Living Mulches

Final report

2020-2022

Author: Henny Lowth (Organic Research Centre)

Summary

Take home messages

- The Living mulches practice can provide excellent soil health benefits and an opportunity to reduce artificial inputs
- There is still work required to perfect the system and reduce the current yield penalty
- The system can be adopted both organically and non-organically

Context

Two key services that need to be delivered for agricultural systems to function productively are weed control and nitrogen supply. Non-organic systems rely heavily on costly herbicides and artificial fertiliser, whilst organic systems need an effective alternative to chemical inputs and a way to reduce tillage. With environmental sustainability in agriculture under increasing scrutiny, there is a drive for finding alternative options to the current systems. The use of (semi) permanent clover groundcover, also known as a living mulch, may provide an opportunity to provide key agricultural services and remedy some of the current environmental concerns.

Trial design

The trial design has a living mulch and control strip present within the same trial field. The trial mix is a 70:30 combination of small leaf and medium leaf clover. The trials so far have tested winter oats and rye as cash crops in the living mulch. Assessments were carried out across the growing season to determine the field performance of the cereal in the mulch and then yield and quality data was collected at harvest. Soil samples were also taken in the Autumn.

Findings

Results so far have found an average yield penalty of 30% in the living mulch compared to the control. There is also a move towards more aggressive perennial weeds in the living mulch as well as more grasses compared to broadleaved weeds. However, with increased clover cover in the second trial year, overall weed cover was reduced in the living mulch system. There are also several soil health benefits in the living mulch system, with significantly increased available nitrogen and earthworm counts and a trend for increased microbial activity and soil organic matter. There are several less easily quantified benefits to the system; reduced tillage, lengthening organic rotations, opportunity for reduced artificial inputs, and reduced leachates and run-off.

Recommendations & next steps

We are only beginning to scratch the surface of how to best implement the Living Mulches system. The soil health benefits have been well documented but fine-tuning the approach is still required to minimise the yield penalty. There are 5 key areas for further research to optimise the system: Mulch species & variety selection, Cash crop species & variety

selection, Mulch management and establishment date, Breeding of mulch and cash crop varieties for living mulch systems.

Useful resources

Hartwig, N., & Ammon, H. (2002). Cover crops and living mulches. Weed Science, 50(6), 688-699

Cougnon, M., Durand, JL., Julier, B. et al. (2022). Using perennial plant varieties for use as living mulch for winter cereals. A review. Agron. Sustain. Dev. 42, 110.

Welsh, J., Bulson, H., Stopes, C., Froud-Williams, R., & Murdoch, A. (2008). The critical weed-free period in organically-grown winter wheat. Annals of Applied Biology. 134. 315 - 320.

Carof, M., de Tourdonnet, S., Saulas, P. et al. (2007) Undersowing wheat with different living mulches in a no-till system. I. Yield analysis. Agron. Sustain. Dev. 27, 347–356

Farmer comment

Mark Lea – Green Acres Farm

“I’m delighted to be trialling the production of cereals direct drilled into clover living mulch understories here in our organic system. There are certainly challenges which we will continue to work to overcome, but we have already demonstrated that the benefits to soil health, carbon sequestration and biodiversity are huge.”

Main report

1 Field lab aims

- Determine the implications of living mulches on cash crop yield and weed composition
- Manage and refine the living mulch system to ensure maximum benefits and minimum yield penalties
- Maintain a group of stakeholders to ensure effective knowledge exchange and learning

2 Background

Two key services that need to be delivered for agricultural systems to function productively are weed control and nitrogen supply. Non-organic systems rely heavily on costly herbicides and artificial fertiliser. Whilst Organic systems need an effective alternative to chemical inputs and a way to reduce tillage. In organic systems, ploughing negatively effects carbon sequestration and disrupts soil microbiomes. Both systems experience soil fertility depletion during the rotation and there is a current lack of enhancing or protecting the soil. With cost of artificial inputs rising in recent years, and environmental sustainability in agriculture under increasing scrutiny, there is a real drive for finding alternative options to the current systems.

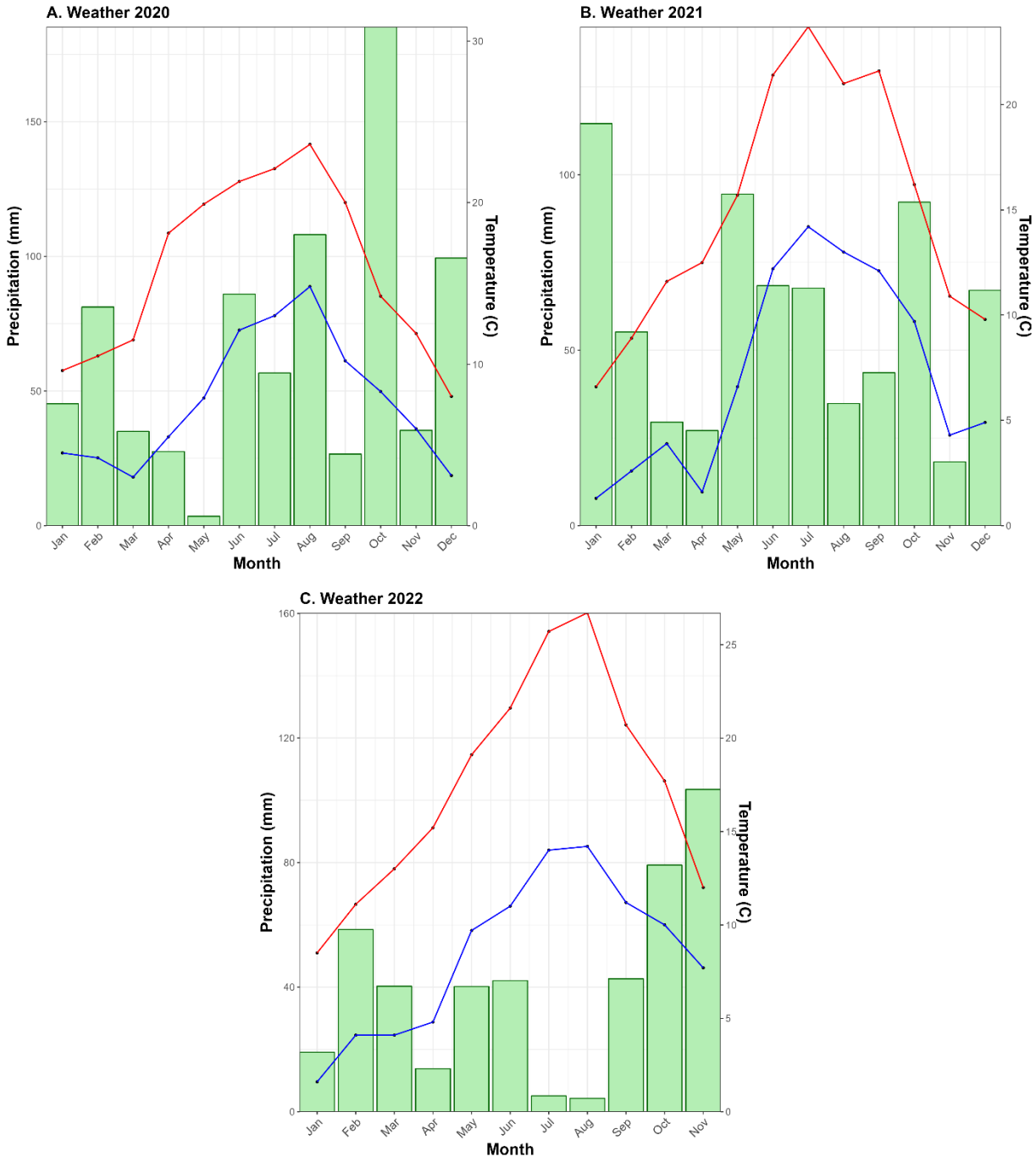
The use of (semi) permanent clover groundcover, also known as a living mulch, may provide an opportunity to provide key agricultural services and remedy some of the current environmental concerns. A Living Mulch is described as, “cover crops planted either before or with a main crop and maintained as a living ground cover throughout the growing season” (Hartwig & Ammon, 2002). In this Living mulch field lab, cash crops have been undersown with clover seed in the Spring and then a winter cereal has been direct drilled into the established clover the following growing season.

As a nitrogen-fixing crop, the clover can provide nitrogen accumulation to the cropping system. The above ground biomass can offer a degree of weed control and protect the soil from climate extremes, whilst also reducing run-off from leachates. The below ground biomass can feed soil microbes enhancing soil ecology and nutrient cycling. With increased weed control and nitrogen benefits, there is the opportunity for reduced tillage practices, by extending the rotation of organic systems and reducing the occurrence of ploughing. In the period between cereal harvest and the sowing of the next cereal crop, the living mulch also acts as a cover crop.

3 Methodology and data collection (up to 800 words)

This Innovative Farmers field lab has brought together many stakeholders; Cover crop technical experts (Cotswold seeds), agroecological researchers (ORC), farming advisors (AHDB, Innovative Farmers), and the trialist farmers. This field lab group consists of both organic and non-organic “regenerative” farmers.

Climate

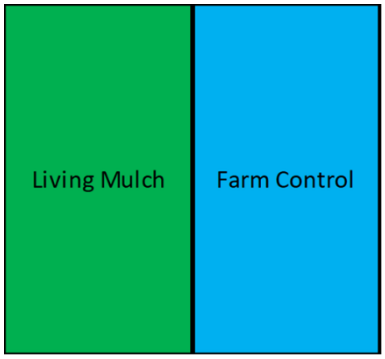


Figures A,B & C. Weather data from the 2020, 2021 & 2022 season. Data from MET office weather station in Oxford.

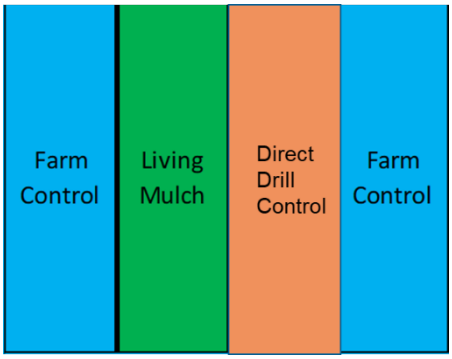
Spring 2020 was characterised by low rainfall and high temperatures (Figure A), which is the first year when clover establishment was attempted. Spring 2021 was characterised by cold weather, with a dry April and wet May (Figure B). Spring 2022 was characterised by record low rainfall followed by record high temperatures in the summer (Figure C).

Trial Layout

There were several proposed trial layouts for the mulch and control strip in the trial field, that optimised scientific robustness and ease of management (See annex A). The successful trials in 2021 and 2022 had the following layout:



Shifnal, Shropshire



Chipping Norton, Oxfordshire

Over the past three years there have been difficulties establishing the clover living mulch in the Spring due to the lack of rainfall, with several anticipated trials unable to contribute.

Trial Mix

The trial mix is a combination of wild small leafed white clover (*AberAce*) and Small/medium leaf white clover (*AberHerald*) in a 70:30 proportion, as recommended by Cotswold Seeds.

Trial Fields 2022

Table 1. Field management details from the 2022 trials that had established clover

Farm Location	Clover Establishment	Crop establishment	Clover Management	Notes
Oxfordshire	Spring 2020 undersown into spring barley	Spring Oats direct drilled in March 2022		Winter Oats direct drilled in Autumn 2020 and evaluated in 2021. Spring crop direct drilled into the maintained living mulch
Shropshire	Spring 2021 clover undersown into a spring wheat broadcast and rolled early May	Autumn 2021 direct-drilled Winter Oats with a Simtech	Grazed early Oct with sheep after drilling	Winter Oat and Rye trials to be monitored in 2023

Data Collection 2022

All assessments were carried out in July (GS65), apart from yield and quality data, which was taken at harvest in August and soil samples that were collected in October (2022) & November (2021) (Table 2).

Table 2. Crop and field assessments carried out in the 2022 growing season

Variable	How it was measured/recorded

Crop cover	Visual assessment of crop ground cover as a % averaged over ten measurements per treatment strip
Crop height	Average of ten measurements per treatment strip, measured in cm.
Crop Biomass – Vigour Score	Visual estimate of above ground crop biomass on a 1-9 scale using the vigour scoring system guide from ITAB (See annex B)
Clover cover	Visual assessment of clover ground cover as a % averaged over ten measurements per treatment strip
Total Weed cover	Visual assessment of weed ground cover as a % averaged over ten measurements per treatment strip
Weed Cover	Visual assessment of weed ground cover by species as a % per quadrat
Panicle number	Number of panicles on three row meters over ten sampling points per treatment strip
Spikelets/panicle	Number of spikelets per panicle on three plants over ten sampling points per treatment strip
Spikelet/m2	Panicle number multiplied by spikelets per panicle
Grain Yield	Yield in t/ha from combine harvest provided by the farmer
Grain quality	Bushel Weight - grain samples collected and tested at Trinity Grain
Soil Analysis	500g samples collected from across the trial strips and sent to NRM for analysis

Data Analysis

For data visualisation and analysis R version 4.2.1 “Spotted Wakerobin” was used. To create graphs for data visualisation the ggplot package was used. For the first year of results, when two trial farms were present, and in comparing the results from the first and second year of trials, a linear mixed effects analysis was performed, using the lme4 and lmer Test packages. This is an analysis of the relationships of interest between output variables and their interaction, for example ‘Yield’, and the fixed effect factor of interest, ‘Management’, with the opportunity to account for random effects. Random effects were specified in the model with a random intercept, for example Farm. Below is an example of the type of full mixed effects model used.

Yield ~ Management + (1|Farm:Crop)

The p-values were obtained by likelihood ratio tests of the full model with the factor in question against the reduced model without the factor present. If a factor resulted non-significant, the reduced model was preferred. In each case a visual inspection of residual plots was performed to check any obvious deviations from homoscedasticity or normality. Estimated marginal means were obtained for the levels of the significant factors and were then analysed using Tukey's Test to perform pairwise comparisons (PWC) to determine which treatment means were statistically different from each other ($p \leq 0.05$). P values close to but above 0.05 were considered to show a trend but still treated as non-significant (ns).

In the results obtained in the 2022 trials, where only one trial was present, a t-test was used to determine significant differences between the mulch and control strips, using the mean values for each output variable.

4 Results and discussions

Results 2020-2021

Detailed results from the 2020-2021 season can be found in annex C. In summary, dry conditions in Spring 2020 and 2021 contributed to several trial failures, an issue that was also present in trial establishment in Spring 2022. A 40% yield penalty was experienced in the mulch system compared to the control. The presence of a direct drill control suggested that the use of a direct drill accounted for ~20% of the 40% yield penalty experienced in the Living Mulch system. The bushel weight was also lower in the mulch compared to the control (Control; 50.4, Mulch; 35.8). The weed surveys showed a significant move towards more aggressive perennials and grass weeds. Weed cover was significantly higher in the mulch strips compared to the control. For soil health, the mulch showed over double the available nitrogen and had a trend for increased microbial activity.

Results 2022

Spring cash crop

In Spring 2022, Spring oats were direct drilled into an established living mulch that had previously grown winter oats, also into an established living mulch. Unfortunately, the trial was not successful. It is possible that the oats were drilled too late in the season and needed to be drilled in February/March in order to allow them time to get away from the clover competition. The mulch could also have been knocked back more to allow the cash crop a greater chance at growing away from the clover. This result highlights one of the difficulties of employing the living mulch system for more than one growing season after the mulch has been established and the difficulty of using Spring cash crops in the mulch.

Winter Oats

The successful trial from the 2021-2022 growing season was a Winter Oat cash crop into an established living mulch. The clover was drilled at a rate of 7.5kg/ha.

Field performance and Yield components

Overall, the oats in the control strip showed better field performance compared to the living mulch oats, with increased height, vigour and ground cover at GS65, with only the height showing a non-significant difference (Table 3). For the yield components, the control oats outperformed the oats in the living mulch, with increased panicle and spikelet density.

Table 3. Field performance and yield components in the living mulch and control strips

Management	**Height at GS65**	**Vigour at GS65**	**Ground Cover at GS65**	**Panicle Number/m2**	**Spikelet/m2**
Control	92.1 ± 3.89	6.86 ± 0.244	70.4 ± 5.26	318 ± 27.9	6602 ± 1010
Living Mulch	83.7 ± 5.41	5.93 ± 0.535	54.6 ± 5.88	273 ± 47.2	6236 ± 2025
Management effect p-values	0.09 (ns)	2.897e-7* (sig)	0.0001* (sig)	0.02 (sig)	0.3851 (ns)

Yield & Quality

Grain yield data showed a significant (p=0.03e-4) yield reduction of ~30% in the living mulch compared to the control (Table 4). This was not a surprising result considering the difference in yield components between the control and the mulch. The bushel weight was slightly lower in the living mulch, although this value was not significant. The difference in bushel weight was much smaller than the results from the previous year.

Table 4. Yield and bushel weight data from the 2022 Winter Oat harvest

Management	**Yield (tn/ha)**	**Bushel Weight (Kg/HL)**
Control	4.57	56.7
Living Mulch	3.22	56

Weed control

In contrast to the previous year results, the living mulch had a lower weed cover compared to the control, although this value was not significant (0.267) (Figure 1). One explanation for this difference in weed cover is that the clover ground cover was about 10% higher compared to the trials in 2021. This relatively small increase in clover cover could appear to have increased the weed suppression without affecting the yield penalty to such a great extent. The trial field had the inclusion of a grazed and un-grazed section through the control and living mulch strip which provided an excellent insight into the benefits of grazing on weed control, with the grazed strip showing significantly (p=0.045) lower weed cover compared to the un-grazed section (Figure 2). Grazing the mulch in the Autumn is a proposed method for controlling the mulch and reducing the competition it imposes on the cash crop.

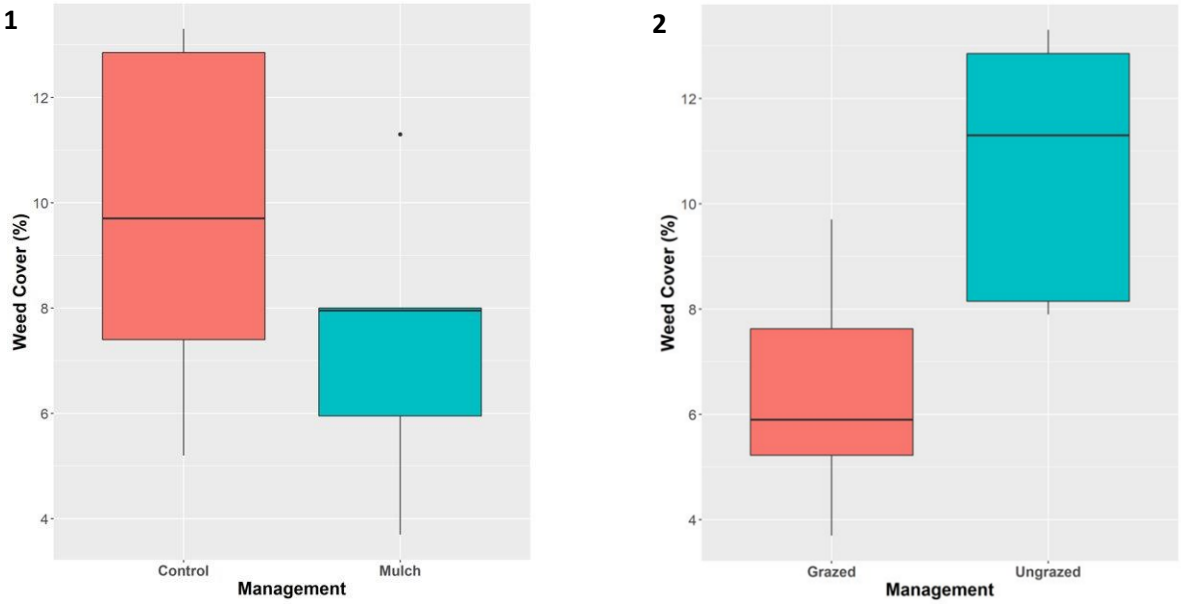


Figure 1. Weed cover as a percentage, in the living mulch and control strips

Figure 2. Weed cover as a percentage, in the grazed and ungrazed sections of the trials

Similar to the results found in the 2020-21 trial season, there was once again a move towards more aggressive perennials and grasses in the living mulch trial strip (Figure 3). Studies by Cougnon et al (2022) found that total weed biomass was negatively correlated with the mulch biomass (Cougnon et al, 2022), significant only for dicots but not for monocots. Which is reflected in the results we have seen over the past two years, with a move towards a relative abundance of grasses versus broadleaved weeds. This suggests the system at the moment, organically, can only be applied for one or two years before remedial action is required. Unless management practices can alleviate this issue throughout the season. As the trials so far have not included non-organic systems (due to failed clover establishment), the use of targeted herbicides could also alleviate the movement towards more aggressive weeds.

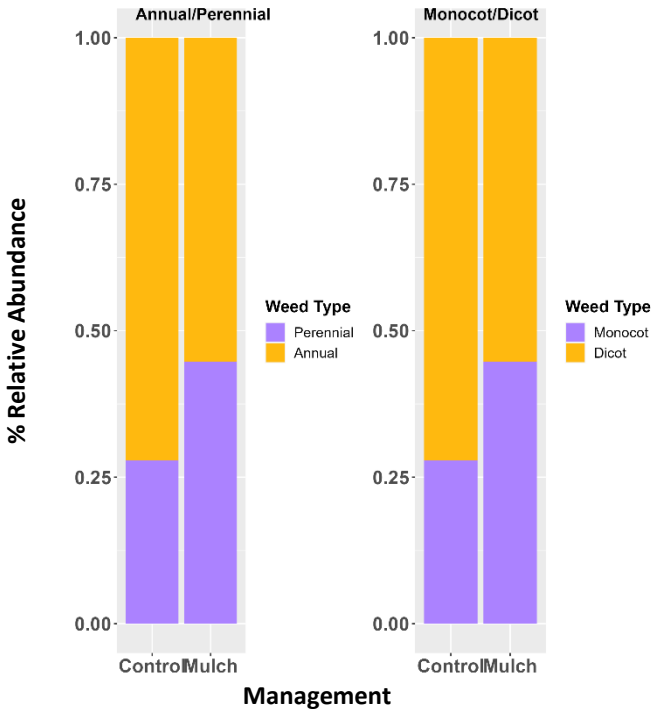


Figure 3. Barplots to show the relative abundance of perennials versus annuals and monocots versus dicots in the control and living mulch strips

Soil Health

The soil analysis results showed significantly (p=0.047*) higher available N in the living mulch compared to the control (Figure 4). There was also a trend for increased soil organic matter, microbial activity and worm counts. When comparing the soil health scorecards for the living mulch and control trial strips, there was a slight improvement in the living mulch scorecard compared to the control.

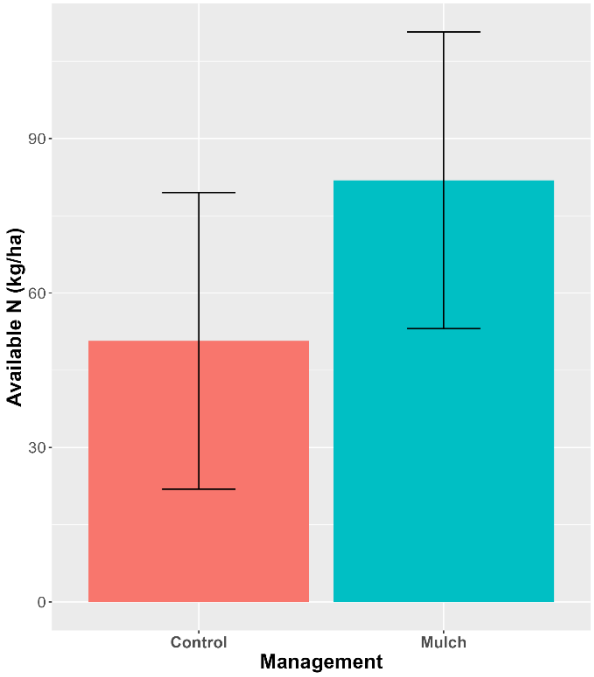


Figure 4. Available nitrogen in the control and living mulch trial strips

Soil Health Scorecards 2022

Farm 1 Shropshire		
Soil Quality	**Control**	**Living Mulch**
VESS	1.2	1.3
pH	6.7	6.9
P (mg/l)	19	18.8
K(mg/l)	142	197
Mg (mg/l)	53.1	60.3
SOM	3.6	4
Average Earthworms ($20cm^3$)	0.3	2.7
CO2 Burst	96	102

Farm 2 Oxfordshire		
Soil Quality	**Control**	**Living Mulch**
VESS	1.5	1.2
pH	8.1	7.9
P (mg/l)	9.2	10.2
K (mg/l)	213	319
Mg (mg/l)	50.5	73
SOM	7.8	9.3
Average Earthworms ($20cm^3$)	0.7	11
CO2 Burst	82	111

When combining the earthworm counts from 2021 and 2022, the results showed significantly (p=0.023*) higher worm counts in the living mulch compared to the control (Figure 5).

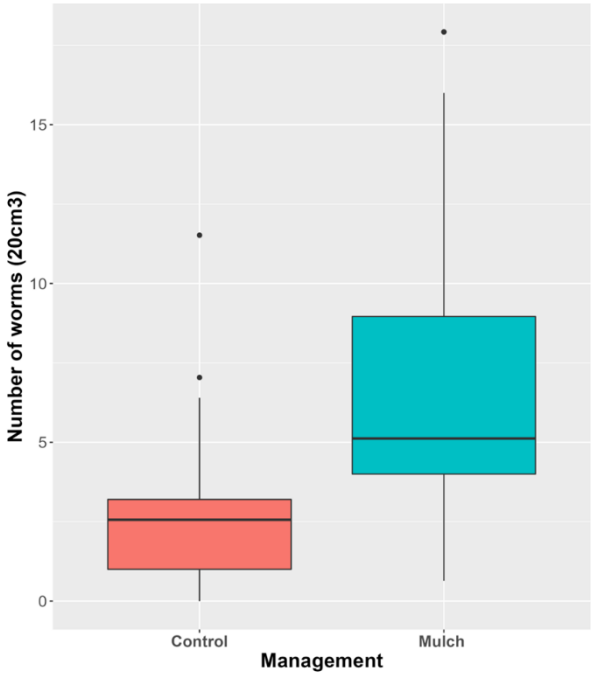


Figure 5. Boxplot to show the number of worms present in the control and mulch trial strips in 2021 and 2022 in a 20cm3 area

Yield results 2021-2022

When combining the yield data from the two years of trials the yield penalty in the living mulch compared to the control averages out at 32% (Figure 6).

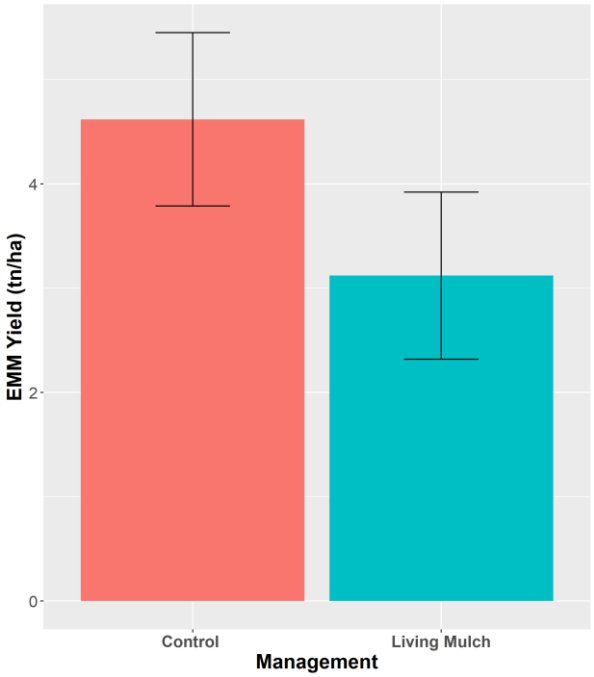


Figure 6. Barplot to show the estimated marginal mean yields of the two management treatments from 2021 and 2022

Discussion

Whilst the yield results indicate a yield penalty in the living mulch system, which for a farming business is a cause for concern, there are other factors that need to be considered when assessing the overall cost-benefit of the living mulch system.

For both organic and non-organic systems, the living mulch system can reduce the external inputs that are usually used. For organic, the use of a living mulch can reduce the use of ploughing, saving on fuel, labour, machinery wear and tear, and soil disturbance. In addition, the living mulch can act as a living ley and extend the rotation for an additional one or two years before a normal rotational ley is required, this adds a bonus year of cash-cropping. For non-organic systems, the living mulch can reduce the requirement for artificial nitrogen inputs and herbicide use. The clover can also act as a cover crop over the winter, which can save on the cost of seed. These cost savings can offset some or all of the value associated with the yield penalty.

The presence of a clover ground cover across the growing season can also provide an opportunity to reduce leaching and run-off, which poses the question of whether water companies would provide funding to implement living mulch systems.

As can be seen from the results, the living mulch provides several benefits for soil health, with increased nitrogen, microbial activity, soil organic matter, and earthworm activity which can improve the fertility and soil quality across the rotation. Studies have shown that the Nitrogen assimilated by the living mulch through the growing season will benefit the following crop (Cougnon et al, 2022). In terms of yield, this result was not reflected in the Spring wheat crop following the 2020/21 living mulch in Shropshire. The yields of the Spring

wheat grown on last season's living mulch and control were almost the same. The quality of the wheat was not recorded, so there may have been a quality benefit to the wheat grown in the mulch, for example an increase in the protein content due to higher available nitrogen.

There are aspects of the Living Mulch system that require further research to fine-tune the system and reduce the current yield penalty associated with the mulch. These areas of further research can be divided into four sectors:

Living Mulch Species & Variety

The trials to date have used a white clover mix of medium and small leaf clover. White clover has finer roots with a lower C/N ratio that are easily mineralized (Cougnon et al, 2022). The small leaf clover is used as it provides good ground cover whilst remaining relatively prostrate, to reduce the competition with the crop and the medium leaf clover is used to provide an opportunity for forage and competition against the more aggressive weeds. Future trials could use only a small leaf clover, providing the seed rate is high enough to allow full ground coverage. Other mulch species could be considered such as lucerne or red clover. Red clover is a more aggressive species, with an upright growth habit. This would provide excellent weed suppression but could also very easily become too aggressive for the cash crop.

Cash crop Species & Variety

The trials so far have tested winter oats and rye as potential cash crop varieties. Rye and oats would be recommended as the most competitive varieties as they show early vigour and increased overall height, compared to barley and wheat. Although heritage and population wheats could provide good competition with the clover as they tend to be taller varieties. Although taller wheat varieties may be susceptible to lodging in high nitrogen environments and therefore may not be suitable for non-organic systems. Spring sown crops should be sown early into the established clover as this should allow them to compete more effectively with the mulch.

Living Mulch Management and establishment

One of the challenges that has been highlighted from the past three years of trials is the difficulty in getting the clover established in the Spring, due to dry conditions. Current climate projections suggest these dry Springs and Summers will become more prevalent in future years. There are several suggested timeframes for clover establishment that may alleviate the issues we have faced so far, however the best approach may differ depending on the farming system.

So far, clover establishment has mostly been attempted in the Spring with a spring cash crop being undersown with clover. If the Spring is not too dry, then this is still a good option for sowing as it gives the clover the opportunity to establish when the cash crop is still germinating. It also means the clover will provide good ground cover during the critical weed free period from October to January (Welsh et al,1999). It would be important to not undersow the clover too early in the Spring as the soil temperature may not be high enough for the clover to germinate.

If the Spring is too dry, then it may be possible to sow the living mulch in the late Spring/early Summer after an early harvested cereal, for example Winter barley, if the soil moisture is good.

If both the Spring and early summer sowing windows have not been appropriate, then the clover could be sown in September with an early sown winter cereal, providing the temperatures are high enough. This is a potentially slightly more risky option, as the clover may not provide enough ground cover over the Winter to provide weed suppression.

Finally, there is the option to undersow a winter cereal with clover in March. This is most likely not appropriate for non-organic systems as the cash crop will be too vigorous for the clover to establish underneath the canopy.

The management of the clover in the living mulch system is one of the key short-term improvements to the system. As seen in the 2022 trials, the inclusion of grazing was beneficial for reducing the weed cover and could reduce the competition of the clover at key points of the growing season. For organic and non-organic systems, the use of strip tillage, inter-row mowing or crimping where the system allows, can provide an opportunity to knock-back the clover and reduce competition with the cash crop, although these technologies can be expensive and are not yet widely available on the market.

The timing of mulch management is an important area of consideration. Carof et al (2007), results indicated that crop–mulch competition was strongest from wheat stem elongation, BBCH stage 30, to BBCH stage 61, which would indicate that disturbing the clover would bebeneficial during this time.

Living Mulch and Cash crop breeding

The varieties and species currently used in the living mulch system are primarily bred for yield and foraging potential. For the system to be truly optimised, specific breeding of mulch varieties would be required and optimally a breeding scheme that involves the breeding of cash crops and mulches together. Cougnon et al (2022) detailed 3 areas that mulch breeding should be focussed on:

- Plant architecture dynamics: short, prostate legumes provide greater soil cover and less crop competition for light as well as minimising the reducing the negative affect of mulch green biomass at harvest

- Plant Phenology: Winter dormant species allow the winter crop to develop unimpeded and therefore compete better with the mulch. Mulch species that start their growth late in the Spring would be preferred. After cereal harvest, growth should be maximal to ensure high biomass, good weed suppression, soil cover and nitrogen fixation. Late Autumn growth would result in competition with the recently sown winter cereal.

- Disease resistance: resistance against root pathogens is necessary for the longevity of the living mulch.

The breeding of Living Mulch suitable varieties is a long-term goal. In the meantime, the focus should be on optimising the system, with the tools that we already have or can more easily introduce.

Trials are going ahead for the 2022/23 growing season, with the intention to establish further new trials in Spring 2023.

6 Tips and recommendations

- Farmers that are interested in using living mulches can find lots of useful resources on the Innovative Farmers resource page. There will be knowledge exchange events held in 2023, any farmers that would like to participate, or learn more about the system can contact henny.l@organicresearchcentre.com
- One of the key tips for carrying out on-farm trials, whether part of a field lab or on your own, is to always include a control strip for comparison.

7 Further reading

Hartwig, N., & Ammon, H. (2002). Cover crops and living mulches. Weed Science, 50(6), 688-699

Cougnon, M., Durand, JL., Julier, B. et al. (2022). Using perennial plant varieties for use as living mulch for winter cereals. A review. Agron. Sustain. Dev. 42, 110.

Welsh, J., Bulson, H., Stopes, C., Froud-Williams, R., & Murdoch, A. (2008). The critical weed-free period in organically-grown winter wheat. Annals of Applied Biology. 134. 315 - 320.

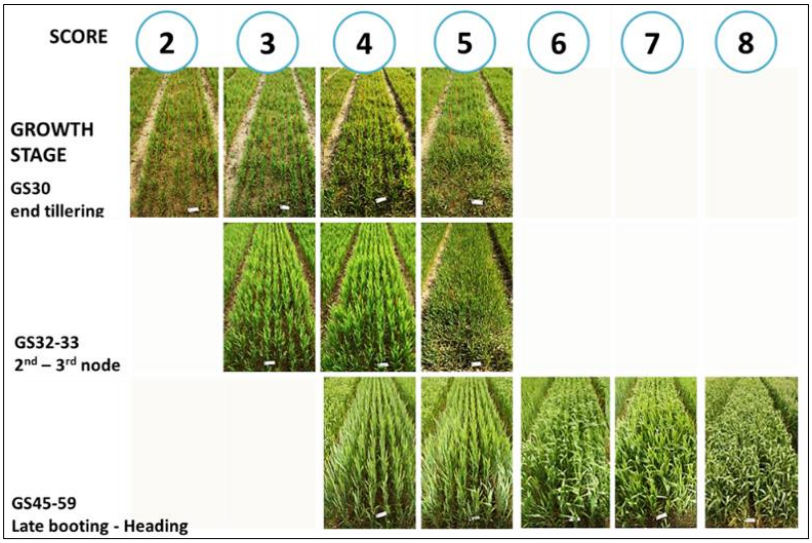
Carof, M., de Tourdonnet, S., Saulas, P. et al. (2007) Undersowing wheat with different living mulches in a no-till system. I. Yield analysis. Agron. Sustain. Dev. 27, 347–356

Annexes

A. Living Mulches Trial Experimental design options

Experiment design options.pptx

B. ITAB Vigour Assessment scoring guide



C. 2020-2021 Living Mulches final report

Living Mulches Two Year Report Final.doc

Innovative Farmers is part of the Duchy Future Farming Programme, funded by The Prince of Wales's Charitable Fund through the sales of Waitrose Duchy Organic products. The network is backed by a team from LEAF (Linking Environment and Farming), Innovation for Agriculture, the Organic Research Centre and the Soil Association