this as a medium term 3–5-year project for returns on infrastructure, investments and ley costs. Beef commodity prices may rise or fall over this timescale, which in turn will impact on farm profitability.
- **TB and disease controls** – if moving livestock between farms, health and disease risks must be considered:
    a. Responsibility for cattle movement controls (BCMS), TB testing and registration of any births or deaths within BPS Cross Compliance should be specified in any agreement or system.
    b. Impact or requirement of farm assurance should be considered when looking at stock ages or farm management plans.
    c. Basic management including fly and parasite management requires a veterinary written health plan, and structured approach for the best practice of the stock.
- **Stock management**– livestock should be managed by trained and experienced stockpeople. Many arable farmers, and their staff, have been removed from stock management for years or even generations. Farms and farm staff new to livestock management should get support, for example from other local stock farmers, vets or consultants. The 'Useful links and further reading' section below includes links to livestock specific LANTRA-approved training courses.

1.5 Managing the system for better returns

Good grass and grazing management will maximise grass growth and utilisation, live weight gain per hectare, and profitability of the system.

- **Choice of ley species mix:** select a species mix which is appropriate for the soil type and climatic conditions, and main use (cutting, grazing, or a combination of cutting and grazing). Grass and clover, and multispecies mixes which include legume species will reduce (or eliminate) the need for artificial nitrogen fertiliser. Deep rooted species such as chicory and plantain are more drought tolerant and help provide resilience in dry weather conditions.

- **Grazing management:** AHDB provides advice on grazing management in their 'Planning grazing strategies for better returns' publication. This advice is based on maximising grass growth and livestock performance. Grass should be grazed at the 2.5-3 leaf stage and then rested when total grass growth falls below 1,250-1,500 kg DM/ha (3-4 cm). This will maximise grass growth and yields by maintaining the optimum leaf area to capture sunlight. Grazing too low can reduce grass growth, whilst grazing too high can increase wastage and the build-up of unproductive dead leaves at the base of the sward. Rotational grazing management, where fields are divided into paddocks and cattle moved to fresh grazing every 2-4 days provides good control over sward height and will help to maximise grass growth and utilisation.
- **Measure to manage:** measuring grass growth against livestock demand can help optimise output per animal and per hectare by identifying periods when there is too little or too much grass. When there is too little grass, the farm may choose to sell stock or to provide supplementary feed. When there is too much grass, fields can be shut up for silage or hay.

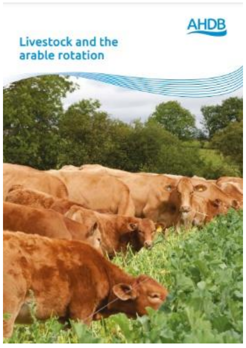
1.6 Summary

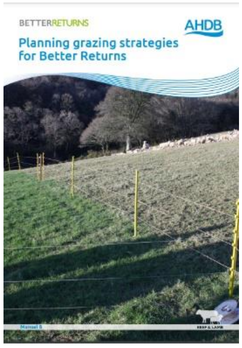
There has been increased interest in recent years on reintegration of livestock into arable systems, and in particular the potential soil and other environmental benefits of a return to a mixed farming approach. This project has quantified benefits of integrating temporary leys into arable rotations on soil health, black-grass control, and yield benefits to the following arable crop. The economic cost benefit analysis has shown that there is potential for beef production to add an income stream to an arable enterprise, and for a 'joint venture' approach to provide an income stream for both a beef producer and arable farmer.

1.7 Useful Links and Further Reading

Guides and webpages:

- AHDB 'Beef in the arable rotation – Mix and match calculator' (developed as part of this project).
- AHDB 'Livestock in the arable rotation' webpages.
- AHDB 'Livestock in the arable rotation' guide.
- AHDB 'Planning grazing strategies for better returns' guide.
- National Sheep Association 'The benefits of sheep in arable rotations' guide.
- Organic Research Centre 'Sheep grazing within arable rotations' bulletin.
- Agricology 'Livestock and the arable rotation' webpages.





Training:

LANTRA courses for stockmanship and other livestock considerations can be accessed via the LANTRA website. Relevant training includes:

- 'Better livestock handling for increased profitability' course.
- 'Fencing and gate installation – post and strained wire' course.
- 'Safe use of veterinary medicines' course.

Networks:

- ADAS, AHDB and Defra Grass & Herbal Leys Network
- Independent livestock and grazing consultant Dr Liz Genever runs the 'Carbon Dating' network, looking to pair livestock and arable farmers:

2 INTRODUCTION

2.1 Background

The high costs and increasing competition for land means that starting or expanding beef enterprises can be challenging. One option for beef producers is to graze cattle on leys on predominantly arable units, either by renting land or by paying arable farmers to keep cattle. Integrating beef enterprises into arable rotations provides new opportunities for both beef producers and arable farmers. For beef producers, this represents an opportunity for new entrants to the beef industry or for enterprise expansion. For arable farmers, beef cattle may be able to achieve the same or higher net margin per hectare compared to traditional arable rotations, with the additional benefits of better weed control and improved soil condition resulting from the establishment of leys. However, expansion is limited by uncertainly for arable farmers of the economic return from beef compared to arable crops, and the practicalities and infrastructure requirements of having cattle on the farm.

2.2 Aims and objectives

The overall aim of this project was to investigate the practical, economic, environmental, and agronomic implications of integrating beef enterprises into arable systems on two farms. The project was divided into five work packages with the following objectives:

Work package 1: Livestock performance

Objective 1**:** To assess the performance of 'growing' cattle grazing leys.

Work package 2: Economic cost benefit analysis

Objective 2: To provide arable farmers with a cost benefit evaluation of integrating grazed leys into the arable rotation.

Objective 3: To provide new and existing beef farmers with the economic information to enable them to evaluate the feasibility of expanding stock numbers by grazing cattle on leys in arable rotations.

Work package 3: Soil quality and benefit to the following crop

Objective 4: Assess the impact of a three year grass & clover/multispecies ley on soil physio-chemical properties.

Objective 5: Quantify the yield benefit of a three year grass & clover/multispecies ley to the following arable crop.

Work package 4: Weed assessments and monitoring

Objective 6: To assess the effectiveness of the grass & clover/multispecies ley within an arable rotation to reduce black-grass numbers.

Work package 5: Knowledge transfer

Objective 7: To collate outputs from work packages 1-4 into a KT programme to demonstrate the costs and benefits of integrating beef enterprises into arable systems.

2.3 Experimental sites

The project included monitoring at two farm sites, one in Cambridgeshire and the other in Somerset.

Site 1: Thriplow Farm, Cambridgeshire (host farmer David Walston)

This site was in an existing multispecies ley (established autumn 2013) and was monitored as part of this project in 2016. The site returned to arable production in 2017. Monitoring at this site in 2016 included livestock performance and an economic analysis of integrating livestock into the arable enterprise. Additional observations on weed species and density were carried out in May 2017 in the following arable crop.

Site 2: Norwood Farm, Old Sodbury, Somerset (Dyson farming, farm manager Peter Lord)

Norwood Farm was bought by Dyson Farming in 2016. It was an arable farm which Dyson Farming have since transitioned to a mixed beef/sheep and arable farm. In September 2017, six fields were sown to grass & clover or multispecies leys as part of this project. All six fields were cropped with winter wheat in 2016 and prior to this had been in long term (>10 years) arable production. Measurements covered a 5-year period including the year before the ley (2017), the three years down to ley (2018 to 2020) and the subsequent arable crop (harvest year 2021).

3 THRIPLOW FARM

3.1 Farm background

Thriplow Farm is a 900-ha arable farm on mainly medium textured sandy clay loam/clay loam soils. The farm has moved to no-tillage with the joint objectives of reducing costs without compromising yields and improving long term soil quality. The typical rotation is winter wheat every other year with a break crop of spring barley, spring beans, peas, or oilseed rape. In autumn 2013 a multispecies ley was established in a 16-ha clay loam field. The multispecies ley included ryegrass, timothy, cocksfoot, white and red clover, bird's foot trefoil, alsike, sainfoin and chicory.

The field remained in the multispecies ley for three seasons (2014, 2015 and 2016) and returned to arable production in autumn 2016 (winter beans). As the field at Thriplow Farm was already established in a multispecies ley when this project started, it was not possible to measure 'baseline' arable soil physio-chemical properties or weed populations within this project. Measurements at this site included grass growth and forage quality, livestock performance, an economic analysis of integrating livestock into the arable enterprise, and assessments of weeds in the following arable crop.

3.2 Grass and grazing management

In 2016, the field was grazed by 78 dairy and dairy cross steers which were turned out at approximately 5-6 months of age.

The cattle were provided by beef producer R&B Beef who paid the host farm (Thriplow) for time and weight gain on the farm (section 3.6 and Figure 1).

The cattle were grazed for 6 months (177 days) between 20/04/16 and 14/10/16.

The 16-ha field was divided into either twenty-four 0.67 ha or forty-eight 0.33 ha cells depending on grass growth, and the cattle were moved daily (Plate 1).

Plate 1. Division of 16 ha field into cells for grazing

3.3 Grazing – forage yields and quality

A good supply of high-quality forage is important to maximise animal performance. Forage yields and quality were measured five times during the 2016 grazing season. Forage yields were estimated by cutting a 3 m^2 area of grass (three 1 m^2 quadrats) to approximately grazing height from the next cell to be grazed. A sample of this fresh grass was sent to Sciantec Laboratory for NIR (Near-infrared spectroscopy) forage analysis on 13/05/16, 09/06/16, 15/07/16, 12/08/16 and 14/10/16 (Table 1).

Grazed grass yields were estimated at 15 t/ha fresh weight (4.1 t/ha dry matter), equivalent to 16.8 kg/cow/day fresh weight (4.8 kg/cow/day dry matter). Grazing height varied during the season from 10-15 cm to a maximum of around 50 cm. Early in the grazing season (late May to June) grass growth exceeded cattle requirement and the sward was not grazed down tightly. When the grass was sampled on 09/06/16, grazing height was estimated at 50 cm (Plate 2) and the total quantity of forage remaining after the cattle had grazed a cell (i.e. 'wastage') was estimated by cutting a 3 m^2 area of grass to 10 cm at 9.6 t/ha fresh weight. The grass was topped in sections between mid-June and mid-July, which resulted in a measurable improvement in both forage quality and cattle performance. Crude protein content of grazed grass sampled on 09/06/16 was 8%, compared to 14-19% on the other sampling dates (see Table 1)


Plate 2. Grass covers on 09/06/16


Plate 3.. Grass covers on 22/07/16

Table 1. Thriplow Farm fresh grass analysis 2016 (NIR analysis)

Analysis	Units	Sampling date				
		13/05/16	09/06/16	15/07/16	12/08/16	14/10/16
Dry matter	%	25.3	34.1	26.3	42.1	41.1
Crude protein	% of dry matter	19.4	7.9	15.5	13.9	14.3
D value		68.6	61.3	65.5	59	61.4
ME	MJ/kg DM	10.8	9.6	10.3	9.3	9.6
Neutral Detergent Fibre	% of dry matter	46.1	63.3	51.1	58.5	53.9
Ash	% of dry matter	7.3	5.4	7.4	7.3	8.2
Total oil	% of dry matter	3.2	1.5	2.5	2	2.3
Sugar	% of dry matter	10.4	12	10.1	6.5	11.2
Nitrate Nitrogen	% of dry matter	0.01	0.01	0.01	0.01	0.01
Buffering capacity	meq/kg	413	370	402	370	370
Water soluble carbohydrate	% of fresh weight	1.7	2.6	2.9	1.0	2.3
Acid Detergent Fibre	% of fresh weight	4.7	12.2	8.2	17.7	10.4

3.4 Cattle performance

3.4.1 Methodology

The performance of the cattle grazing the multispecies ley at Thriplow Farm in 2016 was assessed by R&B Beef (who owned the cattle). The cattle were weighed before they were taken to Thriplow Farm. A mobile crush was used to weigh the cattle during the season (Plate 4). Cattle were weighed –

- 20/04/16 (prior to delivery to Thriplow)
- 22/07/16
- 09/09/16
- 14/10/16 (before cattle moved from Thriplow)

The cattle were housed between mid-October 2016 and mid-February 2017 when they were sold for beef. Cattle were weighed during the housing period (04/01/17) and at the end of the housed period on 13/02/17. Seventy-six of the initial 78 cattle were sold for beef (one animal died during the grazing period and another stunted animal was sold out of the system before finishing). Information on cattle performance is presented for the grazing and housed period. Information on veterinary inputs and any other health related issues were recorded.

Plate 4. Mobile crush used for weighing cattle at Thriplow Farm

3.4.2 Results

The average live weight of the calves at turnout was 175 kg (range 146 to 241 kg) (Table 2). Over the 177-day grazing period the cattle gained an average of 90 kg, equating to an average Daily Liveweight Gain (DLWG) of 0.51 kg/day (Table 3). This was below the R&B Beef target growth rate of 0.7 kg/day (i.e., 120 kg gain over the six-month period). Over the four-month housed period the cattle gained an average of 116 kg, equivalent to 0.95 kg DLWG (Table 3). There was considerable variation in performance across the group, with recorded growth rates ranging from 0.05-0.77 kg/day at pasture and 0.2-1.72 kg/day when housed (Table 3). Tracking performance of the cattle by quartile showed that those cattle that performed best at pasture continued to perform best when housed.

Performance of the calves was poorest during the first half of the grazing season when the sward height had been allowed to become too high and fibrous. The field was topped in sections between mid-June and mid-July which had a measurable improvement in forage quality (Table 1). This was also reflected in cattle performance with live weight gains more than 1 kg/day recorded between the September and October weighing, compared to average growth rates below 0.5 kg/day before that time (Table 4). Cattle performance was similar across breeds, although the group was dominated by Holstein Freisian (85%, Table 5).

Assuming a cost per day to the beef producer of £0.50/head whilst the animals were at pasture, the cost per kg live weight gained at pasture was £0.98, just inside R&B Beef target for grazing of less than £1.00 per kg/gain. This can be compared to, a cost per day to the beef producer of £1.20/head during the housed period, and a cost per kg live weight gained of £1.15 over the four-month housed period. Note, this excludes additional costs of haulage and veterinary medicine.

Table 2. Cattle live weights over six months' grazing and four-month housing period

Cattle live weight (kg)	Grazing period				Housed period	
	20/04/2016	22/07/2016	09/09/2016	14/10/2016	04/01/2017	13/02/2017
Mean	175	200	222	266	338	393
SD	15.0	24.3	26.2	28.3	44.1	47.5
Min	146	143	154	176	185	201
Max	241	253	274	328	442	528
Range	95	110	120	152	257	327
Range as % of min	0.7	0.8	0.8	0.9	1.4	1.6

Table 3. Cattle live weight gain by quartiles during grazed and housed period

	Grazing period		Housed period		Total period	
Percentiles	LWG (kg)	DLWG (kg)	LWG (kg)	DLWG (kg)	LWG (kg)	DLWG (kg)
First	77	0.44	116	0.95	197	0.66
Second	92	0.52	127	1.04	219	0.73
Third	103	0.58	141	1.16	241	0.81
Fourth	136	0.77	210	1.72	330	1.10
Mean	90	0.51	128	1.05	218	0.73
SD	23	0.13	27	0.22	42	0.14
Min	9	0.05	25	0.20	34	0.11
Max	136	0.77	210	1.72	330	1.10
Range as % of minimum	127	0.72	185	1.52	296	0.99

Cattle divided into quartiles based on final live weight (13/02/2017).

Table 4. Mean cattle daily live weight gain during grazing and housed period

Period	Days	DLWG (kg)
20/04/16 to 22/07/16	93	0.3
22/07/16 to 09/09/16	49	0.4
09/09/16 to 14/10/16	35	1.2
Grazing period (20/04/16 to 14/10/16)	**177**	**0.5**
14/10/16 to 04/01/17	82	0.9
04/01/17 to 13/02/17	40	1.4
Housed period (14/10/16 to 13/02/16)	**122**	**1.0**
Total period (20/04/16 to 13/02/17)	**299**	**0.7**

Table 5.Cattle performance by breed

	Grazing period		Housed period		Total period	
	LWG	DLWG	LWG	DLWG	LWG	DLWG
All cattle (n=77)						
Mean *SD*	90 *(23)*	0.51 (0.13)	128 *(27)*	1.05 *(0.22)*	218 *(42)*	0.73 *(0.14)*
Aberdeen Angus Cross (n=2)						
Mean SD	79 *(10)*	0.45 *(0.06)*	113 *(20)*	0.93 *(0.16)*	192 *(30)*	0.64 *(0.10)*
Hereford Cross (n=14)						
Mean SD	93 *(32)*	0.52 *(0.18)*	138 *(41)*	1.13 *(0.33)*	231 *(68)*	0.77 *(0.23)*
Holstein Friesian (n=61)						
Mean SD	90 *(21)*	0.51 *(0.12)*	126 *(23)*	1.03 *(0.19)*	216 *(33)*	0.72 *(0.11)*

In summary, whilst the cattle made a return during the grazing period, the live weight gain was below target. Turnout was later than planned and therefore the calves were unable to utilise the sward efficiently and it rapidly lost much of its nutrient value as the crop matured after flowering. In addition, the 16-ha field provided more forage than this number of cattle could utilise which contributed to the decline in forage quality.

In planning the number of cattle for grazing it was important for the host farm (Thriplow) to allow sufficient forage even in the event of a droughty poor growing season. This is particularly important if there is no other home-grown forage available which would necessitate buying in forage if the grass did not provide sufficient feed, as was the case at Thriplow. However, this also means that there may be an excess of forage under good growing conditions and to maintain forage quality, the sward should be topped or cut if necessary.

The calves used during the trial started grazing at 5 to 6 months of age. Cattle of this age require good quality forage to maintain growth rates of 0.7 to 1 kg/day. This does require a high level of grassland management as the young stock are learning to graze and do not graze out the sward as well as older cattle (yearlings), resulting in lower grass utilisation. Animal performance would improve if the cattle grazed smaller sections of fields rotationally. If grass height was above target, areas of the grazing block could be cut for silage to maintain forage quality. Grass quality could also be improved by allowing yearling cattle to 'graze out' a paddock after the calves had grazed.

3.5 Weed assessments

Leys can significantly help cultural control of black-grass by allowing seed in the seed bank to decline due to competition and seed degradation. However, when integrated into an arable rotation they may also contribute volunteer weed species to the following arable crops; this was noted as a concern by the host farmer at Thriplow Farm. A site visit was carried out on 12/05/17 to observe and record the main weed species or volunteers present in the winter bean crop following the three-year grazed multispecies ley. The ley was sprayed off with glyphosate in autumn 2016 and the winter beans were direct drilled.

3.5.1 General observations

A good crop of winter beans was established following the ley (Plate 5). A general overview of the field looked clean of weeds except a few areas of charlock (flowering). The farmer confirmed that charlock was a significant weed problem in in the previous cereal crop. There was generally good ground cover from the trash of dead cocksfoot tufts (right hand photo Plate 5) and overall the weed cover across the majority of the field (excluding the charlock patches and odd larger chicory patch) was less than 3 plants/m^2.

Plate 5. Winter bean crop

3.5.2 Weed species and general abundance

The weed assessment was carried out by walking the southern headland tramline east-west and then walking each tramline north-south, with two people observing on each side. There was a mixture of common arable weeds and volunteer species from the previous multispecies ley (Plate 6). The species were ranked in order of abundance, with the most abundant at the top of the list below. Weeds were very patchy across the field with the highest charlock density at 200 plants/m^2, but generally charlock populations were 10 plants/m^2. Chicory volunteers were widespread with a mixture of new growth (1^{st} year) and 2^{nd} year growth.

<u>Main and predominant weeds:</u>

- **Charlock** (*large patches near the western side of the field, growth stage 12-60 (2 true leaves - flowering)*)
- **Chicory** (*volunteers, growth stage 12-33 (2 true leaves-150 mm diameter), 1^{st} and 2^{nd} year growth*)
- **Birdsfoot trefoil** *(growth stage 11-34 (1 true leaf – 200mm diameter))*
- **Sainfoin** *(growth stage 11-34 (1 true leaf – 200mm diameter)*

- **Cocksfoot** (*growth stage 11-21 (1 true leaf – 1^{st} tiller visible*)
- **Prickly sowthistle** (*growth stage 14-18 (4 – 8 true leaves*)

<u>Other weeds, low numbers (less than 1 plant/m^2):</u>

- **Fumitory** (*growth stage 14-60 (4 true leaves - flowering)*)
- **Ivy-leaved speedwell**
- **Poppy** (*mainly near the southern headland*)
- **Mayweed**
- **Black-bindweed**
- **Black-grass**
- **White clover**
- **Thistle**

The farmer mentioned that black-grass has been a problem in this field before the ley was sown. There was one distinct patch, in a natural dip that had been particularly affected. This was the only area of the field that black-grass was recorded in 2017 with low populations of generally 1-2 plants/m^2 and up to a maximum of 10 plants/m^2.

Plate 6. Volunteer species in winter bean crop from multispecies ley

3.6 Cost benefit

3.6.1 Introduction

A full economic cost benefit analysis of integrating beef into arable rotations was carried out for both the arable farmer (David Walston at Thriplow Farm) and the beef producer (R&B Beef).

From an arable perspective the analysis assessed whether:

- beef cattle can provide a viable alternative income source
- margins are equal to or better than crop margins per ha.

For the beef producer, the analysis assessed whether grazing cattle in an arable rotation can

- reduce production costs
- provide sustainable margins.

There are several different business models available to farmers when deciding whether to introduce grazing cattle (or other livestock) into an arable rotation, including owner-occupier or tenant farming, rented grazing, contract grazing, and joint ventures.

Figure 1 outlines the system of responsibility and ownership agreed at Thriplow Farm. The economic analysis presented here is based on this system.

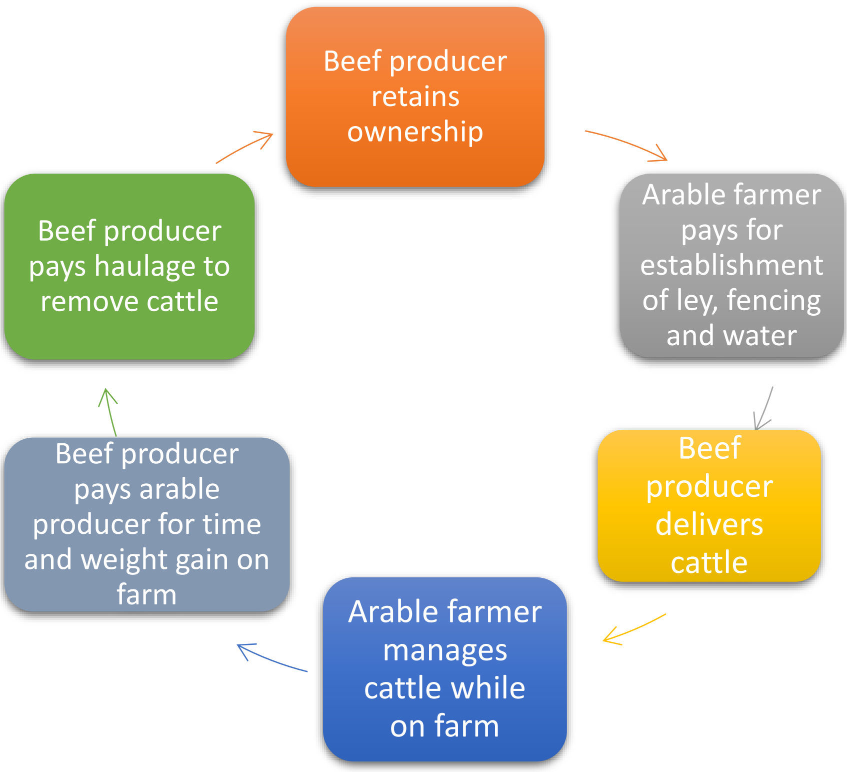


Figure 1. System of responsibility and ownership used at Thriplow Farm

3.6.2 Methods

In conjunction with the host farmer, the cost of establishing the grazing area and managing the cattle were calculated. Infrastructure costs were derived from the market price of items and the farmer's estimates of labour time, while establishment costs were determined using the farmer's assessment of the cost of the tasks involved.

Table 6. List of costs considered in the setting up of the ley and rearing the cattle

Set-up costs	Cattle production costs
Establishment of the ley: Tillage (e.g. discing, drilling, rolling) Inputs (e.g. seeds, sprays, fertiliser)	**Variable costs:** Additional forage or supplementary concentrates Fertilisers or sprays Vet and medicines charges
Infrastructure costs: Fencing posts Fencing wire Electric fencing equipment Water troughs and pipes Handling system Labour	**Fixed costs:** Labour Machinery/vehicles Electricity Water

Ley establishment costs were depreciated over the three years of the ley. Infrastructure assets were depreciated over a reasonable useful lifetime of 15 years, with an assumed zero residual value.

Cattle production costs were minimal for the time that cattle were at Thriplow Farm. The vet and medicine costs were covered by R&B Beef. The farmer gave an estimate of the labour time required to administer medicines and carry out other cattle management tasks.

Electricity and water use costs were estimated as no meter readings were available. Electricity consumption was estimated at 18 watts/day of use based on the fencing equipment used. Water consumption can vary tremendously in growing cattle. According to AHDB Beef and Lamb (BRP+ Water use, reduction and rainwater harvesting on beef and sheep farms), water consumption can range between 15 and 50 litres per day depending on age, temperature and dry matter of forage eaten amongst other factors. Considering the age of cattle reared at Thriplow, water use was estimated at 25 litres/day.

Labour was factored in at a cost of £12/hour.

Livestock weights, used to assess animal performance from the grazing cattle, were provided by R&B Beef.

3.6.3 Results

The total cost of setting up the multispecies ley and infrastructure to handle cattle at Thriplow was estimated at £472/ha. At the time of purchasing the multispecies ley seed mix, the price was £173/ha.

Water supply costs were minimised by constructing water troughs using worn tractor tyres in a way that allowed them to be moved when required.

Although £472/ha cost represents the initial cash outlay, for cost benefit analysis and budgeting purposes, the costs were be spread over the period of the ley and reasonable lifetime of the infrastructure items and equipment. For the 3 years that the ley was at Thriplow, the straight line depreciated setting up costs of the ley was £110 per ha per year (Table 7).

Table 7. Set-up costs at Thriplow Farm

Establishment of ley	£/ha	
Tillage – discing, drilling and rolling	65	All associated costs included
Seeds – multispecies ley mix	173	Actual price at time but can now be sourced for under £100/ha
Total establishment costs	**238**	

Infrastructure	£/ha	
Fencing and gates	130	Including electric fencing
Water troughs and pipes	48	Includes cost of DIY water troughs
Labour	56	
Total infrastructure costs	**234**	

Total set-up costs	£/ha	
Establishment costs	238	
Infrastructure costs	234	
Total	472	This represents the initial cash outlay
Total cost per year spread over the 3-year ley	**110**	This represents the annual cost for budgeting purposes. Based on three-year depreciation of establishment costs and 15-years for infrastructure items
Sensitivity to length of ley		
Total cost per year spread over a 2-year ley	159	
Total cost per year spread over a 4-year ley	85	

Table 8 shows the costs based on the 2016 grazing season. The costs borne by the arable farm in 2016 were minimal with no requirement for additional feed or fertiliser. Labour and water were the main costs incurred. Total costs were estimated at £76.50/ha.

Table 8. Cattle rearing costs covered by Thriplow Farm

Costs to the farm per year (based on 2016)	£/ha	
Additional feed and forage	0	
Fertilisers or sprays	0	
Labour	37	For cattle management tasks
Electricity	0.5	For electric fencing
Fuel	6	For cattle management tasks
Water	33	Mains water
Total cost to the arable farm per year	**76.50**	

Under the arrangement at Thriplow, income to the farm was derived from a mixture of a bed and breakfast type payment and bonuses. For every animal reared the arable farm received £0.50 per animal per day. If during the grazing period the cattle gained more than 100 kg in weight, a bonus payment of £0.50 per kg was paid on the additional weight. A B&B payment was paid on 77 cattle and the cattle gained on average 90 kg in weight over 177 days, therefore a bonus was not paid.

Total income per animal was £89 with 77 cattle reared on the 16 ha, resulting in a £426/ha income. Had the cattle achieved the target 0.9 kg/day an additional £29.85 per head or £2,298 total would have been paid, lifting the return to £569 per ha grazed.

Table 9. Cattle income to Thriplow Farm

Based on 2016	£	
Bed and breakfast charge (£0.50 per animal per day) for 177 days	89	Per animal reared
Total B&B charge over 77 animals	6,815	
Bonus paid on each additional kg of weight gain over 100 kg (£0.50 per kg)	0	Per animal on average weighing above 100 kg threshold
Total bonus paid over 77 animals	0	
Total income (per head)	89	
Total income (per ha)	426	

When the total depreciated set-up costs and cattle rearing costs are deducted from the income received a net margin is calculated at £240/ha per year of the ley at Thriplow Farm.

Table 10. Full economic net margin to the arable farm

Based on 2016	£/ha	
Income	426	Based on 77 cattle
Total establishment and infrastructure costs	110	Based on a 3-year ley
Total cattle rearing costs covered by the arable farm	76.5	Based on 77 cattle
Net margin	**239.5**	
Sensitivity		
Change in daily liveweight gain of +/- 0.1kg changes the bonus payment by	+/- 43	
No mortality	+15	

R&B Beef paid £89 per head to the arable farm for grazing and added £48 from other costs (medicine and haulage etc.) to make a total £136 per head of costs. Based on the 90 kg weight gain, this is equivalent to a cost of £1.51 per kg of gain. When set against the £220/head increase in cattle value, the net value added for the cattle owner was £84 per head.

Table 11. Value added for the Cattle Owner

Based on 2016	Annual £/head	
Estimated change in value of cattle	220	Based on 77 cattle
B&B payment and bonus paid to arable farmer	89	Based on £0.50 per day and on every kg gained over 100kg
Variable costs	48	Medicines and haulage only
Fixed costs	0	Costs borne by the arable farmer
Total costs to the cattle owner	136	
Cost per kg of gain	1.51	
Net value added	84	
Sensitivity		
Change in Daily Liveweight Gain of +/- 0.1kg changes the bonus payment by	+/- 9	
No mortality	+8	

3.7 Thriplow Farm conclusions

This work has shown that there is potential for an arable farmer to make a margin from cattle grazing a ley based on an arrangement like the one used at Thriplow Farm. For other farms, the economics will vary depending on the length and performance of the ley.

General observations in the winter bean crop immediately following the ley suggested that weed numbers were generally low and manageable. Most of the weed burden (charlock) came from the existing weed seed bank, however there were a small number of volunteer chicory plants.

The price paid by the beef producer to the arable farmer resulted in a net margin (income-costs) of £239.50/ha for the arable farmer, despite growth rates not reaching a target of 0.9 kg LWG/day.

From the beef producer's perspective, this work has shown that there is the potential to add value to the cattle with such an arrangement seen at Thriplow Farm. By not having to carry the fixed resources required, costs are kept to a minimum for the beef producer. The cattle gained an average of 90 kg during the grazing season, which represents an increase in cattle value of £220/head gross or £84/head net (after accounting for costs).

However, value added gain is the key to the cattle owner if they are to achieve a sustainable return. This is where the right arrangement between the cattle owner and the arable farmer is crucial. There needs to be sufficient incentive for the arable farmer to allocate time and resources to manage the cattle and grass to maximise liveweight gain. The cattle owner needs to ensure that the payment to the arable farmer is reasonable and based on a reasonable performance of the cattle so that there is value gained from the animals by the end of the grazing period.

However, the experience at Thriplow Farm has also showed that cattle performance, which was below target, could have been improved with better grass management. It is important to manage grazing to ensure there is sufficient grass to meet demand and maximise grass quality. However, these are skills which need to come with the beef producer or be taught to the arable farmer to maximise performance and profitability for the two parties. This will lead to the arable farmer maximising output per hectare and will allow the beef producer to maximise return per head.

4 NORWOOD FARM

4.1 Farm background

Norwood Farm is a 130-ha mixed farm on mainly medium textured clay loam and silty loam soils. The farm is located in Norton St Philip, south of Bath, Somerset and the average annual rainfall is *c*.900 mm. The farm was in long term arable production until 2016, when it was purchased by the Dyson Farming Group and transitioned to a mixed arable, beef and sheep farm. The farm has 570 beef cattle and 2150 sheep. 110 ha of long-term arable land have been sown to a mix of permanent and temporary grass, which are managed by a combination of cutting and grazing. Arable fields are in a rotation of combinable crops and leys.

The overall aim of this project was to investigate the practical, economic, environmental, and agronomic implications of integrating beef enterprises into arable systems. Although Norwood farm is being managed as mixed rather than arable enterprise, the fields used in this project were long term arable, enabling the assessment of the environmental and agronomic benefits of introducing leys into the rotation. The farm was selected as it provided the opportunity to monitor the effect of introducing grass and multispecies leys into the rotation in several fields, and the farm management were willing to allow split field comparisons i.e., grass compared to arable, and grass & clover compared to multispecies ley. The economic cost benefit analysis has been carried out based on number of scenarios including separate arable and beef enterprises.

In September 2017, six fields were sown to grass and clover, or multispecies leys (Figure 2). All six fields were cropped with winter wheat in 2016 and prior to this had been in long term (> 10 years) arable production.

- NOR 07 (6.7 ha) was split equally between grass and clover mix, and arable cropping (Plate 7).
- NOR 05 (9.6 ha) was split between a grass and clover mix (3.6 ha), and a multispecies mix (6.0 ha).
- NOR 06 (7.5 ha) was split between a grass and clover mix (3.3 ha), and a multispecies mix (4.3 ha).

In total there was around 10 ha of grass and clover across NOR 07, NOR 05 and NOR 06, and 10 ha of multispecies mix across NOR 05 and NOR 06 (Figure 2). These three fields were used for assessments of cattle performance, and forage covers and quality.

In addition, NOR 08 (4.2 ha), NOR 02 (9.5 ha) and NOR 01 (10 ha; Figure 6) were sown to the same grass and clover mix and were managed by cutting and grazing. These three fields were included in the soil quality measurements.

Plate 7. NOR 07 showing Grass & clover vs. arable split (12/11/18)

Figure 2. Norwood Farm - field locations

Measurements at Norwood Farm covered a five-year period, including the year before the ley (2017), the three years of the grass and clover, and multispecies leys (2018 to 2020) and the subsequent arable crop (2021).

Detailed measurements were taken to assess the impact of the grass and clover, and multispecies leys on soil physio-chemical properties, black-grass weed populations and yield benefits to the subsequent arable crop as well as assessments of livestock performance and a cost-benefit analysis of integrating beef cattle into the arable enterprise.

4.2 Ley establishment and species assessment

The grass and clover, and multispecies seed mixes were provided by Germinal. The grass and clover mix (Table 12) was a standard long-term general-purpose mixture ('HSG1 Milk and Meat Production') targeted at grazing with the potential for a silage cut. The multispecies mix (Table 13) was based on the HSG1 mix with a reduced rate of perennial ryegrass (50%) and additional herbs and legumes.

Table 12. Grass and clover ley mix

kg/acre	Variety	Type
3	Abergain	Perennial Ryegrass Late (T)
3	AberGreen	Perennial Ryegrass Intermediate
2	AberMagic	Perennial Ryegrass Intermediate
2	AberZeus	Perennial Ryegrass Intermediate
1	AberDai	White Clover Medium
4	AberClyde	Perennial Ryegrass Intermediate (T)

Sown at 15 kg/acre; T = Tetraploid

Table 13. Multispecies ley mix

kg/acre	Variety	Type
2	AberGain	Perennial Ryegrass Late (T)
1.5	AberGreen	Perennial Ryegrass Intermediate
1	AberMagic	Perennial Ryegrass Intermediate
1	AberZeus	Perennial Ryegrass Intermediate
1.5	AberClyde	Perennial Ryegrass Intermediate (T)
1.5	AberChianti	Red Clover
1	AberDai	White Clover Medium
1	Presto	Timothy
0.75	AgricTonic	Plantain
0.30	Puna II	Chicory
0.25	Burnet	Misc
0.30	Aurora	Alsike Clover
0.25	Sheeps Parsley	Misc
0.20	Yarrow	Misc
0.30	leo	Birdsfoot Trefoil

Sown at 12.85 kg/acre; T = Tetraploid

The grass and clover, and multispecies leys established well in autumn 2017. In early May 2018, Germinal carried out a species assessment across the multispecies areas of NOR 05 and NOR 06 to assess the establishment of the multispecies mix (Plate 8). Ten replicate assessments were made in the multispecies sown areas of both fields using a 36 cm diameter ring (0.1 m^2). The number of sown species were counted in each ring and counts were multiplied by 10 to give a plant population per m^2. Perennial ryegrass was not included in the species counts, however in all rings perennial ryegrass numbers were between 270 and 350 m^2. Apart from the plantain, chicory, red and white clover, the other herb and legume species were low in number, possibly due to the late sowing or the competitive nature of the other species in the drill lines.

Plate 8. Establishment of the multispecies ley in NOR 05; photos taken on 27/11/17, two months after sowing

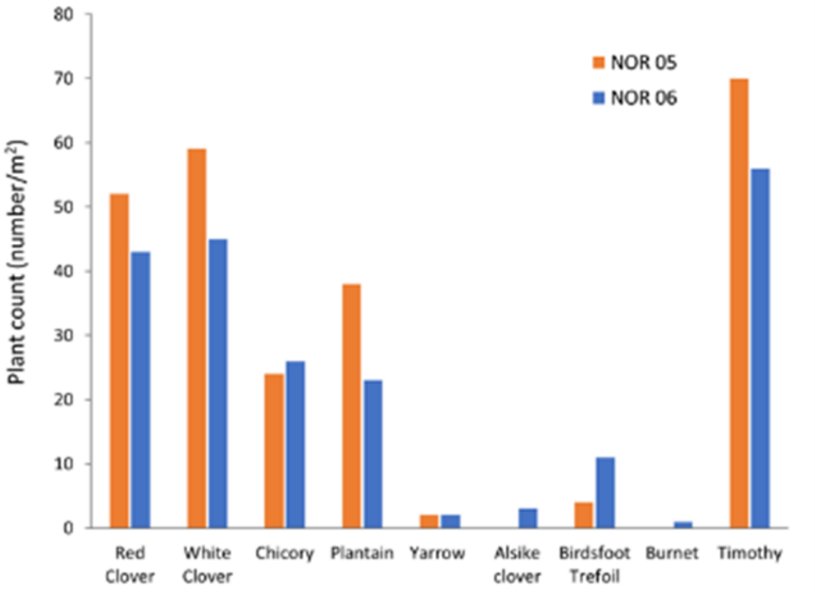


Figure 3. Species assessments in the multispecies areas of NOR 05 and NOR 06 (May 2018)

A second species assessment was carried out in the multispecies areas of NOR 05 and NOR 06 in November 2018 at the end of the first grazing season. The clover content was high, but the plantain and chicory numbers were low (estimated at about $1/m^2$) and it was difficult to identify any of the burnet, sheeps parsley or birdsfoot trefoil.

The grass and clover, and multispecies swards were visually assessed again by Germinal on 29/07/20 (Plate 9). The mixes in all fields were performing well and not yet in need of replacement. The white clover content in the grass/clover mix varied between fields and was estimated at *c*.40% in NOR 08 and *c*.15% in NOR 07. There was a good balance of grass, clover and other species in the multispecies mixes with the red clover doing particularly well. Chicory was visible across the multispecies leys and plantain, yarrow and birdsfoot trefoil were also identified. Burnet was present, but in very limited amounts; it is thought that burnet is not suited to heavier textured clay and clay loam soils. Germinal estimated that legumes were contributing about 30% of the biomass in the multispecies mixes.

NOR 06 Multispecies ley – photo showing red clover

NOR 06 Multispecies ley – photo showing yarrow

NOR 06 Multispecies ley – photo showing birdsfoot trefoil

NOR 06 Multispecies ley – photo showing burnet

Plate 9. NOR 06 multispecies ley; photos taken 29/07/20

4.3 Grass and grazing management

4.3.1 Year 1 - 2018

The grass and clover, and multispecies leys in NOR 07, NOR 06 and NOR 05 were split into approximately 1 ha paddocks and were rotationally grazed, with the cattle moved between paddocks every 2-4 days.

Rainfall in March and April 2018 (193 mm) was almost double the long-term average of 99 mm and consequently the fields were too wet to graze in March and April and cattle were turned out as one group in early May. The grass grew well early in the season and a cut was taken from NOR 05, NOR 06 and NOR 07 in early May. The grass and clover, and multispecies areas were cut separately and the bales from each stored separately in the field.

NOR 05, NOR 06 and NOR 07 were grazed with 102 Aberdeen Angus cross cattle (15-16 months old at turnout in May 2017). The cattle were divided into two groups in early June; one group to graze the grass and clover ley, and the other to graze the multispecies ley. The cattle in the two groups were balanced for sex, herd, sire, and last live weight. Each group of cattle was rotationally grazing either the grass and clover, or multispecies areas. The farm used temporary electric fencing to manage the grazing (Plate 10).

June and July 2018 were very dry (4 mm rainfall in June and 28 mm rainfall in July – 30% of long-term average), and the farm had to provide supplementary feed (silage) to the group of cattle grazing the grass and clover mix in July. The multispecies mix was more resilient to the drought and no supplementary feed was given to the group of cattle grazing this mix.

Grass covers improved with rainfall later in July and August. During September the farm started to move the heavier cattle inside for finishing and all cattle were inside by the end of September. All fields were then grazed with sheep.

Plate 10. Temporary electric fencing used for paddock grazing

4.3.2 Year 2 - 2019

In 2019, the grass and clover areas of NOR 05, NOR 06 and NOR 07 were grazed with 24 in-calf Aberdeen Angus heifers, and the multispecies mix areas of NOR 06 and NOR 07 were grazed with 25 cows and 25 calves. Each group of cattle was managed separately and grazed on the grass and clover (heifers) or multispecies (cows and calves) mixes. Additional weight measurements were not made during the season as these were not growing cattle. Each group of cattle rotationally grazed either the grass and clover or multispecies areas; each split field area (of between 3 and 6 ha) was typically split into three or four paddocks and the cattle moved every two to five days, depending on grass growth. The performance of the cattle at grazing was good – no veterinary inputs were required, and no welfare issues were recorded by the farm. The farm took dung samples for analysis of faecal egg counts during the grazing season and all readings were below the thresholds for action.

4.3.3 Year 3 – 2020

The grass grew well early in the season and a cut was taken in late April and again in late May. The farm noted faster regrowth on the multispecies sections than grass and clover sections of NOR 05 and NOR 06. Although the original plan had been to graze the fields with growing stock, grazing was delayed by TB testing early in the season. The fields were grazed with cows and calves from June to September 2020.

4.4 Forage yields and quality

4.4.1 Forage yields

Grass covers (i.e., biomass) were measured for quantity and quality from the grass and clover, and multispecies leys approximately monthly during the 2018, 2019 and 2020 grazing seasons. Covers were measured using both a plate meter and a 'cut and weigh' method (Plate 11). At each visit, grass covers were measured in the next paddock to be grazed in both the grass and clover, and multispecies area. Grass covers were measured by cutting and weighing grass within three replicate 1 m^2 quadrats from the next area to be grazed in both the grass and clover, and multispecies areas; grass was cut to 10 cm, which was approximately grazing height. In addition, a plate meter was used to measure grass cover within each of the quadrat areas prior to cutting to assess the relationship between the cut and weigh and plate meter measurements.


Plate 11. Assessment of forage yields using plate meter (left) and quadrat yield assessments (right)

Grass covers in the next areas to be grazed were typically around 800-1,100 kg DM/ha measured using the cut and weigh method and around 3,000-3,500 kg DM/ha measured using the plate meter (Table 14). Grass covers measured using the cut and weigh method were an average of 2,500 kg DM/ha less than measured using the plate meter, as the cut and weigh method only measures to grazing height (10 cm), whereas the plate meter provides an estimate of total biomass. The average difference of 2,500 kg DM/ha can be assumed to be an estimate of the amount of 'residual' grass remaining below 10 cm.

There were some differences in covers in the next area to be grazed between the grass and clover, and multispecies swards on individual sampling dates, however on average over the duration of the project, grazing covers were similar between the two sward types.

Table 14. Grass cover measurements (using both cut and weight, and plate meter methods)

Date	Grass cover kg DM/ha			
	Cut & weight (to 10cm)		Plate meter	
	Grass & clover	Multispecies	Grass & clover	Multispecies
05/06/2018	1840	1842	4926	4889
09/07/2018	756	96	2857	1928
17/09/2018	656	607	3879	3370
02/05/2019	802	950	3230	3605
16/07/2019	2037	2420	3584	4728
22/10/2019	648	909	2053	2474
02/07/2020	804	1748	3468	4617
29/07/2020	1540	859	4261	3631
18/09/2020	365	1809	2721	4462
06/05/2021	230	72	2091	1947
09/06/2021	1565	526	4047	2333
14/07/2021	107	1642	2749	4345
10/08/2021	279	686	2432	2997
20/04/2020	783	662	3418	3445
Mean	**887**	**1059**	**3265**	**3484**

Each measurement is a mean of three replicate measurements on each sampling date from the next area to be grazed in both of the grass and clover, and multispecies swards.

There was a good relationship between grass covers measured using the cut and weigh method and using a plate meter ($P<0.001$; $R^2=0.71$). There was no difference in the relationship between the cut and weigh method and using a plate meter between sward types ($P=0.097$).

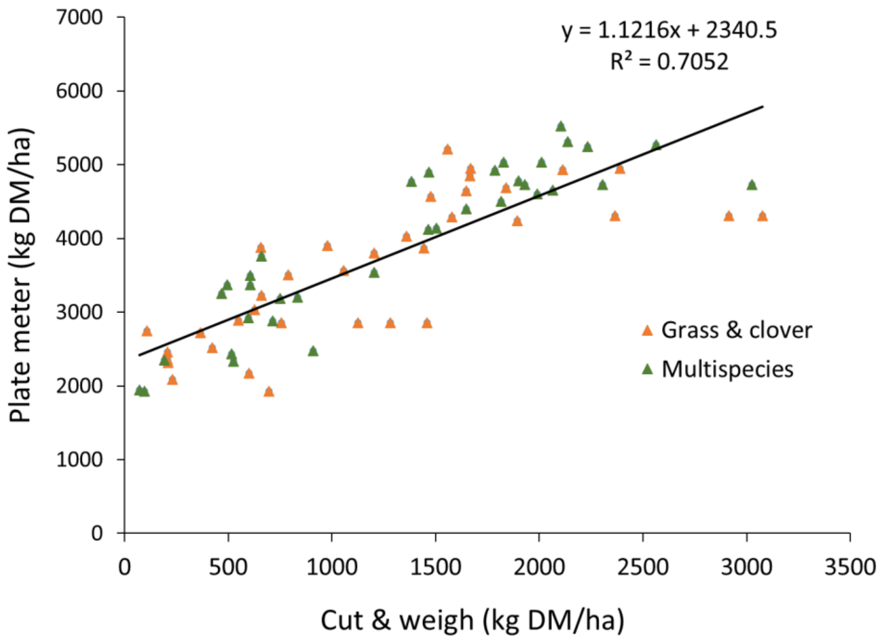


Figure 4. Relationship between grass covers measured using the cut and weigh method and using a plate meter

4.4.2 Forage quality

A sample of fresh grass from the next area to be grazed in both the grass and clover, and multispecies areas was sent for forage analysis on each date. Grass samples were analysed for forage quality including dry matter (oven dry method), NIR (Near-infrared spectroscopy) analysis for crude protein (CP), D-value, metabolisable energy (ME) and neutral detergent fibre (NDF), and wet chemistry analysis for water soluble carbohydrates (WSC), acid detergent fibre (ADF), and crude protein (CP). Wet chemistry was used in addition to NIR analysis for a limited number of determinants as the NIR calibrations used by the laboratory do not include calibration samples from high clover or multispecies swards; therefore, the wet chemistry analysis should be considered more accurate than the NIR analysis.

Forage analysis data is shown in Table 15. Dry matter content was slightly higher (*P*=0.002) in the grass and clover areas (mean 22.9%, range 15.3-30.6) than the multispecies areas (mean 20.4%, range 15.3-29.5). Higher dry matter forages can help improve intake volumes and potentially improve livestock performance. However, there was no difference between the grass and clover, and multispecies areas in crude protein, D-value (*P*=0.865), ME (*P*=0.865), NDF (*P*=0.597), WSC (*P*=0.102) or ADF (*P*=0.593).

Crude protein (by wet chemistry analysis) was an average of 18.5% of DM in the grass and clover areas (range 11.3-25.1%), and an average of 20.0% of DM in the multispecies areas (range 12.2-23.6%). There was a moderate relationship between CP measured by wet chemistry and NIR ($P<0.001$; $R^2=0.40$; Figure 5). There was no difference in the relationship between the wet chemistry and NIR analysis a between sward types (*P*=0.915).

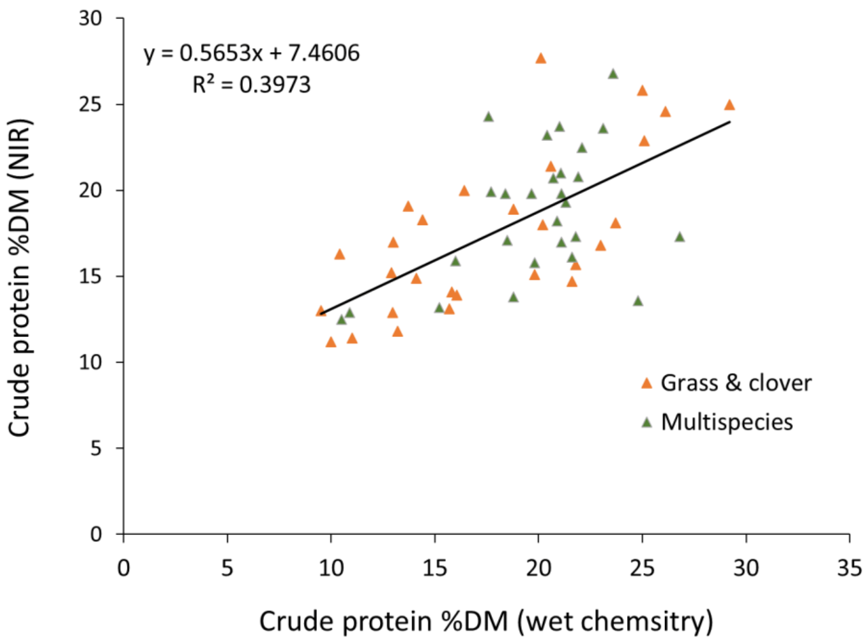


Figure 5. Relationship between grass covers measured using the cut and weigh method and using a plate meter

Metabolisable energy was an average of 11.4 MJ/kg DM in both the grass and clover areas (range 9.9-12.2 MJ/kg DM), and multispecies areas (range 10.3-12.4 MJ/kg DM).

There was no relationship between grass cover measured using a plate meter and CP (*P*=0.914), D-value (*P*=0.150), ME (*P*=0.446) or WSC (*P*=0.638). There was a significant but weak negative relationship between grass cover measured using a plate meter and dry matter content (*P*=0.004, $R^2=10.2$), and a weak positive relationship between grass cover measured using a plate meter and both NDF (*P*=0.006; $R^2=9.2$) and ADF (*P*=0.012, $R^2=7.7$).

Neutral and acid detergent fibre will tend to increase as forage matures and are inversely related to digestibility, and so forages with lower NDF/ADF are usually higher in energy. Therefore an increase in NDF/ADF with forage cover, as observed here, may be expected, however the relationship observed was weak and there was no associated decline in CP, ME or D-value. This indicates that forage covers were kept within a range that ensured high quality forage.

4.4.3 Summary

The grass and clover, and multispecies leys at Norwood were managed by rotational grazing, with the cattle moved between paddocks every 2-4 days. The leys were typically grazed at around 3,500 kg DM/ha, which helped to maintain high quality forage. Although dry matter content was slightly higher in the grass and clover areas, there was no difference in CP, D-value or ME between the two leys. Total forage yields were not recorded (due to the difficultly measuring yields from grazed grass), but the farm reported that both leys performed well.

Table 15. Forage quality analysis; samples taken from the next area to be grazed from both the grass and clover, and multispecies areas

Date	Dry matter %		CP[1] (%DM)		D value[1]		ME[1] (MJ/kg DM)		NDF[1] (% DM)		WSC[2] (g/kg DM)		ADF[2] (% DM)		CP[2] (%DM)	
	G&C	MSS	G&C	MSS	G&C	MSS	G&C	MSS	G&C	MSS	G&C	MSS	G&C	MSS	G&C	MSS
05/06/2018	16.2	15.3	*	*	*	*	11.3	11.3	54	52	101	112	26.9	29.0	21.8	20.9
09/07/2018	29.9	29.5	12.8	24.2	75	71	11.8	11.2	34	43						
17/09/2018	24.0	19.2	12.8	15.6	72	71	11.3	11.2	34	39	331	195	19.4	19.8		
02/05/2019	25.2	21.6	13.4	18.5	67	65	10.7	10.3	29	38	330	261	17.1	17.2	14.5	19.1
16/07/2019	30.6	17.8	16.4	19.8	71	74	11.1	11.7	46	47	189	79	30.6	29.4	12.5	19.9
22/10/2019	16.9	18.2	26.8	26.8	76	73	11.9	11.4	36	44	125	84	23.1	23.8	22.6	23.6
02/07/2020	20.6	21.0	14.9	22.5	73	76	11.4	12.0	37	38	140	199	23.0	20.3	20.7	21.1
29/07/2020	24.8	18.3	17.3	20.2	74	74	11.5	11.6	34	36	201	107	22.4	23.6	17.0	22.0
18/09/2020	21.9	21.0	22.9	19.7	74	75	11.7	11.8	41	36	122	155	22.0	21.6	25.1	19.1
06/05/2021	26.5	22.1	11.8	13.8	78	68	12.2	10.6	33	47	104	106	16.4	27.8	13.2	18.8
09/06/2021	23.4	23.7	12.6	15.8	75	79	11.7	12.4	41	31	292	64	25.2	16.9	11.3	19.8
14/07/2021	21.1	20.8	14.1	12.9	63	75	9.9	11.8	68	43	37	261	33.1	26.6	15.8	12.2
10/08/2021	15.3	18.5	19.2	19.3	73	68	11.4	10.7	40	46	133	70	21.2	31.7	24.7	21.5
20/04/2020	24.3	19.0	20.5	15.6	76	72	11.9	11.3	34	41	167	138	20.1	22.8	22.7	22.5
Mean	**22.9**	**20.4**	**16.6**	**18.8**	**73**	**72**	**11.4**	**11.4**	**40**	**41**	**175**	**141**	**23.1**	**23.9**	**18.5**	**20.0**
***P*-value**	**0.002**		**0.122**		**0.865**		**0.865**		**0.597**		**0.102**		**0.593**		**0.132**	

[1].NIR analysis; [2]. Wet chemistry analysis

G&C = grass and clover; MSS = multispecies sward

Each value is a mean of three replicate analysis on each sampling date from the next area to be grazed in both of the grass and clover, and multispecies swards

4.5 Cattle performance (2018 grazing season)

4.5.1 Introduction

Cattle performance on the grass and clover, and multispecies leys (NOR 05, NOR 06 and NOR 07) was measured during the 2018 grazing season. This information was used in the economic cost benefit analysis (section 4.6).

4.5.2 Methodology

The fields were grazed with 102 Aberdeen Angus cross cattle; these cattle were purchased by the farm as calves in May 2017 and were approximately 13 months old at turnout.

The cattle were turned out as one group in late April and were divided into two groups of 51 cattle in early June. One group grazed the grass and clover area (approximately 10 ha across NOR 05, NOR 06 and NOR 07) and the other group grazed the multispecies area (approximately 10 ha across NOR 05 and NOR 06) (Figure 2).

The cattle groupings were agreed between the farm, AHDB and ADAS and split the cattle to balance for sex, herd, sire, and last live weight.

The cattle were weighed by the farm just prior to turnout on 25/04/18, and then again on 03/08/18 and 23/08/18. The cattle were brought in from early September and weighed in two batches on 06/09/18 and 20/09/18. Daily live weight gain (DLWG) was calculated over the grazing period. In addition, information on veterinary inputs and any other livestock health related issues was recorded by the farm.

Plate 12. Aberdeen Angus cattle grazing grass and clover ley (July 2018) (photo credit Peter Lord)

4.5.3 Results

The average live weight of the cattle at turnout was 398 kg (range 339 to 431 kg) (Table 16). The average live weight gain during the grazing period was very similar between the two groups of cattle; the group grazing the grass and clover ley gained an average of 102 kg, equivalent to 0.74 kg DLWG and the group grazing the multispecies ley gained 106 kg, equivalent to 0.75 kg DLWG (Table 15).

However, there were differences in the pattern of liveweight gain during the grazing period (Table 16). Initially, the cattle grazing the grass and clover ley gained more (mean 0.74 kg DLWG) than the group grazing the multispecies ley (mean 0.58 kg DLWG). Between 03/08/18 and 23/08/18 the cattle grazing the grass and clover ley lost weight (mean loss of 0.71 kg/head/day), compared to a mean gain of 0.75 kg/head/day for the group grazing the multispecies ley. This may reflect the impact of the summer drought on forage quantity and quality; the multispecies ley includes drought tolerant species such as plantain and chicory and fresh grass analysis on 09/07/18 and 17/09/18 showed higher protein content in forage from the multispecies than the grass and clover leys. Liveweight gain during the final measurement period from 23/08/18 to housing (weighed either 06/09/18 or 20/09/20) was greater for cattle grazing the grass and clover ley (mean 2.50 kg DLWG) than for the cattle grazing the multispecies ley (1.52 kg DLWG), which meant that the liveweight gain for the group grazing the grass and clover ley 'caught up' with the group grazing the multispecies ley (Figure 6 and Figure 7).

Table 16. Cattle live weights (kg) over 6 month grazing period

Live weight	25/04/18		03/08/18		23/08/18		Final 06/09/18 & 20/09/18	
	Grass & clover	Multi-species	Grass & clover	Multi-species	Grass & clover	Multi-species	Grass & clover	Multi-species
Mean	400	395	474	453	460	469	502	501
SD	21	20	27	21	35	24	29	20
Min	349	339	402	402	286	409	422	452
Max	431	426	522	495	512	520	550	544
Range	82	87	120	93	226	111	128	92

Table 17. Cattle live weight gain over grazing period

Live weight gain	Grass & clover ley		Multispecies ley	
	LWG (kg)	DLWG (kg)	LWG (kg)	DLWG (kg)
Mean	102	0.74	106	0.75
SD	17	0.14	12	0.10
Min	62	0.42	83	0.57
Max	137	1.02	130	0.96
Range	75	0.60	47	0.39
Liveweight gain by quartiles				
First	93	0.65	97	0.67
Second	100	0.72	106	0.75
Third	111	0.83	117	0.83
Fourth	137	1.02	130	0.96

Table 18. Summary cattle live weight gain during grazing period

Period	Days	DLWG (kg)	
		Grass & clover	Multispecies
25/04/18 to 03/08/18	100	0.74	0.58
03/08/18 to 23/08/18	20	-0.71	0.75
23/08/18 to housed (06/09 or 20/09)	14 or 28	2.50	1.52
Grazing period (24/04 to 06/09 or 20/09)	134 or 148	0.74	0.75

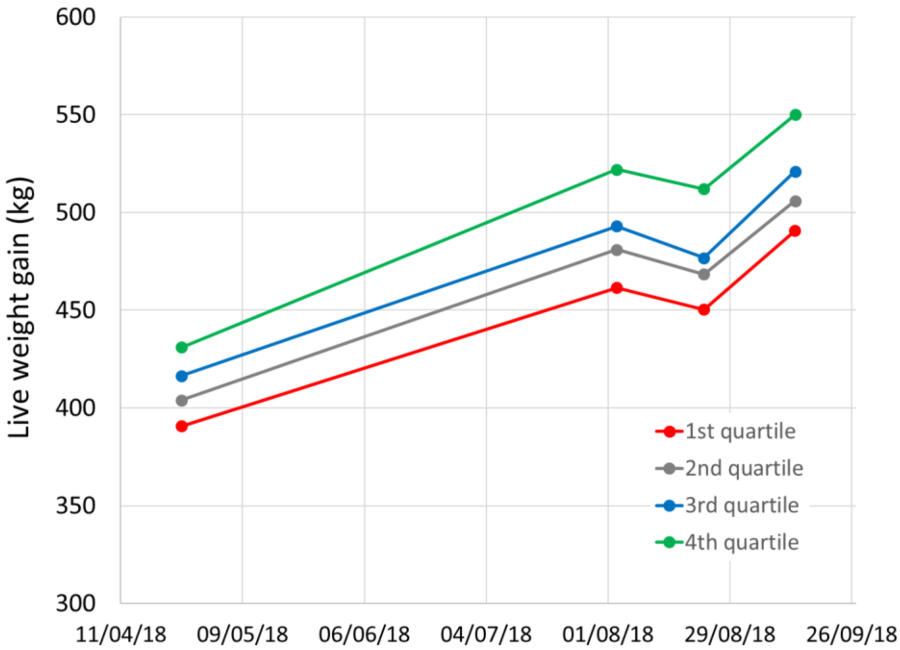


Figure 6. Liveweight gain for cattle grazing the grass and clover ley

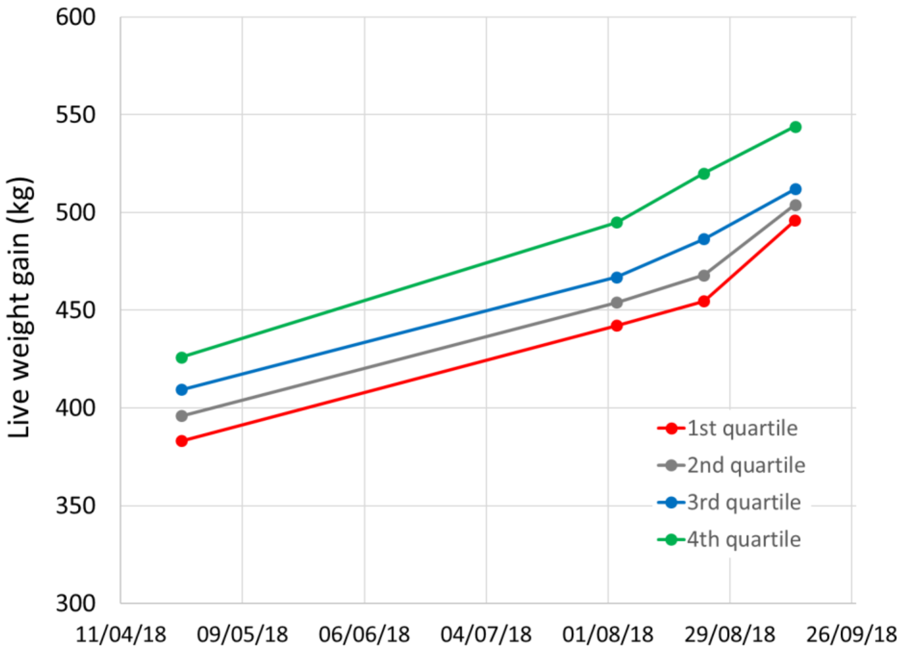


Figure 7. Liveweight gain for cattle grazing the multispecies ley

4.6 Economic cost benefit analysis

4.6.1 Introduction

A full economic cost benefit analysis of integrating grass and clover, and multispecies leys grazed with cattle into the arable rotation was carried out using Norwood Farm as a case study. The cost benefit analysis considered the economic benefits to arable farmers, including whether:

- Beef cattle can provide a viable alternative income source
- Margins are equal or better than crop margins per ha
- There is a positive impact on yields from the following arable crops
- The option of grazing cattle in an arable rotation reduces beef production costs.

There are several different business models available to farmers when deciding whether to introduce grazing cattle (or other livestock) into an arable rotation, including owner-occupier or tenant farming, rented grazing, contract grazing, and joint ventures. Norwood Farm is an owner-occupied mixed arable beef and sheep farm.

4.6.2 Cost benefit analysis of grazing cattle at Norwood in 2018

Methodology

In conjunction with the host farm manager, Peter Lord, some figures were collated on the establishment of the grazing area and managing the cattle such as labour time. Remaining figures, including infrastructure items, were sourced from typical contract costs or market prices for materials (Table 19).

Table 19. List of costs considered in the setting up of the ley and rearing the cattle

Set-up costs	Cattle production costs
Establishment of the ley: Tillage (e.g. discing, drilling, rolling) Inputs (e.g. seeds, sprays, fertiliser)	**Variable costs:** Additional forage or supplementary concentrates Fertilisers or sprays Vet and medicines charges
Infrastructure costs: Fencing posts Fencing wire Electric fencing equipment Water troughs and pipes Handling system Labour	**Fixed costs:** Labour Machinery/vehicles Electricity Water

Ley establishment costs were depreciated over three or five years of the ley[1]. Infrastructure assets were depreciated over a reasonable useful lifetime of 15 years with an assumed zero residual value.

Cattle production costs were minimal for the time that the cattle were grazing the leys at Norwood Farm. The vet and medicine costs were covered and provided by the farm. The farmer gave an estimate of the labour time required to administer medicines. Assumptions were made about the consumption of electricity and water as no meter readings were available. Based on the type of fence

[1] The grass and clover ley in NOR 07 was grazed for three years before returning to arable in 2021. However, the grass and clover, and multispecies leys in NOR 05 and NOR 06 were still performing well in 2022 (fifth grazing season). Therefore, the economic analysis has depreciated the ley costs over both three and five years to show the impact of depreciating costs over a long time for productive leys.

energiser used (battery or solar), electricity consumption was as assumed to be minimal. Water consumption can vary tremendously in growing cattle. According to AHDB Beef and Lamb (BRP+ Water use, reduction and rainwater harvesting on beef and sheep farms), water consumption can range between 15 and 50 litres per day depending on age, temperature and dry matter of forage eaten amongst other factors. Considering the age of cattle reared at Norwood, 25 litres/day was taken as a reasonable assumption.

Labour was factored in at a cost of £12/hour and all costs exclude VAT.

Liveweight gain data for the cattle during the 2018 grazing season was provided by Norwood Farm (section 3.5).

Results

The total cost of setting up the grass and clover ley and infrastructure to handle cattle at Norwood was estimated at £1,280/ha. For the multispecies ley the cost was projected at £1,308/ha (Table 20). The difference of £28/ha was due to the cost of seed. At the time of purchasing the multispecies ley seed mix, the price was £175/ha. However, in 2021 the price had increased to around £205/ha.

Although the total cost per ha represents the initial cash outlay, for cost benefit analysis and budgeting purposes, the costs should be spread over the period of the ley and reasonable lifetime of the infrastructure items and equipment. For a three-year ley, the setting up costs of the ley were calculated at £155/ha/year. For the multispecies ley the depreciated costs were estimated at £164/ha/year. Leys that are kept for a longer period of five years would have annual depreciated costs that were around £35-£38/ha per year lower.

Table 20. Set-up costs at Norwood Farm

Establishment of ley	Grass & clover £/ha	Multispecies £/ha	
Subsoiling, power harrowing, drilling and rolling	113	113	All associated costs included – e.g., fuel, labour, and depreciation
Seeds – grass/clover ley mix	147	175	Actual price in 2018 but both have increased by around £30/ha by 2021
Total establishment costs	**260**	**288**	

Infrastructure	£/ha	£/ha	
Fencing and gates	306	306	Material cost only including electric fencing
Water troughs and pipes	88	88	Material costs only
Crush and weigher	209	209	Cost shared across the total area
Labour	417	417	All labour for the infrastructure tasks
Total infrastructure costs	**1,020**	**1,020**	

Total set-up costs	Grass & clover £/ha	Multispecies £/ha	
Establishment costs	260	288	
Infrastructure costs	1,020	1,020	
Total	1,280	1,308	This represents the initial cash outlay
Depreciated total cost per year (3-year ley)	155	164	This represents the annual cost for budgeting purposes. Based on 3-year depreciation of establishment costs and 15-years for infrastructure items
Depreciated total cost per year (5-year ley)	120	126	This represents the annual cost for budgeting purposes. Based on 5-year depreciation of establishment costs and 15-years for infrastructure items

Table 21. Cattle production costs during the grazing period

Rearing costs	Grass & clover £/ha	Multispecies £/ha	
Additional feed and forage	26	0	Only the grass/clover group received some additional silage
Fertilisers and sprays	145	145	Cost of the fertiliser
Vet and medicines	16.6	16.6	Three insecticide treatments
Labour for cattle management	150	150	For cattle management tasks
Fertiliser machinery and labour	15	15	Cost of the fertiliser operation
Electricity	0	0	For electric fencing, minimal as solar or battery powered
Quad bike fuel	22	22	For cattle management tasks
Water	24	24	Based on mains water
Total production cost (£/ha)	**399**	**373**	
Total production cost (£/head)	**93**	**87**	Average stocking rate of 4.3 animals/ha

The cattle were purchased as three- to four-month-old calves in May 2017. They were grazed on the farm in 2017 and then winter housed on a forage diet. The cattle were turned out in May 2018. Liveweight gain during the 2018 grazing season was recorded as part of the study and included in this economic analysis. At the end of the 2018 grazing season, the cattle were finished inside on a forage-based diet and sold for slaughter between October 2018 and January 2019. Cattle store prices can vary greatly within seasons, by region and by breed. For the purposes of this project a store value on a £ per kg has been attributed to the cattle at the start and end of the 2018 grazing period. The same value was used so that that liveweight gain is the contributor to income rather than any subjective change in the £ per kg value.

The 5kg per animal difference in liveweight gain between the two groups resulted in a small difference in the valuation change. Total change in value for the grass and clover group was £184 per animal and £191 per animal for the multispecies ley group (Table 22).

Table 22. Cattle valuation change

Based on 2018 store cattle values	Grass & clover	Multispecies
Cattle numbers at start	51	51
Cattle numbers at end	51	51
Average liveweight at start (kg)	400	395
Average liveweight at end (kg)	502	501
Total liveweight (LW) gain [LW at end - LW at start] (kg)	102	106
Daily liveweight gain [Total LW / grazing period] (kg per day)	0.74	0.75
Starting value (£ per kg LW)	1.80	1.80
Ending value (£ per kg LW)	1.80	1.80
Starting value per head (£)	720	711
Ending value per head (£)	904	902
Net output per head (£)	**184**	**191**
Net output per ha (£)	**791**	**821**
Change in net output per head if daily liveweight gain +/- 0.10kg/day	**+/-£21/head**	**+/-£24/head**
Change in net output per ha if stocking rate +/- 1 animal/ha	**+/-£184/ha**	**+/-£191/ha**

When the total depreciated set-up costs (based on a three-year ley) and cattle production costs are deducted from the net output received, a net margin (before rent and finance) was £237/ha for the grass and clover group and £284/ha for the multispecies ley group (Table 23). If the ley establishment costs were depreciated over five years, the net margin (before rent and finance) increased to £272/ha for the grass and clover group and £322/ha for the multispecies ley group (Table 23).

Table 23. Annual net margin to the arable farm (before rent and finance)

	Grass & clover £/ha	Multispecies £/ha	
Based on a 3-year ley			
Net output	791	821	Based on 51 cattle/group
Total establishment and infrastructure costs	155	164	Based on a 3-year ley
Total cattle production costs	399	373	Based on 51 cattle/group
Net margin £/ha	**237**	**284**	Before rent and finance
Net margin £/head	**55**	**66**	Based on stocking rate 4.3 head/ha
Based on a 5-year ley			
Net output	791	821	Based on 51 cattle/group
Total establishment and infrastructure costs	120	126	Based on a 3-year ley
Total cattle production costs	399	373	Based on 51 cattle/group
Net margin £/ha	**272**	**322**	Before rent and finance
Net margin £/head	**63**	**75**	Based on stocking rate 4.3 head/ha

Table 24 provides a guide to the sensitivity of the net margin in £/ha to different total annual costs, (ley establishment and infrastructure costs plus cattle production expenses) and cattle valuation changes (net output).

The gain in cattle value will vary depending on stocking rates, daily liveweight gain (DLWG) and length of grazing period. Higher stocking rates and DLWG will increase the value of the cattle and hence the net output. The level of annual costs will be determined by the type of ley infrastructure employed, type and length of ley. Costs will be higher with more permanent infrastructure but will be lower with a longer length of ley.

Table 24. Sensitivity of net margin to cattle net output and total annual costs

Total annual costs (£/ha)	Gain in cattle value (Net output £/ha)							
	500	600	700	800	900	1000	1100	1200
350	150	250	350	450	550	650	750	850
400	100	200	300	400	500	600	700	800
450	50	150	250	350	450	550	650	750
500	0	100	200	300	400	500	600	700
550	-50	50	150	250	350	450	550	650
600	-100	0	100	200	300	400	500	600
650	-150	-50	50	150	250	350	450	550
700	-200	-100	0	100	200	300	400	500
750	-250	-150	-50	50	150	250	350	450

Gain in cattle value = Value of cattle at the end minus the value of the cattle at the start divided by the area grazed
Total annual cost = Annual depreciated cost of setting up the leys and the production costs of the cattle whilst at grazing

Potential additional income

The impact of the grass and clover ley on the following arable crop was measured in NOR 07. This field was split between arable and grass and clover in autumn 2017. The whole field returned to arable production in 2021 and was sown with spring barley. Spring barley yields were an average of 0.7 t/ha higher following grass and clover than following the arable crop (Section 4.8 & Figure 15). If the barley taken at harvest in 2021 was valued at £160/tonne this would equate to £112/ha of additional income due to the higher yield. A change in crop price of +/- £20/tonne would mean a change of +/-£14/ha.

In addition to the increased crop income, other revenue streams could help increase the profitability of grass and mixed species leys (

Table 25).

Table 25. Potential revenue streams with leys in arable rotations

Potential revenue stream	Description	Potential revenue
Sustainable Farming Incentive (England)	The Arable and Horticultural Soils Standard – Grass leys and mixed species leys are eligible for payments under this scheme. The level of payment is determined by the proportion of the land entered into the scheme that is required to be multi species.	Agreements are for 3 years Introductory level - £22/ha/year Intermediate level - £40/ha/year
Countryside Stewardship – GS4 (England)	GS4 legume and herb-rich swards are one of several Countryside Stewardship mix options available for farmers in mid and higher tiers. It is an option for whole or part parcels in rotation on arable land, temporary grassland or permanent grassland that has been cultivated and resown within the past five years. The mixes have to be planted for five years.	This option can pay quite well but 2023 is the last year for application to the scheme to start in 2024 and includes some grazing restrictions and an agreement length of 5 years GS4 option - £309/ha/year
Over winter grazing	The over wintering of sheep or other cattle from other farmers.	A store lambs/wethers/ewe lambs example: 50p/head/week for 6 weeks - £3/head Stocking at 5 head/ha = £15/ha A store cattle or heifers example: £2.50/head/week for 6 weeks - £15/head Stocking at 1-2 head/ha = £15-£30/ha
Selling excess forage	If the leys are more productive than the level of stock grazing them, cutting and selling the excess forage could provide additional income.	Silage bale example: 20 tonnes per ha at a margin after costs (£45/ha) of £15/t = £300/ha net margin

Note: Prices quoted correct at time of writing (July 2022)

4.6.3 Summary

Norwood shows that there is potential for the arable farmer to make a positive margin from cattle grazing a ley in an arable rotation. AHDB Farmbench results show that the beef margins are unlikely to match the returns from a winter wheat crop, however grazing cattle could be more profitable than other crops in the rotation such as winter beans (

Table 26). The economic analysis at Norwood Farm showed a net margin (before rent and finance) of £237/ha for the grass and clover ley and £284/ha for the multispecies ley, where the ley establishment costs are depreciated over a three-year ley.

Table 26. Net margin (before rent and finance) comparisons

	£/ha
Norwood Farm grass & clover ley	272
Norwood Farm multispecies ley	322
Winter wheat	567
Winter barley	222
Spring oats	198
Spring barley	180
Winter oilseed rape	101
Winter beans	27
Spring linseed	-293

Source: AHDB Farmbench, South West farms on clay loam and silty clay loam soils – 3 year average 2018 –2020

The additional 0.7 t/ha yield following the grass and clover ley increased the value of the spring barley crop by £112/ha at harvest 2021 prices.

Grass and clover, or multispecies leys may also provide the opportunity to earn supplementary revenue. This could be done from including the ley in an environmental scheme to receive an annual payment. Renting out the winter grazing or selling the excess forage production are other options that could increase a ley's net margin by around £300/ha.

All these factors should also be considered when looking at the whole picture of whether it is worth including leys and cattle in the rotation.

If infrastructure costs are kept reasonable and grassland management is good with reasonable stocking rates, there is the prospect of realising a positive margin and providing an opportunity for a profitable break in the rotation.

4.6.4 Beef in the arable rotation – Mix and match calculator

The project has provided arable and beef farmers with the economic information to enable them to evaluate the cost and margins of grazing cattle on leys in their arable rotation. A 'mix and match' calculator has been set up with different infrastructure set-ups, ley establishments and cattle rearing systems. The tool enables farmers to look at the costs and margins involved in setting up beef in arable systems and can be found at: https://ahdb.org.uk/beef-in-the-arable-rotation-mix-and-match-calculator

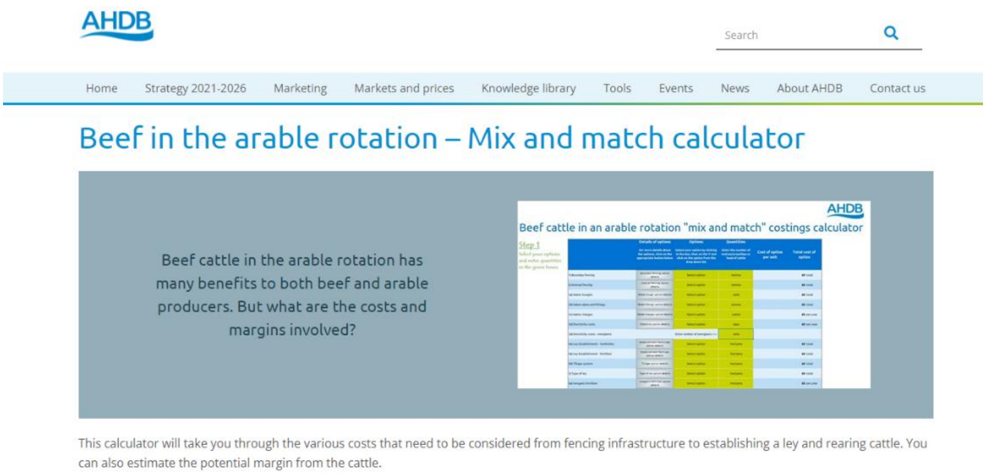


Figure 8. Screenshot showing AHDB Mix and match calculator

4.7 Impact of temporary leys on soil physio-chemical properties

4.7.1 Introduction

Integration of grass and multispecies leys and livestock into arable rotations has the potential to improve soil quality and provide benefits to the following arable crop. Continuous arable cropping with annual cultivations and little or no inputs of organic materials have led to reductions in soil organic matter content, which is central to the maintenance of soil quality and fertility. Temporary leys have the potential to increase soil organic matter levels by increasing the return of organic matter in the form of root and litter turnover. Increasing soil organic matter can lead to improved moisture retention, nutrient turnover and soil structure, and reduced erosion risk. However, there have been relatively few long-term studies comparing soil quality within arable and ley/arable rotations under UK agricultural conditions.

4.7.2 Methodology

At Norwood Farm a comprehensive measurement programme was used to identify the impact of the contrasting grass and clover, and multispecies leys on a range of soil physio-chemical properties. Detailed soil assessments were carried out in each field or split field (9 field areas in total – 6 fields including 3 split fields). Each field/split field was divided into three blocks and each block was sampled separately in 2017 and 2020 (Figure 9).

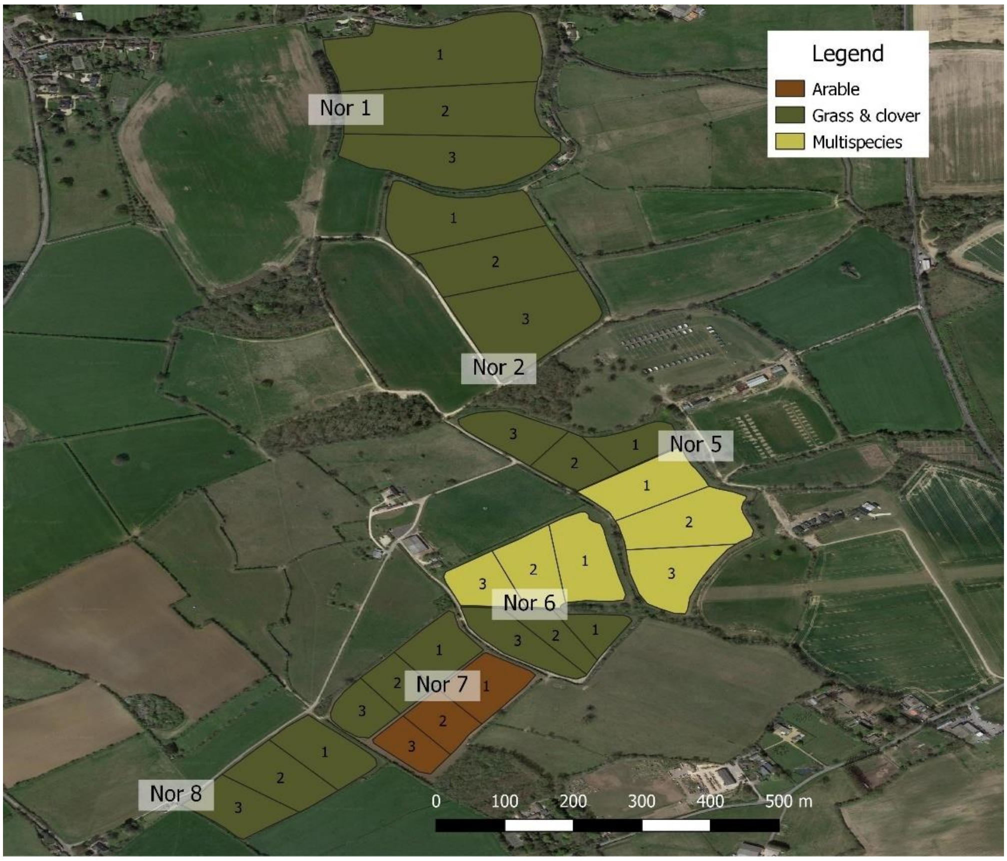


Figure 9. Norwood Farm field locations: soil samples/measurements were taken from three blocks in each field/split field

The initial soil assessments were carried out in August 2017 on stubble before any cultivations to establish the grass and clover, and multispecies leys. Measurements were repeated in October 2020 after three years of the leys and before NOR 07 returned to arable production in 2021.

Soil samples

To characterise the topsoil, baseline topsoil samples (0-15 cm depth) were taken from each block of each field (one sample per field 'block' - three samples per field area) and analysed for:

- Soil pH (measured in water; 1:2.5).
- Particle size distribution (i.e., percentage sand, silt, and clay content; laser method).
- Extractable P (Olsen's method i.e., sodium bicarbonate extractable), K, and Mg (ammonium nitrate extractable).
- Organic matter – loss on ignition.
- Soil microbial biomass (determined by analysis of dissolved organic carbon of a soil sample before and after fumigation, with the before and after difference equating to microbial biomass; Brookes *et al.,* 1985).
- Soil respiration (potassium hydroxide absorbs CO_2 from the atmosphere by a chemical reaction. The amount of CO_2 absorbed is measured by titration of the remaining KOH against hydrochloric acid (HCl); Alef, 1995).
- Potentially mineralizable nitrogen (PMN) measures the amount of N readily decomposed under controlled (anaerobic) conditions and can be used to infer the size and activity of the microbial community (Bhogal *et al.,* 2020). Potentially mineralizable nitrogen was measured on the 2020 samples only.

In addition, Dumas carbon and bulk density to 60 cm depth in three sections (0-15 cm, 15-30 cm and 30-60 cm) was measured from the grass and clover, and arable sections of NOR 07 in autumn 2020 to calculate carbon storage.

Soil physical assessments

Soil physical assessments (penetration resistance, shear strength, bulk density, Visual Soil Assessment and Visual Evaluation of Soil Structure) were carried out:

- In all fields in autumn 2017
- In split fields only (NOR 07, NOR 06 and NOR 05) in autumn 2020
- In NOR 07 in spring 2021. The soil physical assessments were repeated in both sections of NOR 07 in spring 2021 after the spring barley was sown, to identify any differences in soil structure after sowing which may have affected establishment/performance of the spring cereal crop (results are presented in section 4.8).

Penetration resistance

Soil penetration resistance measurements enable the identification of compacted zones which could restrict root growth and water infiltration. A cone penetrometer (Figure 10) was used to quantify the range and depth of maximum penetration resistance. The penetrometer was pushed into the soil to 50 cm depth at 20 points across the field. The points with maximum, minimum and median resistance were used for the bulk density, VSA and VESS soil assessments (described below).

Shear strength

Shear strength measurements (0-5 cm) were made using a shear vane (Figure 10) at 20 points across each field 'block' (in the same place as penetration resistance measurements). When the vane is rotated, the soil fails along a cylindrical surface passing through the edges of the vane, as well as along the horizontal surfaces at the top and bottom of the blades. The shear strength of the soil was calculated from the dimensions of the vane and from the measured torque.

Soil shear strength is a measure of soil friability. Soils with low shear strength are typically easy to cultivate and have porous aggregates that allow roots to penetrate and exploit soil water and nutrients. Soils with high shear strength are typically difficult to cultivate resulting in increased energy use and equipment wear.

Figure 10. Measurement of soil penetration resistance (left) and shear strength (right)

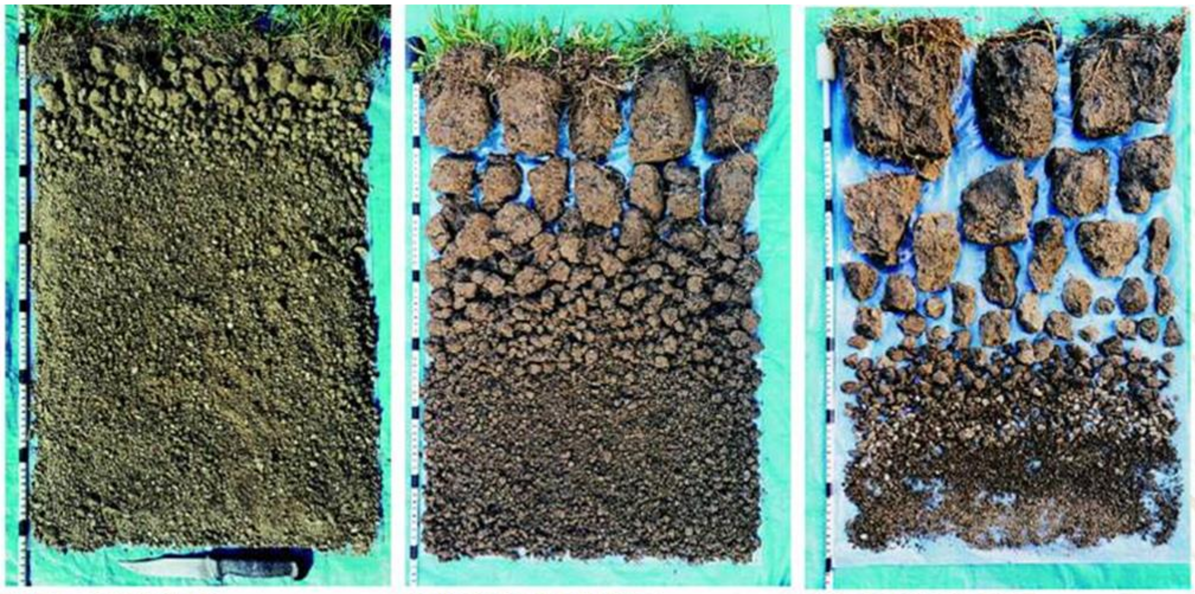
Soil bulk density

Bulk density is the weight of soil in a given volume. It decreases with the number and size of soil pores and tends to increase with depth. Soil bulk density is a good indicator of soil compaction, providing a measurement of the volume of soil particles and pore space. Well-structured soils with a range of aggregate sizes have 'low' bulk densities and soils that are poorly structured with compact dense structures have 'high' bulk densities.

Soil bulk density was measured at 10-15 cm depth at the points of minimum, median and maximum penetration resistance within each field 'block'. Measurements were made using the core cutter method by hammering a small cylinder into the ground and trimming the excess soil from the edges. Soil was then dried and weighed, and the bulk density calculated by dividing the weight of dry soil by the known volume of the cylinder used.

Visual Soil Assessment (VSA)

The visual soil assessment (VSA) method was developed by Landcare New Zealand (Shepherd, 2000) and is promoted by the England Catchment Sensitive Farming Delivery Initiative (ECSFDI) and Soil Management Initiative (SMI). At the three points where the maximum, median and minimum penetrometer resistance values were recorded, a 20 cm block of soil was extracted and dropped a maximum of three times from a height of approximately 1 m (waist height) onto a hard board. Clods were then arranged into size order and scored for the following parameters: soil structure and friability, soil porosity, soil colour, number of soil mottles, earthworm counts, presence of a tillage pan, degree of clod development and susceptibility to erosion. For each visual indicator the soil sample was compared with three photographs included in the VSA field guide that correspond to poor, moderate and good conditions to assign the visual score (Figure 11). The maximum possible score is 32 and soils that score less than 10 are classified as 'poor', 10-25 'moderate' and greater than 25 'good' soil quality.



GOOD CONDITION VS = 2
Good distribution of friable finer aggregates with no significant clodding

MODERATE CONDITION VS = 1
Soil contains significant proportions of both coarse firm clods and friable, fine aggregates

POOR CONDITION VS = 0
Soil dominated by extremely coarse, very firm clods with very few finer aggregates

Figure 11. VSA method for visual scoring of soil structure and consistence

Visual Evaluation of Soil Structure (VESS)

The VESS score is an assessment of soil structure and porosity (Ball *et al*., 2007; Guimarães *et al*., 2011). The topsoil is assessed according to how easy it is to break up a block of soil; the size and shape of its constituent soil structural units (or aggregates); the abundance of visual pores, cracks and fissures and the distribution of roots and earthworm channels. At the three points where the maximum, median and minimum penetrometer resistance values were recorded, a 20 x 20 cm block of soil (approximately spade width and depth) was extracted, placed on a plastic sheet, and pulled apart by hand for assessment. If the structure was uniform the block was assessed as a whole, but if there were two or more horizontal layers of differing structure, each layer was scored separately, with a focus on the poorest or 'limiting' layer. The physical nature, visual appearance and smell of the soil aggregates was compared with the pictures and descriptions on the VESS field sheet. The lowest score (Sq1 - Friable) is given to the least compact and most porous condition, and the highest score (Sq5 - Very compact) to topsoil that is difficult to break up into large, plate-shaped aggregates with roots mainly restricted to cracks.

Topsoil sampling

Soil physical assessments

Counting earthworms (part of VSA assessments)

Counting earthworms (part of VSA assessments)

Plate 13. Soil assessments (October 2020)

Data analysis

Topsoil analysis and soil physical assessment data were analysed by ANOVA:

- Data from the grass and clover, and multispecies fields were analysed to assess whether there was a significant change in soil properties over time (between 2017 and 2020), and whether there was an interaction effect between sward type (grass and clover, or multispecies) and change over time.
- Data from the NOR 07 split grass and clover, and arable field was analysed separately to assess whether there was a significant change in soil properties over time (between 2017 and 2020), and whether there was an interaction effect between land use (grass and clover, or arable) and change over time.

4.7.3 Results

Soil texture

Table 27 shows soil texture analysed in 2017. The fields are predominantly clay or clay loam texture with clay content varying between 24 and 48%. Soil texture was not repeated on the 2020 samples as it is not expected to change over time.

Table 27. Soil texture in 2017 (mean of three samples from each field area)

Field	Sand (%)	Silt (%)	Clay (%)	Texture
NOR 07 Arable	15	41	44	Clay
NOR 07 Grass & clover	14	38	48	Clay
NOR 06 Grass & clover	25	40	36	Clay loam
NOR 06 Multispecies	37	39	24	Clay loam
NOR 05 Grass & clover	25	45	30	Clay loam
NOR 05 Multispecies	25	49	26	Clay loam
NOR 08 Grass & clover	35	34	32	Clay loam
NOR 02 Grass & clover	20	41	40	Clay
NOR 01 Grass & clover	19	38	43	Clay
Mean (all fields)	**24**	**40**	**36**	**Clay**

Topsoil analysis for pH, and extractable P, K and Mg

Table 28 shows topsoil analysis for pH, and extractable P, K and Mg in 2017 and 2020.

Ley fields Grass and clover, vs multispecies comparison

Soil pH ranged from 6.8 to 7.8 in 2017 and from 6.5 to 7.4 in 2020. There was a small drop in pH (P<0.001) in the ley fields between 2017 and 2020 from a mean of 7.2 to a mean of 6.9, although all fields were still above the target soil pH of 6.0 for grassland. There was no interaction effect (P=0.799 of sward type (grass and clover, vs multispecies) and time on pH.

Soil P Indices were 0 and 1 in 2017 and 2020. There was a small drop in extractable P (P<0.001) in the ley fields between 2017 and 2020 from a mean of 10.6 mg/l to 8.5 mg/l. The target soil P index for grassland is Index 2 and all fields are below the target Index, which suggests that a yield response to applied phosphate is likely. There was a significant interaction effect (P=0.043) of sward type and time on P status, i.e., the decline was greater in the multispecies compared to grass and clover swards, although the difference is relatively small.

Soil K Indices varied between 1 and 3 in 2017 and 2020 (target Index 2-) and mean extractable K was very similar (P=0.308) in 2017 and 2020. Soil Mg indices were 2 or 3 in 2017 and between 2 and 4 in 2020 (target Index 2). There was an increase in extractable Mg (P<0.001) in the ley fields between 2017 and 2020 from a mean of 122 mg/l to 137 mg/l, but no interaction effect (P=0.222) of sward type and time on Mg levels.

NOR 07 Grass and clover vs arable split field comparison

There was no significant change in soil pH (P=0.103) or extractable P (P=0.194) between 2017 and 2020 in NOR 07. There was a significant increase in extractable K (P=0.017) and Mg (P=0.012) between 2017 and 2020, but no interaction effect of land use (grass and clover, vs arable) and time.

Soil pH tends to slowly decline over time unless lime is applied. Any change in soil extractable P, K or Mg levels is likely due to a surplus or deficit of applied nutrients. Where nutrient inputs (manure and fertiliser) are less than nutrient offtakes, then the soil nutrient levels are likely to decline over time, and where inputs exceed offtakes, then the soil nutrient levels are likely to increase over time.

Table 28. Topsoil analysis (mean of three samples from each field area)

Field[1]	Soil pH		Ext P mg/l (Index)		Ext K mg/l (Index)		Ext Mg mg/l (Index)	
	2017	2020	2017	2020	2017	2020	2017	2020
NOR 07 Arable	6.8	6.7	7.3 (0)	9.9 (0)	145 (2-)	201 (2+)	147 (3)	173 (3)
NOR 07 G&C	7.1	6.8	7.0 (0)	7.1 (0)	152 (2-)	178 (2-)	104 (3)	119 (3)
NOR 06 G&C	7.4	6.7	9.2 (0)	5.0 (0)	189 (2+)	165 (2-)	169(3)	195 (4)
NOR 06 MSS	7.0	6.7	8.3 (0)	5.3 (0)	137 (2-)	120 (1)	141 (3)	171 (3)
NOR 05 G&C	6.9	6.7	8.5 (0)	7.9 (0)	99 (1)	92 (1)	172 (3)	187 (4)
NOR 05 MSS	6.9	6.5	10.3 (1)	6.7 (0)	77 (1)	81 (1)	170 (3)	188 (4)
NOR 08 G&C	7.8	6.9	14.8 (1)	12.3 (1)	251 (3)	236 (2+)	58 (2)	72 (2)
NOR 02 G&C	7.7	7.4	14.5 (1)	11.2 (1)	245 (3)	192 (2+)	76 (2)	79 (2)
NOR 01 G&C	7.1	7.1	12.1 (1)	11.7 (1)	144 (2-)	153 (2-)	85 (2)	89 (2)
Grass & clover and Multispecies ley fields[2]:								
Mean (all)	**7.2**	**6.9**	**10.6 (1)**	**8.4 (0)**	**162 (2-)**	**152 (2-)**	**122 (3)**	**137 (3)**
Mean G&C	**7.3**	**6.9**	**11.0 (1)**	**9.2 (0)**	**180 (2-)**	**169 (2-)**	**111 (3)**	**123 (3)**
Mean MSS	**6.9**	**6.6**	**9.3 (0)**	**6.0 (0)**	**107 (1)**	**101 (1)**	**155 (3)**	**180 (4)**
Year	$P<0.001$		$P<0.001$		$P=0.308$		$P<0.001$	
Year * Trt	$P=0.799$		$P=0.043$		$P=0.839$		$P=0.222$	
NOR 07 Grass & clover vs arable split field[3]								
Year	$P=0.103$		$P=0.194$		$P=0.017$		$P=0.012$	
Year * Trt	$P=0.652$		$P=0.231$		$P=0.220$		$P=0.284$	

[1]G&C = grass & clover; MSS = multispecies sward

[2]Mean and P statistic from ANOVA, where Trt (Treatment) = sward type.

[3]Mean and P statistic from ANOVA, where Trt (Treatment) = arable vs G&C in NOR7.

Soil organic matter content

Topsoil organic matter content (measured by loss on ignition) increased ($P=0.010$) by an average of 0.3 percentage points across all ley fields between 2017 and 2020. This increase is equivalent to an increase of 6 t/ha organic matter in the top 15 cm of soil.

There was no interaction effect ($P=0.528$) of sward type (grass and clover, vs multispecies) and time on soil organic matter content. Soil organic matter increased by a mean of 0.3 percentage points in the grass and clover fields, and by a mean of 0.2 percentage points in the multispecies ley fields, however this difference between the sward types was not statistically significant ($P=0.528$).

Table 29. Soil organic matter measured by Loss on Ignition (mean of three samples from each field area)

Field	Organic matter (% LOI)	
	2017	2020
NOR 07 Arable	8.7	8.8
NOR 07 Grass & clover	9.8	10.3
NOR 06 Grass & clover	8.4	9.4
NOR 06 Multispecies	4.9	5.2
NOR 05 Grass & clover	6.5	6.7
NOR 05 Multispecies	5.7	5.8
NOR 08 Grass & clover	7.5	8.1
NOR 02 Grass & clover	9.2	9.4
NOR 01 Grass & clover	10.5	10.2
Grass & clover and Multispecies ley fields[1]:		
Mean (all)	**7.8**	**8.1**
Mean Grass & clover	**8.7**	**9.0**
Mean Multispecies	**5.3**	**5.5**
Year	***P*=0.010**	
Year * Trt	***P*=0.528**	
NOR 07 Grass & clover vs arable split field[2]		
Year	***P*=0.038**	
Year * Trt	***P*=0.202**	

[1]Mean and P statistic from ANOVA, where Trt (Treatment) = sward type.

[2]Mean and P statistic from ANOVA, where Trt (Treatment) = arable vs G&C in NOR7.

Soil carbon stocks NOR 07

In addition, Dumas carbon and bulk density to 60 cm depth in three sections (0-15 cm, 15-30 cm and 30-60 cm) was measured from the grass and clover, and arable sections of NOR 07 in autumn 2020 to calculate soil carbon storage.

Data indicated that soil carbon levels were higher in the 15-30 and 30-60 cm soil layer in the grass and clover half compared to the arable half (Figure 12). Soil carbon 'stocks' were a mean of 136 t C/ha in the arable half and 157 t C/ha in the grass and clover half (Figure 13).

The higher carbon concentrations in the 15-30 cm and 30-60 cm soil layers in the grass and clover half may reflect greater organic matter inputs from the roots of the grass and clover; however, as baseline samples were not taken to this depth in 2017, it is not possible to determine whether this was an existing difference between the two field halves before the start of the experiment or a change over time due to a difference in cropping.

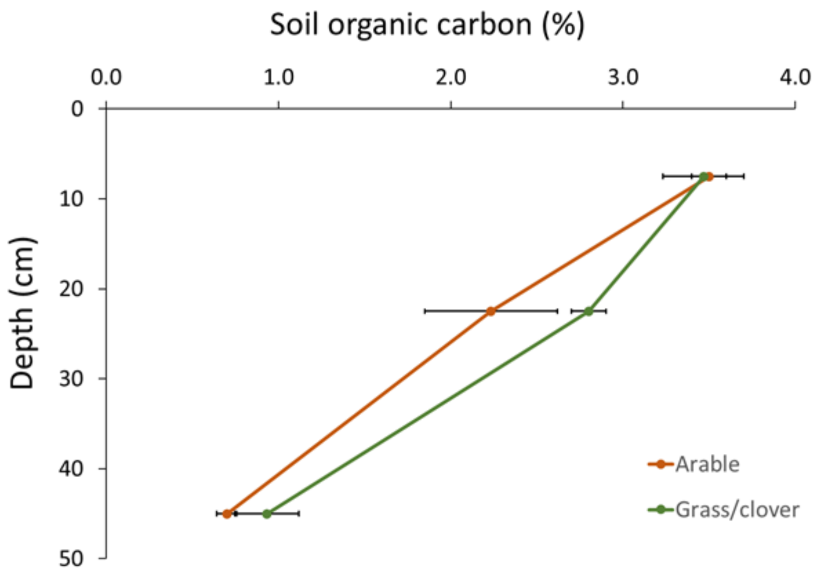


Figure 12. Soil carbon levels to 60 cm depth in the arable and grass and clover sections of NOR 07 measured October 2020.

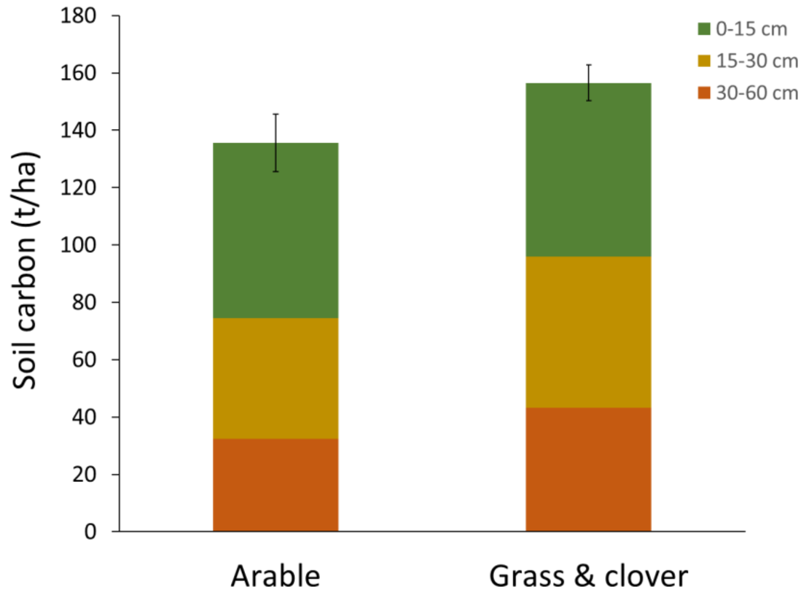


Figure 13. Soil carbon stocks to 60 cm depth in the arable and grass and clover sections of NOR 07 measured October 2020.

Soil microbial biomass and respiration

Table 30 shows results of topsoil laboratory soil biology measurements. Soil microbial biomass and respiration were measured in both 2017 and 2020. Potentially Mineralisable Nitrogen (PMN) was measured on the 2020 samples only.

Ley fields: Grass and clover, vs multispecies comparison

Soil microbial biomass and respiration increased across all ley fields between 2017 and 2020 (P<0.001 for microbial biomass and P=0.020 for respiration). Soil microbial biomass approximately doubled from a mean of 341 mg/kg in 2017 to a mean of 761 mg/kg in 2020, and respiration increased from a mean of 37 mg CO_2-C kg/day in 2017 to a mean of 47 mg CO_2-C kg/day in 2020. There was a significant interaction effect (*P*=0.001) of sward type and time for microbial biomass, with a greater increase in microbial biomass in the grass and clover swards than the multispecies swards, but no interaction effect (*P*=0.680) of sward type and time for respiration.

PMN varied between 101-163mg/kg (mean 128 mg/kg) in 2020; values above 40 mg/kg are considered 'typical'.

NOR 07 Grass and clover vs arable split field comparison

There was a significant increase (*P*=0.001) in soil microbial biomass between 2017 and 2020 in NOR 07, but no interaction effect (*P*=0.435) between land use and time. Although soil respiration was numerically greater in 2020, the increase was not significant (*P*=0.417).

Table 30. Soil microbial biomass and respiration (mean of three samples from each field area)

Field[1]	Microbial biomass C (mg/kg)		Respiration (mg CO_2-C kg/day)		PMN (mg/kg)
	2017	2020	2017	2020	2020
NOR 07 Arable	470	789	12	39	135
NOR 07 Grass & clover	527	918	34	40	134
NOR 06 Grass & clover	276	848	36	41	163
NOR 06 Multispecies	289	444	22	27	116
NOR 05 Grass & clover	289	697	34	38	101
NOR 05 Multispecies	359	652	33	40	128
NOR 08 Grass & clover	439	787	54	60	*
NOR 02 Grass & clover	452	959	46	68	*
NOR 01 Grass & clover	341	781	40	59	*
Grass & clover and Multispecies ley fields[1]:					
Mean (all)	**372**	**761**	**37**	**47**	**128**
Mean G&C	**387**	**832**	**41**	**51**	**134**
Mean MSS	**324**	**548**	**27**	**34**	**122**
Year	***P*<0.001**		***P*=0.020**		*
Year * Trt	***P*=0.001**		***P*=0.680**		*
NOR 07 Grass & clover vs arable split field[2]					
Year	***P*=0.001**		***P*=0.208**		*
Year * Trt	***P*=0.435**		***P*=0.417**		*

[1]Mean and P statistic from ANOVA, where Trt (Treatment) = sward type.

[2]Mean and P statistic from ANOVA, where Trt (Treatment) = arable vs G&C in NOR7.

*Not determined

Earthworm numbers and biomass

The number of earthworms in a 20 cm deep spade of soil was counted and the mass of earthworms recorded (Table 31). Juvenile and adult earthworms were counted and weighed separately.

Ley fields: Grass and clover, vs multispecies comparison

The number of earthworms in the grass and clover, and multispecies ley fields increased (*P*=0.012) by 60% between 2017 and 2020 (from 158 to 254 worms/m^2), and total earthworm biomass increased (*P*<0.001) three-fold from 46 to 137 g/m^2. In 2017, all fields had a greater proportion of juvenile worms to adult worms. In 2020, this trend had been reversed and all fields had a greater proportion of adult to juvenile worms, which reflects a more stable earthworm population from lack of tillage. There was no interaction effect (*P*=0.763) of sward type (grass and clover, vs multispecies) and time on earthworm numbers.

NOR 07 Grass and clover vs arable split field comparison

By contrast, there was no significant change in total earthworm numbers (*P*=0.751) or biomass (*P*=0.188) between 2017 and 2020 in the NOR 07 split grass and clover, and arable field

Table 31. Earthworm numbers and biomass

Field[1]	Juvenile worms numbers (per/m²)		Juvenile worms biomass (g/m²)		Adult worms numbers (per/m²)		Adult worms biomass (g/m²)		Total worm numbers (per/m²)		Total worm biomass (g/m²)	
	2017	**2020**	**2017**	**2020**	**2017**	**2020**	**2017**	**2020**	**2017**	**2020**	**2017**	**2020**
NOR 07 Arable	160	43	19	7	49	111	29	67	209	154	49	73
NOR 07 G&C	77	65	7	25	62	105	21	52	139	169	28	77
NOR 06 G&C	49	123	11	46	46	209	29	138	95	332	40	185
NOR 06 MSS	80	74	10	40	58	154	46	138	139	228	55	178
NOR 05 G&C	166	46	19	11	55	169	35	95	222	215	54	106
NOR 05 MSS	129	139	19	57	68	166	32	75	197	323	51	141
Grass & clover and Multispecies ley fields[2]:												
Mean (all)	**100**	**89**	**13**	**36**	**58**	**161**	**32**	**99**	**158**	**254**	**46**	**137**
Mean G&C	**97**	**78**	**12**	**27**	**54**	**161**	**28**	**95**	**152**	**239**	**41**	**122**
Mean MSS	**105**	**106**	**14**	**48**	**63**	**160**	**39**	**106**	**168**	**275**	**53**	**160**
Year	***P*=0.663**		***P*=0.012**		***P*<0.001**		***P*<0.001**		***P*=0.012**		***P*<0.001**	
Year * Trt	***P*=0.685**		***P*=0.262**		***P*=0.751**		***P*=0.956**		***P*=0.763**		***P*=0.349**	
NOR 07 Grass & clover vs arable split field[3]												
Year	***P*=0.026**		***P*=0.313**		***P*=0.137**		***P*=0.202**		***P*=0.751**		***P*=0.188**	
Year * Trt	***P*=0.050**		***P*=0.002**		***P*=0.759**		***P*=0.882**		***P*=0.301**		***P*=0.633**	

[1]G&C = grass & clover; MSS = multispecies sward

[2]Mean and P statistic from ANOVA, where Trt (Treatment) = sward type.

[3]Mean and P statistic from ANOVA, where Trt (Treatment) = arable vs G&C in NOR7.

Penetration resistance and shear strength

Penetrometer resistance (PR) measurements (20 across each field) were used to determine variability in the degree and depth of soil compaction and to select the three points of minimum, medium and maximum resistance as locations for further assessments (bulk density and visual soil assessments). These soil physical assessments can be influenced by soil moisture content. The gravimetric soil moisture content was similar when soil assessments were carried out in 2017 (37%) and 2020 (35%).

Ley fields: Grass and clover, vs multispecies comparison

Maximum penetration resistance decreased (*P*<0.001) between 2017 and 2020 in the grass and clover, and multispecies ley fields from a mean of 1.51 to 1.00 kPa, whilst the depth to maximum resistance was greater (*P*<0.001) in 2017 (mean 42 cm) than 2020 (mean 22 cm) (Table 32). By contrast, mean shear vane increased (*P*=0.023) between 2017 and 2020 from a mean of 107 kPa to 123 kPa. There was no interaction effect of sward type (grass and clover, compared to multispecies) and time on maximum penetration resistance (*P*=0.996), depth to maximum resistance (*P*=0.167) or shear strength (*P*=0.128).

NOR 07 Grass and clover vs arable split field comparison

Similarly, maximum penetration resistance decreased (*P*=0.046) between 2017 and 2020 in the NOR 07 split grass and clover, and arable field, and depth to maximum penetration resistance also decreased (*P*=0.003). However, whilst there was no significant change in shear strength (*P*=0.560) between 2017 and 2020, there was a significant interaction effect between land use and time (*P*=0.015); shear strength decreased in the arable half but increased in the grass and clover half (Table 32).

Table 32. Penetration resistance and shear strength measurements (20 measurements per field)

Field*	Penetrometer maximum resistance (kPa)		Penetrometer depth to max resistance (cm)		Shear strength (kPa)	
	2017	2020	2017	2020	2017	2020
NOR 07 Arable	1.52	1.12	44	27	120	69
NOR 07 Grass & clover	1.62	1.37	42	23	114	151
NOR 06 Grass & clover	1.69	0.86	45	34	73	113
NOR 06 Multispecies	1.40	0.94	39	17	111	120
NOR 05 Gras & clover	1.38	0.93	43	17	119	114
NOR 05 Multispecies	1.45	0.89	43	18	119	117
Grass & clover and Multispecies ley fields[1]:						
Mean (all)	**1.51**	**1.00**	**42**	**22**	**107**	**123**
Mean G&C	**1.56**	**1.05**	**43**	**24**	**102**	**126**
Mean MSS	**1.43**	**0.92**	**41**	**17**	**115**	**119**
Year	***P*<0.001**		***P*<0.001**		***P*=0.023**	
Year * Trt	***P*=0.996**		***P*=0.167**		***P*=0.128**	
NOR 07 Grass & clover vs arable split field[2]						
Year	***P*=0.046**		***P*=0.003**		***P*=0.560**	
Year * Trt	***P*=0.535**		***P*=0.771**		***P*=0.015**	

[1]Mean and P statistic from ANOVA, where Trt (Treatment) = sward type.

[2]Mean and P statistic from ANOVA, where Trt (Treatment) = arable vs G&C in NOR7.

Soil bulk density

Table 33 shows mid-topsoil bulk density (BD) measurements made in 2017 and 2020. These measurements provide detailed information about the physical condition of topsoil and can be assessed relative to the topsoil BD 'trigger' level of >1.2 g/cm^3 (the level at which soil physical conditions may be an issue for production and further investigation is recommended) (Merrington *et al*., 2006).

Ley fields: Grass and clover, vs multispecies comparison

Bulk density increased (*P*<0.001) slightly between 2017 and 2020 in the grass and clover, and multispecies ley fields from a mean of 1.21 g/cm^3 to 1.28 g/cm^3. There was no interaction effect (*P*=0.072) of sward type (grass and clover, compared to multispecies) and time on bulk density.

This increase in bulk density between 2017 and 2020 reflects land use change; bulk density values are typically higher under untilled than tilled land. Bulk density values were slightly above 'trigger' levels in NOR 05 (grass and clover, and multispecies) and NOR 06 (multispecies); trigger levels are used to prompt further investigation; however, the other visual soil assessments have not identified any soil compaction issues.

NOR 07 Grass and clover vs arable split field comparison

There was no significant effect of time or land use on bulk density in the NOR 07 split grass and clover, and arable field.

Table 33. Soil bulk density values – mean of three assessments from each field area

Field	Mid Topsoil (10-15cm) Bulk Density (g/cm^3)	
	2017	2020
NOR 07 Arable	1.19	1.22
NOR 07 Grass & clover	1.09	1.17
NOR 06 Grass & clover	1.16	1.20
NOR 06 Multispecies	1.30	1.36
NOR 05 Grass & clover	1.25	1.30
NOR 05 Multispecies	1.23	1.38
Grass & clover and Multispecies ley fields[1]:		
Mean (all)	**1.21**	**1.28**
Mean G&C	**1.17**	**1.22**
Mean MSS	**1.26**	**1.37**
Year	***P*<0.001**	
Year * Trt	***P*=0.072**	
NOR 07 Grass & clover vs arable split field[2]		
Year	***P*=0.088**	
Year * Trt	***P*=0.283**	

[1]Mean and P statistic from ANOVA, where Trt (Treatment) = sward type.

[2]Mean and P statistic from ANOVA, where Trt (Treatment) = arable vs G&C in NOR7.

Visual Evaluation of Soil Structure (VESS) and Visual Soil Assessment (VSA)

Visual Evaluation of Soil Structure (VESS) and Visual Soil Assessments (VSA) methods were used to assess the soil physical structure (Table 34). VESS assessments at Norwood Farm found that all fields were in a 'Friable' (Sq1) to 'Intact' (Sq2) condition in 2017 and 2020.

The VSA method provides a score based on eight visual bio-physical indicators of soil quality. The maximum possible score is 32 and soils that score less than 10 are classified as poor, 10-25 moderate and greater than 25 good soil quality. All fields were in 'moderate' or 'good' condition in both 2017 and 2020.

Ley fields: Grass and clover, vs multispecies comparison

Visual Evaluation of Soil Structure (Table 34) and VSA (Table 35) assessments showed a significant improvement in soil physical structure between 2017 and 2020 in the grass and clover, and multispecies ley fields. The VESS score improved (P<0.001) from a mean of 1.8 in 2017 to a mean of 1.3 in 2020, and the VSA score improved (P=0.003) from a mean of 24 in 2017 to 27 in 2020. There was no interaction effect of sward type (grass and clover, compared to multispecies) and time on VESS (P=0.050) or VSA score (P=0.321).

NOR 07 Grass and clover vs arable split field comparison

There was a significant improvement in VESS (P=0.002), but no change in VSA score (P=0.532) in the NOR 07 split grass and clover, and arable field.

Table 34. VESS assessment of soil structure

Field	VESS[1] (1-5 scale)		VESS Poorest layer[1] (1-5 scale)	
	2017	2020	2017	2020
NOR 07 Arable	2.2	1.3	2.6	1.8
NOR 07 Grass & clover	2.2	1.5	2.5	1.8
NOR 06 Grass & clover	1.9	1.1	2.3	1.1
NOR 06 Multispecies	1.6	1.0	2.1	1.1
NOR 05 Grass & clover	1.8	1.3	2.3	1.5
NOR 05 Multispecies	1.5	1.5	1.8	1.8
Grass & clover and Multispecies ley fields[2]:				
Mean (all)	**1.8**	**1.3**	**2.2**	**1.5**
Mean G&C	**2.0**	**1.3**	**2.4**	**1.5**
Mean MSS	**1.6**	**1.3**	**1.9**	**1.5**
Year	***P*<0.001**		***P*<0.001**	
Year * Trt	***P*=0.050**		***P*=0.131**	
NOR 07 Grass & clover vs arable split field[3]				
Year	***P*=0.002**		***P*=0.009**	
Year * Trt	***P*=0.269**		***P*=0.629**	

[1] Scoring 1=Friable, 2= Intact, 3= Firm, 4= Compact, 5= Very Compact

[2]Mean and P statistic from ANOVA, where Trt (Treatment)= sward type.

[3]Mean and P statistic from ANOVA, where Trt (Treatment) = arable vs G&C in NOR7.

NOR 06 Multispecies. VESS assessment pre break-up

NOR 06 Multispecies. VESS assessment post break-up

Table 35. VSA assessment of soil structure

Field	VSA[1] (0-32 scale)		Tillage Pan[2] (0-2 scale)	
	2017	2020	2017	2020
NOR7 Arable	24	23	1.4	1.0
NOR 7 Grass/clover	22	25	1.4	2.0
NOR 6 Grass/clover	24	28	1.5	2.0
NOR 6 Multispecies	27	28	1.8	2.0
NOR 5 Grass/clover	25	27	1.4	2.0
NOR 5 Multispecies	23	26	1.1	2.0
Grass & clover and Multispecies ley fields[3]:				
Mean (all)	**24**	**27**	**1.4**	**2.0**
Mean G&C	**24**	**27**	**1.4**	**2.0**
Mean MSS	**25**	**27**	**1.5**	**2.0**
Year	***P*=0.003**		***P*=<0.001**	
Year * Trt	***P*=0.321**		***P*=0.530**	
NOR 07 Grass & clover vs arable split field[4]				
Year	***P*=0.532**		***P*=0.316**	
Year * Trt	***P*=0.169**		***P*<0.001**	

[1] Poor <10, Moderate 10-25, Good >25.

[2] Scoring 0=Well developed tillage pan, 1= Moderately developed tillage pan, 2= No pan.

[3]Mean and P statistic from ANOVA, where Trt (Treatment) = sward type.

[4]Mean and P statistic from ANOVA, where Trt (Treatment) = arable vs G&C in NOR7.

4.7.4 Summary

Detailed assessments of soil physical, chemical and biological quality showed a significant improvement in soil biology (organic matter, earthworms, microbial biomass, and respiration) and soil physical properties (penetration resistance, VESS and VSA) after three years of grass and clover, and multispecies leys.

In the ley fields, topsoil soil organic matter increased by an average of 0.3 percentage points (from 7.8% in 2017 to 8.1% in 2020), equivalent to an increase of 6 t/ha organic matter in the top 15 cm of soil. Earthworm numbers increased by 60% (from 158 to 253 worms/m^2), and total earthworm biomass increased three-fold from 46 to 137 g/m^2. Soil microbial biomass approximately doubled from a mean of 341 mg/kg in 2017 to a mean of 761 mg/kg in 2020, and respiration increased from a mean of 37 mg CO_2-C kg/day in 2017 to a mean of 47 mg CO_2-C kg/day in 2020.

Although there was a slight increase in soil bulk density between 2017 and 2020, soil penetration resistance and depth to maximum resistance decreased, and the VESS and VSA assessments showed a significant improvement in soil structure between 2017 and 2020 in the ley fields.

These data provide clear evidence of the soil quality benefits of integrating leys into arable rotations.

4.8 Yield benefit to the following arable crop

There is a need to quantify the impact that grass and clover, and multispecies leys have on the soil nitrogen supply for following arable crops to fully understand the value of establishing leys in arable rotations.

NOR 07 was split between arable and grass and clover in autumn 2017. The arable half of the field was cropped with winter oilseed rape in 2018, winter triticale followed by forage rape in 2019 and a wild bird mix in 2019 (HLS stewardship option). The whole field returned to arable production in 2021 and was sown with spring barley on 09/04/21. The field was sprayed with glyphosate, ploughed and combi-drilled. Both halves of the field had the same cultivations and establishment.

Fertiliser N response experiments were carried out in the two different areas of NOR 07 (i.e., the areas which were arable and grass and clover in 2018-2020) to determine the impact of the grass and clover ley on yields and N response.

4.8.1 Methodology

Experimental treatments and design

There were six fertiliser N rates (0-200 kg N/ha) applied to each field half (12 treatments in total) (Table 36). There were three replicates of each treatment arranged in a randomised block design within each field half. Plots were 3 m x 24 m. Figure 14 shows the location of the N response experiment either side of the previous field split in NOR 07.

Figure 14. Location of spring barley N response experiment in NOR 07 in 2021

Table 36. Treatment list

Treatment number	N rate (kg N/ha)	Previous crop
1	0	Arable
2	40	Arable
3	80	Arable
4	120	Arable
5	160	Arable
6	200	Arable
7	0	Grass & clover
8	40	Grass & clover
9	80	Grass & clover
10	120	Grass & clover
11	160	Grass & clover
12	200	Grass & clover

Nitrogen fertiliser treatments were spread to plots by hand as ammonium nitrate fertiliser. The N fertiliser treatments were split into two application timings: at planting and at GS 13 (Table 37).

Table 37. Treatment application timing

Treatment number	Total N applied	N application timing (kg N/ha)	
		N1 (planting)	N2 (GS 13)
1 & 7	0	0	0
2 & 8	40	40	0
3 & 9	80	80	0
4 & 10	120	80	40
5 & 11	160	80	80
6 & 12	200	100	100

Soil assessments for seedbed condition and plant establishment

The soil physical assessments (outlined in section 4.7) were repeated in both sections of NOR 07 in May 2021 after the spring barley was sown, to identify any differences in soil structure after sowing, which may have affected establishment/performance of the spring cereal crop.

Soil assessments were carried out at the points of minimum, median and maximum penetration resistance in each of the three blocks of in the previously arable and grass and clover halves of NOR 07 (18 assessments). In addition, at each of these points a visual estimate of percent ground cover with surface trash was made, and plant establishment count recorded (number of plants in $1m^2$ quadrat).

Measurement of grain yields and nitrogen offtake

Grain yields were measured using a plot combine, and samples were taken for moisture and protein analysis. Grain yields at 85% dry matter (DM) and grain N offtake were calculated. The percentage area of each plot that was lodged at an angle from the vertical of 10^o to 45^o (leaning) and 45^o to 90^o (lodged) was assessed at harvest. The trial was harvested on 02/09/21.

Soil mineral nitrogen

Soil mineral nitrogen (SMN) samples were taken to 90 cm depth in 30 cm sections (0-30 cm, 30-60 cm and 60-90 cm) from the zero N treatment areas in both halves of the field after the spring barley harvest on 12/10/21. Soil mineral nitrogen samples were taken after harvest to assess whether there was any difference in residual N in the two halves of the field.

4.8.2 Results

Soil assessments, seedbed condition and plant establishment

Table 38 shows results from soil physical assessments, seedbed condition and spring barley plant counts in May 2021. There was no significant difference in any of the soil properties measured between the previously arable, and grass and clover halves, apart from total number of worms which was higher (*P*=0.024) in the previously arable half. VESS scores were good and VSA scores were moderate.

On average there was more surface trash (i.e., crop residue) on the previously grass and clover half (mean of 13% surface trash) than the previously arable half (mean of 2% surface trash), but this difference was not statistically significant (*P*=0.099).

Plant counts were greater (*P*=0.034) in the previously grass and clover half (mean 128 plants/m^2) than the previously arable half (mean 98 plants/m^2).

Table 38. Soil physical assessments, seedbed condition and plant counts (13/05/21)

Previous crop	Total worm number (per/m^2)	Total worm biomass (g/m^2)	Penetrometer maximum resistance (kPa)	Shear strength (kPa)	Bulk Density (g/cm^3)	VESS[1] (1-5 scale)	VSA[2] (0-32 scale)	Plant count (per m^2)	Surface trash (%)
Arable	80	33	0.99	26	1.05	1.6	14	98	2
Grass	53	19	1.04	25	0.98	1.7	14	128	13
***P*-value**	**0.024**	**0.261**	**0.627**	**0.921**	**0.263**	**0.687**	**0.982**	**0.034**	**0.099**

[1] Scoring 1=Friable, 2= Intact, 3= Firm, 4= Compact, 5= Very Compact

[2] Poor <10, Moderate 10-25, Good >25.

P statistic from ANOVA.

Spring barley yields and nitrogen offtake

Spring barley yields were an average of 0.7 t/ha higher (*P*<0.001) following grass and clover than following the arable crop (Figure 15 and Table 39). There was no yield response to N fertiliser (*P*=0.661) in either field half and therefore it was not possible to calculate an economic optimum N rate. There was no effect of fertiliser N on grain N content (*P*=0.787). Grain N offtake was an average of 12 kg/ha greater (*P*<0.001) following grass and clover than following the arable crop, reflecting higher grain yields.

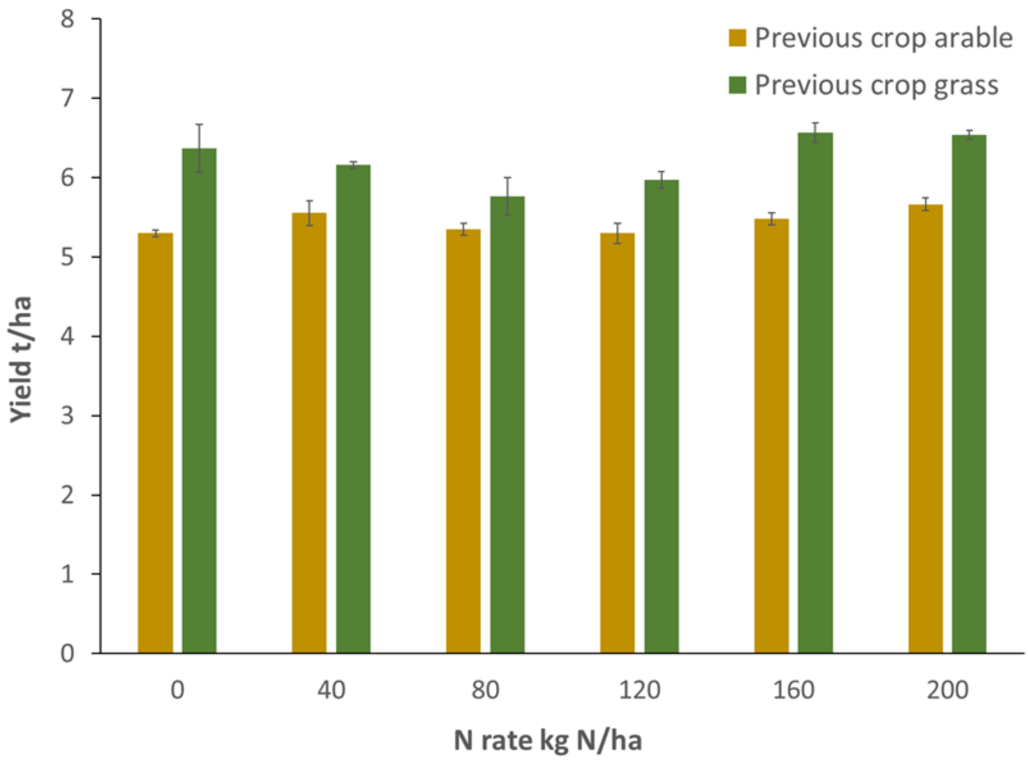


Figure 15. Spring barley yields in 2021

Table 39. Grain yields, N content and N offtake

Previous crop	N rate (kg/ha)	Yield (t/ha @ 85% DM)	Grain N (%)	Grain N offtake (kg/ha)
Arable	0	5.3	2.19	89
Arable	40	5.5	2.18	94
Arable	80	5.3	2.12	84
Arable	120	5.5	2.17	92
Arable	160	5.5	2.08	90
Arable	200	5.5	2.02	86
Grass & clover	0	5.9	1.93	89
Grass & clover	40	5.9	1.97	90
Grass & clover	80	6.4	1.96	100
Grass & clover	120	6.3	2.06	104
Grass & clover	160	6.3	2.14	109
Grass & clover	200	6.2	2.26	112
Mean Arable		**5.4**	**2.13**	**89**
Mean Grass & clover		**6.2**	**2.05**	**101**
***P*-value**	**Previous crop**	**<0.001**	**0.109**	**<0.001**
	N rate	**0.661**	**0.787**	**0.019**
	Interaction	**0.722**	**0.027**	**0.001**

P statistic from ANOVA.

Soil mineral nitrogen after harvest

Soil mineral nitrogen after spring barley was similar on the previously arable (121 kg/ha) and previously grass and clover (95 kg/ha N) half of the field (*P*=0.379) (Figure 16).

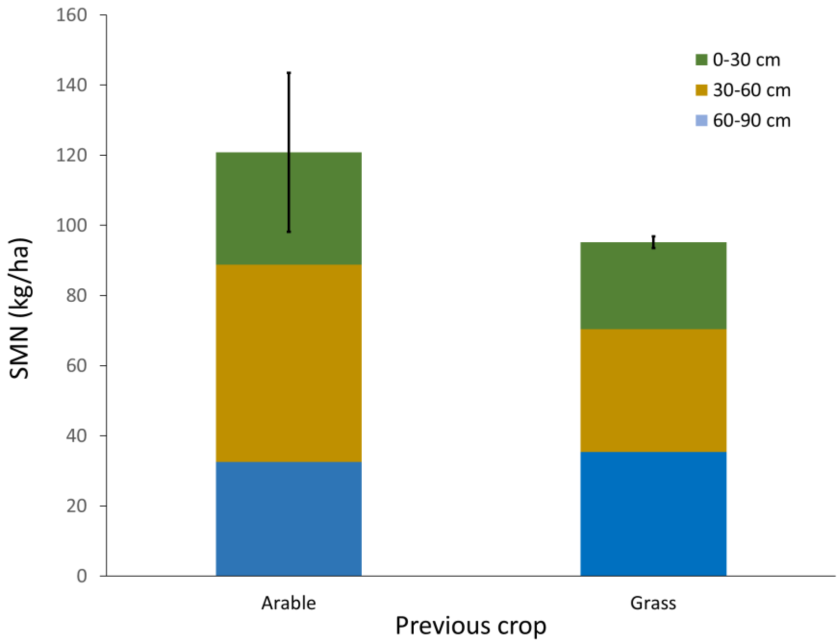


Figure 16. Soil mineral nitrogen from zero N treatment after harvest Oct 2021

4.8.3 Summary

The three-year grass and clover ley in NOR 07 was sprayed off and a spring barley crop established in NOR 07 by plough and combi drill. The same cultivations were used for both halves of the field (previously arable and previously grass and clover). Soil physical assessments showed the soil was in good condition in spring 2021. Spring barley plant counts were higher in the previously grass and clover than the previously arable section of the field, and at harvest yields were on average of 0.7 t/ha higher (*P*<0.001) following grass and clover than following the arable crop. If the barley taken at harvest in 2021 was valued at £160/tonne this would equate to £112/ha of additional income due to the higher yield. There was no yield response to applied N fertiliser in either half of the field, and therefore this increase in yields is unlikely to be due to higher N mineralisation rates following the grass and clover ley.

4.9 Weed assessments and monitoring

The introduction of a ley into an arable rotation potentially enhances the cultural control of black-grass by allowing seed to decline in the weed seedbank. It also reduces the resistance pressure to current herbicides which helps maintain their effectiveness for longer. The aim of this work package was to assess the effectiveness of a ley in reducing black-grass numbers.

4.9.1 Methodology

At Norwood Farm the black-grass population was assessed in the winter wheat crop (prior to establishing the ley) in NOR 07 on 25/06/17 and then again in the spring barley crop in June 2021. Black-grass assessments were only made in NOR 07, as the other fields in the study had low black-grass pressure.

The field was divided into four sections – sections 1 and 2 were sown with a grass and clover ley in autumn 2017, and sections 3 and 4 remained in arable production (Figure 17). In 2017 black-grass head counts were made in ten 0.1m^2 quadrats in each field section (Plate 14). In addition, a visual assessment was made of the 'patchiness' of black-grass in each field section. In 2021 black-grass plant and head counts were made in 11 1m^2 quadrats in each tramline across the field.

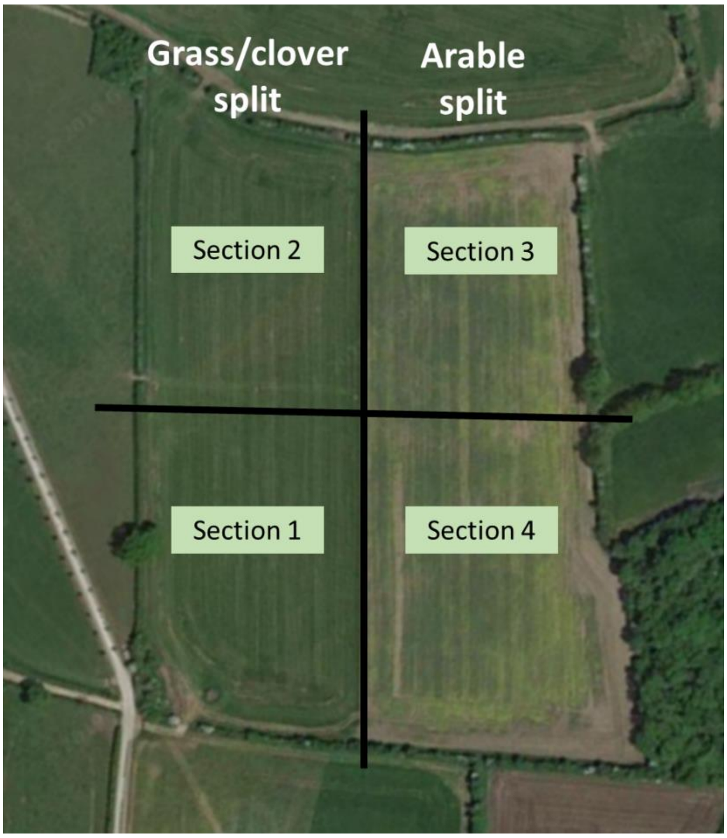


Figure 17. NOR 07 showing field sections for black-grass head counts in 2017 (shown on satellite image showing the grass and arable field split).

Plate 14. Black-grass assessments in NOR 07 (June 2017)

4.9.2 Results

Black-grass abundance

In 2017, black-grass was patchy across the field, and counts ranged from zero heads/m^2 up to a maximum of 400 heads/m^2. Mean head counts for sections 1 and 2 (grass and clover ley from autumn 2017) were 78 and 37 heads/m^2 respectively, and mean head counts for sections 3 and 4 (remaining in an arable rotation) were 105 and 0 heads/m^2 respectively. The overall mean head count from sections 1 and 2 combined (grass and clover ley from autumn 2017) was 57.5 heads/m^2 and the overall mean head count from sections 3 and 4 (remaining in arable rotation) was 52.5 heads/m^2.

In 2021, the amount of black-grass had reduced significantly to a mean head count of 0.2 heads/m^2 in the grass and clover section (99.7% reduction) and to 1.3 heads/m^2 in the arable section (97.5% reduction).

Although black-grass head-counts in the arable section reduced overall by 97.5%, black-grass growth was patchy (Figure 18) and populations were still present in the first tramline (4.6 heads/m^2), so seed set and growth is likely to continue in future years.

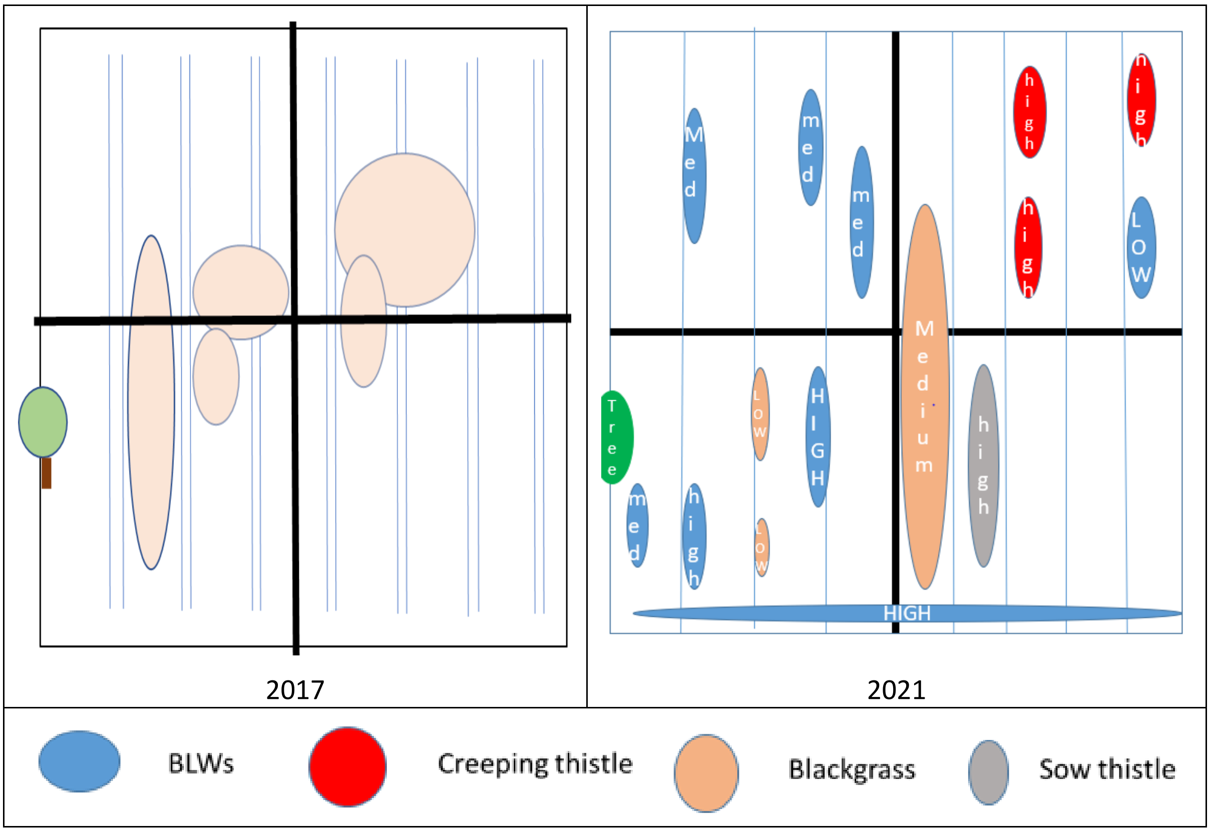


Figure 18: Distribution of weed populations in 2017 (left) and 2021 (right)

Weed species and general abundance

In 2021 there was a mixture of common arable weeds throughout both splits of the field (Table 40). A higher pressure of broad-leaved weeds was present in the half that had the grass and clover ley and these weeds were generally more advanced in growth stage than in the half that had been in continuous arable production.

Table 40: Weed species present across NOR 07 (entire field) in spring barley (June 2021)

Species	Notes (GS: Growth stage, cm =diameter)
Greater plantain (*Plantago major)*	GS: 13-18
Scarlet pimpernel	GS: 60, 12cm
Red dead nettle	GS: 19 - 60, 8cm,
Prickly and smooth sow thistles	GS: 14-60
Redshank	GS: 18
Pale persicaria	GS: 16-19, 10-20cm
Field speedwell	GS: 60
Charlock	GS: 60
Cleavers	10-25cm
Doves foot cranesbill	GS: 19, 8cm
Perennial ryegrass	GS: 19-69
Field pansy	GS: 60
Fat hen	10cm
Orache	10cm
Creeping thistle	GS: 60 First flowers opening

4.9.3 Summary

The grass and clover ley improved black-grass reduction compared to the continuous arable. On reversion to arable production, the grass and clover area contained higher levels of broad-leaved weeds than the continuous arable area and the crop was generally more advanced in the continuous arable area (GS:55 compared to GS:45-55 in the grass clover split). The higher broad-leaved weed burden is likely to reflect a range of factors including increased weed seed bank during ley establishment or slower crop establishment post-ley allowing for less competition with the weeds. Further work to determine the effects of different ley establishment and termination techniques on future weed populations would help to give a clearer indication of the effects of leys on broad leaved weed populations. Perennial ryegrass volunteers were present post-ley but only in low numbers. These ryegrass volunteers from the ley would not be herbicide resistant so control should not pose too great a risk to future weed control, but control must be good to prevent a build-up in the weed seed bank. No other volunteer species from the ley were present in the crop post-ley.

4.10 Norwood Farm conclusions

In September 2017, six long term arable (>10 years) fields were sown to grass and clover or multispecies leys at Norwood Farm in Somerset. Detailed baseline assessments of soil physical, chemical and biological quality were carried out in autumn 2017 prior to ley establishment. The assessments were repeated in autumn 2020 and showed a significant improvement in soil quality three years after the ley was established. Topsoil soil organic matter increased by an average of 0.3 percentage points (from 7.8% in 2017 to 8.1% in 2020), equivalent to an increase of 6 t/ha organic matter in the top 15 cm of soil. Earthworm numbers increased by 60% between 2017 and 2020 (from 158 to 253 worms/m^2), and total earthworm biomass increased three-fold from 46 to 137 g/m^2. These data provide clear evidence of the soil quality benefits of integrating leys into arable rotations.

In 2021, after the three-year grass and clover ley, the amount of black-grass had reduced in number indicating the potential of leys to help cultural control of black-grass.

Spring barley yields following the grass and clover ley were 0.7 t/ha greater than on continuous arable. The increased yield was not a reflection of increased soil nitrogen supply on the former grass and clover ley and may have been a result of improved soil quality as a result of increased soil organic matter content.

A cost benefit analysis of integrating beef into arable systems showed a positive net margin of around £250/ha (before rent and finance). This economic analysis shows that there is potential for the arable farmer to make a positive margin from cattle grazing a ley in an arable rotation.

5 KNOWLEDGE TRANSFER

A key part of this project has been to translate information on the practical, economic, environmental and agronomic implications of integrating beef enterprises into arable systems to both arable farmers and beef producers. The knowledge transfer (KT) programme has been delivered across the project and included two on farm events (one at each site), farmer meetings and conferences, press articles and KT literature.

5.1 Farm events

An open day was held linked to the Thriplow Farm site on 22/09/16. The event included morning presentations on integrating beef into arable systems, growing beef on short term leys, managing grazing and the economics of the system, and an afternoon visit to the ley field. There were 37 delegates (excluding ADAS, AHDB and R&B Beef).

An open day was held at Norwood Farm on 21/09/21. The event included presentations on monitoring soil health, cost benefit analysis of integrating beef into arable systems, benefits of grass and clover and multispecies leys, practicality of integrating livestock onto arable rotations and utilising environment schemes, as well as an overview of the farm from the farm manager (Peter Lord).

5.2 Project webinar and podcast

The project featured in an AHDB Podcast on 14/12/20 entitled 'Could mixing livestock and arable help your business become more sustainable?'

A webinar was held to present the results of the project on 18/10/21 entitled 'Sustainable beef systems on arable units'.

5.3 Beef in the arable rotation – Mix and match calculator

As part of the project the AHDB Market Intelligence team have created a simple Excel based tool to help farmers calculate potential cost and margins of integrating beef into arable rotations. The calculator is populated by the farmer, using a drop-down list of options which provide a 'mix and match' of different infrastructure set-ups, ley establishments and cattle rearing systems.

5.4 Other meetings

Information on the project was also presented at the following meetings:

- AHDB Cereals & Oilseeds Louth Monitor Farm meeting 20/12/16
- AHDB Cereals & Oilseeds Spring Agronomy events 'Soil health – integrating livestock into arable rotations'
    - South Muskham, 08/02/17
    - Dereham 23/02/17
- AHDB Cereals & Oilseeds Huntingdon Monitor Farm meeting 28/02/17
- ADAS Boxworth Farmers Association Spring Meeting 06/02/17
- AHDB Cereals and Oilseeds Agronomy 2017 event on 08/02/2017 in South Muskham, Notts
- AHDB Cereals and Oilseeds Agronomy 2017 event on 23/02/2017 in Dereham, Norfolk
- Agricology Field Day: Mixing it up – Leys, livestock and arable on 03/01/18 at Daylesford Farm, Oxfordshire

- AHDB, Defra and ADAS Grass and herbal leys farm network launch meeting on 19/04/18 in Coventry
- British Society of Soil Science annual conference on 04 & 05/09/18 in Lancaster
- Association of Applied Biologists conference ‘Soil improvement: impact of management practices on soil function and quality’ on 16/10/18 at NIAB, Cambridge
- Lincoln University, Knowledge & Innovation day for farmers, 13/11/18 in Buckminster, Leicestershire
- SAC/SEPA Land use conference ‘Rewarding the delivery of public goods: How to achieve this in practice’, 28 & 29/11/18 at James Hutton Institute, Edinburgh
- Oxford Real Farming Conference session ‘Ley of the land: integrating leys into cropping systems’ hosted by Agricology, Jan 2019
- AHDB Agronomist Induction: ‘Integrating livestock into arable rotations – leys in arable rotations’, Oct 2019
- Grass & Herbal Leys Farm Network meeting on 27/02/20
- Groundswell June 2021 – part of a panel discussion on ‘Leys in arable rotations’
- AHDB Hale Farm Monitor Meeting ‘Livestock in the arable rotation’ 20/01/21
- Groundswell June 2022 – information on the project was included on the ADAS stand
- World Congress of Soil Science August 2022 in Glasgow.

5.5 Farming press

Farmers Guardian attended the open day at Thriplow Farm and have included details from the project as part of their seven-part series on integrating livestock into arable rotations. Farmers Guardian took a number of short video clips at the open day which have been uploaded onto their website as part of this series.

CPM Magazine ‘From theory to field’ article ‘Beef up the rotation?’ October 2019.

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