STC 'LIVING MULCHES'

Management of clover living mulch polyculture using precision agriculture technology for a sustainable future in arable farming

MANTERRA LIMITED

This EIP-AGRI-funded project aims to demonstrate and validate clover living mulches as a viable, achievable and profitable option for UK arable agriculture.

Trials are being conducted at both STC and Manterra Ltd sites to evaluate and gather evidence that living mulches are compatible with current cereal production across PAT-uptake levels, while also creating potential for multiple benefits to farmers.

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The results and conclusions in this report are based on a single replicated experiment. The conditions under which the experiment was 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

Background

As reviewed by Hartwig & Ammon (2002), prior research supports that living mulches can address multiple key challenges being faced by the arable sector, noted by Hartwig & Ammon (2002) as: erosion control, reduction in surface water pollution, added organic matter, improved soil structure and tilth, fixing of atmospheric nitrogen, recycling of unused soil nitrogen, greater soil productivity and weed control. Research since further supports that leguminous living mulches can improve soil fertility (Duda *et al*. 2003), main crop nutrient uptake (Deguchi *et al*. 2007), soil biotic health (Schmidt *et al*. 2003 and Pelosi *et al*. 2009 re: earthworms; Brévault *et al*. 2007 re: various macro-fauna; Nakamoto & Tsukamoto 2006 re: various micro-fauna) and water retention (Siller *et al*. 2016), also suppressing weeds (Hiltbrunner *et al*. 2007a), contributing to pest population control (Prasifka *et al*. 2006; Schmidt *et al*. 2007), protecting soils from erosion (Siller *et al*. 2016) and nutrient losses (Siller *et al*. 2016). Research from the horticultural sector also supports that living mulches can promote on-farm pollinator conservation where appropriate flowering understories are used (Saunders *et al*. 2013), which if repeatable within arable systems could greatly increase the conservation potential of production within this sector. In addition, living mulches can play a role in carbon storage, potentially having a significant impact on climate change if widely adopted across arable land areas. According to the outcomes of a recent global conference on soil carbon sequestration in France, the potential for living mulches to lock up carbon is greater than for any other agro-forestry land management technique (Sequestering Carbon in Soil Summary Report, 2017). The ability of living mulches to negate climate change is further improved where leguminous mulches are used, as these can simultaneously reduce N2O emissions by replacing or reducing N fertiliser use (e.g. Deguchi *et al*. 2007). Living mulches therefore represent a potentially 'multifunctional' solution, both for future arable production and for the environment, with focus on the latter likely to be especially key to both driving market competitiveness post-Brexit and achieving sustainable intensification. Adoption of multifunctional solutions will be critical to realising the sustainable intensification agenda, and thus validation of production techniques that provide high levels of such additionality should be prioritised for near-market validation.

Despite their demonstrated benefits, to date commercial uptake of living mulches in UK arable farming has been prevented by production conflicts and practical difficulties in the management of 'polycultural' systems. Recent work by Siller *et al*. (2016), for example reports significant benefits of living mulches to US corn production, but at the expense of crop yield, with similar yield suppression also reported elsewhere (e.g. Carof *et al*. 2007). Though measures to mitigate yield suppression have been attempted, for example through varying seed rates of the main crop (Hiltbrunner *et al*. 2007b), these have yet to resolve this issue in any commercially meaningful way. Using commercially available machinery and precision agricultural technologies (PAT), however, affords an innovative opportunity to overcome the restrictions that have prevented commercial uptake of living mulches to date. The proposed 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. Of particular importance to demonstrating compatibility of living mulches to modern arable production is state of the art strip-tillage machinery, allowing crops and clover to be simultaneously sown into cultivated bands in a single pass, or for crops to be drilled/cultivated in strips into pre-existing clover understories. As Core Partners of the Innovation Centre for Crop Health and Protection (CHAP), STC have access to one of the UKs only Baertschi Oekosem ROTOR Strip Tillers, a CHAP asset based on site that has the capacity to revolutionise drilling into permanent ground cover (specifications are included in the supporting material), or simultaneous sowing of multiple crop/non-crop bands in a single machinery pass. Manterra Ltd are the UK importer for this Swiss-based machinery.

Funds were secured through the current project to incorporate this new-to-market machinery to allow commercial validation (farm sites), demonstration (STC/Manterra) and dissemination (STC/Manterra and farm sites) of living mulch production, and overall project management (STC) to ensure that the work meets its requirements for reporting and data sharing.

Though the multiple benefits of living mulches *per se* are already available to farmers and not especially innovative in their own right, delivering a viable means for farmers to realise these benefits by incorporating living mulches into profitable, conventional arable cropping is highly innovative. The project innovation will thus be to utilise recent research and development into drilling techniques (i.e. strip-tilling/band-sowing) and precision machinery steering solutions to demonstrate that these practises can deliver living mulches as a viable alternative to standard arable 'monocultures'. Combining precision steering with strip-tilled and band-sown plantings (crops grown in 25cm bands at 50cm centres to produce 25cm rows between crops) should permit establishment and long-term persistence of clover understories to deliver key inputs during the crop growing cycle (particularly N), whilst also protecting soils and improving water/nutrient/OM retention post-harvest. Using PAT, coupling of tractor and implement steer can already provide the required sub-inch accuracy needed to repeat drill into inter-clover strips year after year through GPS/RTK auto-steer, though strip-tilled band-sowing could theoretically be undertaken independently of PAT uptake. Though PAT assisted strip-tilling/band-sowing to promote polyculture is especially innovative, the benefits of polyculture per se are well-established and the production method proposed is achievable with commercially-available machinery and technologies.

Aims and objectives

The aim of the proposed project is to demonstrate and validate living mulches as a viable, achievable and profitable option for arable farmers in the UK. As such a primary outcome from this project will give evidence that living mulches are compatible with current cereal production, across PAT uptake spectra, and can provide multiple-benefits to farmers which would encourage their use. A further outcome, crucial to the project's success, is engagement of the arable sector with the project. This will be assured 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 Factsheet.

ON-FARM VALIDATION

Validation trials at STC and Hessleskew Farms

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

<u>Stockbridge farm (53°49'10.6"N 1°08'57.2"W)</u>

Stockbridge farm 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. Thus this platform was run as low-input conventional in 2018, applying inputs (i.e. N and fungicide) equally across the clover and conventional plot.

<u>Hessleskew farm (53°51'09.2"N 0°34'52.7"W)</u>

This 172ha commercial farm produces a mixture of potatoes, cereals and vining peas in rotation, on Yorkshire Wolds soils mainly comprised of clay loam (see Results section). 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 N use efficiencies to limit N entering the water table. Regular additions of Organic Matter (OM) can nevertheless improve nutrient accessibility and drainage, with living mulches being a potential means to achieve this input (see Results for OM%). Thus inputs at Hessleskew varied according to plot type, with clover plots receiving few to no inputs, *vs* control plots receiving N and fungicide as per standard practice.

<u>Plot areas and crops</u>

The project plot at STC covers 3.1ha, with 2.65ha of this grown as a living mulch (see Fig 1), with a white clover (variety Aberpearl) mulch being validated with spring barley under a low-input regime in terms of nutrient addition and fungicide use. The plot at Hessleskew (Fig 2) covers 23ha overall, with white clover (1:1 mix of the varieties Crusader and Liflex) used as a mulch with winter wheat under a low/zero input production model covering 8ha. Crop inputs for both sites are shown in Appendix 1.

Figure 1. STC plot map (Google maps).

Figure 2. Hessleskew plot map (Google maps).

Methodology and Materials

Validation platform descriptions

The STC site was sown with a malting spring barley (Propino), which has been in the recommend list since 2010 and according to Syngenta "remains the main-stay of the English brewing market." This variety's robust disease profile and suitability to grow in any region and soil type were further reasons why it was chosen over others in the recommended list. Propino was drilled at 180kg/ha to reach a target plant population of 250 - 300 plants/m^2 in both treatments. White clover Aberpearl was sown at 10kg/ha (in the same pass) and the whole plot was then rolled to reduce moisture loss, improve pre-emergence herbicide efficiency and improve establishment via seed to soil contact. Sowing was undertaken using the CHAP Baertschi Oekosem ROTOR strip till cultivator, following initial shallow cultivation of the plot.

Crop nutrition was delivered by application of broadcast N, applied across the whole plot at a relatively low rate (220 kg/ha Nitram; 80 kg/ha N), this model having been selected for use at STC in an attempt to show benefit of the clover living mulch to crop production, particularly in later years once clover had become well established.

A fungicide programme was applied to whole plot on the 19th June 2018, consisting of application of Cello @ 0.75L/ha (for eyespot, powdery mildew, yellow rust, brown rust, ear disease complex, *Fusarium* ear blight and reduction of sooty moulds (Bayer Crop Science)) and Amistar Opti @ 0.5L/ha (to prevent and control brown rust, net blotch, *Ramularia* and *Rhynchosporium*). Both applications were made at a water rate of 200L/ha (see Appendix 2 for timings).

At Hessleskew, winter wheat (var. Zyatc) was drilled at 120 seeds/m^2 in both conventional and clover plots on the 10th October 2017, pre-establishing these plots ahead of the project start. Clover was also pre-established at Hessleskew, having been co-sown with OSR in a single machinery pass in August 2016, at a rate of 4 kg/ha (a higher rate being used at STC to sow clover in 2018 to provide some insurance against poor establishment, given that the plot here was not pre-existing prior to the start of the project).

The conventional plot at Hessleskew had been ploughed and power-harrowed pre-drilling, with the CHAP Baertschi Oekosem ROTOR strip till cultivator used to cultivate strips for winter wheat within clover, which was sown with a precision drill mounted behind the strip-till. The clover/wheat plot received no N or fungicide (zero input) in 2017/18, whereas the conventional control plot received N at 220 kg/ha (split equally across two applications in mid-March and mid-April 2018) and standard fungicide applications at T1 and T2. No T3 fungicide was applied as 2018 was notably dry and a T3 not considered necessary.

Assessments

Field assessments were carried out on both trial sites, though more extensive data collection was undertaken at STC. Data sampling points were initially GPS marked at STC and Hessleskew (see Appendix 1 for dates) and each site then had soil samples (x15) taken at the start of the trail, providing baseline figures for soil to be compared back to at the end of the growing season, and in later years of the project. Data collection then continued throughout the season at both sites, with all assessments that were carried out at Manterra and STC shown in Table 1, and specific methodologies used for all assessments provided in the Appendix.

Table 1. Data collected across STC and Hessleskew farms in the 2018 growing season. Numbers show the number of assessment occasions. For details and dates of assessments see Appendix 1 and 2.

Category	Assessment	STC	Hessleskew
FLORA	Crop emergence	1	1
	Ground cover	3	3
	ATleaf	2	1
	Leaf tissue nitrogen	2	1
	Canopy height	2	1
	Ear length	0	2
	Ear and tiller count	1	2
	Harvest biomass	1	1
FAUNA	Worm counts	1	0
	Visual transect	5	3
	Slug and Carabid	11	0
	Insect Quadrat	0	1
	Avian count	0	1
	Pest and disease	3-4	0
ABIOTICS	Soil moisture	9	1
	Soil analysis - N	1	1
	Soil analysis – health and OM	1	1
	Soil compaction	1	0

Results and Discussion

FLORA

Crop emergence

Emergence of barley was higher at STC when drilled with clover, yet lower at Hessleskew when drilled into a pre-existing clover mulch (Figs 3 and 4). Decreased emergence in the bare soil plot at STC may have resulted from the relatively poorer soil structure observed in parts of the bare soil plot, though it deserves note that sampling was avoided in the worse-affected areas at the far edge of the field. Lower emergence at Hessleskew within the living mulch plot, and particularly the contrast here with results from STC, might be explained by the pre-established nature of the clover at Hessleskew, as well as the autumn-sown nature of the crop; a pre-established living mulch being more likely to have competed with a more slowly emerging crop, particularly in a notably dry year, with a notably mild winter (which would have allowed the clover to continue growing post crop drilling). Data were also collected later in the year at Hessleskew, by which point any competition effects could have been expected to have been exacerbated *vs* earlier season counts at STC.

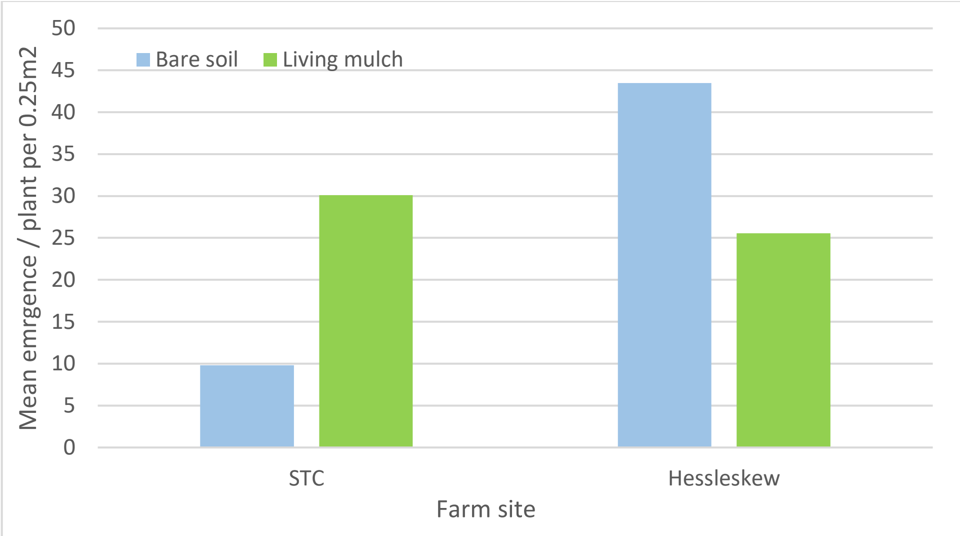

Figure 3. Mean crop emergence count (mean plants per 0.25m^2) for spring barley at STC (01.06.18) and for winter wheat at Hessleskew (03.07.18).

Ground cover

Ground cover of clover and weeds were assessed at both sites throughout the season (Tables 2 and 3). As clover was pre-established at Hessleskew, ground cover was already high for clover early in the season, demonstrating the protective effect that living mulches can exert post crop drilling. Clover cover remained high at Hessleskew over the season, seemingly providing a level of weed surpression. Having been co-sown with the crop, clover cover at STC increased slowly throughout the season, though had reached levels of cover seen at Hessleskew by the end of the year (data not shown, but to be included in the next report). A similar pattern of clover development was seen previously at Hessleskew in 2016/17 – i.e. where clover developed slowly at first, but rapidly post-harvest of crop in the autumn.

Table 2. STC - Ground cover (mean percentage) of clover and weeds (various dates).

	Clover cover		Weed cover		Total cover	
Date	Bare soil	Living mulch	Bare soil	Living mulch	Bare soil	Living mulch
12.06.18	0	0	2	5	2	5
07.08.18	0	7.5	4	12	4	19.5
04.09.18	0	17.5	7	15	7	32.5

Table 3. Hessleskew - Ground cover (mean percentage) of clover and weeds (various dates).

	Clover cover		Weed cover		Total cover	
Date	Bare soil	Living mulch	Bare soil	Living mulch	Bare soil	Living mulch
20.07.18	0.0	94.3	3.1	0.0	3.1	94.3
01.08.18	0.0	93.0	2.7	1.4	2.7	94.4
31.08.18	0.0	88.0	2.7	1.6	2.7	89.6

Leaf chlorophyll

Leaf chlorophyll was assessed at the two sites using a handheld AtLeaf meter (Fig 4). At both sites a consistent trend was seen for reduced leaf chlorophyll under the living mulch *vs* bare soil treatment, though differences were relatively small. Given the lack of clover early in the season at STC it is possible that other factors may explain this result – e.g. banding of the crop in the living mulch treatment leading to higher per plant competition for N per unit area. Should future data support this, it would suggest benefit to utilising N placement techniques in living mulch systems. It is also worth noting that it has been suggested that during initial establishment, clover may be a net N user, despite being a legume. This might also explain this result, and would support benefit of N application to clover post-sowing.

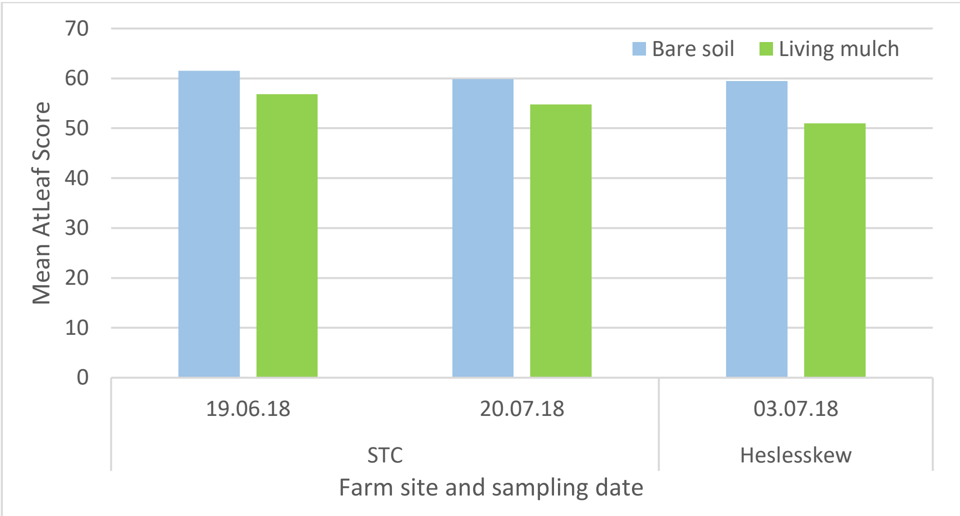

Figure 4. Mean crop AtLeaf scores for spring barley at STC and for winter wheat at Hessleskew (various dates).

Leaf Tissue Nitrogen

Leaf tissue N was assessed at both sites in early July (Fig 3), and again at STC on the 23rd July 2018 (Fig 5). Results showed little difference between treatments, particularly later in the season, though a trend for reduced leaf N was observed, supporting results obtained for leaf chlorophyll content above.

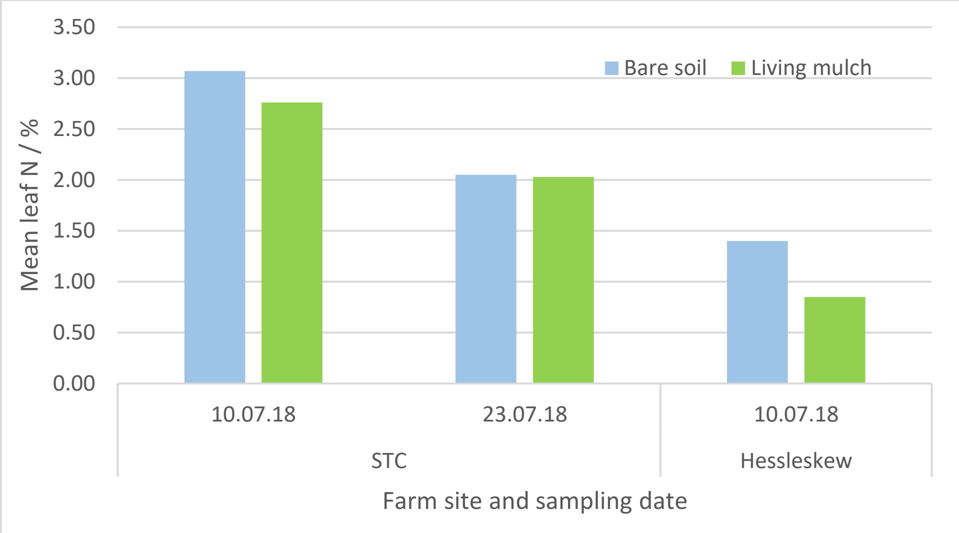

Figure 5. Mean leaf tissue N (%) for spring barley at STC and for winter wheat at Hessleskew (various dates).

<u>Canopy height</u>

Canopy height appeared slightly increased under the living mulch treatment at STC, but decreased under this treatment at Hessleskew (Fig 6). It is possible that the more advanced stage of the clover at Hessleskew, along with the dry year and variable approach to crop inputs, led to increased competition between clover and crop at this site *vs* STC.

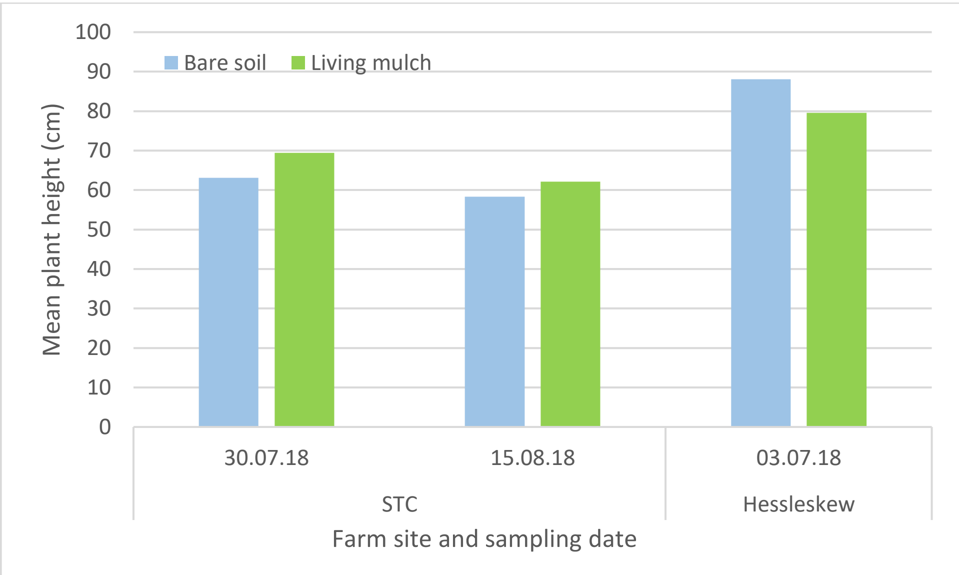

Figure 6. Mean crop height (cm) for spring barley at STC and for winter wheat at Hessleskew (various dates).

Ear length

At Hessleskew data were collected on ear length on two separate occasions, on both of which ear length was increased in the crop when grown with a living mulch (Fig 7).

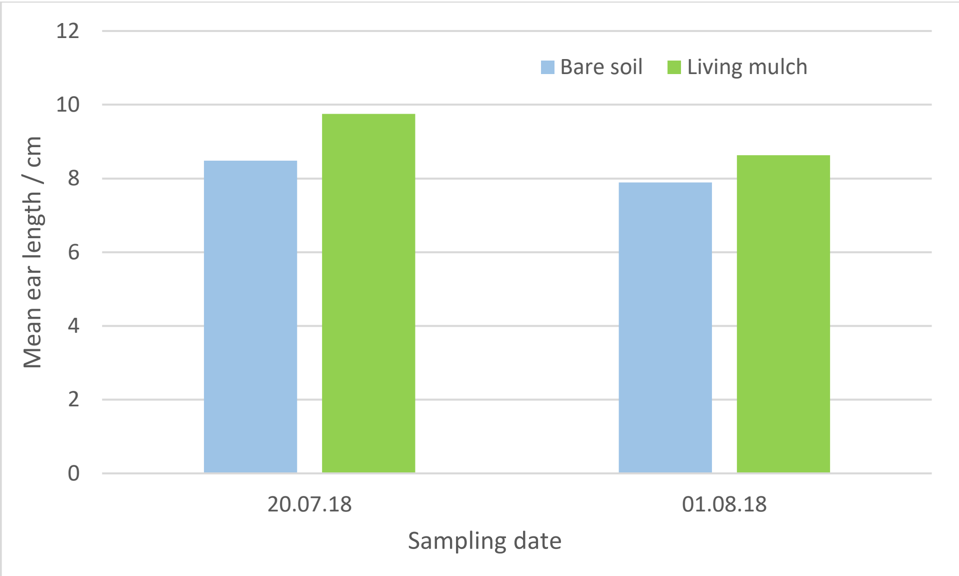

Figure 7. Mean ear length (cm) for winter wheat at Hessleskew (various dates).

Ear and tiller count

At both sites ear and tiller number were reduced under the living mulch treatment (Figs 8 and 9), this being far more pronounced at Hessleskew. As for other variables above, it is possible that the more advanced stage of the clover at Hessleskew, along with the dry year and varying input regime followed, led to increased and unexpectedly high levels of inter-specific competition between clover and crop at this site *vs* STC.

Figure 8. Mean ear and tiller number for spring barley at STC, as assessed on the 17.08.18.

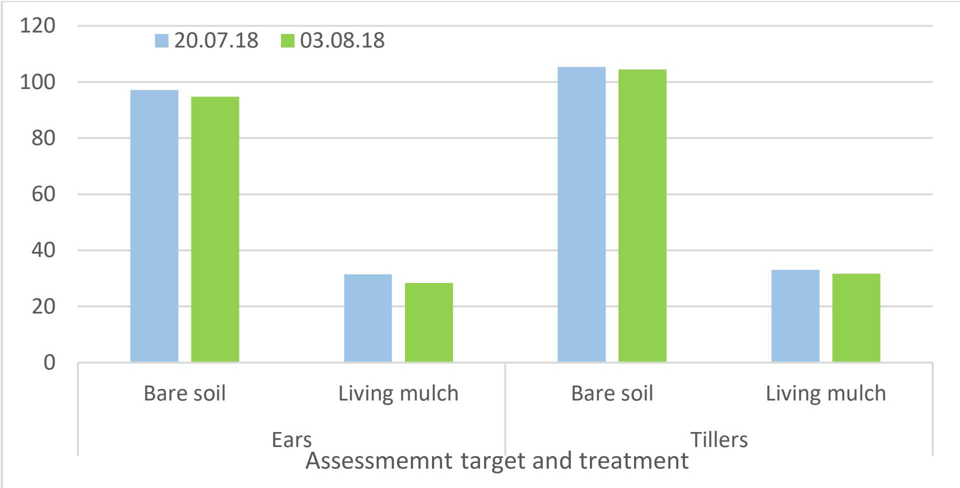

Figure 9. Mean ear and tiller number for winter wheat at Hesseskew (various dates).

Harvest biomass

Fresh weights of both ears and straw were taken at the two farm sites at point of harvest (01.08.18 Manterra; 17.08.18 STC) (Fig 10). For STC, where clover was less mature but beginning to develop by this time, increased crop biomass was recorded under the living mulch treatments, particularly for straw. However, the opposite was true at Hessleskew, with a steep reduction in crop biomass observed for ears and a less significant reduction seen for straw. As mentioned above, in an extremely dry year it is possible that excessive competition with clover at Hessleskew, coupled with varying inputs – especially for N, gave rise to this result. The earlier sowing of the crop could have also played a role, allowing for clover to close-in around the young crop ahead of the crop being able to grow away (particularly with the mild winter of 2017/18). If these results were to be repeated, this might support use of living mulches in fast-developing spring crops, but caution against use in winter-sown crops. Cropping at Hessleskew in 2019 will be to spring barley in order to try to demonstrate improved performance of spring cropping under living mulches on site, though work on a separate H2020 project at STC will look to investigate whether late-sown winter wheat in 2019 will compare more favourably to autumn sown winter wheat under living mulch production.

Figure 10. Mean crop biomass for spring barley at STC and for winter wheat at Hessleskew.

FAUNA

Worm counts

Worm counts were only made at STC in 2018, on the 12th June 2018. Counts were relatively low and found an average of 1.65 worms per sample in the living mulch plots *vs* twice as many in the bare soil plots. This early in the season differences between treatments in worm counts were not expected (as worms would not have time to respond to treatment by this time), with this representing baseline data for comparison against in future years.

Visual transect

Visual transects were walked across the season at both sites (5 times at STC, 3 at Hessleskew) and the numbers of individuals belonging to key insect groups observed, with counts corrected for sampling effort before comparing total figures. At STC (Fig 11) there was little difference in bumblebee and butterfly/moth visitation between treatments, though as clover had yet to fully establish in 2018 this was not unexpected and will be compared against future transects in 2019 when clover cover / flowering will have increased. Interestingly, numbers of hoverflies and ladybirds appeared higher in bare soil plots at STC. Reasons for this remain unknown, though a potential edge effect could explain this pattern (particularly if repeated in future years).

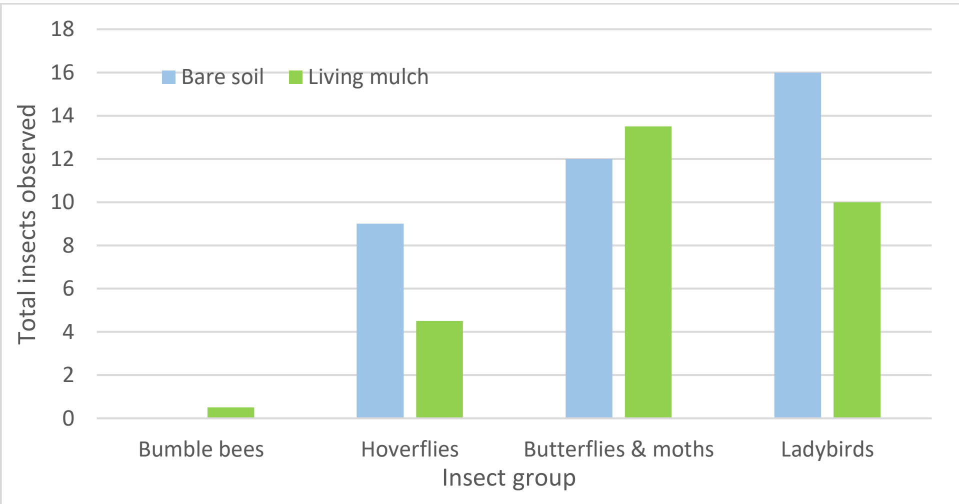

Figure 11. Total insects observed from four key groups across five transect walks at STC (various dates).

Fewer insects were observed at Hessleskew throughout the season (Fig 12), though this was not surprising given that STC is a generally more biodiverse site. The one exception was for bumblebees, where at Hessleskew far more of these key pollinators were observed and there was a clear pattern for increased bee visitation in the living mulch plots *vs* the clover plots. This likely reflects the fact that clover at Hessleskew was fully developed in 2018, and thus provided not only good ground cover (see above), but also good provision of floral resources (with clover being a preferred species for bumble bee foraging). Floral provision was assessed at Hessleskew on three dates in July/August 2018, finding that on each occasion between 5 and 8 flowers were present on average in a 0.25m² quadrat. Scaled-up this equates to a significant bee foraging resource of between 200,000 and 320,000 flowers per ha.

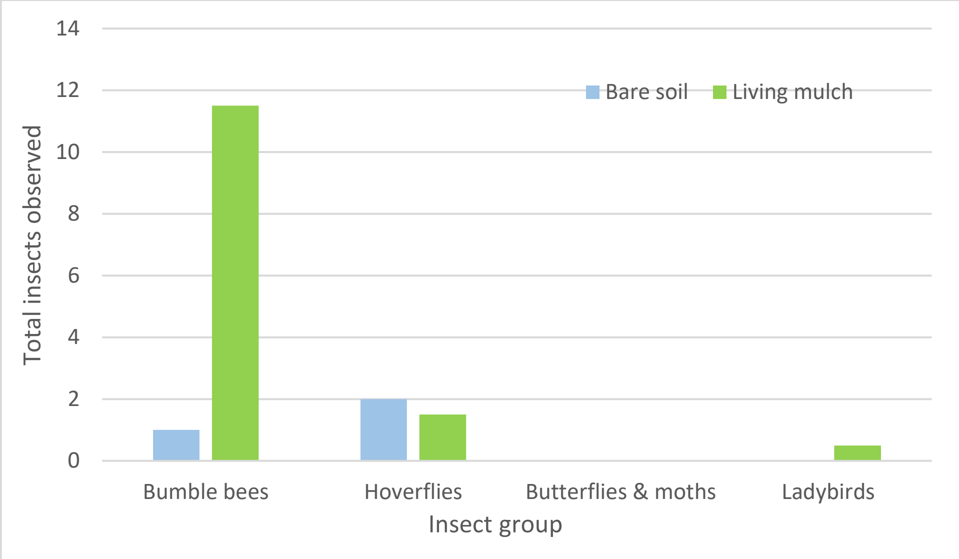

Figure 12. Total insects observed from four key groups across three transect walks at Hessleskew (various dates).

Slugs and Carabids

Slug and carabid counts were undertaken at STC throughout the 2018 season (Fig 13). As a probable result of dry weather, slug counts remained low throughout the sampling period. However, following heavy rainfall in mid-Aug increased trap catches were recovered from living mulch plots, supporting that slugs may pose increased risk under living mulches in much the same way that they pose a threat where cover crops are used. Given the potential significance of this pest, particularly in light of the recent metaldehyde withdrawal, slugs will continue to be monitored in future years. Carabids (a potential predator of slugs) were not observed in 2018, though this not unexpected given that, a). carabids are only monitored here via their occurrence in slug traps (which is not the optimal means to assess their populations), b). low slugs counts support that carabid prey numbers were low, and c). it could be expected that carabids would take longer than slugs to respond to living mulches in terms of population build-up.

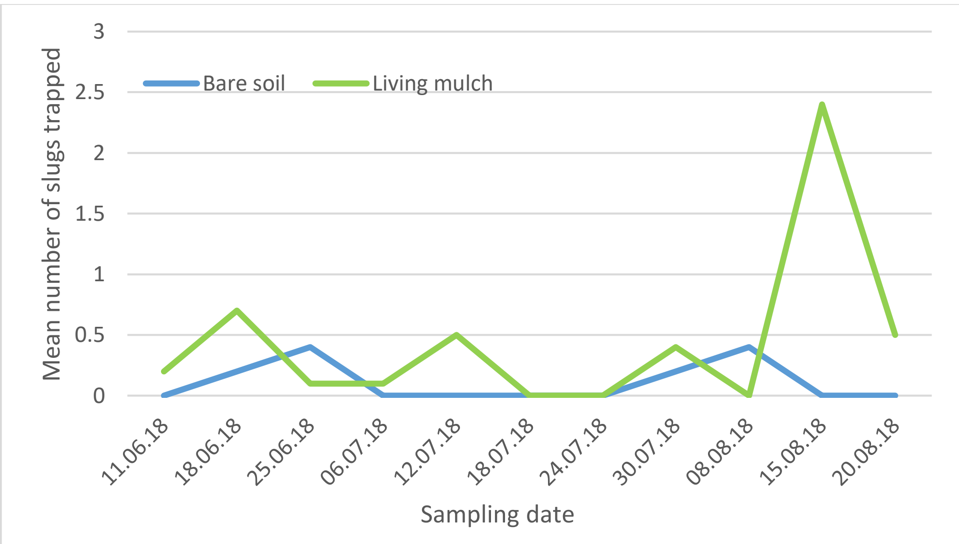

Figure 13. Mean total slugs trapped at STC (various dates).

Insect Quadrat

At Hessleskew only spiders were observed in any numbers during insect quadrat sampling on the 31st August 2018, with an average of 0.8 spiders per quadrat observed in the living mulch, over no spiders at all in the bare soil plots. Though this figure in itself appears low, this equates to over 30,000 spiders per ha in the living mulch treatment, *vs* none in the bare soil treatment.

Avian count

Casual observations of the living mulch plot at Hessleskew had suggested that more birds may have been visiting this *vs* the bare soil plot. A bird count was undertaken on the 31st August 2018 and found 9 corn buntings visiting living mulch plots (in a 15 minute assessment window) *vs* none visiting bare soil plots. An avian count was only made at Hessleskew in 2018, though will be repeated at both sites in 2019.

Pest & disease incidence and severity

Pest and disease assessments were made at STC on multiple (4 and 3, respectively) occasions throughout 2018, though data have yet to be fully processed to produce indices from raw figures on incidence and severity. Given that clover did not begin to establish until late in the season, it is unlikely that differences between treatments will be seen in this data, though it will serve as a useful baseline for comparison in future years.

ABIOTICS

Soil moisture

Soil moisture at STC across the season varied little between bare soil and clover treatments (Fig 14), especially early in the year, though this was not surprising given that clover did not begin to establish until later into the summer. Soil moisture was also typically low in what was a notable dry year (with it being impossible to assess soil moisture on site during the height of the summer due to the ground being too hard for the moisture probe to be inserted), though peaked following heavy rainfall on the 14th August 2018 (12.5 mm). On this sampling date reduced moisture levels under the living mulch treatment were apparent. By this date clover coverage was approaching 10%, potentially supporting that clover coverage, even at this relatively low level, might help to dissipate heavy rainfall and thus increase soil workability during periods of wetter weather. The ability of higher levels of clover cover to potentially exert an even clearer effect on soil moisture levels will be assessed in future years, when (likely) increased rainfall should help to discern differences between treatments.

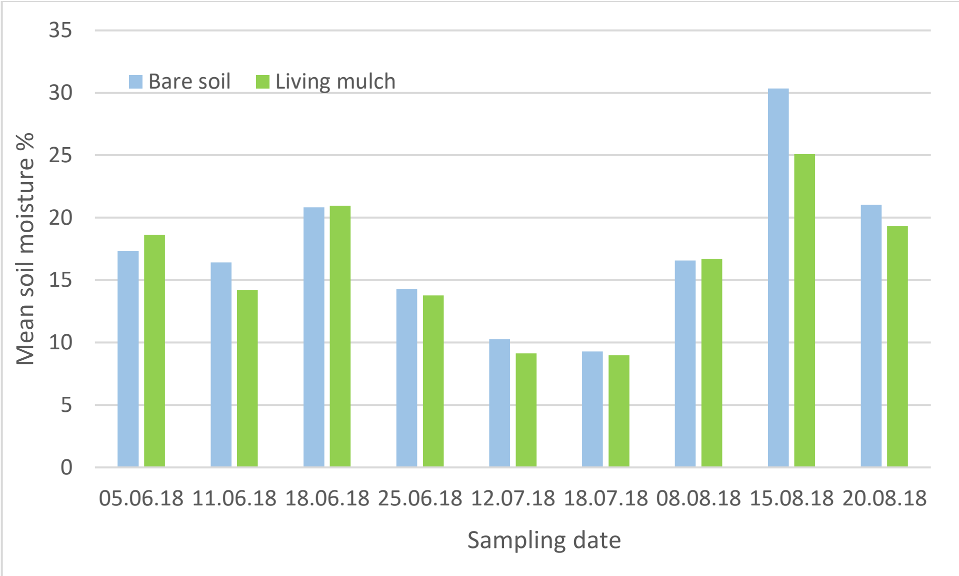

Figure 14. Mean soil moisture (%) at STC (various dates).

At Hessleskew, soil moisture was only assessed on the 20th July 2018, following a period of more than a month with very little (if any) precipitation. Soil moisture was understandably low at this time, though apparently increased under the living mulch treatment, potentially supporting that mature clover mulches are able to help soils retain moisture under very dry conditions, either through improved OM content or some other factor (e.g. microclimate creation).

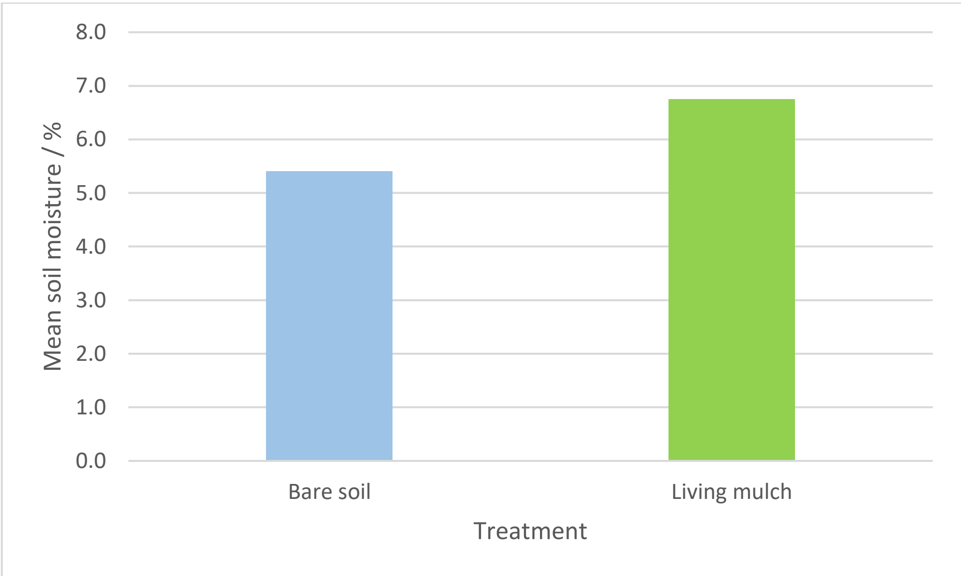

Figure 15. Mean soil moisture (%) at Hessleskew, assessed on the 20.07.18.

Soil analysis

Soil mineral nitrogen

Soil ammonium and nitrate were assessed early in the 2018 growing season at both sites (Fig 16). There appeared to be little difference between treatment areas at STC in either variable, though this was to be anticipated based on clover having only just been sown and N being applied evenly to both plots. At Hessleskew, greater differences were apparent, with both ammonium and nitrate increased in the bare soil treatment. This was not unexpected, however, as the two plots were managed independently in terms of N application (i.e. with the bare soil treatment receiving standard artificial N application, and the living mulch treatment not). Application of artificial N to the bare soil treatment could also help to explain earlier results for leaf chlorophyll and leaf N at Hessleskew, particularly in a year that may have biased any overall interaction between the crop and clover away from 'facilitation' and more towards 'competition' (again, see earlier).

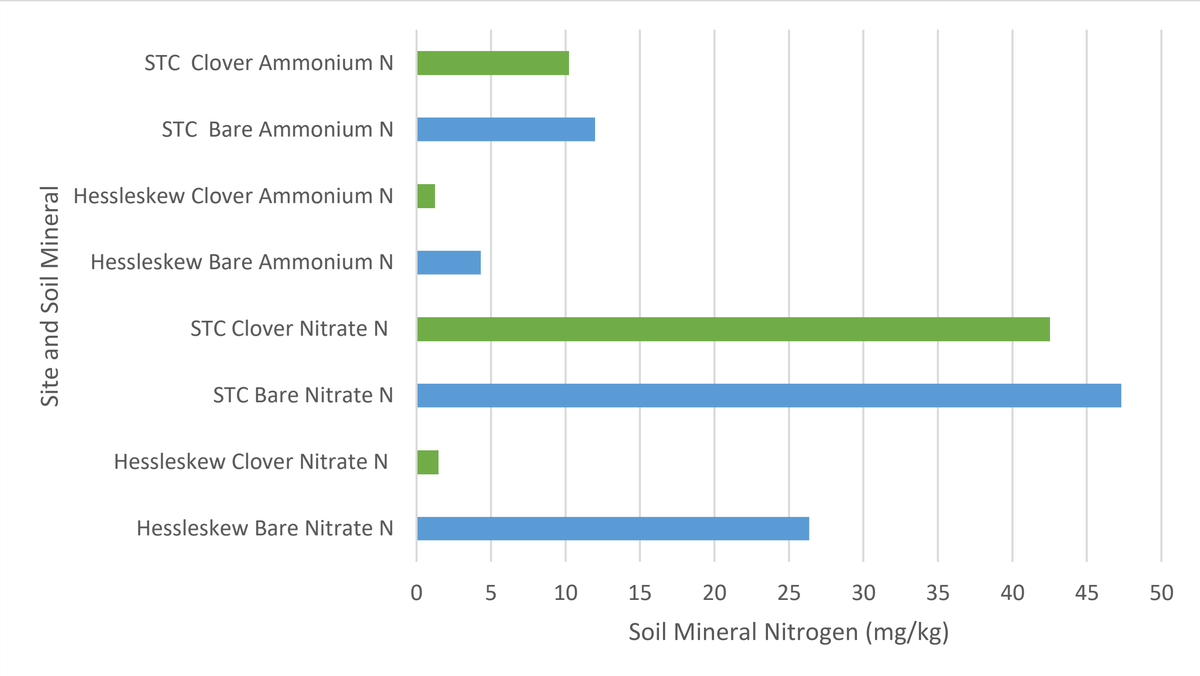

Figure 16. Mean soil Mineral Nitrogen (mg/kg) at STC and Hessleskew Farm, as assessed on the 11.06.18 at STC and the 14.06.18 at Hessleskew.

Soil Health and Soil Organic Matter (%)

Encouragingly, soil health scores, as assessed at the end of the 2018 season, were higher at both sites where crops had been grown in clover living mulches (Fig 17). Absolute differences were slightly higher at Hessleskew (+0.6 on average) than STC (+0.5), though this could have been expected based on the longer presence of the clover living mulch here.

Soil Organic Matter at STC was similar across the two treatments (Fig 17), varying by only 0.3% on average, though this was not unexpected given that clover had yet to fully establish and be mown. Where clover had been pre-established in 2016/17 at Hessleskew, OM content of the soil appeared to have increased (from 3.7% to 5.0% on average), though data in future years should confirm if this is the case (i.e. by comparing to past OM content in the clover on the same plot).

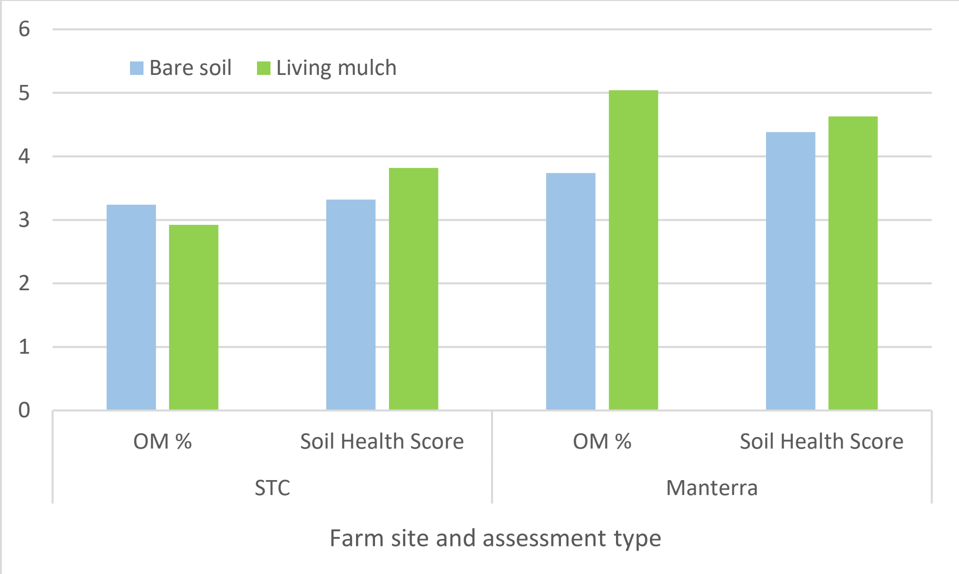

Figure 17. Mean Soil Health Score Organic Matter % at STC and Hessleskew Farm, as assessed on the 05.09.18.

<u>Soil compaction</u>

Soil compaction at STC could only be reliably measured on the 8th June 2018, due to very dry conditions preventing assessment on later dates (i.e. the compaction probe could not be inserted into the soil without damage). This data was somewhat variable depending on depth (Fig 18), but nevertheless provides a baseline assessment for comparison against in future years.

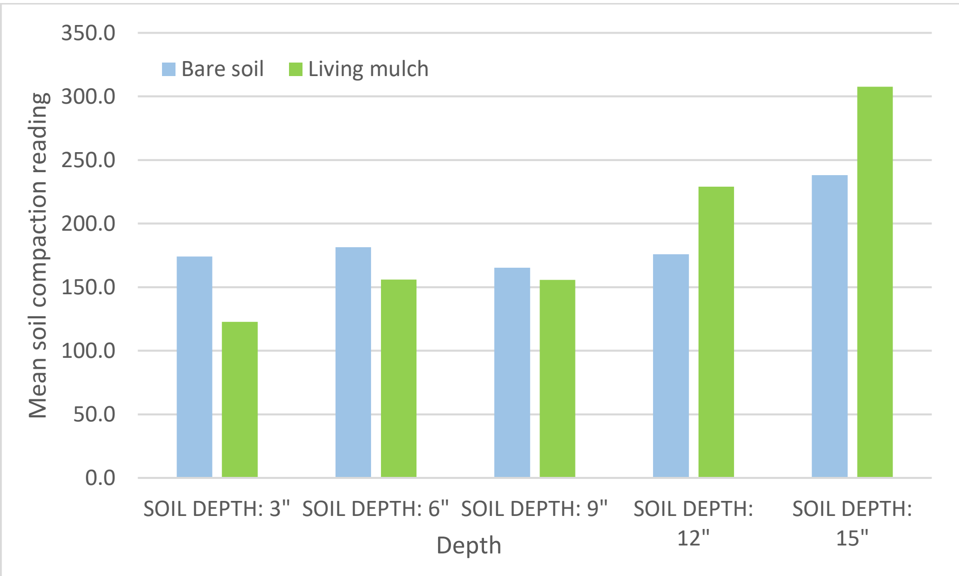

Figure 18. Mean Soil compaction readings at varying depths at STC, as assessed on the 08.06.18.

Conclusions

STC

Clover establishment at STC was slow during 2018, as a likely result of notably dry conditions prevailing throughout the summer period. Nevertheless, clover had begun to establish by the end of the season, with early 2019 assessments supporting good clover cover with no need to re-sow the living mulch for 2019. This same pattern of establishment has been observed previously at Hessleskew with autumn sown crops and supports that crop and clover can be effectively established in both spring and winter crops in a single pass operation with appropriate machinery. This also suggests, however, that if following this approach only low levels of clover cover are likely to be attained in the first season, particularly if weather conditions are sub-optimal for establishment.

Given the slow establishment of clover, it was not unexpected that few differences would be observed between bare soil and living mulch treatments at STC in 2018, where for most variables recorded 2018 data represent a 'baseline' against which future measurements will be compared. Nevertheless, for selected later season data benefits appeared to be emerging within the living mulch plot, particularly in terms of soil moisture management and, potentially, soil health. At the same time, however, possible negative effects of living mulches were also highlighted at this time – e.g. for slug risk and biomass.

Hessleskew

At Hessleskew the potential risk of living mulches to crop biomass was more pronounced, though 2018 results may have been exacerbated by weather conditions from the winter of 2017/18 and the spring/summer of 2018, which could have been expected to drive more pronounced inter-specific competition between the crop and clover than would be expected in a more 'normal' year. Absence of applied N would have also impacted crop performance *vs* the conventional plot, particularly in a 'high-stress' year for crop growth *per se*, though it deserves note that crops still yielded in clover plots under a zero input regime, potentially deriving natural N inputs from the clover. Although improved biomass etc. could have been expected had N been applied to the living mulch plot, a potential risk of living mulches to winter crops has been suggested here, and results may support that this approach is better suited to spring cropping where crops are able to advance faster post-sowing to establish themselves more firmly before clover is able to 'close-in' around them. Spring crops will be sown at Hessleskew in 2019 in the hope that crop biomass results will be more positive, though the possibility of improving results in winter cereals through late sowing and N provision will be investigated as part of a separate project at STC.

Data collected on the environmental gains of living mulches at Hessleskew were more positive than those collected on crop performance. The potential for living mulches to encourage pollinators and predators was particularly evident, with bumblebee visitation more than an order of magnitude higher where clover was present, and spiders only observed in living mulch plots. Results on soil condition and health were equally encouraging, with marked gains in soil organic matter, and smaller improvements in 'soil health', seemingly existing for production under living mulches at Hessleskew. Although the NRM soil health assessment scores do not allow further comment on which elements of 'soil health' might be being promoted here, further work is planned for 2019 that will hopefully allow comment on this in future years of the project.

KNOWLEDGE TRANSFER

WP2: Industry demonstration

An initial ‘Demonstration Event’ at STC was planned to take place early in the project (by the 31st March 2018), but was delayed, now being scheduled to run in June 2019. The event was initially delayed due to the start date of the project being put back until the 6th March 2018, leaving insufficient time to organise a large event for the end of March, at which time the event was rescheduled for November 2018. However, following a difficult year for clover establishment under very dry conditions post-sowing, it was felt that it would be beneficial to postpone this event until the following June, by which time it was hoped that the clover should be better established (this now being confirmed as being the case).

Over the course of the reporting period it was also confirmed that the project would feature at LAMMA 2019, using project resources to part-fund an exhibition stands under Milestone 2.3. Planning for this activity took place during the reporting period, though the event itself, which ran in January 2019, will be reported on in the next Scientific Report.

WP4: Peer-to-Peer Exchange

Over the course of the reporting period the project was featured at the following on-farm events for peer-to-peer exchange.

Event*	Location	Date(s)	Audience	No. engaged
Anderson’s Agri-Consultants Event (Pr/Pl)	STC	14.03.18	Agronomists; Farmers; Policy;	25
Manterra Open Days 2018 (Pl)	Hessleskew Farm	29-31.05.18	Farmers	100
ARUP/Yorkshire Water Meeting (Pr/Pl)	STC	05.06.18	Agronomists; Farmers; Policy;	5
Bayer Open Day (Pr)	STC	07.06.18	Agronomists; Farmers;	100
Procam Open Day (Pr)	STC	08.06.18	Agronomists; Farmers;	70
CIH Conference (Pr/Pl)	STC	16.06.18	Growers	25
NFU Open Day (Pr)	STC	21.06.18	Agronomists; Farmers; Policy;	20
Cockrill’s Open Day (Ex/Pr)	STC	02.08.18	Agronomists; Farmers;	40
Delegation of Argentine Farmers Meeting	STC	20.08.18	Farmers; Academia	5
AHDB Senior Staff Visit (Pr)	STC	05.09.18	Policy	2
KTN Masterclass (Pr/Pl)	STC	11.09.18	SMEs	60
CHAP Open Day (Ex/Pr/Pl)	STC	12.10.18	Agronomists; Farmers; Policy; Academia; Press	70
HortScience Live (Ex/Pr/Pl)	STC	17.10.18	Agronomists; Farmers	80
Press Visit by YP (Pr/Pl)	STC	20.11.18	Press	1

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

The project was also included at the following off-site events, making use of marketing material produced during the reporting period, including a project leaflet (draft), flier/poster/signage and 'mini strip-till tractor' (see Appendix 3).

Event*	**Location**	**Date(s)**	**Audience**	**No. engaged**
Northumberland Show (Ex)	Northumberland	28.05.18	Public; Farmer	50
Great Yorkshire Show (Ex)	Yorkshire Showground	10-12.07.18	Public; Farmers	150
Bert's Barrow Farmer Day (Ex)	Bert's Barrow, Yorkshire	12.08.18	Public	50
FDF Agronomists Meeting (Pr)	Fera, Sand Hutton, Yorkshire	21.08.18	Agronomists	25
BASF/CHAP Agronomists day (Pr)	Fera, Sand Hutton, Yorkshire	03.10.18	Agronomists	25
Countryside Live (Ex)	Yorkshire Showground	20-21.10.18	Public	100
YFFRN Defining a Future for Yorkshire Farming conference (Ex/Pr)	Fera, Sand Hutton, Yorkshire	15.11.18	Agronomists; Farmers; Policy; Academia; Press	150
Harper Adams Invited Lecture (Pr)	Harper Adams University	29.11.18	Academia	20

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

Finally, the project has been covered on a regular basis in the Yorkshire Post, both as part of STC's regular column and independently by Chris Berry ('Putting heart into saving our soil' - published on the 1st December 2018). STC's broader work on clover mulches was also published in the journal Food Science and Technology (Vol. 32: pp. 32-35), though without specific named reference to the current project.

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	P
	1.4 Annual Final Meeting Yr3	-	14.12.20	-	14.12.20	P
	1.5 Ongoing planning meetings (all yrs 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	-	Delayed to 31.06.19 to ensure good platform establishment after a. later than planned start, and b. poor year for establishment due to drought	D
	2.2 End of project conference Yr3 (winter barley)	-	31.03.20	-	31.03.20	P
	2.3 Presence at external industry event (x1)	01.03.18	31.03.20	01.03.18	31.03.20	CP
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	P
	3.3 Commercial validation Yr3	31.03.20	30.09.20	31.03.20	30.09.20	P
	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	P
	4.3 Yr3 peer-to-peer on-farm workshop (x3)	31.03.20	30.09.20	31.03.20	30.09.20	P
WP5: Reporting and Publication	5.1 Yr1 Report	-	31.12.18	-	Delayed to 31.01.19 due to staff changes at STC	D
	5.2 Yr2 Report	-	31.12.19	-	31.12.19	P
	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	P

*C=Complete; O=Ongoing; P=Planned; D=Delayed; X=Cancelled. Dark green=achieved as planned; Light green=achieved despite delay; Orange=not achieved

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APPENDIX

Appendix 1. Details of assessment methodologies used

Assessment	Materials	Method
Emergence count.	Quadrat.	Place the quadrat at random near the sample plot, count the number of emerged plants and input the data.
Growth stage.	BBCH- Growth stage Guide.	Look at 5 – 10 random plants at a sample point, use the BBCH- Growth Stage Guide to assess the average growth stage of the crop.
Ground cover biomass (weed/clover).	Quadrat, crop scissors, sample bags, balance (accurate to two decimal places), foil trays and a drying oven.	Place the quadrat at random near the sample plot, use the crop scissors to harvest any weeds. Once harvested place in to a sample bag, after collecting all the samples use a balance to give the biomass. Empty contents into foil trays, place into drying oven for 24 hours and then reweigh each sample.
Ground cover (Weed/clover cover %).	Quadrat and camera.	Place the quadrat at random, take an over view picture of the quadrat and estimate the percentage cover.
Atleaf chlorophyll measurement.	Atleaf reader.	At random select a leaf on the crop and use the atleaf chlorophyll reader. Repeat these 5 times per plot.
Canopy height.	Meter ruler and 1-meter cane.	Use the cane to indicate where the top of the canopy is, then measure the height with the meter ruler.
Habit/Lodging.	Quadrat.	Place the quadrat at random and estimate the percentage of the crop that has lodged.
Slug and carabid count.	Plant pot saucers, bricks, bucket, trowel and chicken feed	Place some chicken feed on the ground near a sample point, place the plant pot saucer upside down over the feed. Use the trowel to create a channel for the slugs to enter and place a brick on top. Collect data weekly and move/replace feed when necessary.
Worm count.	Spade and two trays.	Dig a hole half a foot by half a foot and a foot deep, place onto tray. Go through the removed soil and count the number of worms. Replace all the worms and soil back into the hole and reconsolidate the soil.
Leaf sample.	Quadrat, crop scissors and sample bags.	Place the quadrat at random near the sample plot, use the crop scissors to harvest the sample. Place into sample bags, return to the field lab and prepare the samples to be sent to NRM for analysis.
Soil moisture and temperature.	Delta-T soil moisture, temperature and EC probe.	Insert the Delta-T soil probe at each sample point, input the temperature and moisture on a data sheet.

Soil Nitrogen (N) / soil health.	Trowel, NRM sample boxes.	Collect soil from selected data points, ensure enough soil is collected to completely fill the NRM sample box.
Avian and Mammal assessment.	Binoculars, bird book (if needed)	While slowly walking between plots, look around for any avian or mammalian animals.
Insect quadrat.	Quadrat	Place the quadrat at random near the sample point, then count the number of insects visible in the quadrat, write them in to the correct order e.g. Diptera, Hymenoptera. This can be taken future to family or genus even species.
Harvest assessment (fresh weight ears and straw, dry weight ears and straw, No. of ears, straw height).	Quadrat, crop scissors and sample bags. Balance and drying oven.	At each data point the quadrat will be placed randomly, use the crop scissors to harvest the contents of the quadrat. Once harvested place each sample in to a bag, after collecting all the samples return to the field lab. Remove all the ears and count them, then measure the length of ten random straws. After this use a balance to obtain the weight of all the straws and ears. Place the straw and ears separately into foil trays, place into drying oven for 24 hours and then reweigh each sample and repeat the process a final time.

Appendix 2. Crop diary

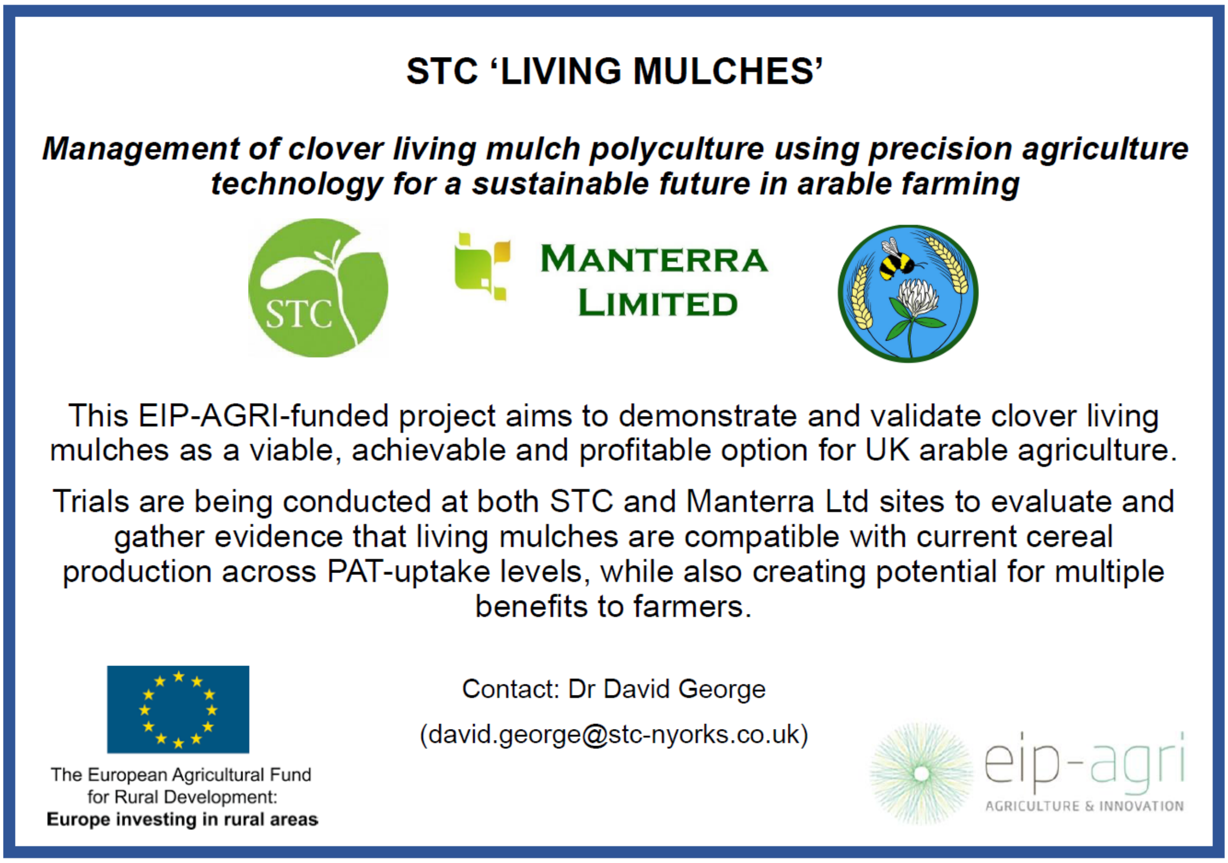
Data collected / activity	Site:	Date
Sampling points marked out and GPS taken.	**Manterra**	08.06.18
Soil samples taken (x15 nitrogen).	**Manterra**	11.06.18
Leaf sampling NRM – plant foliar suite x 10 samples Data collection: disease assessment and severity. Data collection: canopy height, AtLeaf, germination,	**Manterra**	03.07.18
Data collected: tiller number, ear number, internode length, canopy temp, ear disease, weeds %, clover %, no. of clover flowers, ear length, soil moisture, soil temperature, insect visual and transect.	**Manterra**	20.07.2018
Data collected: tiller number, ear number, internode length, canopy temp, ear disease, weeds %, clover %, no. of clover flowers, ear length, insect visual and transect. Harvest samples taken.	**Manterra**	01.08.18
Harvest samples processed. Data collected; Fresh and dry weight of straw and ears, ear numbers, straw diameter and straw height.	**Manterra**	02.08.18- 09.08.18
Soil samples taken (x15 soil health).	**Manterra**	22.08.18
Data collected: Weed cover%, clover cover%, clover flower no., clover growth stage, pictures taken (overview/each plot), soil/clover temperature, insect visual transect, insect invertebrate and avian/mammal assessment. Photographs taken.	**Manterra**	31.08.18
Drilled platform – spring barley (‘Propino’, 180kg/ha); white clover (‘Aberpearl’, 10kg/ha). Total area 3.1ha made up of 2.65 ha planted clover/barley and the remainder of 0.47ha sown with barley only.	**STC**	17-18.05.18

Platform rolled.	**STC**	18.05.18
Sampling points marked out and GPS taken.	**STC**	23.5.18
220kg/ha Nitram applied across whole field area (equal to 80 kg/ha N)	**STC**	27.5.18
'No clover' sampling points moved to capture more crop emergence (moved closer to the clover plot and shortened). New GPS taken. Crop emergence recorded with a $0.25m^2$ quadrat (1x per/sampling point) (BBCH 12).	**STC**	01.6.18
Slug traps set out.	**STC**	04.06.2018
Data collected: Soil moisture, soil temperature.	**STC**	05.06.2018
Soil samples taken (x15 nitrogen) at STC field Data collected: growth stage (on data sheet from 5/6/18).	**STC**	06.06.18
Data collected: soil compaction tests (PSI).	**STC**	08.06.18
Data collected: slugs, carabids, temperature, moisture and BBCH growth stage.	**STC**	11.06.18
Data collected: worm count and weed cover %.	**STC**	12.06.2018
Data collected: slugs, carabids, temperature, moisture and BBCH growth stage.	**STC**	18.06.2018
Data collected: AtLeaf	**STC**	19.06.2018
Fungicides applied to whole plot. Cello @ 0.75L/ha. Amistar Opti @ 0.5L/ha. Water rate 200L/ha.	**STC**	19.06.2018
Data collected: invertebrate assessment.	**STC**	21.06.2018
Data collected: visual transect.	**STC**	22.06.2018
Data collected: slugs, carabids, temperature, moisture and BBCH growth stage.	**STC**	25.06.2018
Data collected: disease incidence and severity.	**STC**	26.06.2018
Leaf sampling NRM – plant foliar suite (STC) x 10 samples	**STC**	02.07.18
Data collected: slugs, carabids, temperature, moisture and BBCH growth stage.	**STC**	06.07.2018
Data collected: slugs, carabids, temperature, moisture and BBCH growth stage.	**STC**	12.07.2018
Data collected: slugs, carabids, temperature, moisture and BBCH growth stage.	**STC**	18.07.2018
Leaf sampling NRM - plant foliar suite (STC) x 10 samples	**STC**	18.07.18
Data collected: invertebrate assessment.	**STC**	19.07.2018
Data collected: AtLeaf and visual transect.	**STC**	20.07.2018
Data collected: slugs carabids, growth stage.	**STC**	24.07.2018
Data collected: temperature, moisture and disease incidence and severity.	**STC**	25.07.2018
Data collected: slugs, carabids, growth stage, invertebrate assessment and visual transect. Data collected: canopy height, plant length and internodes.	**STC**	30.07.2018
Data collected: weed and clover %age cover, fresh biomass weight.	**STC**	07.08.2018
Data collected: slugs, carabids, soil temperature and moisture, BBCH growth stage.	**STC**	08.08.2018
Data collected: disease incidence and severity, invertebrate assessment and visual transect.	**STC**	14.08.2018
Data collected: slugs, carabids, soil temperature and moisture, BBCH growth stage, growth habit, canopy height, lodging.	**STC**	15.08.2018

Harvest assessments: samples collected from each plot and data taken. Plant length, internodes, straw width, ears and tillers per plant, net weight of straw and ears, samples of each plot straw and ears.	**STC**	17.08.2018
Data collected: slugs, carabids, soil temperature and moisture, BBCH growth stage.	**STC**	20.08.2018
Harvest assessments: dry weights recorded for ground cover and first weighing of straw and ear samples from assessment on 17.08.18.	**STC**	22.08.2018
Soil samples taken (x15 soil health) at STC's field.	**STC**	23.08.18
Data collected: dry biomass weight.	**STC**	23.08.2018
Harvest assessments: final dry weight of samples collected 17.08.18.	**STC**	30.08.2018
Data collected: visual transect, clover and weed %age cover. GPS points taken.	**STC**	04.09.2018
Data collected: soil compaction.	**STC**	05.09.2018

Appendix 3. Marketing material

Project signage



Project leaflet (draft)

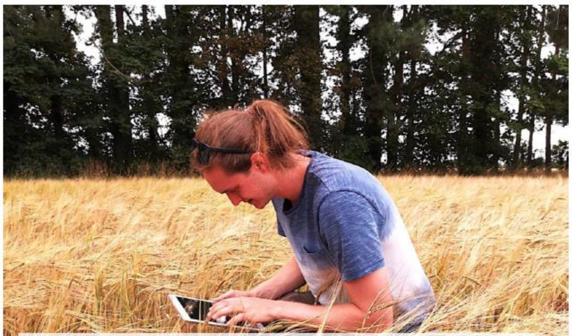
RPA:

MANAGEMENT AND PRODUCTION OF POLYCULTURE SYSTEMS USING ADVANCE PRECISION ASSISTED TECHNOLOGY FOR A SUSTAINABLE FUTURE IN ARABLE FARMING.

STC

Stockbridge Technology Centre

Leaders in Technology Transfer to Agriculture and Horticulture



HIGH QUALITY PRODUCE BASED ON SUSTAINABILITY CREDENTIALS IS BECOMING A KEY INITIATIVE IN MODERN DAY FARMING IN AN EVER-GROWING POPULATION. IN ORDER TO KEEP UP WITH SUPPLY AND DEMAND WHILE REDUCING ENVIRONMENTAL IMPACTS WE MUST EVOLVE FROM INVASIVE FARMING METHODS TO NEW SUSTAINABLE PRACTICES WHERE THERE IS POTENTIAL TO IMPROVE AND INCREASE YIELD WHILE SAFEGUARDING OUR SOILS.

STC

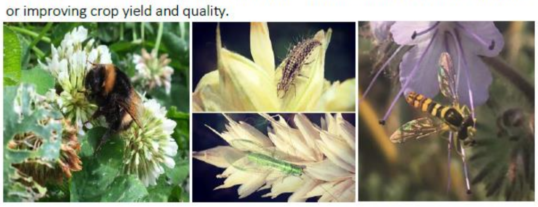
MANTERRA LIMITED

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

eip-agri
AGRICULTURE & INNOVATION

THE CHALLENGE

The need to produce food and reduce the impact of farming on the environment is a universally recognised issue. Living mulches have significant potential as a sustainable means of arable production; creating a natural ecosystem of ground cover which supresses weeds and lowers soil erosion whilst improving water holding capacity and increasing beneficial predatory insect diversity. Leguminous living mulches, such as clover used in this research, aid soil fertility by making atmospheric nitrogen available to crops. The research carried out at STC will give growers confidence to manage polyculture systems using precision agricultural technologies (PAT) so that sustainable practices can be adopted while maintaining or improving crop yield and quality.



THE OPPORTUNITY

RPA is primarily overseen by STC who are working in collaboration with Manterra Ltd. The three year project focuses on spring barley and clover; where precision assisted sowing techniques to strip/band till will be implemented to confirm the valuable benefits of these polyculture systems in modern day farming. The research will be carried out at STC and Hessleskew Farm (Manterra Ltd) and will be supported by pre-existing living mulch platforms which includes a range of arable crops and under-sown crops into permanent ground cover.

THE SOLUTION

Technological advances in drilling mean that living mulch strategies are becoming more compatible in arable production. The Swiss made Baertschi Oekosem ROTOR Strip Tiller (imported by Manterra Ltd) overcomes past restrictions as it can under sow directly into permanent ground cover and also be used in multi-crop drilling; such as strip tillage where the arable crop and clover are sown simultaneously in a single machinery pass. This research will validate that living mulches along with GPS guided strip tilling/band sowing techniques can be beneficial both sustainably and for profitability.

Project ‘mini-tractor’ (pictured in use at ‘Hort Science Live’ 2018)