STC 'Living Mulches'

Year 2 Report

(01st December 2018 – 31st November 2019)

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Contents

The results and conclusions in this report are based on trials at two separate locations. The conditions under which the trials were carried out and the results have been reported with detail and accuracy. However, because of the nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results especially if they are used as the basis for commercial production.

Introduction

Living mulch understories are thought to represent a potential, multifunctional component in addressing key challenges faced by the arable sector such as erosion control, reduction in surface water pollution, unused soil nitrogen recycling, declining soil productivity, structure and health, and weed control (Hartwig & Ammon, 2002). Research has further shown that leguminous living mulches, such as those comprised of various clover species, can support improvements to soil fertility (Duda *et al.*, 2003), cash crop nutrient uptake (Deguchi *et al.*, 2007), soil macro- and micro-biotic health (Schmidt *et al.*, 2003; Nakamoto & Tsukamoto, 2006; Brévault *et al.*, 2007; Pelosi *et al.*, 2009), water retention (Siller *et al.*, 2016), while conferring protection from soil erosion and nutrient losses or leaching (Siller *et al.*, 2016). Their use as an in-crop, intercropped partner has also been shown to support weed suppression (Hiltbrunner *et al.*, 2007a), with recent meta-analyses reporting lower weed biomass and, in the majority of cases, either unaffected or higher cash crop yields relative to non-weeded or weeded control treatments (Verret *et al.*, 2017). This suppressive effect has the potential to play an important role in reducing herbicide inputs in production. As nitrogen-fixers, leguminous living mulches may also play a role in reducing or replacing fertiliser inputs which, combined with reductions in nutrient leaching, will provide support for reductions in water pollution while also supporting reductions in N_2O emissions (e.g. Deguchi *et al.*, 2007). Horticultural sector research has also shown that, where appropriate flowering understories are used, living mulches can also promote on-farm pollinator conservation efforts (Saunders *et al.*, 2013). Were this repeatable in the arable sector, conservation potential of production in this sector would be improved. Living mulches may also play a role in future carbon sequestration efforts (Sequestering Carbon in Soil, 2017). With future arable production likely to focus on sustainable intensification and environmental responsibility, adoption of multifunctional solutions will be important to achieving policy- and market-driven competitiveness while maintaining yield, and thus near-market validation of production techniques that provide high levels of such additionality are important priorities.

Despite demonstrated benefits, commercial uptake of in-crop living mulches in the UK has, to date, been limited by production conflicts and practical management challenges of such systems. Although recent work has shown that weed suppressive effect can be achieved without impacting yield, other work has shown that yield can be suppressed (Carof *et al*, 2007; Siller *et al.*, 2016), and although measures to mitigate such yield suppression have been evaluated, such as through varying cash crop seeding rates (Hiltbrunner *et al.*, 2007b), consistent, commercially-relevant resolutions still need investigation and validation. Challenges also remain in terms of management of perennial weeds, such as thistles and docks, and in control of crop pests and diseases, although some research has shown potential for pest population control (Prasifka *et al.*, 2006; Schmidt *et al.*, 2007. On the latter, greater research focus will be required to understand underlying mechanisms mitigating burden levels of different pest and disease species, and the impact of living mulches on these burdens across and within growing seasons (Alyokhin *et al.*, 2020).

Use of commercially available machinery and Precision Agriculture Technologies (PAT) can afford innovative opportunity to overcome some of the restrictions and challenges that have prevented commercial uptake in the UK. PAT-assisted strip-tillage, in particular, represent a minimum-tillage soil conservation approach that allows cash crop and clover to be simultaneously sown into cultivated bands in a single pass, and for crops to be drilled into cultivated strips in pre-existing, permanent clover living mulch understories.

The STC 'Living Mulches' project aims to make use of these innovations to demonstrate and commercially validate that living mulches are compatible with, and both profitable and beneficial for, UK arable production. Though the multiple benefits of living mulches, *per se*, and existing machinery are already available to farmers, and are not innovative in their own rights, viable means for farmers to realise the benefits of such systems through incorporation into profitable arable cropping represents an opportunity for innovation, relative to current 'monocultural' production. Combining PAT-assisted steering with strip-tillage and band-sown drilling should permit establishment and long-term persistence of clover living mulch understories, to deliver key inputs, particularly nitrogen, while simultaneously protecting soils and improving water, nutrient and organic matter retention post-harvest. PAT approaches should facilitate the sub-inch accuracy needed to repeatedly drill clover relay intercrops, year on year, though such band-sowing could also be undertaken independent of PAT-assisted steerage and PAT uptake, through sacrifice of accuracy. Although such PAT-assisted approaches to promote and support successful polyculture and intercropping are relatively innovative, the potential benefits of living mulches are broadly well-established, and the production methods targeted for integration are achievable with current commercially available machinery and technologies.

Aims and Objectives

The aim of this project is to **demonstrate and validate clover living mulches as a viable, achievable and profitable option** for arable farmers in the UK. As such, the primary outcome from this project be to obtain evidence that (1) living mulches are compatible with current cereal production, across PAT uptake spectra, and (2) living mulches can provide multiple benefits to farmers which would encourage their use. A further outcome, crucial to project success, is engagement of the arable sector with the project. This will be achieved through a series of selected outward-facing events coupled with zero-cost opportunistic dissemination and engagement of a broader industry network via 'Early Adopters' and a project leaflet.

On-Farm Validation

In order to validate the use of strip-tilled living mulches in cereal production the project is being run on-site at Stockbridge Technology Centre (STC) (Cawood, North Yorkshire) and Hessleskew Farm (Sancton, North Yorkshire). Results from both sites will be compared, allowing validation across soil types, production systems and winter and spring crops.

STC: Platform description

STC sits on 200 acres of mixed soils comprised mainly of sandy loam, sandy clay loam and clay loam. The sand in the clay loam helps improve drainage while still retaining moisture and nutrients. Though benefits of living mulches could still be expected across these soil types, wider environmental gains of this approach are also a key focus on site. As a mixed cropping research farm with a strong history in agri-environmental projects, a key driver for living mulch validation at STC, alongside improvements to soil, is promotion of soil-dwelling beneficial organisms and insect pollinators.

The validation platform at STC covers 3.1 hectares (ha), with 2.65ha of this grown with a living mulch understory (Fig. 1). The understory consists of a white clover (*Trifolium repens* var. 'Aberpearl'). In 2019, the platform was validated with a spring barley main crop under a low-input approach in terms of nitrogen addition and spray regimes for herbicides or fungicides, which were applied across the whole platform.

Figure 1. Plot map of STC validation platform, showing approximate locations of sampling points (not to scale). In 2019, the platform validated a spring barley (var. 'Laureate') with a white clover living mulch understory ('Clover understory') against a monoculture control ('No clover').

Hessleskew Farm: Platform description

A commercial farm of 172ha, producing a mixture of potatoes, cereals and vining peas in rotation, on Yorkshire Wolds soils mainly comprised of clay loam. In general, such soils are good for water and nutrient retention, and as such can be a good growing medium. Lack of drainage can become a problem if too much precipitation occurs, however, meaning the land can be hard to work at certain times of the year. Simultaneously, sitting over chalk adds pressure to improve nitrogen use efficiencies to limit nitrogen entering the water table. Regular additions of organic matter can nevertheless improve nutrient accessibility and drainage, with living mulches being a potential means to achieve this input.

The validation platform at Hessleskew Farm covers 23ha overall, with 8ha of this grown with a living mulch understory (Fig. 2). The understory consists of a mixture of white clover varieties (a 1:1 mix of var. 'Crusader' and 'Liflex'). In 2019, it was validated with a spring barley main crop under a low- to no-input production model that varied by plot type (with clover plots receiving few to no inputs, *vs* control plots receiving nitrogen and fungicides as per standard conventional practice).

Figure 2. Plot map of Hessleskew Farm validation platform, showing approximate locations of sampling points (not to scale). In 2019, the platform validated a spring barley (var. 'Laureate') with a white clover living mulch understory ('Clover understory) against a monoculture control ('No clover').

Methods

STC platform management

Prior to drilling, field management was undertaken comprising of (1) application of a reduced rated glyphosate (3L/ha) for weed management, and (2) conventional soil preparation (ploughing and power harrowing) of the 'no clover' monoculture control area. Spring malting barley 'Laureate' was drilled in April 2019 at a rate of 180kg/ha, using a Baertschi Oekosem ROTOR strip till cultivator. The platform was rolled to reduce moisture loss, improve pre-emergence herbicide efficiency and improve establishment through seed-to-soil contact. White clover ('Aberpearl') had been sown in the field in 2018, and there was no top-up sowing in 2019.

Fertiliser was broadcast approximately one month after drilling, in May 2019, across the whole field at a relatively low rate (220kg/ha Nitram, equivalent to 80kg/ha N), as per previous year and in line with the model selected for use at STC to determine benefit of clover living mulches (particularly in years following initial clover establishment). Fungicide was applied to the whole plot in June 2019; $\text{Siltra}_{\text{Xpro}}$® (Bayer Crop Science; 60 g/L (6.2% w/w) bixafen + 200 g/L (20.2% w/w) prothioconazole) was applied at a rate of 0.75L/ha to provide control of barley diseases, including *Rhynchosporium*, net blotch, brown rust and *Ramularia* owing to the prevailing weather conditions experienced over the growing season. Application of the herbicide Hurler® (Barclay Chemicals; 200g/L fluroxypyr) was also made at a rate of 0.5L/ha. Harvest samples were collected in late August, with the field subsequently combine harvested in early September 2019.

Hessleskew Farm platform management

In the clover area, a pre-drilling application of glyphosate at a reduced rate (360g at 3.5L/ha) was undertaken to control weeds and suppress clover, to reduce competition with crop in the early stages of plant growth. Standard conventional management was undertaken in the conventional no-clover area. Spring malting barley 'Laureate' was drilled in early April 2019 at a rate of 125kg/ha, using a Baertschi Oekosem ROTOR strip till cultivator in the clover plot, and using conventional methods in the conventional, no-clover plot (equivalent to 200kg/ha in the conventional plot, but reduced in proportion to sown area due to clover intercrop structure).

The no-clover conventional area of the trial was managed in line with a standard programme. By contrast, no fertiliser application was made in the clover plot over the growing season. An application of the fungicide Amistar Opti® (Syngenta; 100 g/l azoxystrobin + 500 g/l chlorothalonil) was applied to the clover area in May 2019 at a rate of 0.75L/ha, as was a fluroxypyr-based herbicide, also at a rate of 0.75L/ha, to stress the clover and thus reduce competition, and to manage weeds. Harvest samples were collected in mid-August 2019, prior to combine harvesting in the same month.

Assessments

Field assessments were carried out on both trial sites, though more frequent data gathering was undertaken at STC (Appendix I, II). Data sampling points had been GPS marked at each site in 2018. At STC, the same sampling points were then marked out for data gathering in 2019. At Hessleskew Farm, the same sampling points were marked out in the clover area, however as the conventional no-clover plot changed between the two years (to allow for rotations), new sampling points were selected in the new area for 2019 and subsequently GPS marked. Data gathering activities continued through the 2019 growing season.

Crop growth stage – Average crop growth stage was determined based on random selection of 5-10 plants at each sampling point, in line with the BBCH growth scale for cereals (Meier, 2001).

Establishment – A $0.25m^2$ quadrat was placed at random near each sampling point marker, and the number of barley plants counted.

Leaf chlorophyll – An atLEAF chlorophyll meter (CHL STD; FT Green LLC, USA) was used to obtain a relative measure of leaf chlorophyll content. On each of five plants around each sampling point, a leaf was selected at random and a reading taken with the chlorophyll meter.

Canopy height – At each sampling point, a cane was used to establish the representative top of the canopy. A meter ruler was then used to measure the distance between the ground and the horizontal cane level.

Leaf nitrogen analysis – Crop in a 0.25m^2 quadrat area was manually harvested, prepared and submitted to NRM (external provider) for foliar tissue analysis.

Harvest assessments – include ear and tiller counts, and fresh and dry weights of ears and straw. At each sampling point, a 0.25m^2 quadrat was placed at random, and the crop within the quadrat harvested after the number of tillers were counted. The harvested plant material was then placed into a labelled sample bag and returned to the field lab for processing. The number of ears were counted, and the ears and straw separated. Ten ears per sample were selected at random and measured for length. Similarly, ten straw segments were selected at random and measured for length. A fresh weight for all plant material was obtained, before a sub-sample was removed from each sample, weighed and placed into individual foil trays for drying. Trays were placed in a drying oven for 24 hours before being reweighed, and this process was repeated until weight stabilised to obtain the dry weight of each sub-sample.

Yield – the weights obtained in the harvest assessment were extrapolated to yield in tonnes per hectare or, where possible, combine data was also obtained.

Ground cover (clover and weeds) - A 0.25m^2 quadrat was placed at random near each sampling point marker, and the ground cover (of clover, in clover plots, and weeds) recorded as a percentage of area covered within the quadrat.

Flowering – The number of flowers in a 0.25m^2 quadrat area placed at random near each sampling point marker was counted and recorded.

Invertebrate assessments on crop plants – The same method was applied for insect pest and beneficial assessments. A 0.25m^2 quadrat was placed at random near each sampling point marker. The number of aphids (bird cherry-oat aphid, *Rhopalosiphum padi*; English grain aphid, *Sitobion avenae*; and rose-grain aphid, *Metapolophium dirhodum*), cereal beetles (*Oulema melanopus*) and, if observed, orange wheat blossom midges ('OWBM', *Sitodiplosis mosellana*) were recorded from 10 plants. Similarly, the number of parasitoid wasps, ladybird life stages and hover fly life stages were also recorded.

Invertebrate visual transects – In order to capture data on more mobile invertebrates, visual transects were also undertaken. A 1.5m transect around each sampling point was observed, and the number of bumble- and honey-bees, other solitary wasps, adult Lepidoptera (moths and butterflies), adult hoverflies and parasitoid wasps were recorded, as well as the number of other flies (to Order level).

Slug and carabid counts – An upturned pot saucer was placed at each sampling point, weighted down with a brick. Approximately 2-3 tablespoons over poultry feed (Layers Mash) was placed under each saucer. The saucer was removed and the numbers of both slugs and carabids (which sheltered and congregated in the traps) under the saucer or in the covered area were counted, before the bait was refreshed and the saucer replaced.

Disease assessments – A $0.25m^2$ quadrat was placed at random near each sampling point marker, and the percentage of plants infected with mildew, rust or *Septoria* recorded. An estimate of disease severity, on a scale basis (where 0 = no presence, and 9 = very severe), was also made.

Worm counts – At each sampling point, an area of soil 30 cm (h) x 30 cm (w) x 30 cm (d) (a volume of approximately $0.27m^3$) was carefully dug up and placed in a white tray. The soil was carefully separated and sifted into a second tray, and the number of worms recovered were counted.

Bird and mammal counts – The number of different birds and mammals around each sampling point were recorded from a relative distance over a period of 15 minutes. During this time, and for a brief period preceding the recording interval, the reporting individual remained as still as possible.

Soil moisture and temperature – A Delta-T HH2 Moisture Meter with a WET-2 sensor was used to take measures of soil moisture and temperature at each sampling point, though only where good soil penetration by the meter without breakage could be achieved (this was not possible, for example, if soil became too hard in periods of no rainfall).

Soil compaction – A DICKEY-john Soil Compaction Tester was used at each sampling point to achieve measures of soil compaction. The meter was pressed into the ground at the value recorded on the instrument dial recorded.

Soil analyses (e.g. mineral nitrogen, health scores) – Soil samples were collected from designated sampling points and submitted to NRM (external provider) for soil analysis.

Statistical analyses

Where statistical analyses were carried out, these were done using the statistical program, R (version 3.6.1, R Development Core Team (2019)). Where data met the assumptions of parametric testing, data were analysed by one- or two-way ANOVA, as required. Packages '`nortest`' (Gross & Ligges, 2015) and '`car`' (Fox & Weisberg, 2019) were used to conduct Anderson-Darling and Levene's Tests to establish the assumptions of normality and homoscedasticity of data, respectively. Where data did not, or could not be transformed to, meet the assumptions for parametric testing, these were analysed by means of a non-parametric Kruskal-Wallis Test. No comparisons were made between trial sites or with previous years of the trials for the purposes of this report.

Results and Discussion

Crop performance

Crop establishment

In 2019, establishment of spring barley was evaluated one month after drilling on both platforms. On the STC platform, establishment numbers were higher in the area of the field in which there was not a clover understory in comparison to the area with a clover understory, though the difference was not found to be statistically significant ($F_{1,13}$ = 4.26, n.s.; Figure 3). In the case of Hessleskew Farm, however, significantly more plants successfully established in the area where they were drilled into strip tilled strips of clover understory ($F_{1,13}$ = 4.26, p < 0.05; Figure 3).

Figure 1. Crop establishment of spring barley 'Laureate' on the STC (grey bars) and Hessleskew Farm (hatched bars) validation platforms. Means are shown ± SEs.

These findings suggest that, in 2019, strip tillage into pre-existing clover understories on both sites, and the management strategies undertaken in advance of drilling, particularly at Hessleskew Farm, may have suppressed pre-existing clover to sufficient levels as to mitigate any competition with the establishing spring barley crop at this early stage of the growing season.

In the 2018 trials, emergence counts of the evaluated winter wheat crop at Hessleskew Farm found lower emergence rates where the crop was strip tilled and drilled into an existing clover understory. It was considered at the time that this may have been due to higher levels of competition by the clover with a more slowly emerging crop (given prevailing climatic conditions which would have allowed the clover to compete more strongly). The findings in 2019 at both sites suggest that it may be that spring sown crops may help mitigate establishment challenges, where the crops are strip tilled and drilled into existing clover understory platforms.

Relative leaf chlorophyll

Two assessments were made of relative leaf chlorophyll content at each site (STC: 30th May, 30th July 2019; Hessleskew Farm: 23rd May, 18th June 2019). While relative chlorophyll measures from spring barley at the STC validation platform were found to differ between assessment dates ($F_{1,27} = 4.26$, $p < 0.001$; Figure 4a), with lower values recorded later in the season, there was no difference noted between the values depending on whether the barley was grown with or without a clover living understory ($F_{1,27} = 0.74$, n.s.; Figure 4a). At Hessleskew Farm, by contrast, no statistical difference was found between relative chlorophyll measures between assessment dates ($F_{1,27} = 2.12$, n.s.; Figure 4a) or depending on whether crop was grown with or without a clover living understory ($F_{1,27} = 1.23$, n.s.; Figure 4a).

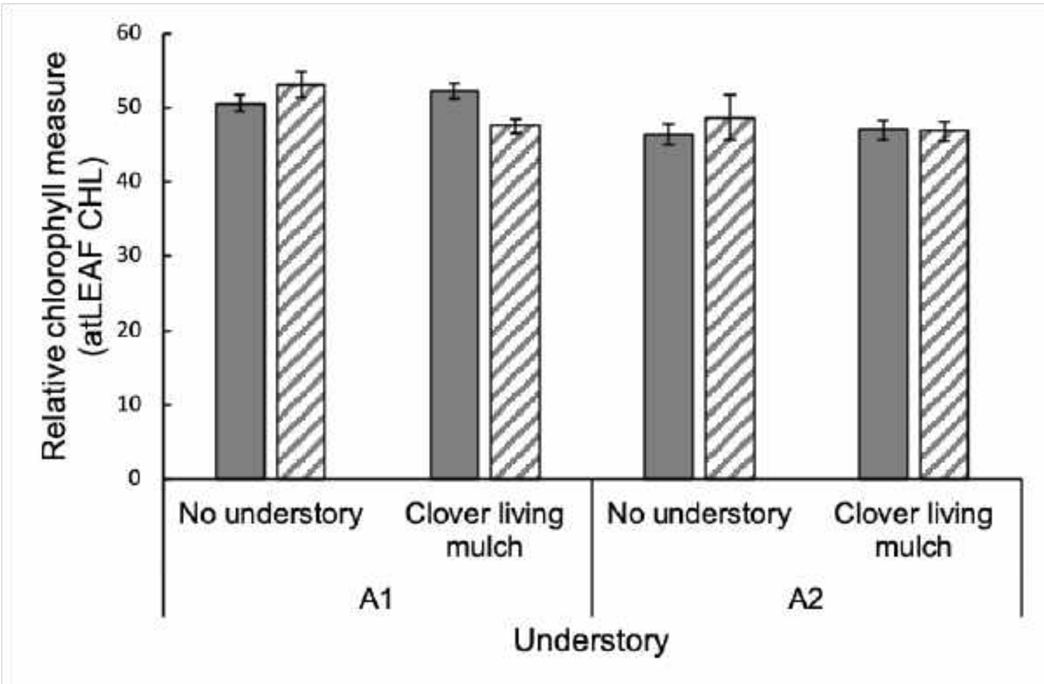

Figure 4. Mean relative atLEAF chlorophyll meter units (a) of spring barley 'Laureate' on the STC (grey bars) and Hessleskew Farm (hatched bars) validation platforms. STC values gathered on 30th May (A1) and 30th July (A2) 2019. Hessleskew Farm values gathered on 23rd May (A1) and 18th June (A2) 2019. Means are shown ± SEs.

Values were pooled to obtain a treatment mean for conversion to total chlorophyll content via the dedicated conversion tool available on the atLEAF website[1] (Figure 5a,b). The pooled values clearly show the consistent differences obtained from raw measurements. Namely, higher values for chlorophyll content were achieved in spring barley grown with a clover living mulch understory on the STC platform, whereas the opposite was true at Hessleskew Farm. Differences between assessment dates at STC could be explained by the larger gap between measures (two months) when compared to the gap between Hessleskew measures (one month), which would have brought the STC crop nearer harvest and, therefore, further along in terms of plant maturation and subsequent senescence. Furthermore, it is also worth noting that, on the STC platform, a fertiliser application was broadcast across both areas of the field, whereas at Hessleskew the clover area received no such application. This may have led to

[1] Conversion tool available at: https://www.atleaf.com/SPAD

higher per plant competition for nitrogen per unit area in the crop grown with a clover living understory.

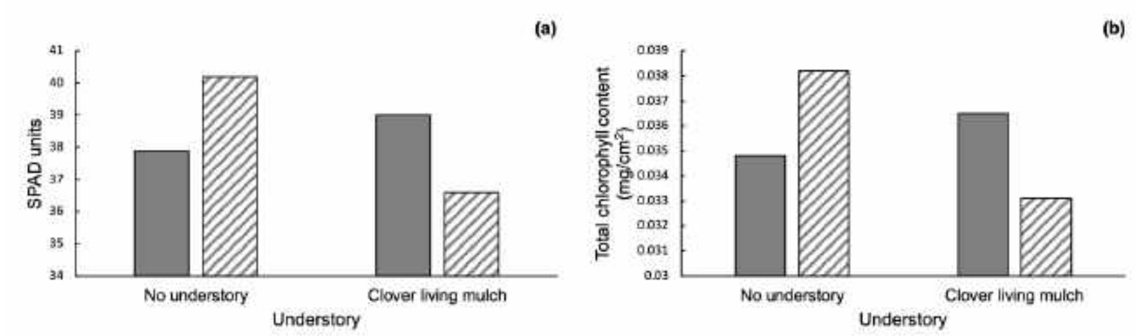

Figure 5. Pooled mean SPAD units (a) and mean total chlorophyll content (mg/cm^2) (b) of spring barley 'Laureate' on the STC (grey bars) and Hessleskew Farm (hatched bars) validation platforms. Values were converted from atLEAF chlorophyll meter units[1].

Chlorophyll levels present in plant leaves are closely related to the nutritional condition and health of a plant, with chlorophyll content increased in proportion to the amount of nitrogen present in a leaf. Measures can be used to inform decisions on nitrogen management and fertiliser application programmes. The findings in 2019 are inconsistent, suggesting trends toward improved nitrogen availability to crop plants grown with clover living mulches at STC, whereas reduced nitrogen is suggested at Hessleskew Farm. It is important, however, to note that based on raw meter outputs the resulting differences are not statistically discernible between crops grown with or without clover living understories. This is of particular note for the findings from Hessleskew Farm, where no fertiliser was applied on the clover area only. The pattern at Hessleskew Farm was, furthermore, consistent with that observed in 2018, providing support to the potential benefit of precision placement techniques for nitrogen application in strip tilled systems.

Leaf nitrogen

Comparison of leaf nitrogen level could only be made for samples gathered from the STC platform, as samples pertaining to the no clover area at Hessleskew Farm were lost after postage to the external analysis provider. Although the percentage of nitrogen in leaf tissue was lower in spring barley drilled into strip tilled clover living mulch, the difference was not found to be statistically significant (H_1 = 2.92, n.s.; Figure 6). This absence of significant difference between the two treatments supports results obtained for leaf chlorophyll content (although the general trend appears reversed).

In addition to leaf nitrogen, analyses reported values of several other foliar elements. These are summarised in Table 1.

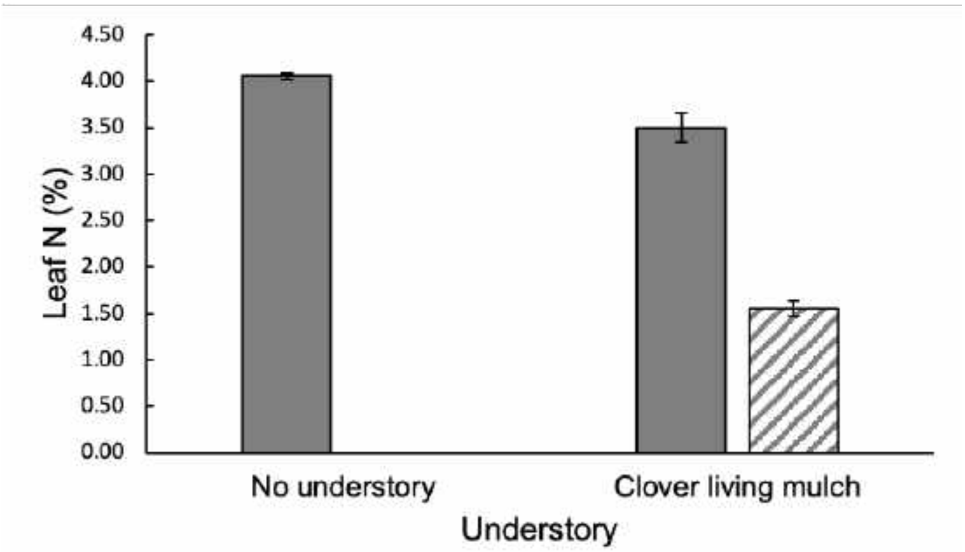

Figure 6. Mean percentage leaf tissue nitrogen (N) in spring barley ('Laureate') on the STC (grey bars) and Hessleskew Farm (hatched bars) validation platforms. Means are shown ± SEs. Analyses conducted and reported by NRM Laboratories (Cawood Scientific).

Table 1. Foliar tissue analyses outcomes of spring barley 'Laureate' on the STC and Hessleskew Farm validation platforms. Analyses conducted and reported by NRM Laboratories (Cawood Scientific).

	STC		***Hessleskew Farm***
	No understory	**Clover living mulch**	**Clover living mulch**
	Mean ± SE	***Mean ± SE***	***Mean ± SE***
Nitrogen (N) %	4.05 ± 0.04	3.50 ± 0.16	1.55 ± 0.08
Sulphur (S) %	0.30 ± 0.01	0.25 ± 0.01	0.37 ± 0.24
Phosphorus (P) %	0.41 ± 0.02	0.47 ± 0.02	0.30 ± 0.01
Potassium (K) %	4.06 ± 0.06	3.81 ± 0.13	1.47 ± 0.08
Calcium (Ca) %	0.64 ± 0.03	0.43 ± 0.03	0.39 ± 0.01
Magnesium (Mg) %	0.13 ± 0.00	0.15 ± 0.01	0.07 ± 0.002
Manganese (Mn) mg/kg	23.53 ± 2.83	18.19 ± 2.10	44.50 ± 6.49
Iron (Fe) mg/kg	130.00 ± 11.15	83.77 ± 1.75	73.95 ± 6.37
Copper (Cu) mg/kg	6.89 ± 0.16	5.79 ± 0.22	4.80 ± 0.09
Zinc (Zn) mg/kg	30.97 ± 1.42	32.29 ± 0.93	18.84 ± 0.51
Boron (B) mg/kg	4.32 ± 0.24	4.11 ± 0.11	5.20 ± 0.23

Canopy height

In 2019, canopy height of spring barley in mid-June, approximately two months after drilling, on the STC field validation platform was found to be higher in areas grown with a clover living mulch compared to areas grown with no understory ($F_{1,12}$ = 4.87, p < 0.05; Figure 7). By contrast, in both mid-June ($F_{1,13}$ = 77.23, p < 0.001) and mid-July ($F_{1,13}$ = 73.41, p < 0.001, *ln*-transformed), or approximately two and three months after drilling, respectively, canopy height of spring barley at Hessleskew Farm was lower in areas grown with a clover living mulch.

The differences in canopy height in 2019 followed the same trends at each site as was what observed in 2018; increased canopy height in barley grown with a living mulch at STC, decreased height at Hessleskew Farm. The more advanced stage of clover living mulch may provide an influence, allowing the clover to recover and compete more strongly through the growing season, reducing crop height increases through the growing season. It is also worth noting that no fertiliser application was made at Hessleskew, and therefore that a reduced application may provide crop plants with a head start, again suggesting potential benefit of precision placement of nitrogen in strip tilled systems.

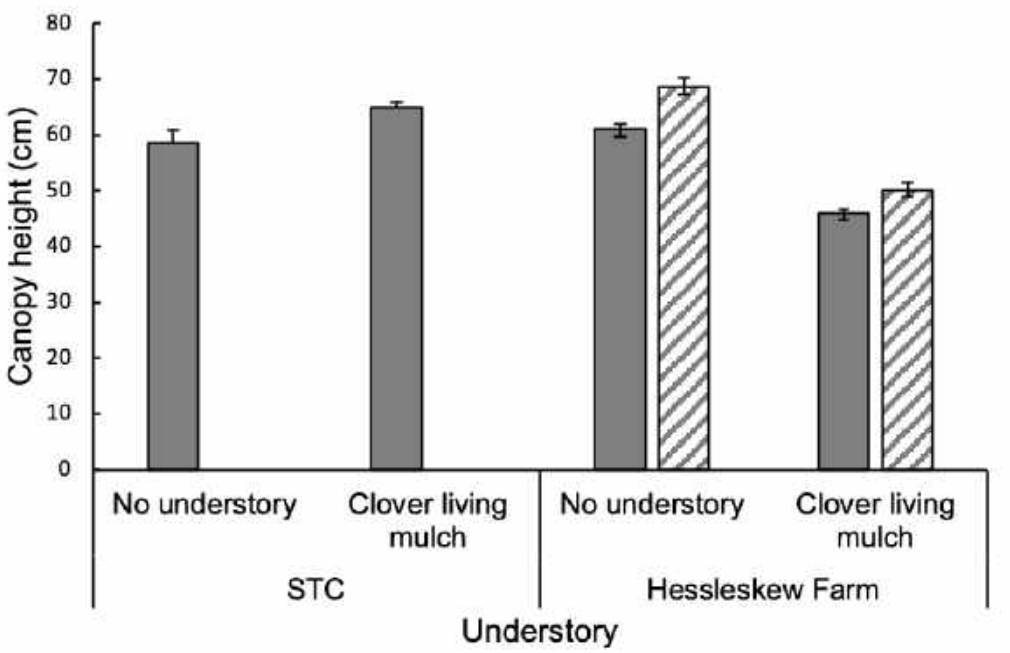

Figure 7. Spring barley 'Laureate' mean canopy height in mid-June 2019 (grey bars, approximately two months after drilling) and mid-July 2019 (hatched bars, approximately three months after drilling) on the STC and Hessleskew Farm validation platforms. Means are shown ± SEs.

Ears and tillers

In 2019, the number of barley ears on the STC platform was increased where the crop was grown with a clover living mulch, although this increase was not found to be statistically significant (H_1 = 2.35, n.s.; Figure 8). At Hessleskew Farm, however, the number of ears was significantly reduced where the crop was grown with a clover living mulch (H_1 = 9.41, p < 0.01; Figure 8).

Figure 8. Mean number of ears of spring barley ('Laureate') on the STC (grey bars) and Hessleskew Farm (hatched bars) validation platforms in a $0.25m^2$ quadrat area. Means are shown ± SEs.

Tiller counts were made at Hessleskew Farm in mid-June and mid-July, approximately two and three months after drilling, respectively. At both counts, the number of tillers were significantly reduced where the crop was grown with clover living mulch compared with where there was no clover living mulch (mid-June: $H_1 = 6.02$, $p < 0.05$; mid-July: $H_1 = 9.36$, $p < 0.01$; Figure 9), with the difference more pronounced later in the growing season as the plants developed.

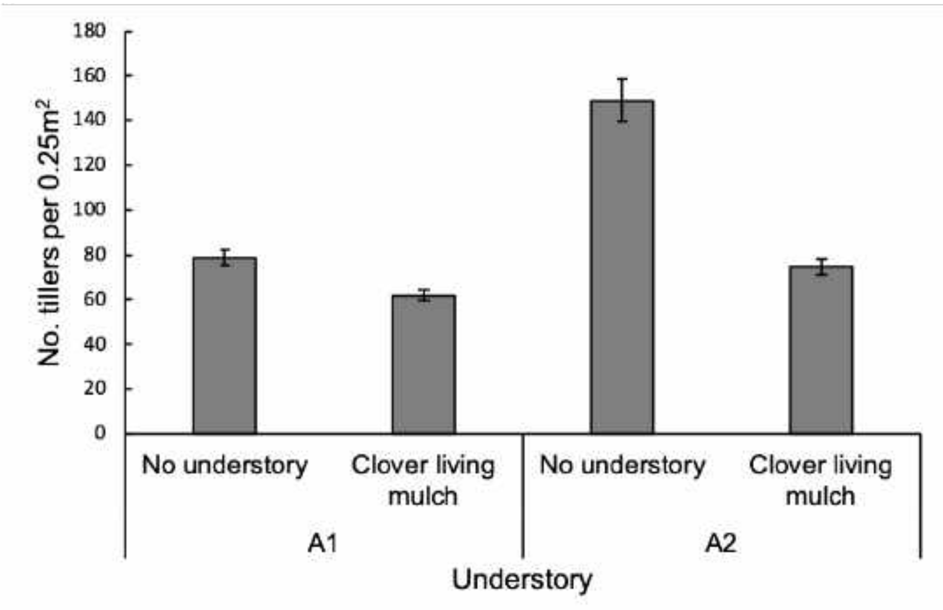

Figure 9. Mean number of tillers of spring barley ('Laureate') in a $0.25m^2$ quadrat area at Hessleskew Farm two month (A1, mid-June 2019) and three months (A2, mid-July 2019) after drilling. Means are shown ± SEs.

As with other crop performance indicators, it may be that the decreased number of tillers and ears at Hessleskew Farm may be explained by a more well-established and advanced clover living mulch competing more strongly with the crop at this site, when compared to STC.

Harvest biomass and yield

Spring barley fresh weight of ears (H_1 = 5.42, p < 0.05; Figure 10a) and extrapolated yield in tonnes per hectare (H_1 = 5.42, p < 0.05; Figure 10b) were both increased when grown with a clover living mulch at STC. By contrast, both measures (fresh weight: H_1 = 9.38, p < 0.01; tonnes/hectare: H_1 = 9.38, p < 0.01; Figure 10a,b) were significantly reduced.

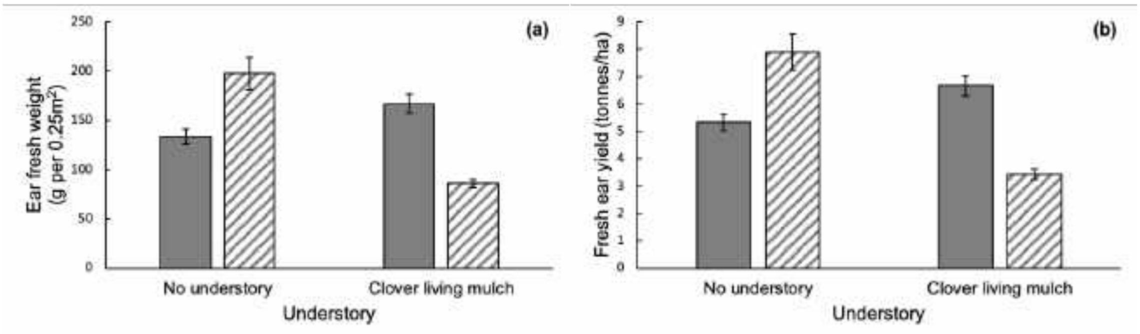

Figure 10. Mean spring barley ('Laureate') fresh ear weight (a) and extrapolated yield (tonnes/ha) on the STC (grey bars) and Hessleskew Farm (hatched bars) validation platforms. Means are shown ± SEs.

As would be expected, the dry weight of ears (H_1 = 5.42, p < 0.05; Figure 11a) and extrapolated yield in tonnes per hectare (H_1 = 5.42, p < 0.05; Figure 11b) were increased when grown with a clover living mulch at STC, but reduced at Hessleskew Farm (dry weight: H_1 = 9.38, p < 0.01; tonnes/hectare: H_1 = 9.38, p < 0.01; Figure 11a,b).

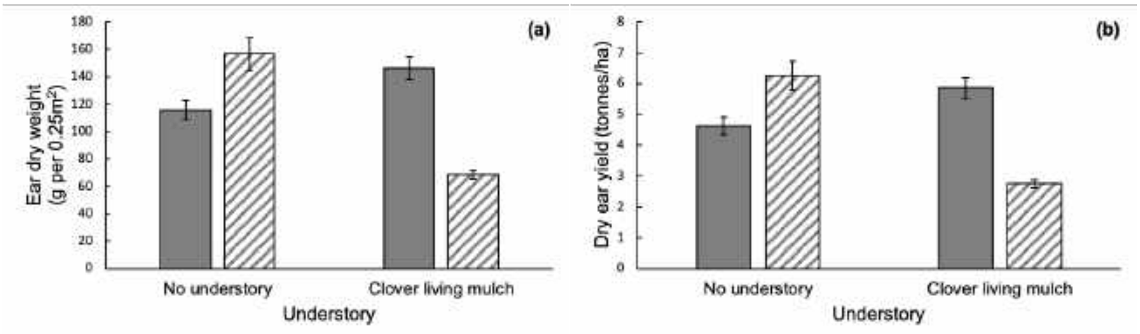

Figure 11. Mean spring barley ('Laureate') dry ear weight (a) and extrapolated yield (tonnes/ha) on the STC (grey bars) and Hessleskew Farm (hatched bars) validation platforms. Means are shown ± SEs.

The percentage of dry matter was also established for the harvested grains. On the STC platform, there was a slight increase in barley grown with a clover living mulch (H_1 = 6.0, p < 0.05; Figure 12), whereas there was no difference between the crops grown grown with or without a clover living mulch at Hessleskew Farm (H_1 = 0.24, n.s.; Figure 12).

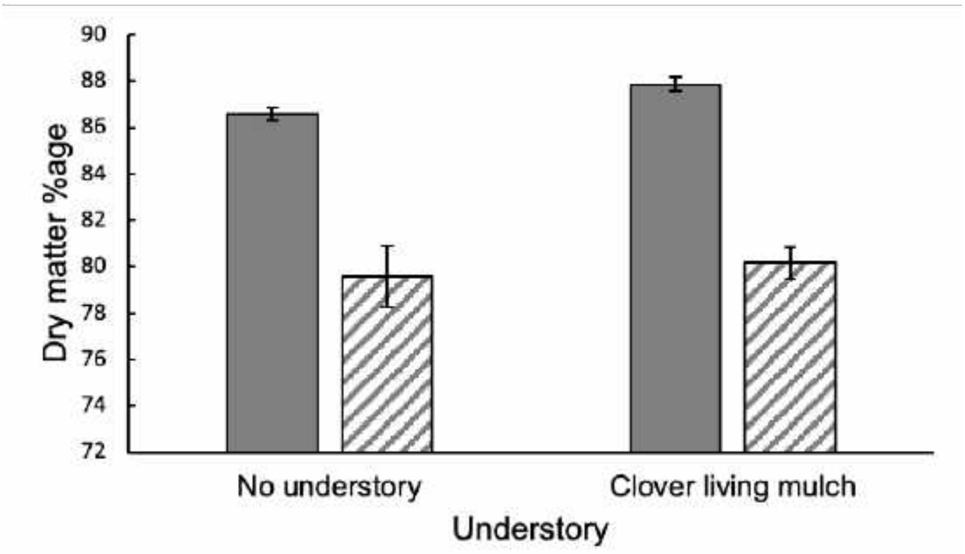

Figure 12. Mean percentage dry matter content of spring barley ('Laureate') on the STC (grey bars) and Hessleskew Farm (hatched bars) validation platforms, as calculated following oven drying for 48 hours. Means are shown ± SEs.

No difference in the fresh weight of straw (H_1 = 1.82, n.s.; Figure 13a) nor the extrapolated straw yield in tonnes per hectare (H_1 = 1.82, n.s.; Figure 13b) when barley was grown with a clover living mulch at STC. By contrast, both measures (fresh straw weight: H_1 = 9.38, p < 0.01; straw tonnes/hectare: H_1 = 9.38, p < 0.01; Figure 13a,b) were significantly reduced in barley grown with a clover living mulch.

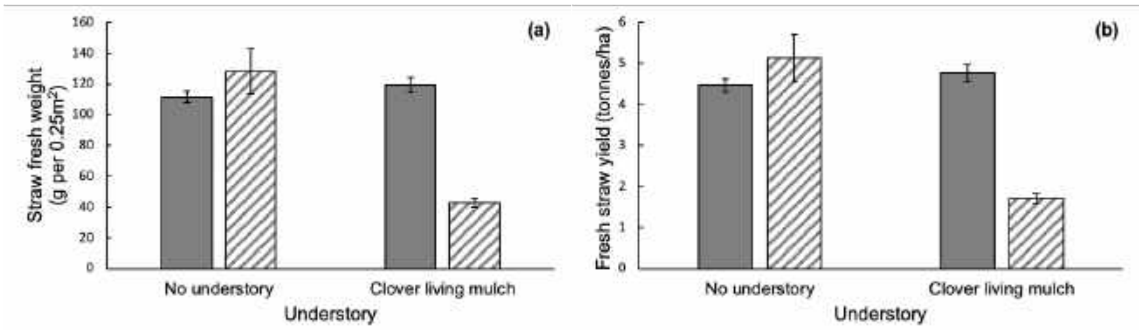

Figure 13. Mean spring barley ('Laureate') fresh straw weight (a) and extrapolated yield (tonnes/ha) on the STC (grey bars) and Hessleskew Farm (hatched bars) validation platforms. Means are shown ± SEs.

The dry weight of straw at STC, however, was found to be higher when barley was grown with the clover living mulch (H_1 = 6.00, p < 0.05; Figure 14a), as was the extrapolated yield in tonnes per hectare (H_1 = 6.00, p < 0.05; Figure 14b). The opposite was true at Hessleskew Farm, where significant reductions in straw dry weight (H_1 = 9.38, p < 0.01; Figure 14a) and extrapolated tonnes per hectare (H_1 = 9.38, p < 0.01; Figure 14b) were observed, although these were expected given straw fresh weights.

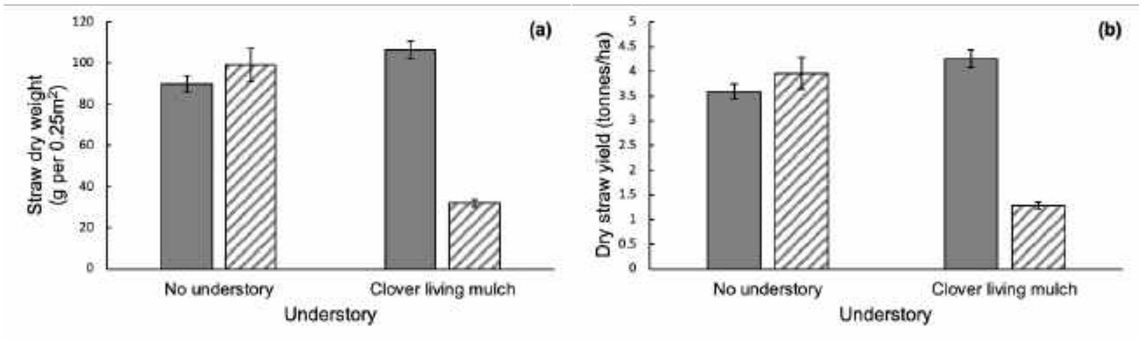

Figure 14. Mean spring barley ('Laureate') dry straw weight (a) and extrapolated yield (tonnes/ha) on the STC (grey bars) and Hessleskew Farm (hatched bars) validation platforms. Means are shown ± SEs.

Straw length was not found to differ between barley crop straws grown with or without a clover living mulch at STC (H_1 = 0.24, n.s.; Figure 15), whereas at Hessleskew Farm the length of straw segments was significantly shorter where a crop was grown with a clover living mulch (H_1 = 9.38, p < 0.01; Figure 15).

Figure 15. Mean straw length of spring barley ('Laureate') on the STC (grey bars) and Hessleskew Farm (hatched bars) validation platforms. Means are shown ± SEs.

Overall, the results show, in broad terms, increased crop biomass where spring barley was grown with clover living mulch at STC, although this platform consisted of a younger, less well-established clover cover. By contrast, crop biomass was consistently and considerably reduced in the clover living mulch area at Hessleskew Farm. It should be noted, however, that combine data from Hessleskew Farm returned a yield of 4.3 tonnes per hectare. Furthermore, grain qualities for malting were acceptable, with a specific weight of 64.5kg/hl and nitrogen content of 1.52% reported.

As previously considered, the clover platform at Hessleskew is well-established, and the more mature clover could have resulted in stronger inter-plant competition by the clover on the barley crop. It should also be noted, however, that no inputs other than fungicide, and herbicide to stress the clover and manage weeds, were made on the clover areas at

Hessleskew, in comparison to the conventional area which received a standard input programme (including fertiliser applications). The STC platform, by contrast, received an, albeit reduced rate, application of fertiliser early in the season to support crop in early growth stages. Such broadcast applications may not be preferable in such systems, however, as nitrogen would not be focused on the crop plants but also be spread on the non-target clover. It may be that precision-placed targeted inputs into the crop growing area in strip tilled clover mulch systems may support and mitigate clover competition impacts on plant productivity and subsequent yields, while reducing inputs by minimising land area coverage (through omission of land covered by clover strips).

Clover performance

Clover ground cover

Clover ground cover was assessed at both sites periodically through the growing season, with a pre-season winter assessment also undertaken at STC (Figure 16). As observed in 2018, clover ground cover was already high early in the season and at time of drilling at Hessleskew Farm. Clover cover was consistently high (100%) throughout the rest of the growing season. This supports the protective effect of clover early in the season and also weed suppressive potential through the growing season, but the data also provides evidence suggesting that the level of cover may have contributed to the consistent decreased crop biomass and productivity at Hessleskew Farm, reported above.

Clover cover at STC, by contrast, did not exceed 52.5% on any assessment date, considerably lower than the cover at Hessleskew Farm, and decreased over the growing season. This may be attributable to the overwinter and early spring conditions experienced at STC, characterised by relatively low rainfall. This, combined with the early stage and relative age and establishment of the platform, and management strategies deployed on the platform to limit clover competition, may have resulted in excessive stress to clover at the start of the growing season, resulting in relatively slow recovery. This may have allowed weeds to get a foothold in the platform (see 'Weed burden' section below), further compromising the clover's growth through the season. These findings suggest that it may be of benefit to undertake a top up sowing of clover in the early stages/initial years of clover living mulch establishment, to ensure sufficient coverage and support successful establishment that will persist through time.

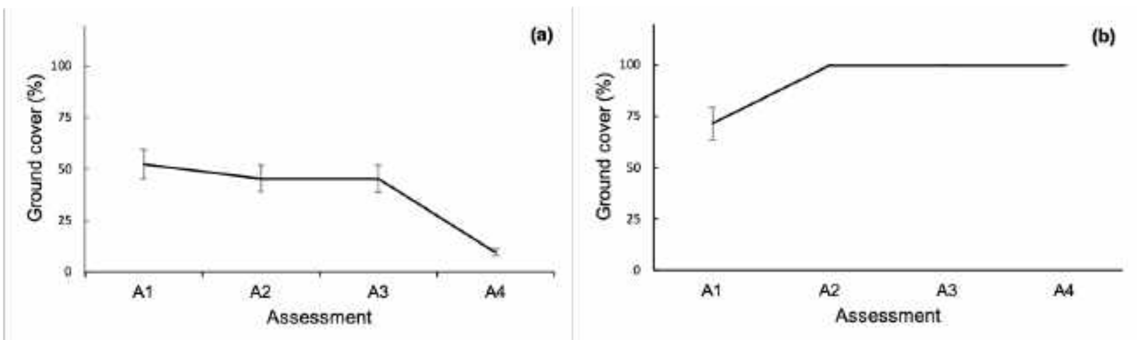

Figure 16. Mean clover percentage ground cover on the STC (a) and Hessleskew Farm (b) living mulch validation platform areas. Means are shown ± SEs. STC assessment dates: 18th January (A1), 1st April (A2), 8th May (A3) and 1st July (A4) 2019; Hessleskew Farm assessment dates: 17th April (A1), 23rd May (A2), 18th June (A3) and 17th July (A4) 2019.

Clover flowering

Clover flowering was assessed in early and late July 2019 on the STC clover platform, however, likely due to the poor clover recovery, no clover flowers were observed in 2019 at the sampling points. It is worth noting, however, that there were areas on the platform where clover flowers had bloomed, although as these were not in the vicinity of the sampling points these could not be recorded in the dataset (*pers. obs.*).

By contrast, considerable numbers of flowers were recorded through the growing season (Figure 17), as would be expected from the well-established, mature living mulch. Numbers equated to some 181,000 clover flowers in bloom per hectare in May, 1.3 million in June and 1.5 million in July. Such numbers have enormous potential to support pollinator communities, including bumble bees, in addition to other biodiversity and other environmental gains.

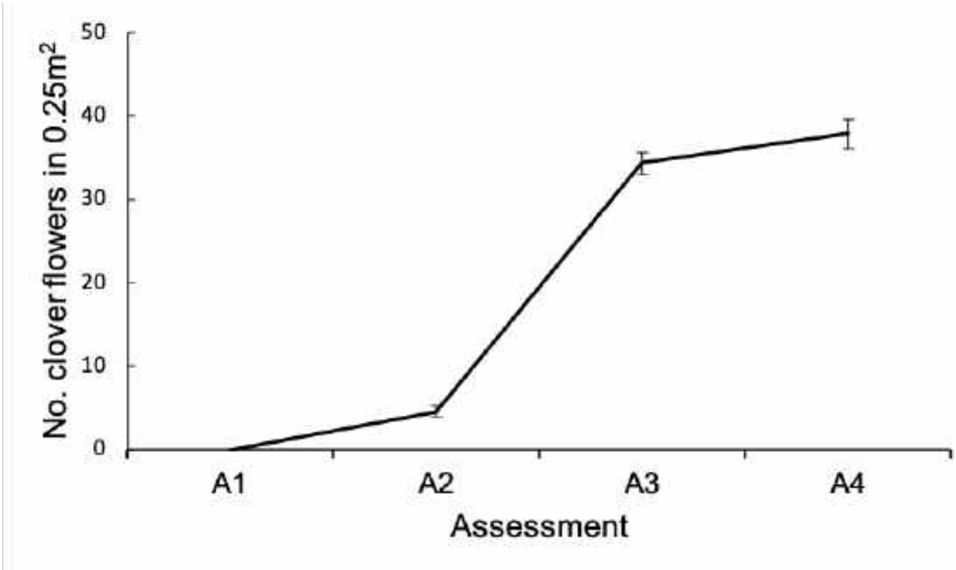

Figure 17. Mean number of clover flowers in a 0.25m^2 quadrat area on the Hessleskew Farm clover living mulch validation platform area. Means are shown ± SEs. Hessleskew Farm assessment dates: 17th April (A1), 23rd May (A2), 18th June (A3) and 17th July (A4) 2019.

Weed, pest and disease pressure

Weed pressure

Periodic assessments of weed pressure were undertaken on both sites. At STC, relatively higher weed percentage ground cover was observed in the clover living mulch area of the platform, although these differences were only found to be statistically significant in May to early July (A1: H_1 = 2.38, n.s.; A2: H_1 = 0.97, n.s.; A3: H_1 = 4.32, p < 0.05; A4: H_1 = 7.63, p < 0.01; A5: H_1 = 0, n.s.; Figure 18a). The higher level of weed pressure in the clover living mulch could be due to the comparatively low clover coverage, which would have allowed weeds to get a foothold on the platform with few feasibly management options.

Hessleskew Farm showed, overall, much lower weed pressure. Although weed pressure was marginally higher in the clover living mulch area, this was not found to be statistically significant at any point in the growing season (A1: H_1 = 0.38, n.s.; A2: H_1 = 0.46, n.s.; A3: H_1 = 0.77, n.s.; A4: H_1 = 3.01, n.s.; Figure 18b).

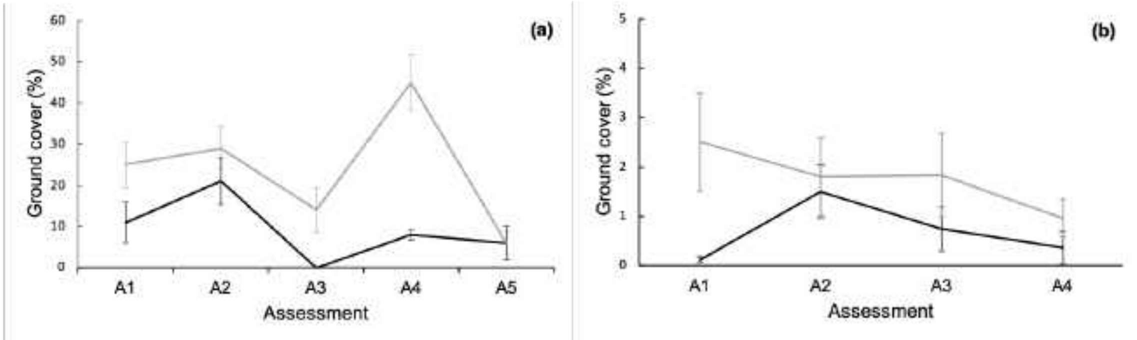

Figure 18. Mean weed percentage ground cover on the STC (a) and Hessleskew Farm (b) validation platform areas, in the conventional no clover areas (black lines) and the clover living mulch areas (grey lines). Means are shown ± SEs. STC assessment dates: 18th January (A1), 1st April (A2), 8th May (A3), 1st July (A4) and 29th July (A5) 2019; Hessleskew Farm assessment dates: 17th April (A1), 23rd May (A2), 18th June (A3) and 17th July (A4) 2019.

The findings, generally, support the potential of clover living mulches for weed suppression. They also, however, suggest potential challenges in managing weeds on such platforms. Few herbicides can be safely applied to clover without reducing survival significantly, and often these must be applied at a reduced rate. This can reduce impact their impact on target weeds, and thus fail to address the issue on a longer term. The Hessleskew Farm data suggestes that a good clover coverage can, however, reduce weeds to a similar level as a standard programme of herbicide applications on a conventional plot, thus showing potential to reduce herbicide input and control weeds in this manner. This situation can, as shown by crop performance indicators, impact crop productivity and yield, and thus mitigation of clover competitiveness must be sought through other means. The STC data suggests that minimal, targeted inputs in a strip tillage system may provide such a means to mitigate clover competitiveness. Other means, such as in-crop mowing of clover strips may also provide another aspect, though this would need to be investigated and confirmed on a commercial scale.

Cereal crop pests

Pest numbers in 2019 were, overall, low on the platforms in 2019, with few reported. Repeated assessments of pest pressure were undertaken throughout the growing season at both sites. No aphids, cereal beetle or OWBM were observed on barley plants at the designated sampling points on the Hessleskew Farm clover living mulch and conventional no clover areas in 2019. At STC, only two cereal beetles were recorded in assessment quadrats throughout the growing season, one at a sampling point in the clover living mulch area and the other in the conventionally managed area, and thus, this data could also not be analysed. The same was true of the aphid, *S. avenae*, and furthermore no OWBM were observed on the STC platform.

Relatively few other aphids were observed in the sampling period on the STC validation platform, and as such analysis was conducted on total numbers observed, over an approximately two-month period, for each of *R. padi* and *M. dirhodum*. A trend was shown for suppression of aphid numbers in barley grown with the clover living mulch, although this decrease in number was not statistically significant for either *R. padi* (H_1 = 1.27, n.s.; Figure 19a) or *M. dirhodum* (H_1 = 2.97, n.s.; Figure 19b).

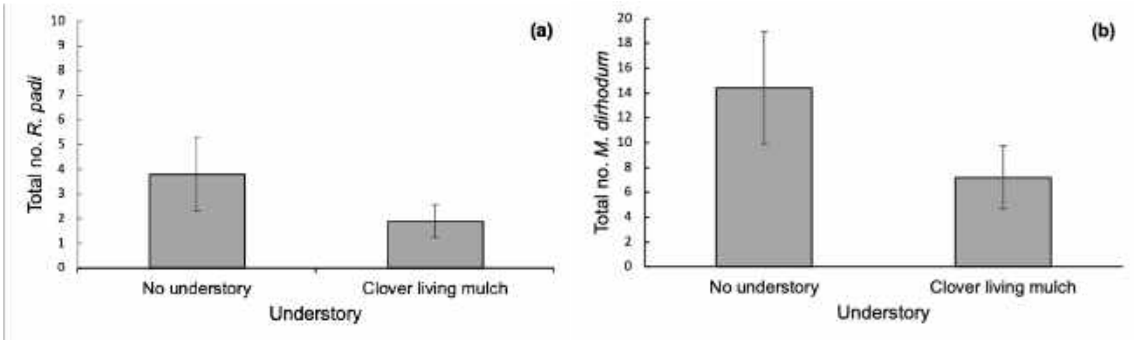

Figure 19. Mean total number of *Rhopalisiphum padi* (a) and *Metapolophium dirhodum* (b) aphids observed on a spring barley ('Laureate') crop on the STC validation platform, between mid-May and late July 2019, in 0.25m^2 quadrats. Means are shown ± SEs.

Although relatively little data could be analysed, observations suggest that, at least in terms of foliar pests such as aphids and cereal beetle, presence of a clover living mulch does not increase the number of such pests, and that in some instances may assist in pest suppression.

The number of slugs was monitored weekly on both platforms between May and August 2019 (Figure 20). Relatively few slugs were captured on a week-by-week basis, and so a statistical comparison was made on total numbers counted over the season. There was no statistically significant difference in the total number of slugs observed in the traps between the clover living mulch areas and the conventional no clover areas at either STC (H_1 = 2.37, n.s.) or at Hessleskew Farn (H_1 = 0.06, n.s.), although slug numbers on a week-by-week basis showed a trend towards being higher in clover living mulch areas at Hessleskew Farm.

Slugs remain a pest of potential significance in clover living mulch systems, especially given the recent metaldehyde withdrawal, however results in 2019 suggest that the use of clover may not necessarily lead to higher slug pressure. Regardless, there are trends to suggest higher or, at least, sustained population levels, and as such monitoring will continue in the 2020 growing season across both sites, where possible.

<u>Cereal crop diseases</u>

Despite the conditions over the summer, relatively little disease was observed at the sampling points in 2019 at Hessleskew Farm. On the STC validation platform, although no significant difference in the plant area showing symptoms of yellow rust (H_1 = 2.49, n.s.; Figure 21a) and *Rhyncosporium* (H_1 = 0.02, n.s.; Figure 21b), significantly more *Ramularia* symptom area was observed on plants grown with a clover living mulch (H_1 = 8.08, p < 0.01; Figure 21c). These findings suggest that, while clover living mulches may not lead to increased disease pressure for certain pathogens, there is a risk of increased disease level for others.

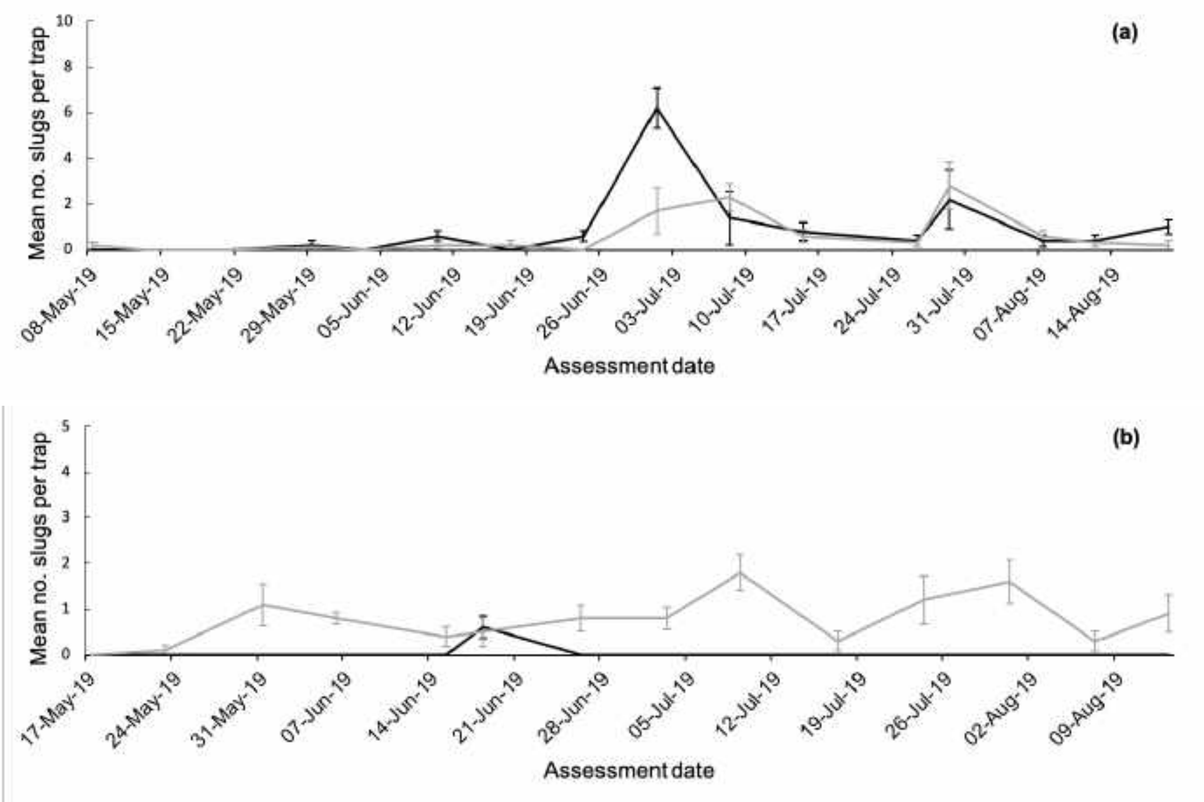

Figure 20. Mean number of slugs observed per trap in a spring barley ('Laureate') on the STC (a) and Hessleskew Farm (b) validation platform areas, in the conventional no clover areas (black lines) and the clover living mulch areas (grey lines). Means are shown ± SEs.

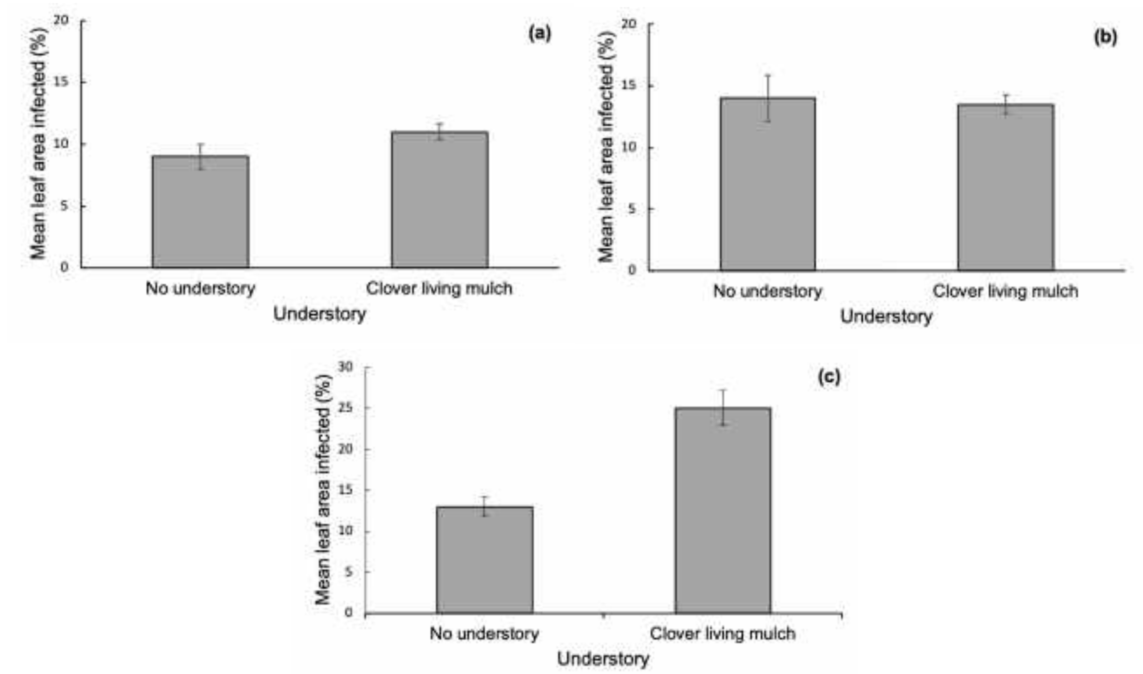

Figure 21. Mean percentage leaf area of spring barley ('Laureate') showing symptoms of yellow rust (a), *Rhyncosporium* (b) and *Ramularia* (c) infection in late June 2019 on the STC validation platform. Means are shown ± SEs.

Environmental biodiversity

Worm counts

Repeated assessments of earthworm number were undertaken through the 2019 growing season. On the STC platform, fewer worms were recovered under clover living mulches in mid-May and mid-June, although the lower recovery number was not found to be statistically significant (May: H_1 = 0.76, n.s.; June: H_1 = 1.95, n.s.; Figure 22). By contrast, by late-August significantly more worms (at least twice as many) were recovered from sampling points in the clover living mulch area in comparison to those points grown with no living mulch (H_1 = 5.44, $p < 0.05$).

At Hessleskew Farm, very few worms were recovered from all sampling points (a total of two, one from each of the clover living mulch area and the conventional no clover area), leading to a very low mean recovery and, consequently, no difference between the numbers in the two different areas (H_1 = 0.27, n.s.; Figure 22). By mid-June, however, a significant difference in the number of recovered worms was observed (H_1 = 9.56, $p < 0.01$; Figure 22), with over nine times more worms recovered at sampling points in the clover living mulch area.

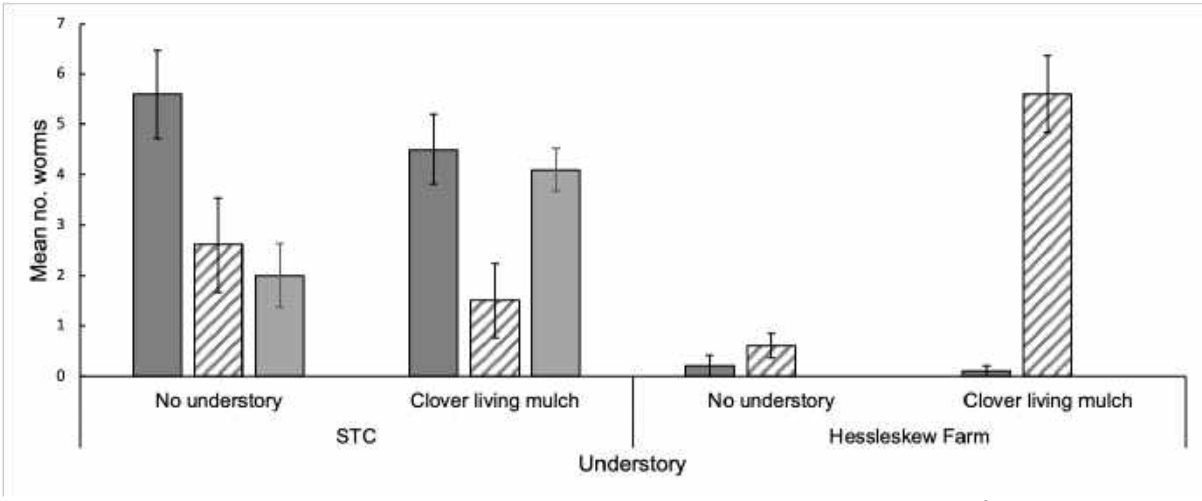

Figure 22. Mean number of worms recovered from an approximately 0.27m^3 soil volume in a spring barley crop ('Laureate'), grown either with no understory or a clover living mulch. Means are shown ± SEs. STC assessment dates: 13th May (dark grey bars), 11th June (hatched bars) and 07th August (light grey bars) 2019; Hessleskew Farm assessment dates: 23rd May (dark grey bars) and 18th June (hatched bars) 2019.

It is possible that the relatively dry start to the growing season led to the lower than expected recover of worms at both sites in May. It is interesting to note that there was no statistically discernible difference during these early stages, although a slight downward trend is observed. Later in the growing season, however, worm numbers were at least twice as high in clover living mulch areas (and considerably higher at Hessleskew, where the clover has been in place for a longer period of time). These findings support the strong potential role of clover living mulches in terms of benefit to earthworms, known for their important role in soil health.

<u>Beneficial invertebrates</u>

Four visual assessments of beneficial insect numbers were made through the growing season in 2019 at both sites, through a combination of visual transects (bumblebees, hoverfly adults, ladybird adults, and Lepidoptera (moths and butterflies)) and quadrat counts made directly on barley plants (hoverfly and ladybird juvenile stages, and parasitoid wasps). Relatively fewer insects were observed overall at Hessleskew Farm through the 2019 growing season, in line with findings from 2018. The exception for this was in bumblebee numbers, where signigicantly more were reported from Hessleskew Farm, likely due to the greater maturity of the clover living mulch platform and the significant number of clover flowers supporting populations of this particular pollinator.

Relatively few bumblebees were observed on the STC validation platform over the course of the year, most likely due to the general absence of clover flowers at and around the designated sampling points. In patches and areas where clover had recovered more strongly and flowered, bumblebees were observed (*pers. obs.*). As a result of these low numbers at the sampling points, however, no statistically significant difference was reported between conventional no clover areas and areas with clover living mulch at STC (H_1 = 1.73, n.s.), although more were observed, in terms of raw data, where clover was used (Figure 23a). By contrast, at Hessleskew Farm, whereas no bumblebees were reported across the growing season in the conventional no clover area, significantly more bumblebees were observed in the crop grown with a clover living mulch (H_1 = 9.78, p <0.01; Figure 23b).

As with results observed in 2018, fewer hoverflies were observed in areas with a clover living mulch at both STC and Hessleskew Farm, although these differences were not found to be statistically significant (STC: H_1 = 1.30, n.s.; Hessleskew Farm: H_1 = 2.00, n.s.; Figure 23a,b). Reasons for this remain unknown, although edge effects are thought to play a potential role. Unlike bumblebees, which have a 'tongue' to allow access to nectar in tubular and deeper flowers when foraging, hoverflies have relatively simple mouthparts suited to shallower, open flowers. As such, presence of clover flowers may not support their population numbers within a crop to the same extent as other floral resource strategies (such as flowering field margins), as they may not represent the same extent of foraging resource for this group.

No parasitoid wasps were reported in 2019 from Hessleskew Farm. By contrast, at STC more parasitoid wasps were reported in crop areas grown with a living mulch, although this increase was not found to be significantly increased relative to the conventional no clover area (H_1 = 0.23, n.s.; Figure 23a). Mummified aphids were also observed, but again numbers of these did not differ between clover and no clover areas (H_1 = 0.04, n.s.). The relatively low aphid pressure of 2019 may have played a role in the findings for 2019.

In contrast to 2018, significantly greater number of ladybirds were reported in clover living mulch areas on the STC validation platform in comparison to areas grown with no clover understory (H_1 = 4.78, p < 0.05; Figure 23a), with nearly three times as many in crop areas grown with clover. Only one ladybird was reported from Hessleskew Farm, and although the low frequency of observation meant that no statistical difference could be discerned (H_1 = 0.50, n.s.), it should be noted that this single ladybird was found in the clover living mulch area.

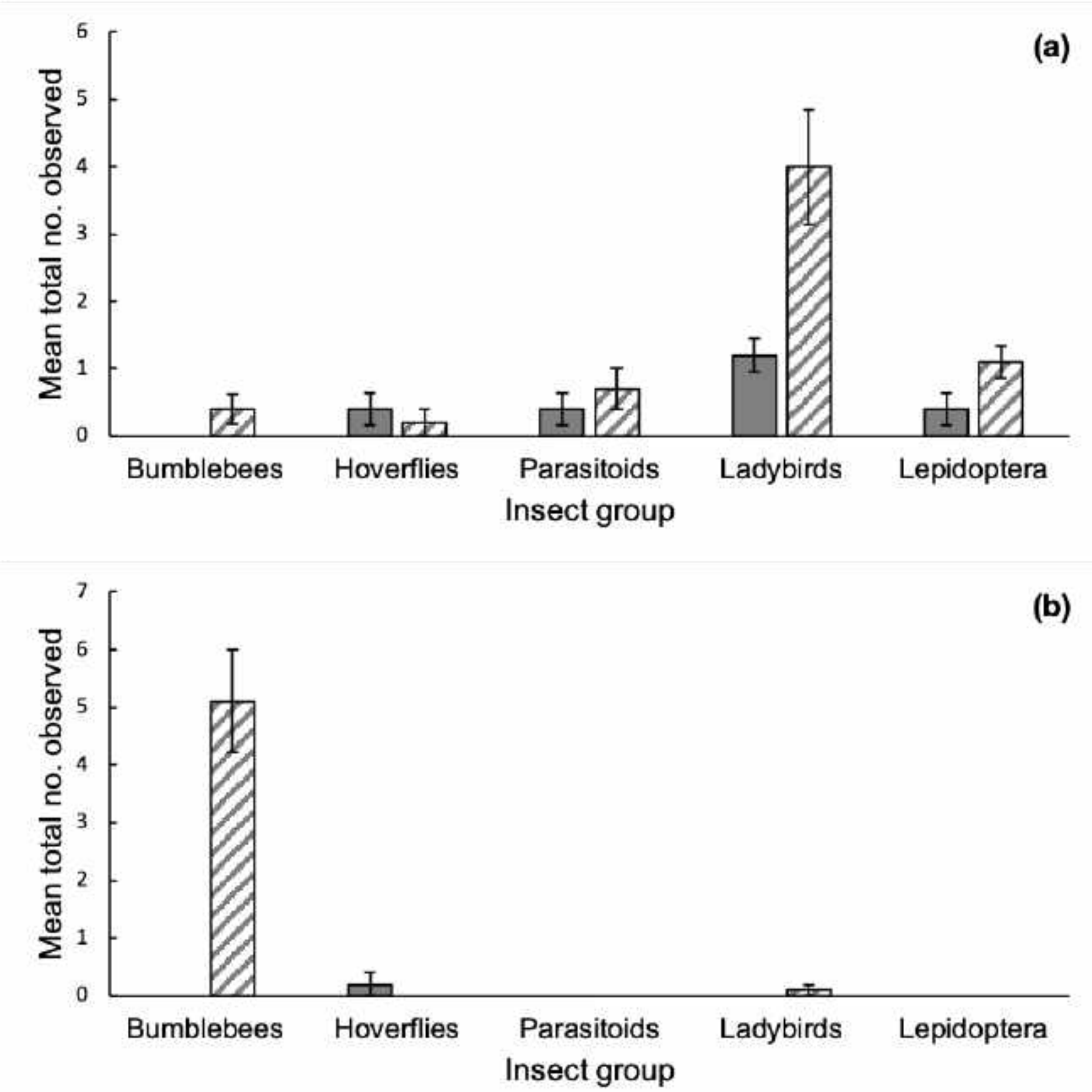

Figure 23. Total numbers of five groups of beneficial insects observed in a spring barley ('Laureate') crop across four assessment dates between May and July on the STC platform (a) and between April and July at Hessleskew Farm (b) in crop areas grown with no understory (grey bars) and with a clover living mulch (hatched bars). Means are shown ± SEs.

Over twice as many lepidopteran species were observed in areas of barley grown with clover living mulch on the STC validation platform, although this was not statistically significant (H_1 = 2.96, n.s.; Figure 23a). No Lepidoptera were reported from assessments at Hessleksew Farm.

Informed from previous observations, carabid beetles were known to shelter in the baited traps set out for slugs, and as such the traps were assessed for both slug and carabid numbers. Some carabid species are predators of slugs, and therefore if numbers were to be supported in clover living mulch areas then this may contribute to control of slug pressure in crops grown in such a system. It is important to note, however, that baited slug traps are not an ideal census or assessment measure for carabid beetle numbers, and as such this data remains illustrative, rather than specifically informative.

As expected, given the assessment method, relatively few carabids were captured on a week-by-week basis, and so a statistical comparison was made on total numbers counted over the season. There was no statistically significant difference in the total number of carabids observed in the traps between the clover living mulch areas and the conventional no clover areas at either STC (H_1 = 0.10, n.s.; Figure 24a) or at Hessleskew Farn (H_1 = 0.39, n.s.; Figure 24b). Although no statistical differences were identified, there appeared to be a trend towards persistent, if low, numbers in the clover living mulch areas, in contrast to relative spikes in conventional no clover areas.

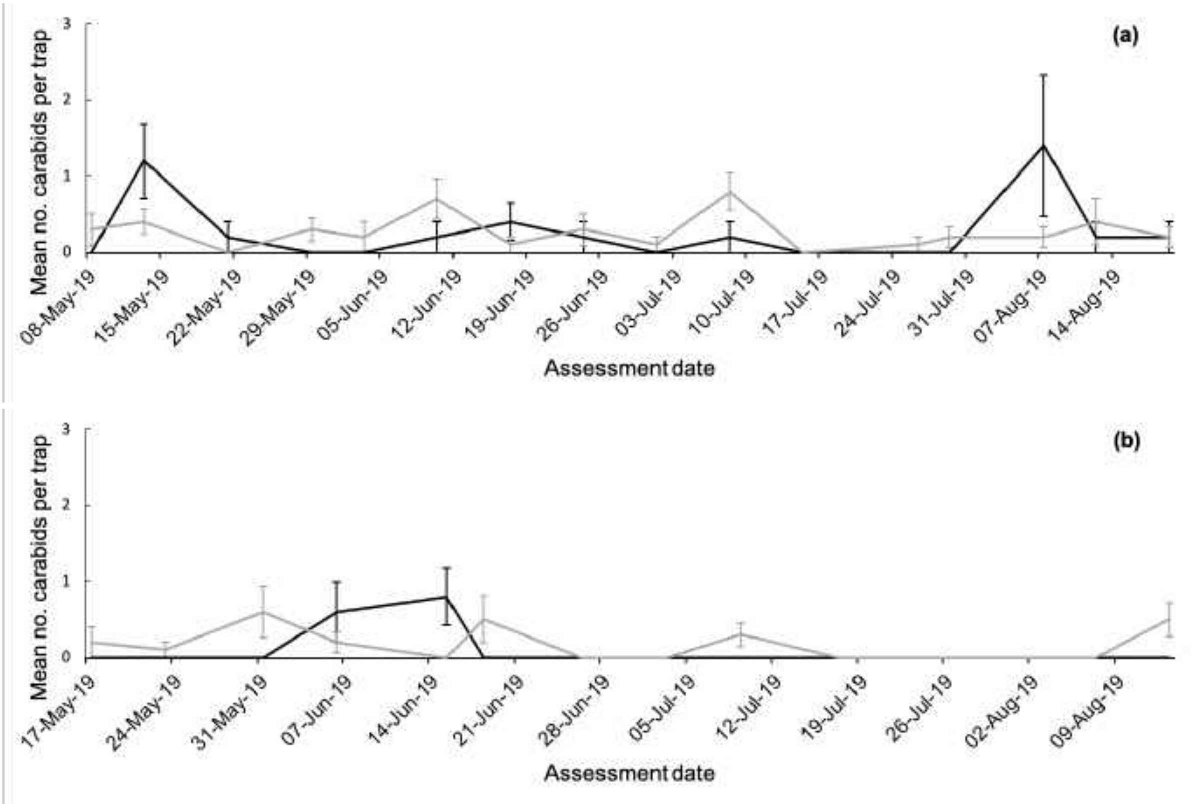

Figure 24. Mean number of carabid beetles observed per trap in a spring barley ('Laureate') crop on the STC (a) and Hessleskew Farm (b) validation platform areas, in the conventional no clover areas (black lines) and the clover living mulch areas (grey lines). Means are shown ± SEs.

Overall, the findings suggest that use of clover living mulches in arable systems have potential to support beneficial insect population densities, though level of benefit is linked to insect group, and is likely to differ between years and establishment stage of the platform.

Bird and mammal counts

Relatively few birds and mammals were observed across multiple assessments in 2019. This may have been due to increased sampling effort, which may have disturbed the targets before counting. As a result, no significant differences were reported at the two sites for either birds (STC: H_1 = 0.02, n.s.; Hessleskew: H_1 = 0.04, n.s.) or mammals (STC: H_1 = 1.17, n.s.; Hessleskew: H_1 = 2.55, n.s.), although there was a trend towards between greater numbers in areas of clover living mulch for both groups of animals (Figure 25a,b). A broader range of species were reported from visual assessments at STC: skylarks, corn buntings, partridges, crows and woodpigeons in terms of birds, and hare, mice and rabbits in terms of mammals. At Hessleskew Farm, species reported were more limited, with skylarks and seafulls sighted, and only mice in terms of mammals. Blackbirds and lapwings were also, however, heard, though not seen, at Hessleskew Farm.

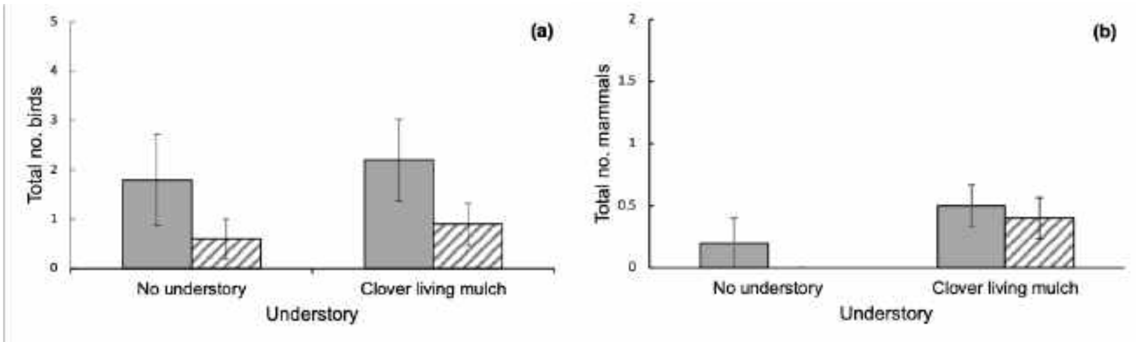

Figure 25. Mean total number of birds (a) and mammals (b) observed in a spring barley ('Laureate') on the STC (grey bars) and Hessleskew Farm (hatched bars) validation platforms between mid-May and mid-June 2019. Means are shown ± SEs.

Soil parameters and health

Soil moisture and temperature

Soil moisture and temperature were recorded regularly, on a near-weekly basis on the STC validation platform (Table 2). Broadly, soil moisture patterns were similar in areas grown conventionally with no clover or with a clover living mulch (Figure 26a). With the exception of two assessment dates (08^{th} July and 7^{th} August 2019), soil moisture under the clover tended to be lower than that in the conventional no clover area. Although only three such assessments were undertaken on the Hessleskew Farm validation platform (Table 3), a similar trend was shown (Figure 26b). Two of the three assessments recorded lower soil moisture levels under clover (May and June), with the final assessment in July showing a higher soil moisture level.

These findings suggest a trend towards greater uptake of water in systems with clover living mulches, potentially suggesting that, even under incomplete clover coverage, clover living mulches may assist in maintenance of a functioning water pump in a field and thus in dissipating heavy rainfalls to increase soil workability during periods of wet weather. On the other hand, however, this may also suggest greater water uptake and requirement throughout a growing season, and thus that the clover may compete with the crop plants for water. In periods with low rainfall, this may have a consequent impact on plant biomass production and subsequent yield. Such effects would require further investigation, but it is likely that selection of deep-rooting crop varieties may mitigate such potential impacts by accessing water in soil located below the comparatively shallow root systems of white clover.

Soil temperature appeared, in terms of trends, to either vary little between areas grown with or without a living mulch, or to be, generally speaking, lower in crop areas grown with a clover living mulch (Table 2,3; Figure 27a,b). They main exception to this was in May at Hessleskew Farm, where soil in clover living mulch areas returned values averaging 5°C higher than those in the conventional plots. The reasons for this are not clear. These outcomes suggest a cooling effect of clover living mulches on soil. This may potentially limit water evaporation from soil later in a growing season during the summer months, aiding in water retention, however it should also be noted that early in the season cooler soil temperature could affect time of drilling and early plant growth and development. As values were broadly similar, however, it is likely that differences would not be distinct enough to have a significant impact on these.

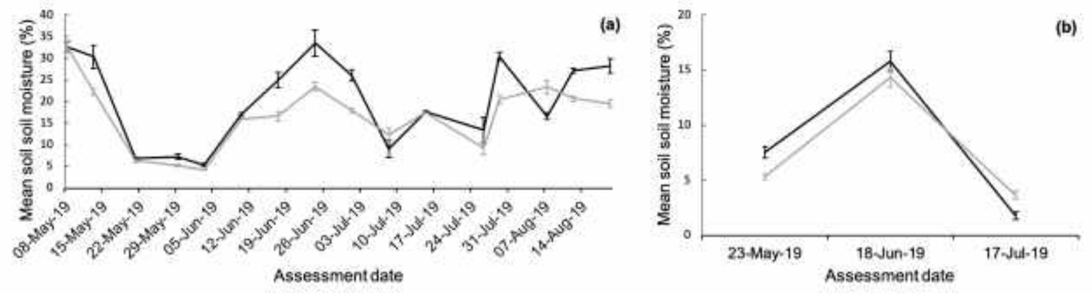

Figure 26. Mean percentage soil moisture level observed per trap in a spring barley ('Laureate') on the STC (a) and Hessleskew Farm (b) validation platform areas, in the conventional no clover areas (black lines) and the clover living mulch areas (grey lines). Means are shown ± SEs.

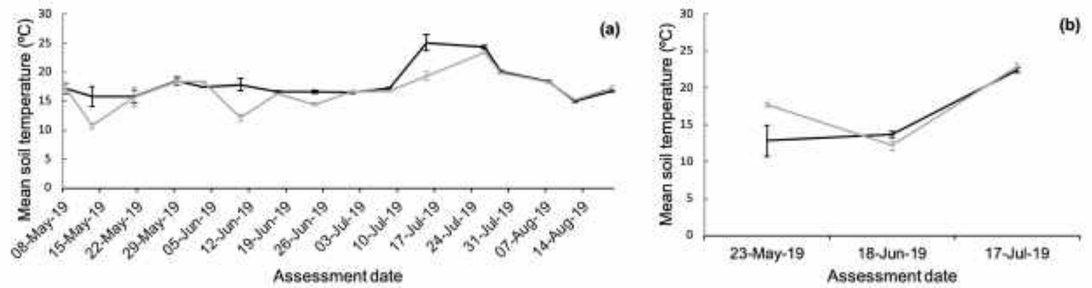

Figure 27. Mean soil temperature (°C) observed per trap in a spring barley ('Laureate') on the STC (a) and Hessleskew Farm (b) validation platform areas, in the conventional no clover areas (black lines) and the clover living mulch areas (grey lines). Means are shown ± SEs.

Table 2. Kruskal-Wallis Test statistics returned on soil moisture and soil temperature readings from the STC spring barley ('Laureate') validation platform in 2019 (significance of output is denoted by: n.s. = not significant, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$).
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	Soil moisture (%)			***Soil temperature (°C)***		
	No understory	**Clover living mulch**		**No understory**	**Clover living mulch**	
	Mean ± SE	***Mean ± SE***	H_1	***Mean ± SE***	***Mean ± SE***	H_1
8th May	32.66 ± 1.31	32.60 ± 1.42	0.14 *n.s.*	17.18 ± 0.94	17.27 ± 0.94	0.14 *n.s.*
13th May	30.34 ± 2.63	22.23 ± 0.80	6.62 *	15.74 ± 1.70	10.75 ± 0.46	6.64 **
21st May	6.94 ± 0.10	6.46 ± 0.65	1.99 *n.s.*	15.78 ± 1.10	15.63 ± 1.70	0.14 *n.s.*

	Soil moisture (%)			***Soil temperature (°C)***		
	No understory	**Clover living mulch**		**No understory**	**Clover living mulch**	
	Mean ± SE	***Mean ± SE***	H_1	***Mean ± SE***	***Mean ± SE***	H_1
29th May	7.24 ± 0.66	5.19 ± 0.29	6.34 *	18.42 ± 0.66	18.36 ± 0.55	0.00 *n.s.*
3rd June	5.36 ± 0.27	4.28 ± 0.18	6.01 *	17.40 ± 0.09	18.31 ± 0.16	9.41 **
10th June	17.02 ± 0.43	15.93 ± 0.14	6.05 *	17.78 ± 1.05	12.13 ± 0.55	8.66 **
17th June	24.92 ± 1.78	16.67 ± 1.09	7.95 *	16.66 ± 0.14	16.26 ± 0.09	5.30 *
24th June	33.52 ± 3.01	23.44 ± 0.94	4.34 *	16.62 ± 0.26	14.44 ± 0.19	9.46 **
1st July	26.08 ± 1.34	17.91 ± 0.51	9.38 **	16.44 ± 0.17	16.59 ± 0.14	0.19 *n.s.*
8th July	9.12 ± 1.97	12.40 ± 1.35	1.50 *n.s.*	17.18 ± 0.15	16.78 ± 0.17	2.38 *n.s.*
15th July	17.68 ± 0.23	17.43 ± 0.09	0.77 *n.s.*	25.08 ± 1.43	19.29 ± 0.76	8.66 **
26th July	13.34 ± 3.01	9.16 ± 1.49	1.50 *n.s.*	24.34 ± 0.28	23.43 ± 0.22	5.42 *
29th July	30.48 ± 0.98	20.46 ± 0.97	9.39 **	20.06 ± 0.21	19.93 ± 0.25	0.74 *n.s.*
7th August	16.58 ± 0.82	23.36 ± 1.56	5.42 *	18.40 ± 0.15	18.27 ± 0.15	0.38 *n.s.*
12th August	27.14 ± 0.61	20.7 ± 0.65	9.39 **	15.00 ± 0.18	15.19 ± 0.08	0.19 *n.s.*
19th August	28.24 ± 1.65	19.57 ± 0.89	8.64 **	16.68 ± 0.18	17.19 ± 0.39	0.00 *n.s.*

Table 3. Kruskal-Wallis Test statistics returned on soil moisture and soil temperature on the Hessleskew Farm spring barley ('Laureate') validation platform in 2019 (where significance of output is denoted by: n.s. = not significant, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$).

	Soil moisture (%)			***Soil temperature (°C)***		
	No understory	**Clover living mulch**		**No understory**	**Clover living mulch**	
	Mean ± SE	***Mean ± SE***	H_1	***Mean ± SE***	***Mean ± SE***	H_1
23rd May	7.53 ± 0.49	5.31 ± 0.25	7.95 **	12.83 ± 2.09	17.74 ± 0.34	9.04 **
18th June	15.81 ± 0.87	14.30 ± 0.88	1.82 *n.s.*	13.69 ± 0.38	12.19 ± 0.64	3.85 *
17th July	1.77 ± 0.35	3.64 ± 0.36	6.64 **	22.42 ± 0.35	22.86 ± 0.46	0.54 *n.s.*

Soil compaction

Soil compaction could only be reliably assessed at a 3-inch depth, and was found to be, on average, higher in areas grown with a clover living mulch (Figure 28). This was only statistically significant on the STC platform (H_1 = 4.89, $p < 0.05$), with no statistical difference reported for Hessleskew Farm (H_1 = 0.46, n.s.). Higher soil compaction levels may be expected from conservation- and minimum-tillage approaches such as strip tilling, and this may explain the difference between soil compaction levels on the STC site. The readings obtained at Hessleskew Farm, however, suggest that clover living mulches, at least once they have become well-established, may not significantly increase soil compaction in strip-tilled cropping systems, potentially serving to mitigate some compaction effects of minimum-tillage approaches.

Figure 28. Mean soil compaction across the 2019 growing season in a spring barley ('Laureate') crop on the STC (grey bars) and Hessleskew Farm (hatched bars) validation platforms. Means are shown ± SEs.

Soil mineral nitrogen

All soil mineral nitrogen levels at STC were found to differ significantly between understory types in 2019. Soil nitrate levels were significantly reduced in clover living mulch areas ($F_{1,13}$ = 31.39, $p < 0.001$, *ln*-transformed; Figure 29), as was available nitrogen ($F_{1,13}$ = 16.36, $p <$ 0.01, *ln*-transformed; Figure 29). Soil ammonium levels, by contrast, were found to be increased in clover living mulch areas ($F_{1,13}$ = 26.38, $p < 0.001$, *ln*-transformed; Figure 29). At Hessleskew Farm, differences were also reported. A consistent trend towards reduced values was reported in clover living mulch areas, though differences were generally not as pronounced. Significant differences were reported for ammonium ($F_{1,13}$ = 50.92, $p < 0.001$, *ln*-transformed; Figure 29) and available nitrogen ($F_{1,13}$ = 20.37, $p < 0.001$, *ln*-transformed; Figure 29) levels, though there was no significant difference in nitrate levels between the understories ($F_{1,13}$ = 3.27, n.s.; Figure 29).

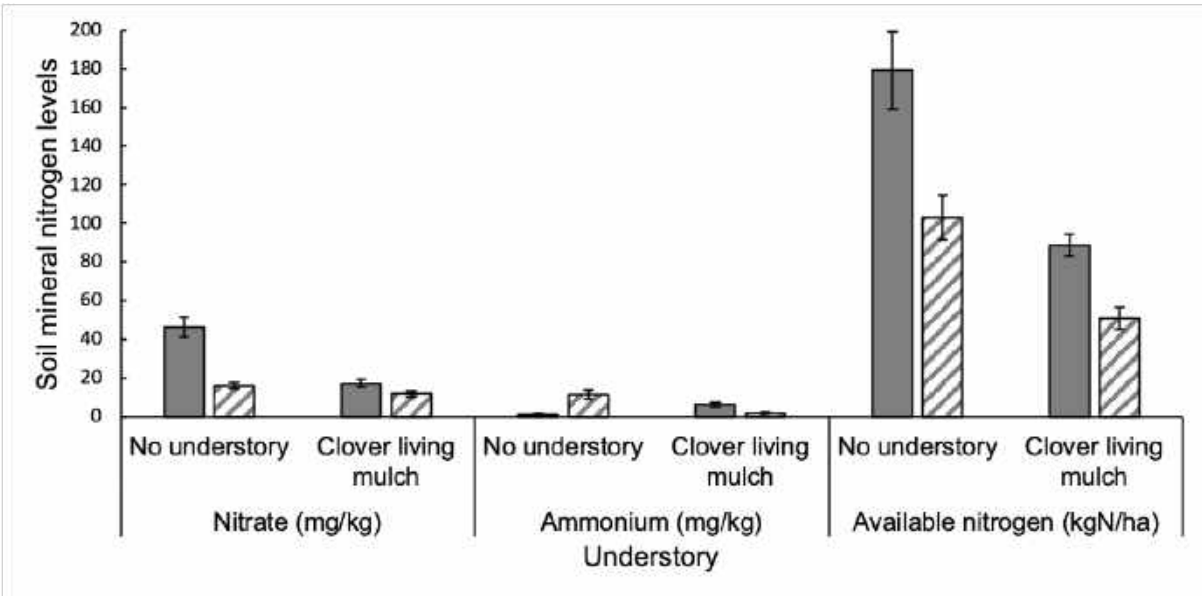

Figure 29. Mean soil mineral nitrogen levels on STC (grey bars) and Hessleskew Farm (hatched bars) validation platforms. Means are shown ± SEs. STC values reported for July 2019, Hessleskew Farm values reported for April 2019. Analyses conducted and reported by NRM Laboratories (Cawood Scientific).

Soil analyses were reported in July at STC, and April at Hessleskew Farm. As such, it is not possible to compare between sites in terms of general trends. Regardless, differences would not be unexpected. At Hessleskew Farm, where the conventional no clover area was managed in line with standard programmes while the clover area received no fertiliser application, the impact of different nitrogen management regimes would trigger differences between platform areas.

Soil organic matter content

By the end of the growing season, in early September, soil organic matter content levels were found to be reduced in clover living mulch areas at STC (H_1 = 5.26, p < 0.05; Figure 30). This is unexpected, and the reasons for are unclear. It is possible that this may be a result of the reduced clover cover over the course of the growing season. By contrast, soil organic matter content was increased considerably in the clover living mulch area at Hessleskew Farm (H_1 = 9.44, p < 0.01; Figure 30), with an increase of nearly 35% relative to the conventional no clover area reported from analyses. This is in line with the expectation of increased soil organic matter, with increases potentially supported by the age and time since establishment of the clover living mulch platform.

Soil health indicators

Soil health indicator results were encouraging for both sites, despite the lower than expected soil organic matter levels reported at STC. Microbial activity CO_2 burst was significantly increased in areas grown with clover living mulches at STC ($F_{1,8}$ = 56.97, p < 0.001; Figure 31a), and though the higher values reported from Hessleskew Farm were not statistically higher ($F_{1,8}$ = 4.06, n.s.; Figure 31a), the upward trend remains apparent. The microbial index score returned from analyses was significantly increased at both STC (H_1 = 5.91, p < 0.05;

Figure 31b) and Hessleskew Farm (H_1 = 3.95, p < 0.05; Figure 31b). As soil microbial activity is important for soil health, and activity levels are considered indicators of soil health, these findings suggest improved overall soil health in systems using a clover living mulch.

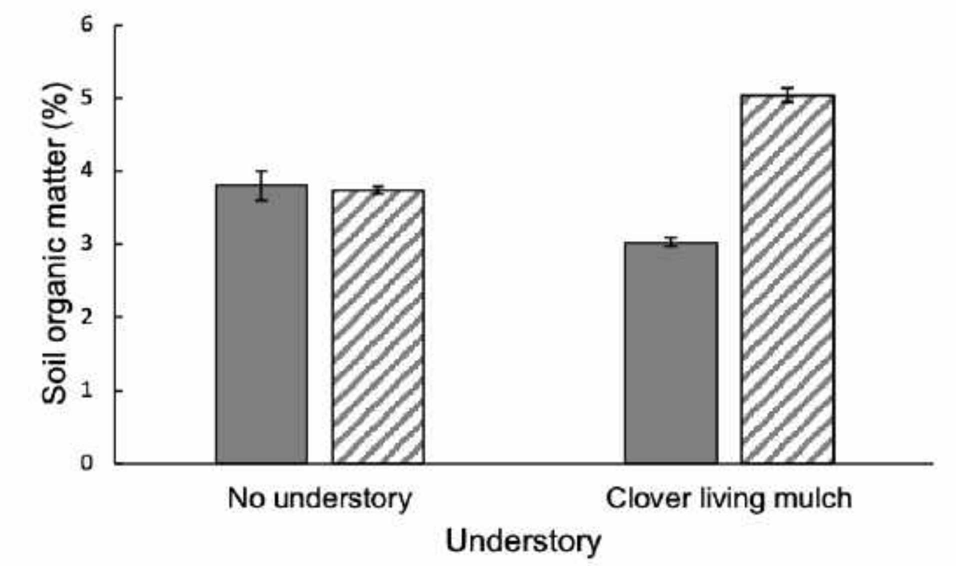

Figure 30. Mean percentage soil organic matter content (LOI) on the STC (grey bars) and Hessleskew Farm (hatched bars) validation platforms, following a crop of spring barley ('Laureate') in 2019. Means are shown ± SEs. Values reported for September 2019. Analyses conducted and reported by NRM Laboratories (Cawood Scientific).

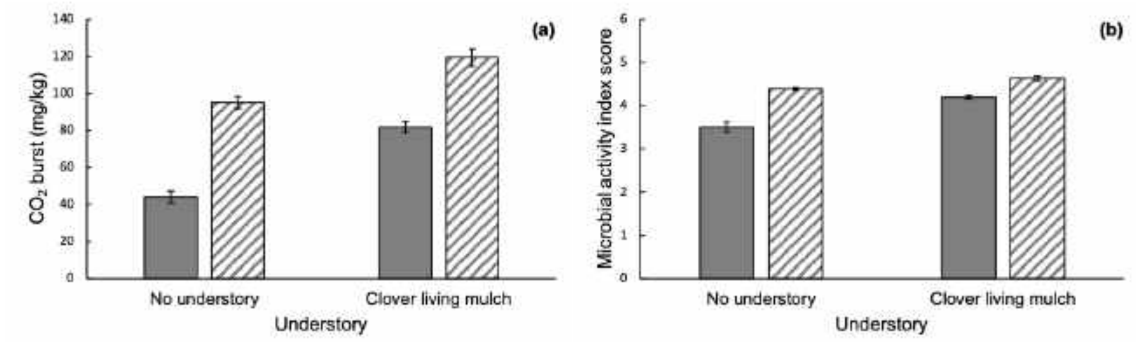

Figure 31. Mean soil microbial activity as reported from CO_2 burst (mg/kg) levels (a) and soil microbial index score (b) on the STC (grey bars) and Hessleskew Farm (hatched bars) validation platforms, following a crop of spring barley ('Laureate') in 2019. Means are shown ± SEs; where: 0-1 = very low, 1-2 = low, 2-3 = moderate-low, 3-4 = moderate, 4-5 = high, 5-6 = very high. Values reported for September 2019. Analyses conducted and reported by NRM Laboratories (Cawood Scientific).

Overall soil health scores were also found to be significantly higher in areas grown with a clover living mulch at both STC (H_1 = 4.75, p < 0.05; Figure 32) and Hessleskew Farm (H_1 = 6.04, p < 0.05; Figure 32). As with the soil microbial activity indicators, these findings suggest that clover living mulches have the potential to support improved soil health in arable systems over a long term.

Figure 32. Soil health index score reported from the STC (grey bars) and Hessleskew Farm (hatched bars) validation platforms, following a crop of spring barley (‘Laureate’) in 2019. Means are shown ± SEs; where: 0-1 = very low, 1-2 = low, 2-3 = moderate-low, 3-4 = moderate, 4-5 = high, 5-6 = very high. Values reported for September 2019. Analyses conducted and reported by NRM Laboratories (Cawood Scientific).

Conclusions

Although positive results were obtained on the STC validation platform in 2019 in terms of crop productivity, clover cover remained generally low through the growing season, decreasing through time and allowing a greater proportion of weeds to establish that required subsequent management. It is likely that clover management options (stressing by means of glyphosate application and mowing) prior to drilling to mitigate clover-crop competition effects over-stressed the clover combined with a relatively dry spring impeded its recovery post-drilling, and while this may have allowed the crop greater time to establish and develop strongly early in the season, predicted benefits in terms of weed suppression were not met. A trend towards a potential suppressive effect on insect pest population levels was shown, though trends for disease levels were not clear. Slug numbers were not found to broadly differ between conventionally managed areas and those grown with a clover living mulch, which, considering the potential importance of slugs as a pest in such systems is an encouraging observation (though it should also be noted that, in damper years, slug pressure may be higher early in the season, with greater impact on crop productivity). Trends towards biodiversity gains were also reported, though were not always significant. By contrast, soil health indicators were broadly significantly increased, with the exception being soil organic matter content, though the reasons for the latter remain unclear.

The 2019 data for Hessleskew Farm showed, as did the data from 2018, a more pronounced impact on crop biomass and productivity, highlighting once again the potential risk of clover living mulch systems to yield. It is probable that the relative age and maturity level of the platform allowed the clover to compete more strongly with the spring barley crop, despite attempts to mitigate such impacts of the clover prior to drilling and once again during the growing season. These findings support the need to manage clover competition more regularly through a growing season, ideally by means other than chemical input, and potential such means are currently subject to investigation through other separate projects. The difference between nitrogen and other input (herbicide, fungicide) programmes between the conventional no clover area could also have driven the differences observed, though yield was nonetheless derived from the clover area, despite the addition of no fertiliser. Biodiversity benefits were also observed at Hessleskew Farm, particularly for bumblebees, where the number of clover flowers were again found to significantly boost numbers through increased forage opportunity. Results on soil health indicators were also, again, apparent in the area grown with a clover living mulch, supporting the potential role of such systems in the improvement and long-term management of soil health and sustainability.

Overall, the findings of 2019 suggest a potential role for strip tillage as a means of mitigating clover competition impacts on spring crops in clover living mulch systems. Findings suggest that clover living mulch systems may be more suited to spring-sown crops, where the crop can establish and develop more rapidly following drilling, before clover has sufficient time to recover from drilling stressors. The findings also suggest that, to further mitigate competition impacts, targeted, precision placement of inputs such as nitrogen may allow a sown crop to compete more strongly with the clover in the early stages of growth, minimising impacts on subsequent crop productivity even where such inputs are applied at a reduced rate. Targeted applications would also contribute towards reduced input levels overall. Furthermore, multiple benefits have again been noted, with demonstrable benefits to soil health indicators, and trends suggesting potential for positive impacts on other environmental and biodiversity indicators in arable system. Regardless, across the two years of trials undertaken thus far, a variable impact of year has been shown, with different years introducing high variability in climatic and associated pressures. The importance of clover establishment levels and recovery levels, and platform maturity in supporting such benefits is also evident.

Knowledge Transfer

Industry Demonstration

The project featured at LAMMA 2019 in January of the year, using project resources to part-fund the Manterra Ltd (Hessleskew Farm) stand under Milestone 2.3. The event was well-attended, and in response to impact achieved through attendance at the 2019 event it was confirmed that further industry demonstration would be undertaken at LAMMA 2020 on the same basis.

The initial 'Demonstration Event' (Milestone 2.1) had originally been planned to take place before the 31st March 2018. It was delayed, however, initially due to the start of the project being pushed back (which limited time available to plan and authorise such an event) and then in response to challenging growing conditions for the clover in 2019, with postponement allowing the clover to become better established for demonstration purposes. The event was held at STC on the 24th June 2019 as a conference, 'Growing in the Green'. Presentations were given by two external speakers (Dr R. Brooker, Mr N. Fuller), as well as STC's Dr David George. Attendees were also shown the machinery used to drill the platform (PAT-assisted tractor and CHAP's Baertschi Strip-till) before being taken to STC's validation platform to discuss performance and challenges encountered. The event was attended by 18 delegates, comprising nine farmers and agronomists, one representative from each of the RPA and CHAP, two external speakers, and six STC staff including Dr George.

Peer-to-Peer Exchange

Over the course of 2019 the project featured at eight on-farm events for peer-to-peer exchange (Table 4). These ranged from one-to-one meetings through to presentation to small groups, and in addition to discussion of the project context and findings typically involved site visits to the validation platforms themselves. Unfortunately, it was not possible to hold an Open Day at Hessleskew Farm in 2019 due to time constraints imposed by prior engagements.

Table 4. On-farm peer-to-peer demonstration events undertaken in 2019.
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Event*	***Location***	***Date(s)***	***Audience***	***No. engaged***
CHAP 'Family Day'	STC	31.01.2019	Academia	30
NFU and CHAP representatives site visit; *Pr, Pl*	STC	14.03.2019	Industry, policy	3
Grower visit to site; *Pr, Pl*	STC	04.04.2019	Farmer	1
Crop protection company representative site visit; *Pr, Pl*	STC	11.04.2019	Industry	2

Event*	***Location***	***Date(s)***	***Audience***	***No. engaged***
Crop protection company representative site visit; *Pr, Pl*	STC	22.07.2019	Industry	3
RHS Fruit, Vegetable and Herb Committee site visit; *Pr*	STC	18.09.2019	Public/civil society	20
Agricultural student site visit; *Pl*	STC	02.10.2019	Academia	1
Delegation of Department for Internatial Trade Officers site visit; *Pr*	STC	09.10.2019	Policy, industry	27

**Ex=Exhibit; Pr=Presentation; Pl=Plot tour*

Context and findings of the project thus far were also disseminated at a number of off-farm events (Table 5) to maximise dissemination reach and number, and made use of, initially, the authorised draft and then finalised leaflet (Appendix III) as well as other materials derived from the validation platforms as appropriate to the event (photographs, for example).

Table 5. Off-farm peer-to-peer demonstration events undertaken in 2019.

Event*	***Location***	***Date(s)***	***Audience***	***No. engaged***
AICC Conference; *Pr*	Towcester	09.01.2019	Academia	120
Askham Bryan Horticulture Conference; *Ex*	Askham Bryan	24.01.2019	Academia, industry	100
Patrington Agricultural Society meeting	Patrington	04.02.2019	Industry, civil society	20
Young Horticulturalist of the Year, Regional Final; *Pr*	Bedale	23.03.2019	Industry, public	25
UK AgriTech Centres Capabilities Event – ‘Transform Food Production’; *Ex*	Newcastle	26.03.209	Industry	150
Harper Adams CROPSS invited lecture; *Pr*	Newport	01.07.2019	Academia	16
Croptech 2019; *Ex*	Peterborough	27.11.2019	Academia	220

**Ex=Exhibit; Pr=Presentation; Pl=Plot tour*

The project has also been mentioned on a regular basis in the Yorkshire Post, as part of STC regular Comment column piece, though without specific mention to project findings and outcomes.

Outputs and Milestones

		Originally proposed		Revised if needed		
Work Package	**Milestone/output/outcome**	**Start (01.02.18)**	**End (31.12.20)**	**Start (01.02.18)**	**End (31.12.20)**	**Code***
WP1: Project Management	1.1 Kick-off meeting	-	01.03.18	-	01.03.18	C
	1.2 Annual Meeting Yr1	-	14.12.18	-	14.12.18	C
	1.3 Annual Meeting Yr2	-	14.12.19	-	14.12.19	C
	1.4 Annual Final Meeting Yr3	-	14.12.20	-	14.12.20	P
	1.5 Ongoing planning meetings (all years by request)	01.02.18	31.12.20	01.02.18	31.12.20	O
WP2: Industry Demonstration	2.1 Demonstration event Yr1 (winter wheat)	-	31.03.18	-	DATE	D
	2.2 End of project conference Yr3 (winter barley)	-	31.03.20	-	Delayed (TBC)	P
	2.3 Presence at external industry event (x1)	01.03.18	31.03.20	01.03.18	31.03.20	C
WP3: Commercial Validation	3.1 Commercial validation Yr2	31.03.18	30.09.18	31.03.18	30.09.18	C
	3.2 Commercial validation Yr2	31.03.19	30.09.19	31.03.19	30.09.19	C
	3.3 Commercial validation Yr3	31.03.20	30.09.20	31.03.20	30.09.20	O
	3.4 Commercial feedback/survey	30.09.20	30.11.20	30.09.20	30.11.20	P
WP4: Peer-to-Peer Exchange	4.1 Yr1 peer-to-peer on-farm workshops (x3)	31.03.18	30.09.18	31.03.18	30.09.18	C
	4.2 Yr2 peer-to-peer on-farm workshops (x3)	31.03.19	30.09.19	31.03.19	30.09.19	C
	4.3 Yr3 peer-to-peer on-farm workshop (x3)	31.03.20	30.09.20	31.03.20	30.09.20	O
WP5: Reporting and Publication	5.1 Yr1 Report	-	31.12.18	-	Delayed to 31.01.19‡	C
	5.2 Yr2 Report	-	31.12.19	-	Delayed to 31.03.20‡	D
	5.3 Yr3 Final Report	-	31.12.20	-	31.12.20	P
	5.4 End of project press article for dissemination to industry press	-	31.12.20	-	31.12.20	P
	5.5 Co-production of project leaflet	30.09.20	31.12.20	30.09.20	31.12.20	C

**C = Complete; O = Ongoing; P = Planned; D = Delayed; X = Cancelled.*

Dark green *= achieved as planned;* ***Light green*** *= achieved despite delay;* ***Orange*** *= not achieved.*

‡These delays were required due unforeseen to staff changes at STC.

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Appendix I. Trial Diary (STC, 2019)

Date	'Event'/Notes
15.04.2019	Drilling completed – spring barley ('Laureate', sown at 180kg/ha).
15.04.2019	Platform rolled.
08.05.2019	Data collected: slugs, carabids, growth stage. Clover And Weed ground cover, flower count
12.05.2019	Data collected: Avian and mammal count.
13.05.2019	Data collected: Slugs, carabids, growth stage, Worm count.
14.05.2019	Fertiliser applied (broadcast). Nitram 34.5% N at 220kg/ha (= 80kg/ha N). Data collected: Emergence.
15/05/2019	Data collected: Insect invertebrate assessment and visual assessment.
21.05.2019	Data collected: Slugs, carabids, growth stage.
24.05.2019	Data collected: avian assessment. Disease assessment.
29.05.2019	Data collected: Slugs, carabids, growth stage.
30.05.2019	Data collected: soil compaction. Atleaf measurements.
31.05.2019	Data collected: Insect invertebrate assessment and visual assessment.
03.06.2019	Data collected: Slugs, carabids, growth stage. Clover and weed cover, clover flower count.
05.06.2019	Data collected: Plant growth habit.
06.06.2019	Data collected: Disease assessment.
10.06.2019	Data collected: Slugs, carabids, growth stage.
11.06.2019	Leaf sampling NRM – plant foliar suite (STC) x 10 samples Soil samples taken (x15 nitrogen) Data collected: worm count.
14.06.2019	Data collected: Insect invertebrate assessment and visual assessment.
17.06.2019	Data collected: Slugs, carabids, growth stage.
19.06.2019	Data collected: canopy and plant height. Avian and mammal count.
21.06.2919	Fungicide application – Siltra X Pro @ 750ml/ha. Herbicide application – Hurler @ 0.5L/ha.
24.06.2019	Data collected: Slugs, carabids, growth stage.
25.06.2019	Data collected: compaction and Atleaf.
01.07.2019	Data collected: Slugs, carabids, growth stage. Clover and weed ground cover, clover flower count.
02.07.2019	Leaf sampling NRM – plant foliar suite (STC) x 10 samples
08.07.2019	Data collected: Slugs, carabids, growth stage.
09.07.2019	Data collected: Insect invertebrate assessment
15.07. 2019	Data collected: Slugs, carabids, growth stage.
16.07.2019	Data collected: Insect quadrat and visual assessment
23.07.2019	Data collected: Insect invertebrate, quadrat and visual assessment
26.07.2019	Data collected; soil moisture temperature. Slugs and carabids.

29.07.2019	Data collected: Slugs, carabids, moisture, temperature and growth stage. Clover and weed ground cover, clover flower count
30.07.2019	Data collected: Soil compaction, atleaf and lodging.
31.07.2019	Disease assessment conducted
01.08.2019	Biomass sampling conducted (0.25m²). Assessments: weed biomass, crop biomass (fresh/dry), ear numbers/tiller numbers.
07.08.2019	Data collected: Slugs, carabids, growth stage. Worm count.
09.08.2019	Data collected: Canopy height.
12.08.2019	Data collected: Slugs, carabids, growth stage.
19.08.2019	Data collected: Slugs, carabids, growth stage.
22.08.2019	Harvest assessments: ear numbers, plant length (5 plants) fresh/dry ear and straw weights. Soil samples taken (x15 soil N, x10 soil health)
07.09.2019	Platform combine harvested.

Appendix II. Trial Diary (Hessleskew Farm, 2019)

Date	'Event'/Notes
05.04.19	Platforms drilled (barley 'Laureate', 125kg/ha) following application of pre-drilling herbicide (glyphosate 360g at 3.5L/ha).
17.04.19	Assessments and sampling from plots 1-10, (11-15 not sampled as the field was not drilled). Soil samples taken (x10 nitrogen). Data collected; diseased plant numbers, weeds %, clover %, no. of clover flowers, soil temperature, insect visual and transect, crop establishment, clover growth stage, slug damaged plants and avian/mammal assessment. Photographs taken
23.04.19	Assessments and sampling from plots 11-15 (finishing off work conducted on 17/4/19, sampling points 11-15 have been moved to another field). Soil samples taken (x5 nitrogen). Data collected; diseased plant numbers, weeds %, clover %, no. of clover flowers, insect visual and transect, crop establishment, clover growth stage, slug damaged plants and avian/mammal assessment (soil temperature not taken due to equipment issue). Photographs taken
17.05.19	Slug traps assessed (to record carabid and slug numbers) and rebaited.
23.05.19	Data collected; soil moisture content and temperature (taken at 0cm and 15cm depths), soil compaction, earthworm counts, phytotoxicity , disease assessment, invertebrate assessment, weeds %, clover %, clover growth stage, no. of clover flowers, insect visual and transect, crop establishment, crop growth stage, at leaf reading, Slug traps assessed (to record carabid and slug numbers) and rebaited. avian/mammal assessment. Photographs taken.
25.05.19	Herbicide (fluroxypyr, 0.75L/ha) and fungicide (Amistar Opti, 0.75L/ha) applied to clover platform.
31.05.19	Slug traps assessed (to record carabid and slug numbers) and rebaited.
06.06.19	Slug traps assessed (to record carabid and slug numbers) and rebaited.
15.06.19	Slug traps assessed (to record carabid and slug numbers) and rebaited.
18.06.19	Data collected; soil moisture content and temperature (taken at 0cm and 15cm depths), soil compaction, earthworm counts, phytotoxicity , disease assessment, invertebrate assessment, weeds %, clover %, clover growth stage, no. of clover flowers, insect visual and transect, crop establishment, crop growth stage, at leaf reading, Slug traps assessed (to record carabid and slug numbers) and rebaited. avian/mammal assessment, lodging, canopy height, tillering. Photographs taken. Leaf sampling (NRM – plant foliar suite x 10 samples. Vegetative biomass samples taken (1/plot).
26.06.19	Slug traps assessed (to record carabid and slug numbers) and rebaited.
03.07.19	Slug traps assessed (to record carabid and slug numbers) and rebaited. Leaf sampling (NRM – plant foliar suite x 10 samples.
09.07.19	Slug traps assessed (to record carabid and slug numbers) and rebaited.

17.07.19	Data collected; soil moisture content and temperature (taken at 0cm), soil compaction, phytotoxicity , invertebrate assessment, weeds %, clover %, clover growth stage, no. of clover flowers, insect visual and transect, crop establishment, crop growth stage, at leaf reading, Slug traps assessed (to record carabid and slug numbers) and rebaited. avian/mammal assessment, lodging, canopy height, tillering and ear count. Vegetative biomass samples taken. Earthworm count, 15cm reading MC/temp reading unable to be taken due to hard soil, also atleaf and disease assessment were not taken due to a senescing crop.
18.07.19	Assessments: weed biomass (fresh & dry) crop biomass (fresh & dry),
24.07.19	Slug traps assessed (to record carabid and slug numbers) and rebaited.
31.07.19	Slug traps assessed (to record carabid and slug numbers) and rebaited.
07.08.19	Slug traps assessed (to record carabid and slug numbers) and rebaited.
13.08.19	Harvest samples taken (0.25m²). Soil samples taken 15x soil N and 10x soil health. Slug traps assessed (to record carabid and slug numbers)
14.08.19	Harvest samples processed. Data collected; Fresh and dry weight of straw and ears, ear numbers and straw height. Soil samples taken (x15 soil N, x10 soil health)
28.08.19	Platforms combine harvested.

Appendix III. Project leaflet (finalised)

"TO KEEP PACE WITH POLITICAL, SOCIETAL & ENVIROMENTAL DRIVERS, WE MUST EVOLVE CURRENT FARMING METHODS TO INCREASINGLY REALISE SUSTAINABLE PRODUCTION PRACTICES. IF CAREFULLY CONSIDERED THERE SHOULD BE SCOPE TO IMPROVE YIELDS WHILE NOT ONLY SAFEGUARDING OUR SOILS & NATURAL SYSTEMS, BUT ALSO DERIVING PRODUCTION BENEFITS FROM THEM. CLOVER LIVING MULCHES ARE LIKELY TO BE ONE SUCH EXAMPLE OF THIS."

DR DAVID GEORGE

MANTERRA LIMITED

The European Agricultural Fund for Rural Development: Europe investing in rural areas

eip-agri AGRICULTURE & INNOVATION

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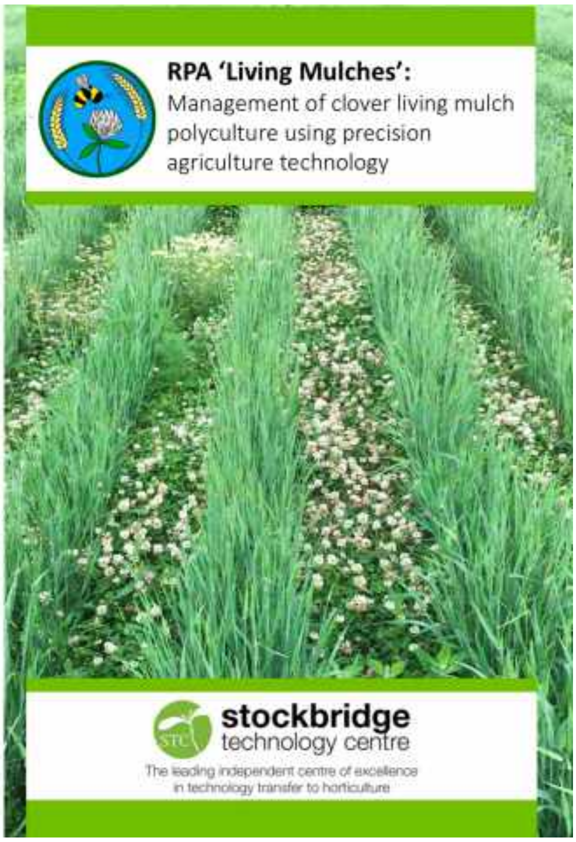

RPA 'Living Mulches':
Management of clover living mulch polyculture using precision agriculture technology

stockbridge technology centre
The leading independent centre of excellence in technology transfer to horticulture

THE CHALLENGE

Political, social and environmental forces are driving current food production to become more 'sustainable' with reduced ecological impact. Living mulches have significant potential to realise these aims; creating a natural ecosystem of ground cover which supresses pests, weeds and diseases whilst reducing soil erosion, improving soil organic matter and water holding capacity, and increasing beneficial biodiversity both above and below ground. Leguminous living mulches, such as clover, can also aid soil fertility by making nitrogen available to crops. Realising these benefits is not easy, however, and is dependent on developing cost-effective living mulch production systems that are easy to implement and manage on-farm, and that have minimal impact on yield and crop quality.

THE OPPORTUNITY

Until recently it was hard to imagine how living mulches could be integrated into conventional arable systems, which have evolved to monocultural models. It may be possible, however, to overcome potential problems that living mulches pose through modern machinery and precision agricultural technology. Modern strip-tills, for example, can comfortably cultivate through clover cover, allowing band sowing of crops in GPS-marked seed beds to promote good crop establishment whilst maintaining at least 50% clover cover at drilling. The current three year project is validating this approach in autumn and spring cereals, confirming that crop and clover can be considered compatible, and that the latter can deliver on-farm gains for 'sustainable' aims.

THE SOLUTION

Funded by the Rural Payments Agency under EIP-Agri, commercial-scale trials are being carried out at STC and Hesslekew Farm, with input from Manterra Ltd, to validate commercial viability of clover living mulches to arable systems. To deliver 'gain without pain' from our mulches, the project is utilising the CHAP (Crop Health and Protection) Innovation Centre's Baertschi Oekosem ROTOR Strip Till, a Swiss-made piece of machinery, coupled to GPS-guided drilling. Benefits to soils, crops and biodiversity are being recorded over three consecutive years of growing into clover, and compared to monoculture controls.