Ramial Woodchip in agricultural production

WOOFS Technical Guide 2

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Introduction

Soil health plays a pivotal role in sustainable agriculture. Multiple benefits to a soil's health can be obtained by maintaining and enhancing soil organic matter content through the application of organic amendments such as compost. These amendments influence the rate of nutrient release for crop uptake and the growth of crop roots, leading to both direct and indirect effects on crop yields and the wider delivery of ecosystem services[1]. With most soil bacterial and fungal organisms obtaining their energy and carbon from organic matter, the addition of organic amendments also increases soil microbial activity. As microbial activity increases, the conversion of soil organic matter to humus increases which in turn results in increased carbon sequestration.

Ramial (fresh) woodchip[2] is a relatively novel potential source of carbon and soil organic matter for agricultural soils. The WOOdchip for Fertile Soils (WOOFS) project investigated the use of ramial and composted woodchip as a means of increasing soil health as well as giving farmers an incentive to manage on-farm woody elements such as hedgerows as an integrated part of the farm system to increase the diversity of material being added to the soil. This is the second of three technical guides from the WOOFS project and outlines key results from the project's on-farm trials.

The basis of healthy livestock, crops and human beings is a healthy soil. A healthy agricultural soil is one that supports crop growth providing a physical structure for root growth, the capacity to absorb and infiltrate water, storage and release of nutrients and the suppression of pests and diseases. In addition to crop production, wider ecosystem services are provided by healthy soils including the sequestration of carbon, maintenance of biodiversity and water quality, prevention of nutrient and sediment loss to waterways and minimisation of greenhouse gas emissions.

Soil health is influenced by the dynamic interactions that occur between the physical, chemical and biological components of the soil. Many factors affect the properties of soil but the variable that has the greatest impact on soil health in an agricultural setting is soil organic matter (SOM) content[3]. The incorporation of organic matter into soil, as either manure or compost, is well established in many farming systems and helps avoid excessive release of soluble nutrients such as nitrogen and phosphorus, while simultaneously contributing an essential source of energy and carbon for growth and activity of soil microorganisms[4] and those ultimate soil engineers, earthworms. The gums and polysaccharides excreted by these microbes and earthworms promote the formation of stable soil aggregates and increase the ability of a soil to retain both water and nutrients.

Given the importance of SOM, finding alternative or supplementary sources of organic matter in the absence of available manure or compost is important to sustain soil health in agricultural soils. Ramial woodchip (RCW) produced from the management of hedgerows and trees that many farms already possess, may offer a solution. RCW has been found to increase the soil organic matter content and water holding capacity of soil[5]. A review of the impact of RCW on crop yield and soil properties in temperate and tropical regions found that in most instances application of RCW has a positive effect on crop yield, with the exception of crops planted in sandy soils straight after the incorporation of RCW[6]. Another study found RCW to increase total soil carbon and the water holding capacity of a sandy soil and, with NPK fertiliser used, there was no adverse impact on potato yield[7]. In tropical systems tomato yields were found to almost double following RCW application[8].

This publication, the second of a series of three technical leaflets from the WOOdchip for Fertile Soils (WOOFS) project, summarises key results from three commercial stock free arable and vegetable farms trialling the addition of RCW to their soils.

What is Ramial Chipped Wood (RCW)?

RCW is fresh un-composted woodchip made from smaller diameter younger tree branches. Nutritionally these are the richest parts of trees, with young tree branches containing as much as 75% of the minerals, amino acids, proteins, phytohormones and enzymes found in the tree[9]. A review of the use of RCW in agricultural systems documents evidence for increased soil biological activity and soil organic matter (SOM) associated with its application to cultivated soils[10]. Chipping or crushing the smaller diameter green branch wood in winter when the leaves have fallen encourages fast entry of soil microorganisms, enabling both nutrients and energy to be transferred to the soil humus complex[11]. Ideally material should be less than 7 cm in diameter and spread in autumn/winter soon after chipping to keep the chip moist and provide optimum conditions for decomposition.

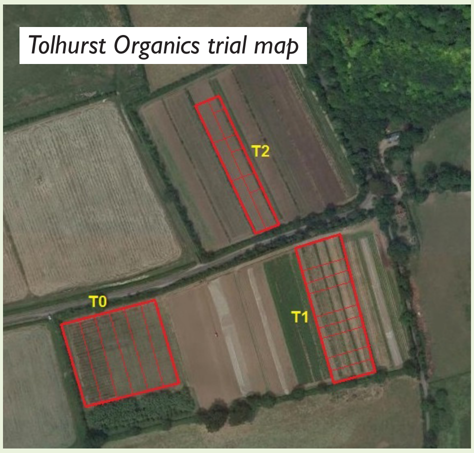
Trial set up and data collection

Replicated field trials were established on three farms in Southern England in winter 2017/18 (T1) and repeated in winter 2018/19 (T2) to give two trials on each site. At Tolhurst Organics an additional RCW trial established in winter 2016/17 (T0) was also included. Each trial tested different combinations of RCW application against either green waste compost, woodchip compost and/or a control of no amendment. All three farms are livestock free with no animal inputs, and fertility comes from fertility-building crops, compost and/or mineral fertilisers.

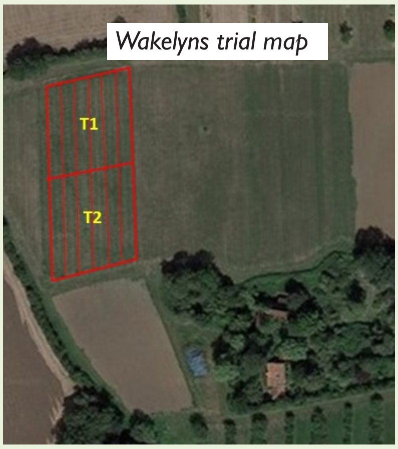
Substrate analysis of the RCW and compost was carried out prior to application. Then throughout the trial data was collected on soil nutrients, soil organic matter and soil biology. Worms were counted in the different treatments and, where the trial plot was cropped, crop health and yields were measured.

Table 1: Farms participating in the trials and treatments used in the trials (SRC is Short Rotation Coppice)

Farm	Soil type	Treatments (3 replicates)	Application rate and timing
Tolhurst Organics: Organic vegetable production	Sandy silt loam	1. RCW from mixed hedgerow 2. Composted woodchip 3. Control of nothing	T0: 70 m³/ha applied to 1st year of 2 year legume ley T1 & T2: 40 m³/ha applied to 1st year of 2 year legume ley
Wakelyns Agroforestry: Agroforestry alley cropping with organic arable rotation	Sandy loam	RCW from: 1. Poplar SRC agroforestry 2. Willow SRC agroforestry 3. Hazel SRC agroforestry 4. Mixed hedgerow 5. Control of nothing	T1: 40 m³/ha applied to 1st year of 2 year legume ley T2: 80 m³/ha applied to 2nd year of 2 year legume ley (rate doubled and reapplied)
Down Farm: Conventional arable cropping	Sandy silt loam	1. RCW from mixed hedgerow 2. Green waste compost 3. Control of nothing	T1 & T2: 150 m³/ha applied to winter stubble before sowing of spring crop (barley/ oilseed rape) with mineral N application



Tolhurst Organics trial map



Wakelyns trial map

Down Farm trial map

Substrate analysis

Both compost and RCW provide a source of valuable organic material for increasing soil organic matter whilst also acting as slow-release fertilizers for nitrogen and phosphate and other key plant nutrients. The composition of compost will vary according to the materials used and the composting process. Table 2 shows the approximate nutrient values that you can expect in compost and RCW.

Table 2: Approximate fresh weight values of a typical compost[12] and RCW[7] (kg/tonne)

Nutrients	Green Waste Compost (kg/t)	RCW (kg/t)
Nitrogen as N	8.1	4.6 – 11.5
Phosphate as P_2O_5	3.3	1.4 - 5.3
Potash as K_2O	6.6	3.0 – 13.0
Magnesium as Mg	2	0.26 - 1.1
Sulphur as S	1	-


RCW spread on ley at Tolhurst Organic

RCW impact on soil nutrients

Increased Phosphorus

Phosphorus (P) was the only key nutrient that appeared to respond to treatment (compost or RCW). P has a major impact on root development, root exudate formation and plant-microbe interactions and is essential for biological nitrogen fixation.

P increased with the application of RCW in all trials regardless of application rate, increases in P with compost application were also seen compared to the control, however the trend with RCW was more consistent and significant (Table 3). This is counter to a previous trial which reported reduced P with RCW application[7], in this trial 150 m^3/ha of RCW was added to an acidic sandy soil (pH 4.8) and incorporated to the top 10 cm prior to planting potatoes, they hypothesised that the reduction was due to an immobilisation of P by microorganisms. However, P availability is impacted by pH – values below 5.5 or above 7.5 limit availability – and this difference may be because all soils in the WOOFS trials already had a relatively high baseline soil health and near neutral pH values. Most agricultural operations acidify soil and the WOOFS trials saw some indication that RCW application had an impact on pH, at Tolhurst Organics the pH was significantly lower in the woodchip compost and RCW than control, this trend was not seen at the other farms. Depending on input material composts can have a small neutralising effect on the soil about 10% as effective as limestone[12] and can therefore stabilise soil pH and reduce the acidifying effects of inorganic fertilisers.

No significant differences between treatments for Magnesium (Mg) and Potassium (K) were seen and when compared to the control plots with no amendments added there was also very little change in SOM between treatments for any of the trials. All three trial farms already had relatively high baseline levels of SOM before the trials started, as well as regular organic matter additions and SOM maintenance as part of farm planning. Where a fertility building ley was in place increases in SOM were seen between years, as would be expected with an absence of cultivation.

Table 3: Soil Health Test analysis results from the three trial farms. Values averaged across years and trial

Site	Application rate	Treatment	P (mg/l)	K (mg/l)	Mg (mg/l)	SOM	pH	CO_2 (mg/kg)	C:N (2020)
Tolhurst Organics	None	Control	23.9	85.6	80.0	4.9	7	132.0	10.7
	40-70 m^3	Compost	26.9	84.4	81.1	4.6	6.7	172.5	10.7
		RCW	26.4	87.6	82.9	4.7	6.6	172.9	10.5
Down Farm	None	Control	24.2	287.7	81.1	3.9	7.2	147.5	14.4
	100-150 m^3	Compost	22.3	293.1	83.4	4.4	7.4	149.8	15.3
		RCW	25.2	305.1	82.9	3.9	7.3	137.8	13.9
Wakelyns Agroforestry	None	Control	10.4	102.7	50.9	4.9	7.8	115.4	11.3
	Low (40 m^3)	Hazel	10.6	107.6	50.8	4.9	7.4	114.0	11
		Mixed	9.2	111.9	51.8	4.5	7.6	114.2	-
		Poplar	9.5	109.8	50.8	4.5	7.8	114.3	-
		Willow	8.9	105.3	50.9	4.7	7.7	112.0	10.5
	High (120 m^3)	Hazel	11.6	117.5	52.8	5.3	7.4	100.0	10.6
		Mixed	10.3	130.3	50.3	5	8.2	112.3	-
		Willow	11.1	109.5	49.7	5.2	7.9	96.0	10.5

Will RCW lock up N?

RCW has a reported carbon to nitrogen ratio (C:N)[7,13] of between 70 and 150. When organic matter with a high carbon to nitrogen ratio (C:N),– RCW has a C:N ratio[6,13] between 70 and 150 – is added to the soil, the microorganisms decomposing the material utilise available nitrogen. The nitrogen is thus immobilised and unavailable to the following crop until the C:N ratio is lowered[14].

There was a trend in all three farms towards a lower C:N ratio in RCW plots compared to the control. The average C:N ratio of the soil at Wakelyns and Tolhurst Organics was between 10 and 11, whereas at Down Farm it was slightly higher at 14-16 (Table 3). A lower C:N ratio in RCW compared to the control was unexpected and suggests that by this point in the trials the RCW has decomposed to the extent where it is not causing N lockup. In a trial of RCW application on tomatoes it was found that RCW depressed tomato growth and yield during the first cropping due to intense N immobilization. Improvements in growth and yield were observed during the second cropping and ascribed to improved nitrogen release following the extended incubation of the RCW in the soil[4].

The yield and plant health data collected in the WOOFS trials supports this and indicates that in htese trials no significant degree of N immobilisation is occurring with RCW use. However, it should be noted that the WOOFS trials were established on commercial farms and legume leys or mineral N were used as a precaution against the possibility of RCW causing N lock up.

Three and a half years after RCW application there was some indication that early growth may be have been impacted in brassicas grown at Tolhurst Organics (Fig. 4) but crop yields were not adversely affected.

Changes in the total SOM in relation to changes in management practices are generally slow to register and take place over a long time period. Defra research[15] has shown measurable nutrient supply benefits of improved organic matter management, such as the use of organic amendments, but these are often only realised after at least six years of implementation. The biological activity of the soil is closely linked to the mineralizable fraction of organic matter present in the soil and this labile or active fraction can be a better measure of response to management practices[16]

The WOOFS trials attempted to capture any changes in the active fraction of SOM in response to treatment using a number of sampling and analysis methods; the Solvita CO_2 burst; fungal and bacteria counts and activity levels and; monitoring of worm populations and community composition.

Solvita CO_2 burst

This test is part of the NRM Soil Health Suite[17] it measures the respiration of soil microbes following the rewetting of a dried sample and gives a rough indication of soil life. At Tolhurst Organics soil respiration was significantly higher in both the RCW and the compost plots than control in all trials, but RCW and compost were not significantly different from each other, suggesting that both amendments can have a positive action of soil biological activity. However, this trend was not seen at the other two farms and at Wakelyns increasing the RCW application rate appeared to lower the soil respiration slightly (Table 3).

Fungi/bacteria

Bacteria and fungi are the primary decomposers at the bottom of the soil food web, they feed on organic matter. Total and active bacteria and fungi counts were carried out in samples from the different treatments as well as analysis of mycorrhizal root colonisation. Results here were very variable between sites, trials and years and were mainly inconclusive. However, some small differences between treatments were observed. For example:

- In 2019 total bacteria was significantly higher in the RCW plots compared to the compost plots at Down Farm and Tolhurst Organics. It was also significantly higher in the willow woodchip plots at Wakelyns when compared to the other treatments, a pattern not seen in 2018 or 2020. The total biomass of bacteria provides an indicator of abundance of food for predators, nutrient capacity and general diversity of the bacterial population and the health of the soil, suggesting some positive effects of the RCW over the compost or control treatments.
- Some trends towards higher total fungi counts were also seen in the RCW plots. Fungi are recognised for their ability to degrade lignocellulosic material more effectively than bacteria. A higher ratio of fungi to bacteria indicates greater carbon storage potential via altered C cycling patterns. At Down Farm total fungi was significantly higher in RCW plots in all years and at Wakelyns total fungi counts were significantly higher in plots with a higher application rate and also increased between years.
- An increase in the number of fungi fruiting bodies was observed in the RCW plots at all trial sites. Other studies have shown increases in fungi populations following application of RCW to the soil[18].

Fungi present in the RCW plot at Wakelyns Agroforestry

What is the impact of higher rates of RCW?

The trial at Wakelyns Agroforestry applied 40 m^3 of RCW from different farm sources in the first year. In the second year, to investigate the effects of increasing the application rate, instead of setting up another trial in a different field an additional application at 80 m^3 of willow, hazel and mixed RCW was applied to half the plots, making the total application rate in these plots 120 m^3 over a two year period.

Results indicate a significant increase in soil organic matter in the hazel, willow and mixed plots when the application rate was increased compared to the single application rate (Table 2) as well as significantly more P in the higher application rate plots. Results also show a trend towards increased K and reduced CO_2 with higher application rates. However, within the timeframe of the sampling the impact of increasing the application rate was not significant for most of the other parameters measured.

There were no observable differences on the ground between the high and low application rates and analysis of aerial photos taken with a drone of the 2020 mustard cover crop show no obvious differences in plant health and growth between plots. However, some caution must be used when interpreting results of this trial as the blocks (high and low application rate) were non-random and effects may be a result of underlying differences in the field.

RCW impact on earthworms

Many farming activities can reduce earthworm numbers in the soil, particularly in arable systems with regular soil disturbance, potential compaction and where there is little organic matter in and on top of the soil. This means that the number and diversity of earthworms can be used as indicators of the condition of the soil and any management practices that affect it.

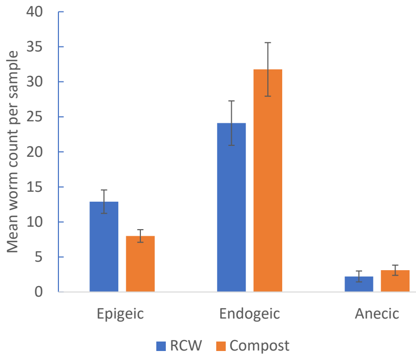


Figure 1: Mean worm number per sample in T0 two years after RCW application at Tolhurst Organics

Earthworms can be divided into three ecotypes describing where in the soil they live and what they feed on. In many arable soils, the earthworm species that feed on leaf litter on the soil surface ('epigeics') are often rare or absent, as are the anecic species that build permanent vertical burrows and drag surface litter to lower soil horizons. By adding ramial woodchip or compost to the soil surface, we would expect to see higher numbers of the epigeic earthworms, as well as more anecic earthworms, depending on how frequent soil cultivations are.

Earthworm counts were carried out each year within the different treatments at all three farms. In 2020 a more detailed earthworm survey was conducted, and as well as counting and classifying to ecotypes adult earthworms were identified to species. The highest diversity of earthworms was recorded at Tolhurst Organics with 11 different species found in total.

Table 5: Average number of earthworms per square metre and number of species recorded in March 2020

Site	Worms/m^2	Total no. species	Average no. species per plot
Tolhurst Organics	793	11	5.5
Down Farm	353	8	5
Wakelyns Agroforestry	354	6	3.8

Arable soils contain an average of 150-350 earthworms per m^2, populations of greater than 400 per m^2 have been linked to significant benefits in arable crop production[19.1] In March 2020 at Tolhurst Organics an average of just under 32 worms per sample (20cm x 20cm x 20cm) was recorded, which, when scaled up, works out as just under 800 earthworms per square metre. By comparison, the two other farms (Down Farm and Wakelyns Agroforestry), which are both arable farms, averaged under half that at just over 14 worms per sample and 350 wormsper square metre.

The biggest significant differences in all farms were between trials and years. Both Tolhurst Organics and Wakelyns saw an increase in total numbers of worms over time in the individual trials across all treatments, though this was not seen at Down Farm. This increase is likely to be largely a result of the reduced cultivation associated with the longer-term fertility building leys.

In 2020 the total number of worms at Down Farm in T1 was significantly higher in the compost and control plots than RCW. This trend was not seen in other years.

At Tolhurst Organics, across all trials and years, the total worm number was significantly higher in RCW and compost plots than the control plots with significantly more epigeic and anaeic worm ecotypes also seen in the RCW and compost plots compared to the control. At Tolhurst Organics trial T0 in 2018, whilst there was no difference seen between total worm numbers more endogeic (soil living) worms were counted in the compost plots and significantly more epigeic (worms that live in and feed on the leaf litter) in the RCW plots (Figure 1). This early trial had no control plot of no treatment.

Does RCW vary depending on the species and age of tree(s) used to produce it?

A variety of on-farm tree and hedge species were coppiced and chipped to produce the RCW used in the WOOFS trials. Species selection depended on the availability on farm and the management requirements, but they were all broadleaved UK native species. RCW from mixed species hedges (a mixture of hawthorn, blackthorn, hazel and other hedge species) was the constant and was used at all three farms.

Hazel coppice at Wakelyns Agroforestry

The trial at Wakelyns used RCW from an additional three sources, poplar, willow and hazel short rotation coppice (SRC) from the agroforestry systems, so we can look here for differences between tree species. The substrate analysis of the RCW from different sources showed a large amount of variability between the woodchip sources, RCW from willow SRC had very low nutrient indices for P, K, Mg and N compared to the other sources. However, analysis of the data shows that at the lower application rate (40 m^3/ ha) differences between the four treatments and the control were minimal. Some differences showed up when the application rate was increased, for example at the higher application rate the pH was significantly higher (0.357 ± 0.13) in the willow plots compared to the hazel plots (Table 3).

But, it doesn't appear from the trial results that the material used to produce the RCW is of has much impact on the nutrient or other status of the soil. We didn't include RCW from conifers or other evergreen tree species where more of an impact may have been seen.

Potatoes and brassicas at Tolhurst Organics

In 2019 (T0) and 2020 (T1) total potato yields were calculated for each treatment as well as the marketable yield based on the number of potatoes that were of high enough quality and a large enough size to sell. From these figures the marketable proportion of the total yield was calculated.

Table 6: Total and marketable potato yields from the WOOFS trial at Tolhurst Organics

Trial	Treatment	Total Yield (t/ha)	SE	Marketable Yield (t/ha)	SE	Proportion of marketable yield
T0 (2019)	Compost	47.04	0.19	32.87	0.91	69%
	RCW	41.94	1.21	30.19	0.65	72%
T0 (2020)	Compost	50.16	6.42	45.99	6.69	91%
	RCW	53.40	2.86	48.61	2.38	91%
	Control	53.55	8.27	47.38	7.85	88%

Potato trial harvesting at Tolhurst Organics

In 2019 (T0) total potato yield was significantly higher in compost treated soil (47 t/ha +/- 0.19) compared to 42 t/ha +/- 1.21 for RCW; however, this difference was not significant for the marketable yield. In 2020 (T1) there was no significant difference between total yields but there was a higher proportion of marketable yield in compost and RCW compared to the control. This difference was partially due to increased pest damage in the compost plots (Table 6).

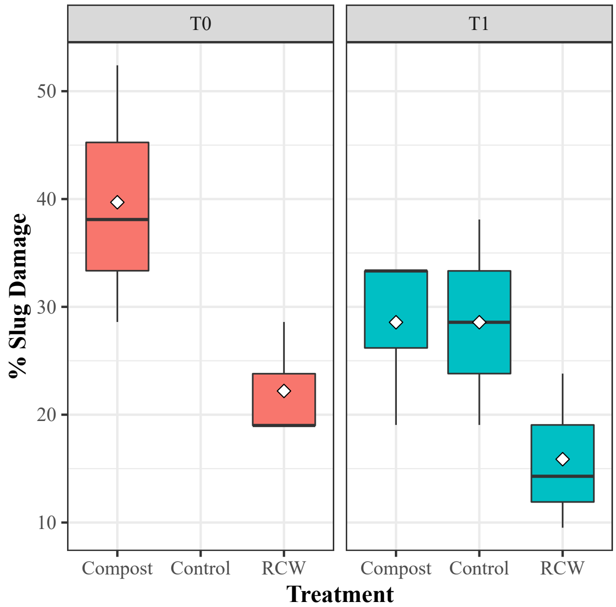


Figure 2 Incidence of slug damage between treatments at Tolhurst Organics in 2019 (T0) and 2020 (T1). Diamond indicates mean.

Damage from pests and any signs of disease (e.g. scab) were recorded in a sample of potatoes from each replicate at harvest. The most significant damage was caused by slugs. Slug damage was significantly lower in the RCW plots in both 2020 (T1) and 2019 (T0). This was unexpected, and partially explains the difference between the marketable and total yields. There were no significant differences seen in the other pests and diseases monitored. A trial in Canada of RCW in a potato crop[7] found that RCW did not promote the development of pathogens responsible for common scab and suggested that increasing SOM can increase biological activity including saprophytes which can reduce pathogen incidence.

Following the potato crop in 2020, three and a half years after the woodchip application, brassicas were planted in the trial T0. On visual inspection bands of weaker growth could be seen in some of the younger brassica plants, which appeared to correspond to the treatment replicates (Fig 4).

Following this observation assessments of three different brassica varieties were carried out (white kale, kohl rabi, swede). Samples were taken from each plot and the average mass at harvest calculated as well as a visual assessment of diseases/ deficiencies. Results showed that swede weight at harvest was significantly higher in RCW plots than the control (compost) plots and that incidence of downy mildew on the swede leaves was lower. White kale showed a trend towards higher average weight in compost plots than RCW, none of the other leaf health and disease assessments showed any difference between treatments.

Figure 4: Photo of the young brassicas in T0 at Tolhurst Organics, red circle indicates bands of weaker growth

Barley and OSR at Down Farm

In 2018 yields were low in all plots reflecting the drought conditions that year and the control plots had a lower average yield of 5.99 t/ha than either the woodchip (6.42 t/ha) or compost (6.63 t/ha) treatments. Yields were higher in 2019, and the trend towards higher yields in the compost and RCW plots can be seen again. But these differences were not significant.

Due to a problem with the technology the yield figures for the Oil Seed Rape in 2020 were an approximation and were only available for T1. There was a trend towards lower yields in the RCW plots than either the compost or the control plots (Table 7).

Table 7: Average barley and oil seed rape yields at Down Farm (t/ha)

Trial	Year	Crop	Treatment	Average Crop Yield (t/ha)	SE
T1	2018	Spring Barley	Control	5.99	0.48
			RCW	6.42	0.54
			Compost	6.63	0.04
	2019		Control	9.17	0.88
			RCW	9.49	0.42
			Compost	9.26	0.63
	2020	Oil Seed Rape	Control	2.76	0.02
			RCW	2.64	0.03
			Compost	2.77	0.02
T2	2019	Spring Barley	Control	10.11	0.58
			RCW	10.25	0.59
			Compost	10.39	0.57

Conclusions

Results from these trials suggest that, when applied to a legume ley or with fertiliser, RCW has a minimal or a positive impact on crop yields and may increase crop resilience to pests and diseases. The marketable yields of potatoes suggest that RCW may help to inhibit slug activity and reduce damage. The 2018 spring barley yields suggest that woodchip and compost may both act to increase the water holding capacity of the soil and increase the crop resilience to extreme weather events.

No significant differences were observed between treatments for the majority of the soil parameters measured with the exception of P. The addition of RCW increased P availability across all the trial farms and if as a farm you have low P both RCW and compost might be worth considering. Soil biology results were mostly inconclusive.

These trial results suggest that RCW may have many of the same beneficial effects as compost and hence could offer an option for farmers where livestock are scarce or the raw materials for composting are unavailable. RCW also provides a potential use for brash from tree and hedge management activities and a useful alternative to burning this material in the field, keeping the fertility on the farm and helping move fertility from the hedges and edges out into the field. The introduction of active management to farm hedges and trees has additional benefits, improving their structure, function and viability and ensuring that the full range of potential ecosystem services can be realised.

However, it is important to note that the breakdown of woodchip, colonisation by fungus and subsequent action on the soil is a long-term process and, although not indicated by these results, compost and RCW are likely to have slightly different actions on the soil and could be used in a complimentary way. One recommendation going forward might be to mix woodchip with compost or to alternate application according to availability to get the best of both.

It should also be noted that the WOOFS trial farms already had biologically active soils with high nutrient availability and regular applications of organic matter and it could be that these sites are more buffered against any impacts of RCW, positive or negative. Organic amendments rich in cellulose and lignin such as RCW are particularly suited to degraded soils where the soil carbon has been depleted and biological activity is low[6] and it would be interesting to conduct RCW trials on less biologically active soils in temperate areas.

The key to developing soils that are resilient, self-regulating and resistant to degradation is to increase carbon (SOM) inputs to the soil and reduce carbon losses. RCW is a useful additional amendment which has been found to add 0.09 t/ha of carbon to the soil for each cubic metre applied[13] and a long term study[20] observed a 16-37% increase in soil carbon with RCW applications of 25 – 100 t/ha.

In conclusion, RCW is not a panacea, but has the potential to offer some significant benefits in terms of carbon capture and storage, overall soil and crop health as well as helping farms move towards self sufficiency in inputs and closed system farming.

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