RiverinePlains

Soil carbon in cropping systems

OPPORTUNITIES AND REALITIES

Australian Government
Department of Agriculture

Fast-track Ag Innovation

FRRR
Foundation for Rural & Regional Renewal

The William Buckland Foundation

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Introduction

Broadacre cropping is an incredibly complex undertaking, as any farmer could tell you. It requires managing a suite of different crops, with unique agronomic needs, controlling a multitude of pests, diseases and weeds with an alphabet of different chemistries and integrated management strategies. This is carried out amidst the evolution of technology in machinery to maximise efficiency and timeliness, the extreme vagaries of weather, and finally, the profitability of the business, which is largely driven by international prices… and I've barely scratched the surface of the challenges farmers face on a daily basis!

However, one thing stays constant throughout the seasonal flurry of activity on farm, and that is the importance of the soil resource in sustaining production. However, the irony is that the soil is probably the one aspect of agriculture we know least about. Soil scientists have been working to unlock the miracle that is the black box of soil physical-chemical-biological integration for decades in order to understand the factors governing soil dynamics and the extent to which we can support these factors to improve soil function.

The advent of new analytical techniques during the past 10–15 years has allowed us to measure, monitor and visualise soil functions like never before, significantly improving our understanding of how soils operate — what makes them tick, and more importantly, what restricts soil function.

By understanding the detail behind soil processes, we can work on removing the *most-limiting factor* (science-speak for getting rid of the biggest roadblock to function) and improving the ability of soil to release nutrients, support large and diverse microbial communities and provide infiltration and water storage for optimal plant growth among many other things.

Unravelling the mystery of soil carbon

One example of how soil scientists have gained new understanding of soils through technology is our evolving knowledge of soil carbon (C). Not that long ago soil carbon was considered to be a uniform substance in soil, somehow separate and unique, and was treated as a single, ubiquitous material that could be characterised by one number on a soil test. Now, not only do we regard soil carbon as being part of the team called 'organic matter' (OM), in partnership with a host of other nutrients, we can also visualise and describe different chemical structures within the umbrella of soil carbon, which means we can separate components (or fractions) based on different criteria, including particle size.

This growing base of knowledge has supported how we view the different roles carbon plays in soil, and we acknowledge it is not the same entity of soil carbon that supports nutrient cycling, as supports carbon sequestration (and thus mitigates greenhouse gases). This knowledge leads to the next step; understanding how we can effectively increase the amount of total soil carbon in cropping systems, which is notoriously hard to do due to the annual, disrupted nature of cropping systems. Moreover, we are yet to understand if we can more effectively utilise the large stash of carbon-rich material our crops produce each year and find ways to convert more of the above-ground stubble into soil carbon and derive optimal value from it.

Producer-led investigation

In response to the remaining knowledge gaps, Riverine Plains Inc conducted the *Increased soil carbon by accelerated humus formation from crop residues* project from 2012–15, with funding from the Australian Government's Department of Agriculture *Action on the Ground* program. We would like to sincerely thank the Australian Government for funding this project, with support from our project partners: the Murray Local Land Services, North East Catchment Management Authority and the Victorian Irrigated Cropping Council, who provided the means to determine the feasibility of building soil carbon through stubble on a large scale.

A large-scale field project, such as this one, demands a lot of time and commitment to carry out, and this project stands testament to the efforts of Dr Bill Slattery, the project officer for this project and a highly-respected soil scientist. Not only did Bill complete all the required measurements for the project, he was also instrumental in improving the quality and timing of the greenhouse gas (GHG) measurements so they were comparable with the international scientific standards. Bill's wife, Jo Slattery, also a soil scientist, provided technical support to the project. We would sincerely like to thank Bill and Jo Slattery for their contributions and extend our appreciation to them.

While this publication outlines the results and conclusions from a three-year field trial, we have not reached the end of the soil carbon story. Consider this to be an interim progress report on field-based research in the Riverine Plains region. Continuing research and field-based validation may provide new insights, which may seem contrary to those presented here. However, it is not a case of right or wrong, merely filling in the blanks to complete the picture across landscapes and seasons.

The motivation behind this publication is to present this research information in an easy-to-digest manner to increase your understanding around soil carbon; what it is and what it does, so new information can be digested and understood within the context of the cropping system. To that end, we acknowledge the financial support for this publication from the Sustainable Agriculture Victoria — Fast Tracking Innovation Initiative, which is made possible with the support of the Foundation for Rural and Regional Renewal (FRRR) together with the William Buckland Foundation.

We hope this publication is of value in broadening your appreciation of the intricate complexity of the soil environment, and it provides some useful information.

Dr Cassandra Schefe
Riverine Plains Inc

Units of measurement

While the research sector has moved toward metric measures of row spacing, many growers remain comfortable with imperial measurement. Following is a quick conversion table to refer to when reading this publication.

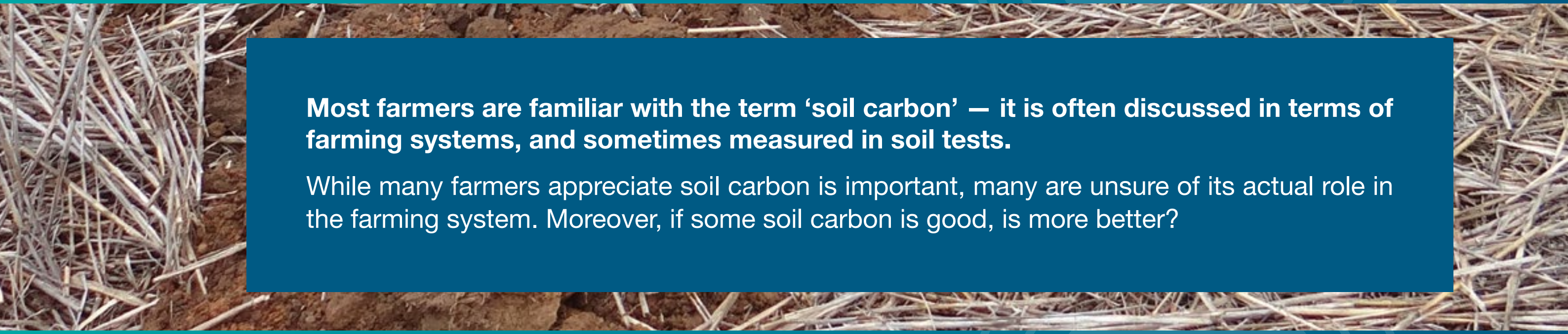
Table 1. Row spacing conversions

Inches	Centimetres
7.2	18.0
9.0	22.5
9.5	24.0
12.0	30.0
14.4	36.0
15.0	37.5

Statistical analysis

Statistical tests, such as analysis of variance (ANOVA) and least significant difference (LSD) are used to measure the difference between the averages of results carried out in research trials. A statistically-significant difference is one in which we can be confident the differences observed between results are meaningful and not the result of chance. The statistical difference is measured at the 5% level of probability, represented as '$P<0.05$'. If there is no significant difference, the P values are greater than 0.05.

1 Introduction to soil carbon



Most farmers are familiar with the term 'soil carbon' — it is often discussed in terms of farming systems, and sometimes measured in soil tests.

While many farmers appreciate soil carbon is important, many are unsure of its actual role in the farming system. Moreover, if some soil carbon is good, is more better?

2 The difference between soil organic matter and soil carbon

2.1 Soil organic matter

Soil organic matter (SOM) consists of organic material derived from living organisms, including plants, animals and micro-organisms. Organic matter makes up around 2–10% of the total soil mass and plays an important role in the physical, chemical and biological function of soils.

1. **Physical** — SOM improves aeration and the physical structure of the soil. It increases plant available water (PAW), lowers bulk density and protects soil from wind or water erosion.

2. **Chemical** — SOM contributes to the cation exchange capacity (CEC) of the soil (it has a negative charge and binds to essential nutrients, such as ammonium (NH_4), calcium (Ca), magnesium (Mg) and potassium (K)). It also acts as a buffer against acidification and maintains the plant availability of phosphorus (P).

3. **Biological** — SOM provides energy for micro-organisms. Some micro-organisms convert unavailable forms of soil nitrogen (N) into plant-available forms (nitrate (NO_3) and ammonium, together known as 'mineral nitrogen'), through the process of mineralisation.

Soil organic matter consists mainly of carbon (C) (known as soil carbon) as well as hydrogen (H) and oxygen (O), nitrogen, phosphorous, sulphur (S), potassium, calcium and magnesium.

2.2 Soil carbon as a component of soil organic matter

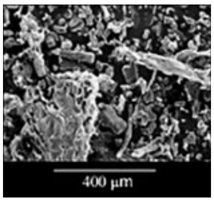
The carbon found in SOM consists of a range of compounds, which can be split into several fractions or 'pools' based on a range of physical and chemical properties. In Australia, the Australian Soil Carbon in Agriculture Research Program defines the fractions of soil carbon as:

1. **Particulate organic carbon (POC)** — organic carbon >52μm* in size, comprised of partially-decomposed plant and animal material. Particulate organic carbon usually represents 10–60% of total SOM.

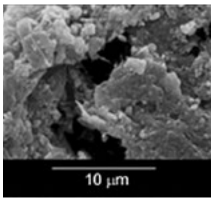
2. **Humus organic carbon (HOC)** — organic carbon <52μm in size. It consists of fine decomposed material, which is present as organic molecules attached to clay particles. Binding with clays protects HOC from microbial breakdown and makes it more stable. The long residence time and stability in soil is why HOC is the form of carbon measured to determine sequestration. Humus organic carbon makes up 20–80% of SOM.

3. **Recalcitrant organic carbon (ROC)** — the ROC pool is made up of charcoal and other forms of relatively inert carbon. Recalcitrant organic carbon represents 10–60% of SOM. Recalcitrant organic carbon is largely unavailable to micro-organisms, so can take hundreds of years to decompose. Highly-weathered soils and soils with a history of burning have a high proportion of ROC (Figure 1).

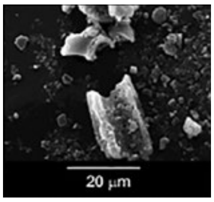
NOTE: In this context 'organic carbon' means carbon that can be decomposed by microbes and is not in the form of calcium carbonate ($CaCO_3$) or charcoal (which cannot be decomposed by microbes).
*1 micrometre (μm) = 0.001 mm



Particulate carbon (POC)



Humus carbon (HOC)



Resistant carbon (ROC)

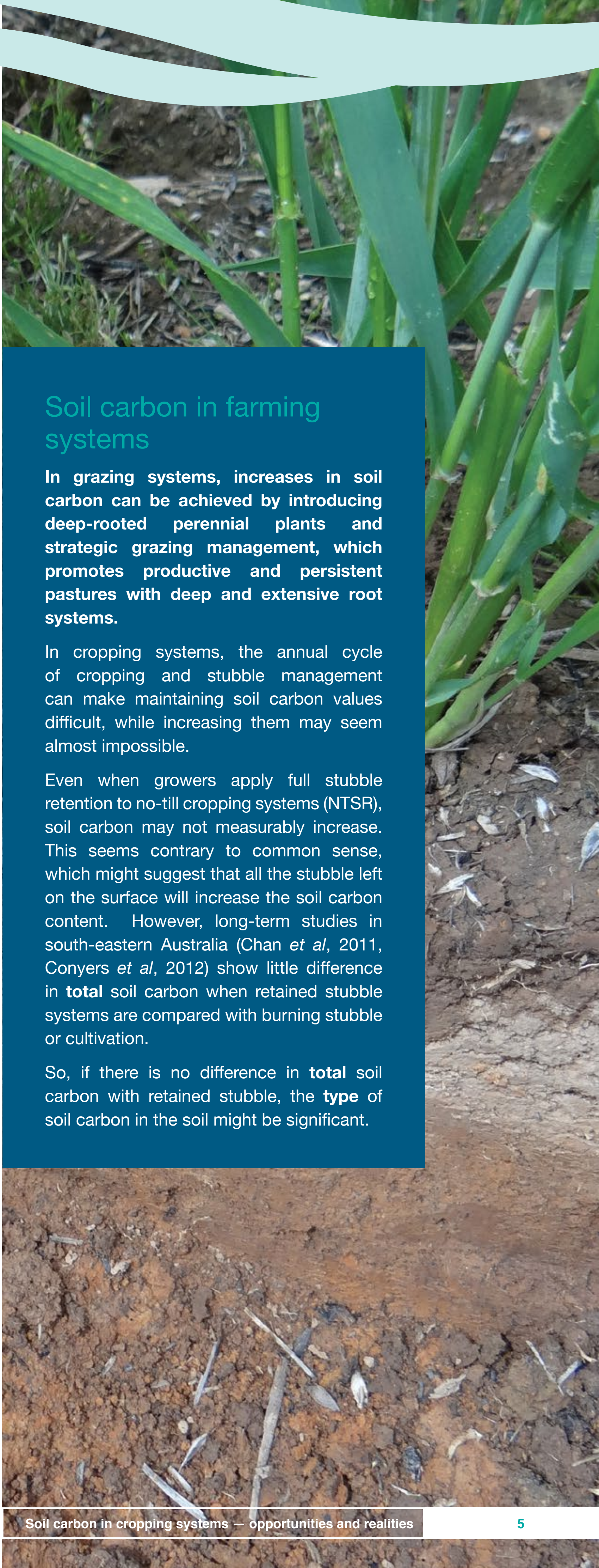
Figure 1.
The various fractions of soil organic carbon
Source: Dr Jeff Baldock, CSIRO

2.3 Soil carbon and sequestration

From an environmental perspective, carbon sequestration (or long-term storage of carbon) is valued because it can offset greenhouse gas (GHG) emissions by holding carbon in the soil.

However, for carbon sequestration to occur, the carbon must exist in a stable form, such as HOC or ROC with a measurable increase in the HOC fraction at a depth of 0–30cm under specific, international protocols for carbon sequestration.

While POC has great value in nutrient cycling and organic matter turnover in soil, it only has a short residence time in soil as it is constantly being consumed and renewed by the soil microorganisms. This prevents POC from accumulating in the soil and as such, it does little to contribute to carbon sequestration.



Soil carbon in farming systems

In grazing systems, increases in soil carbon can be achieved by introducing deep-rooted perennial plants and strategic grazing management, which promotes productive and persistent pastures with deep and extensive root systems.

In cropping systems, the annual cycle of cropping and stubble management can make maintaining soil carbon values difficult, while increasing them may seem almost impossible.

Even when growers apply full stubble retention to no-till cropping systems (NTSR), soil carbon may not measurably increase. This seems contrary to common sense, which might suggest that all the stubble left on the surface will increase the soil carbon content. However, long-term studies in south-eastern Australia (Chan *et al*, 2011, Conyers *et al*, 2012) show little difference in **total** soil carbon when retained stubble systems are compared with burning stubble or cultivation.

So, if there is no difference in **total** soil carbon with retained stubble, the **type** of soil carbon in the soil might be significant.

2.4 Identifying the dominant type of soil carbon

It is time consuming and expensive to measure the different carbon pools in a soil sample. For this reason, measurement of carbon fractions has not been incorporated into routine soil testing and is generally only carried out as part of research programs. This makes it difficult to identify which types of carbon dominate any given soil.

Figure 2 shows how a soil with the same **total soil carbon value** may have different properties due to the types of carbon present.

While soil A and soil B may have the same total soil carbon value, they will behave quite differently due to the varying proportions of each type of carbon they contain.

Soil A mostly contains *particulate carbon* and supports a high population of microbes, which are great at cycling nutrients. The *particulate carbon* fraction is constantly being turned over as new plant matter is decomposed, and is therefore unstable.

Soil B has less *particulate carbon* and more *humus carbon*. The *humus carbon* will stay in the soil for a long period of time — because the turnover rate is slow for *humus carbon* it can contribute to long-term carbon storage.

So, if *humus carbon* can be stored in the soil for long periods of time, it poses the question of whether it is possible to increase the proportion of carbon stored as *humus carbon* and whether this is possible within existing, large-scale agricultural systems.

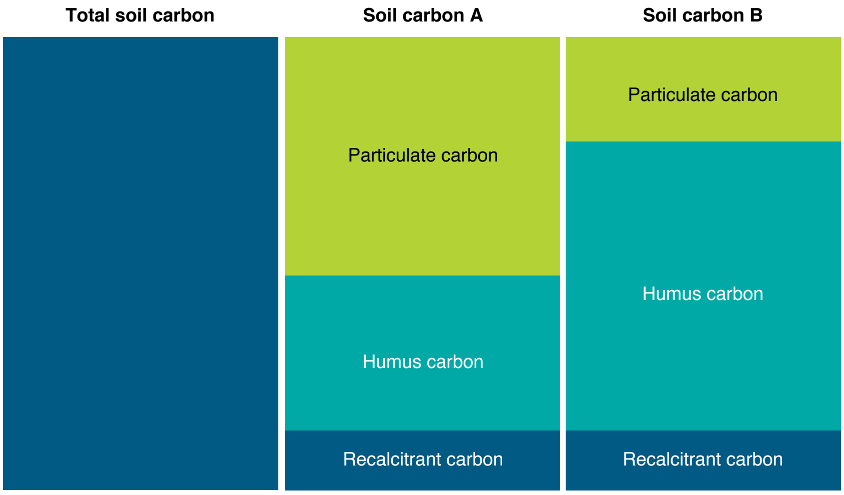


Figure 2.
The different carbon fractions in hypothetical soils A and B with the same total soil carbon levels

2.5 Calculating total soil carbon

Measures of SOC can be used to calculate the total amount of total SOM present in a soil. Soil testing laboratories measure the total amount of SOC (including the HOC, POC and ROC fractions) in a sample and apply the following formula:

Soil organic carbon (%) x 1.72 = soil organic matter (%).

Soil testing laboratories may report results as either organic carbon (OC) percentage or as organic matter (OM) percentage. If your soil test reports for OM, then OC levels can be calculated using the formula:

Soil organic matter (%) ÷ 1.72 = soil organic carbon (%)

The ideal soil carbon level for a particular soil is difficult to determine and is the focus of several research studies. In general, soils with a soil OC level of less than 1% (or a OM of <1.7%) are unlikely to achieve their full yield potential.

Soils with a history of perennial pastures, either continuous or as part of a long-term rotation, are more likely to have a higher OM content (and therefore OC content) than similar soils under continuous annual cropping. In addition, as soils in the higher-rainfall areas tend to produce more plant biomass (shoot and root matter), they often have higher OM contents than soils in the medium and low-rainfall zones if plant residues have been retained.

Andrew Dickie

Business name	Location	Farm size	Soil types
W Dickie Trust	Youanmite, Victoria	1500ha (950ha owned, 550ha leased/share-farmed)	Mostly clay loams with some granite loams

Q Describe your farming enterprise.

We continuously crop about 1300ha and have another 200ha of dryland lucerne/vetch/balansa/arrowleaf clover mix on which we run 600–700 crossbred ewes.

Q What is your cropping sequence/rotation?

Our continuous cropping operation runs on a four-year rotation. We usually start with wheat, followed by canola then another wheat. We then move into vetch, either as a hay crop or as a green manure.

The overall mix is about 50% wheat, 25% canola and 25% vetch. The vetch has been a better option for us financially than lupins or peas, and has returned a similar amount to canola. We are also trying faba beans as another pulse option.

We use the dryland lucerne as a forage crop for the sheep, with an occasional hay cut. We usually get 5–7 years out of each lucerne stand. Lucerne is sown as a mixed pasture during mid-May, with vetch, arrow leaf clover and balansa clover.

Q How do you manage the stubbles within your cropping system?

We don't use conventional sowing equipment and have instead developed a sowing and management system that allows us to retain all of our stubbles. We haven't burnt any stubble or cut straw since we adopted this system 13 years ago, though we have burnt when bringing in a new lease or share farm block in order to reduce the weed seed burden.

Our stubble management process starts after harvest (usually during early to mid January), when we make a pass over all our stubbles with a Lemken Gigant multi-disc. This incorporates most stubble residues and helps to achieve an effective breakdown of the stubble residue. At the same time as we incorporate our stubbles, we also apply a little bit of urea (about 30kg), which seems to prevent problems with nitrogen tie-up at crop emergence.

At sowing, we broadcast our seed and follow up with another pass of the Lemken multi-disc to incorporate the seed into the soil. In 2016, for the canola and vetch, we used a Kelly prickle chain and rubber-tyred roller (this is intended to help alleviate problems with the seed being placed too deeply), with effective results. Using this system we have never had to bait for mice or slugs etc.

During 2004 we started this process by trying to incorporate stubbles with the Kelly disc chain, but while we got stubble contact with the soil, there wasn't enough incorporation to aid breakdown. During 2010 we purchased the multi-disc and the results have been positive.

Q What soil carbon values do you have across your property, on average (0–10cm depth)?

During 2004 we tested the soil in an old lucerne paddock, coming back into crop, which showed the OM to be 2.04% — when we retested that same paddock during 2012, it showed the OM had increased to 2.8%.

Testing we carried out during 2012 in another paddock came back with OM at 3.6% so we feel our OM percentages are increasing steadily over time.

Q What value do you place on maintaining/improving soil carbon in your cropping system?

We think improving our OM percentage and humus fraction is important for improving our soil structure and biology. It has been high on our priority list since 2004 when we started trying to retain more stubble in our system. Some farmers at the time were moving to no-till, but we couldn't see how we could retain all our stubbles that way. After listening to one of Clive Kirkby's presentations we felt we were probably on the right track.

Q Are you trying to improve your soil carbon values? If so, how?

We retain all of our stubbles to improve our soil structure and OM percentages. We also use our legume crops to actively increase our soil OM levels and provide nitrogen for subsequent crops. We don't actually use much urea in-crop — we apply a base amount and generally find our soil, plus the use of legumes in our rotations, provides a good nitrogen background.

Q Are you likely to change your management practices to attempt to improve soil carbon?

We feel we are already doing quite a lot to improve soil carbon so we're not sure there's much more we can do. In saying that, we are open to looking at new possibilities as they become available.

We did try stubble digesters a while ago in an attempt to improve stubble breakdown rates, but couldn't get consistent results because we weren't getting enough summer rainfall.

3 | How does soil carbon form in cropping systems?

Soil organic matter, including the soil carbon fraction, is made up of the remains of bacteria and other micro-organisms that consume and break down crop and pasture residues. Crop residues are an important building block for soil carbon in cropping systems.

Cereal stubble provides an abundant source of food for soil micro-organisms, so why is it so difficult to increase soil carbon in cropping systems?

While soil microbes use carbon for energy, they also need a suite of other nutrients, such as phosphorus, nitrogen and sulphur to enable them to efficiently access the carbon present in stubble. Because these other nutrients are limited in stubble, and because Australian soils are generally low in these nutrients, the microbes simply don't have the balanced diet they need to convert the stubble into soil carbon. Most of the carbon found in crop residues is actually used by micro-organisms in breaking down the stubble. About 70% of the carbon decomposed by micro-organisms is transpired and released back into the atmosphere as carbon dioxide (CO_2) gas. This means only around 30% of the carbon from stubble is potentially available to be converted into soil organic matter. Without the extra nutrients, only a small proportion of stubble carbon can be converted into soil carbon.

This process is illustrated in Figure 3.

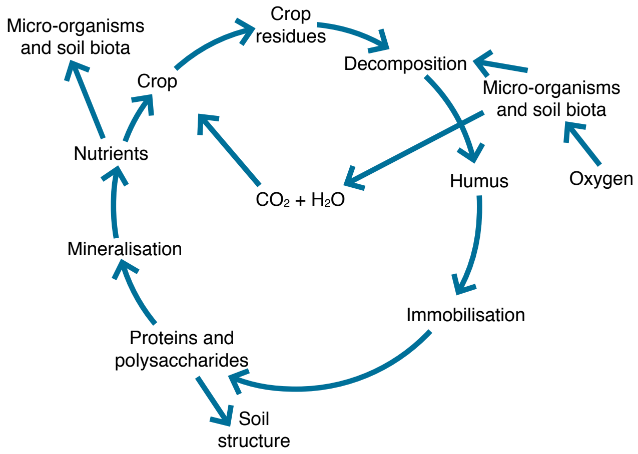


Figure 3.
The soil carbon cycle

CSIRO researcher, Dr Clive Kirkby, has found that SOM collected from different soils has a consistent ratio of nutrients, which is different to wheat stubble. Wheat stubble has proportionately less nitrogen, phosphorus and sulphur than SOM (Table 2), which explains why additional inputs of these nutrients are often required to facilitate the breakdown of stubble by micro-organisms.

1 tonne
of wheat stubble contains around
450kg carbon

Table 2.
Relative proportions of nitrogen, phosphorus and sulphur per 1000kg of carbon found in soil organic matter and in wheat stubble

	Carbon present (kg)	Nitrogen present (kg N/1000kg C)	Phosphorus present (kg P/1000kg C)	Sulphur present (kg S/1000kg C)
Soil organic matter	1000	80	20	14
Wheat stubble	1000	11	1.1	2.2

Source: Soil Organic Matters Fact Sheet 2 (GRDC)

4 | The relationship between stubble, microbes and soil carbon

4.1 Project background

During the past 20 years, numerous studies have shown that stubble-retained cropping systems have more soil microbes present compared with non-stubble-retained systems.

Microbes enhance nutrient cycling and promote a higher level of aggregate (soil particle) stability, resulting in greater water infiltration and a more resilient (able to withstand change) soil system. The question remains, how can the conversion of stubble to soil carbon be promoted in stubble-retained cropping systems?

Laboratory studies have shown that if all the nutrients are added in the right amounts, it is possible to increase the amount of **humus organic carbon (HOC)** produced as microbes break down stubble. Key to this laboratory work was the finding that the additional nutrients required for more effective stubble breakdown need to be applied soon after harvest to give ample opportunity for microbial decomposition of stubbles before sowing the next crop. This means fertiliser is applied to feed soil microbes, rather than feeding plants.

While this concept has been proven in controlled laboratory studies, the theory was yet to be validated in large-scale field studies in a cropping system. It was this lack of field-scale data that prompted Riverine Plains Inc to undertake the: *Increased soil carbon by accelerated humus formation from crop residues* project, from 2012–15.

The *Increased soil carbon by accelerated humus formation from crop residues* project was developed to determine the feasibility of such an approach on a large scale and was funded by the Australian Government's *Action on the Ground* program.

4.2 Project aims

This project broadly asked two key questions:

1. Is it possible to retain more of the carbon in stubble, and so increase our soil carbon values?
2. Is it worth the effort?

In answering these broad questions, the project investigated the differences in soil carbon accumulation under different stubble management (tillage) systems. It also investigated how the timing and quantity of post-harvest nutrient (fertiliser) applications affected stubble breakdown.

The final part of the project aimed to determine how post-harvest fertiliser applications affected nitrous oxide (N_2O) emissions.

4.2.1 Nitrous oxide — a background

Nitrous oxide is a potent greenhouse gas, which can be produced from agricultural soils due to the conversion of soil and fertiliser nitrogen into gas. A key component of this project was to quantify any additional emissions of N_2O released from the soil due to post-harvest fertiliser applications.

Such measurements would indicate a net gain or loss of carbon from the system — if the relative amount of N_2O produced is less than the amount of any extra soil carbon retained via the treatments applied, then a positive net gain in soil carbon sequestration could be demonstrated. On the other hand, if applying fertiliser post-harvest results in high GHG emissions, then any benefits from increased soil carbon would be negated by these emissions.

On completion of the project, a formal project report was submitted to the Australian Government *Action on the Ground* program. The report detailed all results and agronomic measurements carried out on a complex set of treatment combinations.

This publication focusses on the key outcomes of most value and interest to those in the farming community. A copy of the full project report can be obtained by contacting Riverine Plains Inc.

4.3 How the project was carried out

4.3.1 Trial design

Field trials for this project were carried out during 2013 and 2014 at three locations across northern Victoria and southern New South Wales: Rutherglen in northern Victoria (dryland), Culcairn (dryland) and Tocumwal (irrigated) in southern NSW.

Each field trial investigated the effect of different stubble management practices and the application of post-harvest fertiliser at different rates on agronomic production and soil carbon.

The **stubble management treatments** compared responses from:

a. standing stubble (stubble left after harvesting the crop)

b. mulched stubble (stubble cut and left on the soil surface)

c. disced stubble (shallow discing of stubble)

d. burnt stubble (stubble burnt during April, only at Rutherglen).

The **post-harvest fertiliser** treatments compared the application of:

a. 100% of the nitrogen, phosphorus and sulphur requirements for microbial breakdown of stubble, as calculated for each site based on nutrients remaining in stubble residue

b. 50% of the nitrogen, phosphorus and sulphur requirements for microbial breakdown of stubble, as calculated for each site based on nutrients remaining in stubble residue

c. 0% — no post-harvest fertiliser.

The post-harvest fertiliser was applied as Granulock® 15 (14.3%N, 12%P, 10.5%S). The amount of each nutrient applied post-harvest during 2013 and 2014 is listed in Table 3.

4.3.2 Fertiliser applications and stubble treatments

Fertiliser application rates at individual sites were kept constant across all the stubble treatments on that site. Variations in background paddock fertility between the different sites meant fertiliser application rates between sites varied.

Fertiliser was applied:

a. onto stubble residue post-harvest during February–March. While the ideal time for post-harvest fertiliser application is December–January, logistical issues delayed application time. The rate of fertiliser applied post-harvest at each site was calculated based on existing nitrogen, phosphorus and sulphur concentrations of the stubbles at each site: as a result, the fertiliser rates varied significantly between the sites.

b. at sowing with the seed (IBS).

c. as required through the growing season, at the discretion of the host farmer (determined by background paddock fertility and expected yield).

The timing of the various treatments is described in Table 4.

NOTE: The project also examined the effect of variable rates of fertiliser at sowing on crop yield, however the results were not statistically significant and as such have been omitted from this report.

4.3.3 Sowing and rainfall information

The trials were sown during the typical (main season) sowing window for the region. During 2013, sowing at the Tocumwal site was delayed until late May. During 2014, wet conditions delayed sowing at the Rutherglen site until late May (Table 5).

4.3.4 Plot size

Replicated field trials (three replicates) were sown at each site. Plots were 12m x 70m to accommodate the farmer's equipment. Fertiliser treatments were applied perpendicular (at right angles) to the stubble management treatments.

Table 3.
Nutrient content of stubble residue, stubble mass (previous crop), crop type and total nutrient applied to stubble residues during 2013 and 2014 at each site

				Nutrients in stubble residue (%)				Nutrients applied to stubble residues (kg/ha)		
Year	Site	Stubble biomass (t/ha)	Stubble type	C	N	P	S	N	P	S
2013	Rutherglen	6.0	Oats	44.6	1.01	0.10	0.11	6	5	5
	Culcairn	7.9	Wheat	43.7	0.31	0.02	0.09	62	52	45
	Tocumwal	5.3	Wheat	43.3	0.22	0.01	0.05	46	38	33
2014	Rutherglen	10.3	Wheat	44.6	0.38	0.03	0.05	103	87	76
	Culcairn	11.2	Wheat	43.7	0.62	0.09	0.09	59	50	44
	Tocumwal	9.5	Wheat	44.0	0.49	0.04	0.09	83	70	61

Table 4.
Stubble treatment and fertiliser application dates across all sites

Activity	2013	2014
Post-harvest fertiliser application	Mid February – late March	Mid February – late March
Stubble treatments applied	Early February – mid March	Late February – early March
MAP or DAP (at sowing)	Mid – late April	Late April – mid May
Sulphate of ammonia	April (Tocumwal only)	Late April (Culcairn and Tocumwal)
Urea — first application	June – July	Mid July
Urea — second application	Late July – late August	Mid July – late August

Table 5.
Sowing dates, **crop varieties and annual rainfall at each site during 2013 and 2014**

	2013			2014		
	Rutherglen	Culcairn	Tocumwal	Rutherglen	Culcairn	Tocumwal
Sowing date	Late April	Late April	Late May	Late May	Late April	Late April
Annual rainfall (mm)	544	572	389	562	449	538
In-crop flood irrigation events	-	-	3	-	-	3
Crop (cultivar)	Wheat (*cv.* Suntop$^{\Phi}$)	Wheat (*cv.* Sentinel$^{\Phi}$)	Wheat (*cv.* Suntop$^{\Phi}$)	Wheat (*cv.* Suntop$^{\Phi}$)	Canola (*cv.* ATR Gem)	Canola (*cv.* Crusher TT)

4.4 Soil characterisations — site overviews

During 2012, a detailed soil chemical analysis, including a baseline soil carbon measurement, was carried out at each site. These analyses were also used to determine the main soil constraints at each site.

Soil texture below the surface 10cm soil layer varied greatly across each of the sites. Subsoil textures varied from light to heavy clays, with a range of granular material (buckshot at the Rutherglen site) and composition (dispersive at the Tocumwal site).

Each site was additionally sampled for soil chemistry during the August–September period (subject to rainfall and soil sampling conditions). Final soil sampling to measure changes in soil carbon was carried out during 2015 (Figure 4).

Figure 4.
Soil sampling at the Rutherglen site during 2014

5 | Trial details — agronomy and crop yield

Extensive agronomic measurements, including germination counts, tillering and head counts, total biomass at crop maturity and observations of crop growth at booting were taken throughout the project. These results did not provide clear insights into the differences between treatments and are omitted from this report.

Yield is one of the most important predictors of profitability in cropping systems. Yield measurements across all sites and treatments indicated if any yield benefits or penalties were associated with any of the stubble or post-harvest fertiliser treatments. This then also allowed the soil carbon results to be considered in the context of the production system from which they were obtained.

5.1 Operational constraints

During the first year the project team experienced difficulties with sowing operations. At the Rutherglen site, on the more duplex textured soils (lighter-textured surface soil above heavy clay-textured subsoil) of the three sites, the stubble-disced treatments left large mounds (up to 0.5m high) of stubble and soil randomly across the treatment plots. At the other sites the stubble-disced treatments were also rough and germination seemed to be more variable across these treatment plots compared with the other tillage treatments (Figure 5). The stubble remaining on the soil surface, as observed during April, was about 20–40% where stubbles were disced and about 40–60% where stubbles were mulched. On this basis, the stubble discing could be expected to provide better soil-to-stubble contact, resulting in an improved capacity to increase soil carbon levels.

5.2 Field site: Rutherglen

5.2.1 Soil chemistry

A detailed soil chemical analysis indicated the Rutherglen site (Table 6) was fertile and moderately acidic.

The 2012 soil characterisation indicated the topsoil (0–10cm) had a baseline soil organic carbon (SOC) content of 1.9%, which is considered high for cropping soils in the region. The carbon content decreased below 10cm, with most of the carbon found in the topsoil. The topsoil is where most of the plant matter decomposes and is where most of the soil microbes are located, so this is as expected.

5.2.2 Fertiliser

At Rutherglen, the amount of fertiliser applied at sowing and in-crop (as urea) was the same in both 2013 and 2014. However, the total amount of nitrogen added to the Rutherglen site varied between 2013 and 2014 (Table 7) due to the large difference in the rate of post-harvest nitrogen fertiliser applied (6kg/ha in 2013 and 103kg/ha in 2014).

The stubble from the 2012 oat crop had a high residual nutrient content (44.6% C, 1.01% N, 0.10% P and 0.11% S), which meant little nitrogen was required during the 2013 autumn post-harvest fertiliser application. In contrast, a large amount of nitrogen was required in the 2014 autumn post-harvest fertiliser application as the 2013 wheat crop stubble was particularly low in nutrients (44.6% C, 0.38% N, 0.03% P and 0.05% S). The 2013 wheat crop was severely frosted and it is possible the low stubble nutrient content was caused by nutrients leaking from plant cells damaged by freezing.


Stubbled disced | Stubble mulched | Stubble standing

Figure 5.
Photographs of stubble treatments and germinating crop at the Rutherglen site in 2013

Table 6.
Soil characterisation at the Rutherglen site during 2012

	Soil layer (cm)		
Soil parameter	**0–10**	**10–20**	**20–30**
Soil pH$_{Ca}$ (CaCl$_2$)	5.3	5.3	5.4
Soil pH$_w$ (water)	6.0	6.1	6.4
Bulk density (gm/cm^3)	1.3	1.5	1.7
Colwell-P (mg/kg)	43	28	20
EC (dS/m)	0.15	0.09	0.06
Organic carbon (%)	1.9	0.9	0.5
ESP (% of CEC)	1.7	2.2	3.2
CEC (meq/100g)	7.7	5.9	6.2
S (mg/kg)	25	18	13
Nitrate-N (mg/kg)	63	29	21
Soil texture	Sandy clay surface soil over a medium to heavy clay subsoil		
Soil classification*	Chromosol Brown mesotrophic, mottled-sodic		

EC = electrical conductivity, ESP = exchangeable sodium percentage, CEC = cation exchange capacity.
* Classification according to Isbell (1996).

Table 7.
Total nitrogen fertiliser application through the season for the Rutherglen site, including post-harvest application during 2013 and 2014

Fertiliser treatment	2013	2014
Post-harvest nitrogen fertiliser @ 100% (kg/ha)	6	103
Sowing fertiliser (kg/ha)	14	14
In-crop nitrogen fertiliser — urea (kg/ha)	74	74
Total nitrogen applied	**94**	**191**

5.2.3 Rutherglen yields 2013

The 2013 Rutherglen wheat yield results showed that stubble management had a significant impact on crop performance, with the standing stubble and burnt stubble treatments yielding more than the mulched and disced treatments. The negative impact of the mulched and disced treatments may be due to issues at establishment resulting from poor plant growth through piles of stubble (disced treatment) and high volumes of stubble covering the soil surface (mulched treatment) (Figure 6). This was in spite of a damaging frost event, which occurred during October 2013.

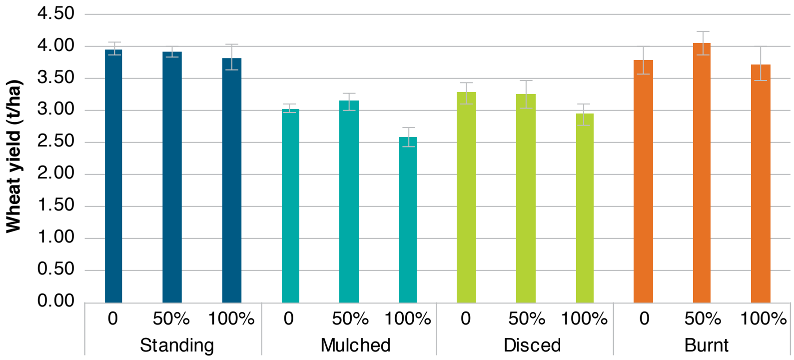


Figure 6.
Grain yield at the Rutherglen site for the stubble and post-harvest fertiliser treatments in 2013
The bars are measures of standard error.

The high residual nutrient content of the 2012 oat crop stubble meant low rates of post-harvest fertiliser were applied during 2013 (6kg/ha at the 100% rate). Because the application rates were so low, the application of post-harvest fertiliser (at any rate) did not influence yields.

5.2.4 Rutherglen yields 2014

A wet start to the 2014 cropping season across the Rutherglen region (461mm rainfall up to September 2014) resulted in slow germination at the trial site; with wheat failing to germinate in some plots. Crop growth at the Rutherglen site was generally poor in the plots receiving no post-harvest fertiliser. As the 2013 crop residue was low in nutrients, there were likely insufficient nitrogen reserves in the soil to support adequate plant growth in the nil post-harvest fertiliser treatments.

Observations of stubble breakdown showed clear visual differences between treatments. Where stubble was disced (speed tilled) there was a clear placement of stubble at about 5cm below the soil surface, which was likely due to high soil moisture content at the time of discing, resulting in the dragging and burial of stubble, rather than cutting and mixing with soil on the surface (Figure 7). This stubble remained intact, with no appreciable breakdown from February through to September, 2014. It is likely the saturated, low-oxygen conditions experienced at the site during winter inhibited microbial access and breakdown of the buried stubble.

Figure 7.
Soil from the disced treatment at the Rutherglen site showing intact stubble buried about 5cm below the soil surface
Source: BIll Slattery

It was also observed that the disced treatments remained wetter than the other stubble treatments. This was likely to be partly because of the neighbouring stubble-mulched treatment, which appeared to shed water down the slope into the disced treatment, and partly from the incorporated stubble facilitating the movement of water into the soil, reducing evaporative losses.

During 2014, low paddock fertility (indicated by low stubble residual nutrient levels and low soil nitrogen results) meant the addition of post-harvest fertiliser was the greatest driver of yield. Grain yield increased significantly with the addition of nitrogen fertiliser (Figure 8) for all stubble treatments, but was not significantly different between stubble treatments for any single fertiliser rate.

This indicates that at least some of the nutrients applied post-harvest to aid microbial activity were used by the following crop.

The corresponding yield map for 2014 is shown in Figure 9. It is worth noting the yield patterns shown on the yield map matched closely the post-harvest nitrogen-fertiliser rates. The red sections of the yield map (lowest yield) aligned closely to the nil post-harvest nitrogen-fertiliser treatment plots and the green sections aligned well with the high fertiliser rates. This result is supported by visual in-crop height differences observed during September 2014 and captured in the yield map (Figure 9) for the post-harvest fertiliser nitrogen rates 103kg N/ha (100%), 52kg N/ha (50%), and 0kg N/ha).

5.3 Field site: Culcairn

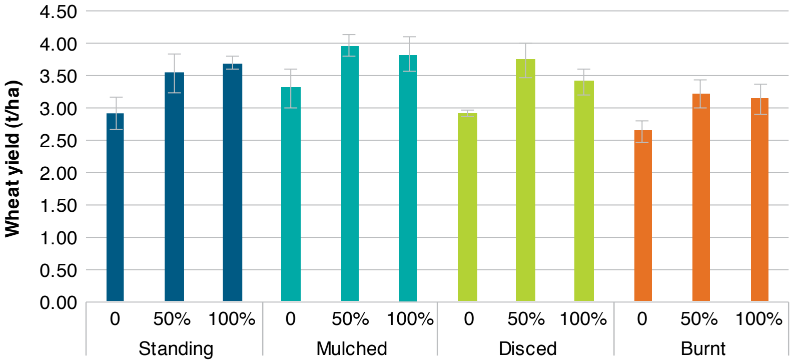
5.3.1 Soil chemistry

The soil at the Culcairn site was fertile and moderately acidic (Table 8). The total SOC content in the 0–10cm layer was 1.8%, which is high for a continuous cropping soil in the region. The carbon content decreased sharply below 10cm, indicating that most of the carbon in the soil was in the topsoil.

5.3.2 Fertiliser

The Culcairn site wheat stubble analysis showed low residual nutrient contents in both 2013 and 2014 (Table 3 on page 10), so similar amounts of post-harvest fertiliser applications were required in both years. The amount of fertiliser applied at sowing and in-crop was also similar between 2013 and 2014 (Table 9).

Figure 8.
Grain yield at the Rutherglen site for the stubble and post-harvest fertiliser treatments during 2014
The bars are measures of standard error.



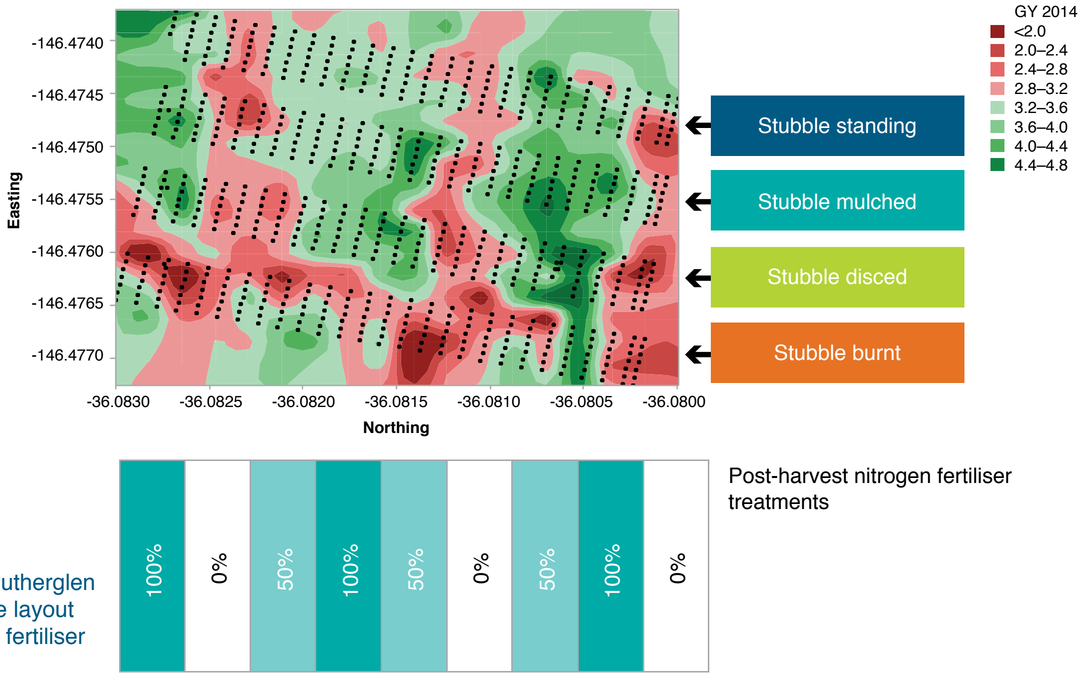


Figure 9.
Grain yield map at the Rutherglen site together with the site layout and pre-sowing nitrogen fertiliser treatments

Table 8.
Soil characterisation at the Culcairn site during 2012

	Soil layer (cm)		
Soil parameter	**0–10**	**10–20**	**20–30**
Soil pH_{Ca} ($CaCl_2$)	5.1	5.0	5.1
Soil pH_w (water)	5.7	5.9	6.1
Bulk density (gm/cm^3)	1.2	1.5	1.6
Colwell-P (mg/kg)	55	26	16
EC (dS/m)	0.16	0.08	0.05
Organic carbon (%)	1.8	0.8	0.4
ESP (% of CEC)	1.0	1.6	1.8
CEC (meq/100g)	7.9	5.7	7.9
S (mg/kg)	17	11	9
Nitrate-N (mg/kg)	61	23	11
Soil texture	Sandy clay loam surface overlaying a medium to heavy clay.		
Soil classification*	Chromosol Yellow mesotrophic, mottled		

EC = electrical conductivity, ESP = exchangeable sodium percentage, CEC = cation exchange capacity.
* Classification according to Isbell (1996).

Table 9.
Total nitrogen fertiliser application through the season for the Culcairn site, including post-harvest application during 2013 and 2014

Fertiliser treatment	2013	2014
Post-harvest nitrogen fertiliser @ 100% (kg/ha)	62	59
Sowing fertiliser (kg/ha)	19	14
In-crop nitrogen fertiliser — urea (kg/ha)	41	41
Total nitrogen applied	122	114

5.3.3 Culcairn yields 2013

Wheat yields at Culcairn during 2013 were low because of the late frosts during October 2013 (Figure 10). While Figure 10 appears to show the mid-range (50%) application rates of post-harvest fertiliser treatment were less affected by frost than the 0 and 100% post-harvest treatments, the large variability in yield means there was no significant difference between treatments.

While frost impacted yields, the biomass results were high (data not shown) and thus the crop residue returned to the soil was also high during 2013.

5.3.4 Culcairn yields 2014

Canola yields at the Culcairn site for 2014 showed no difference between the standing and mulched stubble treatments across all post-harvest fertiliser rates (Figure 11). However, discing stubble increased canola yields in the nil and 50% post-harvest treatment compared with the standing and mulched treatments. The increased yield in the disced treatment may be due to several factors, including the physical removal of stubble from the sowing row, and the associated increase in early vigour — fallen stubble lying across sowing rows physically impedes canola growth.

The 2014 canola yields (Figure 11) indicate the yield in the 50% post-harvest fertiliser treatments was less than both the nil-fertiliser and 100% treatments. This may be explained based on nutrient uptake during the 2013 crop. For reasons unknown, the 50% treatment tended to yield the highest during 2013, even after significant frost damage. This means more nutrients (especially phosphorus) would have been removed from the 50% treatment during the 2013 harvest, while most nutrients were retained in the other treatments, which yielded poorly. Therefore, the 2014 crop in the 50% post-harvest fertiliser treatment may be reflecting a lower nutrient base than the other treatments, resulting in a yield penalty.

5.4 Field site: Tocumwal

5.4.1 Soil chemistry

The soil at the irrigated Tocumwal site was fertile and moderately sodic (Table 10). The total SOC content was lower in the surface soil (0–10cm layer) than at the other sites.

Irrigation causes increased periods of high soil moisture, which under warm conditions can increase the rate at which soil carbon breaks down through soil microbial activity. This increased activity can deplete soil carbon reserves and may explain the relatively low carbon results observed at this site.

5.4.2 Fertiliser

Similar to the Rutherglen and Culcairn sites, the Tocumwal site was severely affected by frost events during October 2013, which may have caused nutrients to leak from damaged plant cells reducing the residual nutrient levels heading into 2014. The higher levels of crop residue observed from the 2013 crop (9.5t/ha) compared with 2012 (5.3t/ha) provided nearly twice the volume of stubble for microbes to digest. This, when combined with the relatively low residual nutrient content of the 2013 stubble (Table 4 on page 11) explains the need for more autumn post-harvest nitrogen during 2014 compared with 2013 (Table 11).

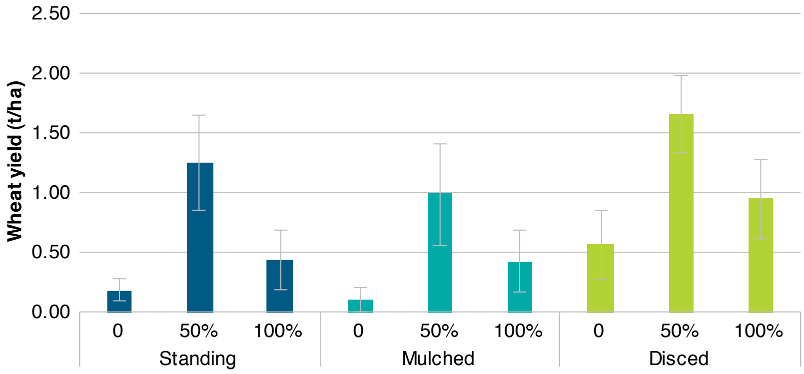


Figure 10.
Grain yields at the Culcairn site for the stubble and post-harvest fertiliser treatments during 2013
Bars are measures of standard error.

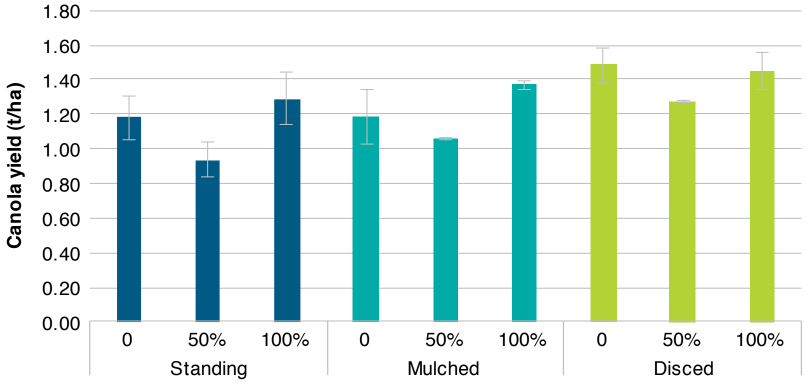


Figure 11.
Grain yield at the Culcairn site for the stubble and post-harvest fertiliser treatments during 2014
Bars are measures of standard error.

Table 10.
Soil characterisation at the Tocumwal site during 2012

Soil parameter	Soil layer (cm) 0–10	10–20	20–30
Soil pH_{Ca} ($CaCl_2$)	5.9	6.0	6.1
Soil pH_w (water)	6.7	7.0	7.1
Bulk density (gm/cm^3)	1.1	1.2	1.1
Colwell-P (mg/kg)	36	23	12
EC (dS/m)	0.19	0.15	0.15
Organic carbon (%)	1.3	0.7	0.6
ESP (% of CEC)	5.8	8.8	9.9
CEC (meq/100g)	21.8	22.5	24
S (mg/kg)	67	41	38
Nitrate-N (mg/kg)	20	19	19
Soil texture	Clay loam surface soil over a heavy clay, showing shrinking/swelling		
Soil classification*	Sodosol Grey mottled-eutrophic, mottled-sodic		

EC = electrical conductivity, ESP = exchangeable sodium percentage, CEC = cation exchange capacity.
* Classification according to Isbell (1996).

Table 11.
Total nitrogen fertiliser application through the season for the Tocumwal site, including post-harvest application during 2013 and 2014

	2013	2014
Post-harvest nitrogen fertiliser @ 100% (kg N/ha)	46	83
Sowing fertiliser (kg N/ha)	22	25
In-crop nitrogen fertiliser — urea (kg N/ha)	104	104
In-crop nitrogen fertiliser — SOA (kg N/ha)	9	9
Total nitrogen applied	**181**	**221**

SOA=sulphate of ammonia

5.4.3 Tocumwal yields 2013

There were no differences in wheat yields between the stubble treatments at the Tocumwal site during 2013 (Figure 12), which may be partly due to the impact of frosts during October, which effectively masked any treatment effects. As yields were only slightly lower than the average wheat yields of 4–5 t/ha for this region in an above-average year, the impact of frost was less than that measured at Culcairn.

During 2013, post-harvest fertiliser applications accounted for up to 25% of the total nitrogen received by the crops (46kg N/ha at 100% rate, 23kg N/ha at 50% rate and 0kg N/ha post-harvest). The remaining fertiliser (133kg N/ha) was applied at sowing or in-crop as urea or sulphate of ammonia (SOA). This meant the 0% and 50% post-harvest fertiliser treatments received almost as much nitrogen as the 100% post-harvest treatment, which resulted in only a small difference in fertility across the treatments. This is reflected in the lack of response to fertiliser treatments during 2013.

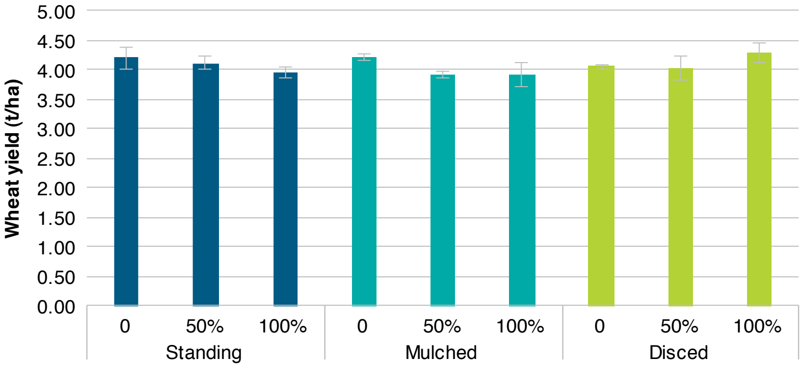


Figure 12.
Grain yield at the Tocumwal site for the stubble and post-harvest fertiliser treatments during 2013
Bars are measures of standard error.

5.4.4 Tocumwal yields 2014

During 2014, the Tocumwal site was sown to canola. Yield results show the mulched and disced treatments performed significantly better than the standing stubble treatment across the various post-harvest fertiliser treatments (Figure 13). Germination counts for canola during 2014 (data not shown) showed a significant decrease in plant numbers for the standing-stubble treatment compared with the other two stubble treatments. Where the standing stubble was flattened over the sowing row during sowing, the decreased plant numbers under this treatment could be due to the flattened stubble presenting a physical barrier to the growth of the young canola seedlings. These results are reflected in the yield results (Figure 13).

Within each stubble treatment, the 50% post-harvest fertiliser treatment performed significantly better than the nil and 100% post-harvest fertiliser rates, which was possibly due to nitrogen 'overload' in the 100% post-harvest treatments. As the 100% post-harvest application rate treatment received 83kg N/ha during early autumn, followed by 25kg N/ha at sowing and 113kg N/ha in-crop, it is possible the high dose of nitrogen around sowing was enough to tip the scales beyond that required for optimal plant growth, resulting in a negative yield response (Figure 13).

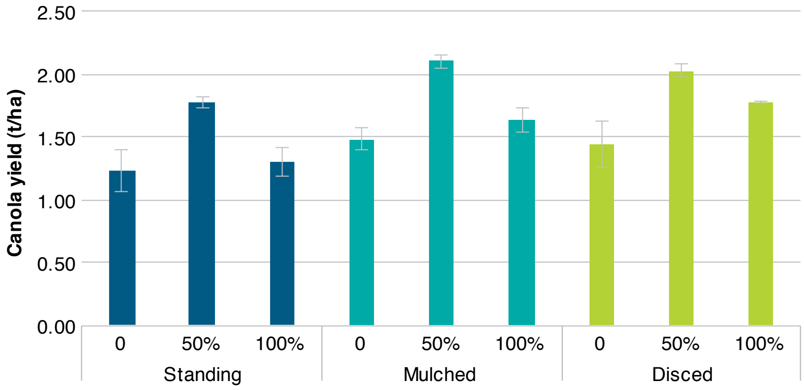


Figure 13.
Canola yields at the Tocumwal site for the stubble and post-harvest fertiliser treatments during 2014
Bars are measures of standard error.

6 | Canopy composition and crop production

Agronomic measurements at all three sites during both 2013 and 2014 showed that inputs of biomass residue had not been restricted by treatment effects or adverse climatic conditions. Yields of total crop biomass remained high despite low grain yields, however this presented other challenges in respect to sowing crop emergence and weed control.

During 2014 at all sites, a speed tiller was used to incorporate stubble residues rather than relying on shallow discing. While this practice provided maximum soil–stubble residue contact, there were significant problems associated with sowing through buried stubble with narrow knife points at the Rutherglen site, which required the use of a disc seeder to sow through buried stubble residues.

Andrew Russell

Business name	Location	Farm size	Soil types
Lilliput Ag	Lilliput, Cornishtown and Browns Plains	2500ha	Generally red/grey duplex loams over a clay base

Q Describe your farming enterprise.

We have just introduced sheep back into our business after 10 years and this has shifted the enterprise mix, so we now use 90% of our land for cropping and hay, while the other 10% is for livestock (including an intensive cattle operation).

Q What is your cropping sequence/rotation?

We are now running a four-year rotation based around 50% cereals, 30% canola and 10% grain legumes (mostly faba beans), with the remaining 10–15% of our area used for forage/hay legumes, such as arrowleaf and balansa clovers.

The rotation (more or less) follows the pattern of faba beans or forage legumes, canola, then two years of cereals. This gives the canola an opportunity to use the 'free' nitrogen provided by the previous year's beans.

Our rotations are quite complex because we are also running a seed business and all cereal seed crops need to be sown into ground that has not grown cereals for the previous 24 months.

Grain legumes, such as lupins, used to make up 25% of our rotation, but we've recently reduced this to around 10% of our area in response to seasonal conditions and difficulties in marketing.

Sheep are back in the mix because we can't afford to have a legume crop that isn't profitable. By decreasing our grain legume percentage and increasing our forage legume/hay percentage by the same amount, we can retain an overall legume percentage of around 25%. This means we have the break crop options we need as well as simultaneously improving soil health and soil carbon.

We've also changed our grain legume mix by growing more faba beans at the expense of lupins. Faba beans can handle wet feet better than lupins and are easier to manage. They also seem to better tolerate the dry spring conditions we have been experiencing.

Q How do you manage the stubbles within your cropping system?

While we still have to burn most of our cereal crop stubbles, all our canola gets a pass with the stubble cruncher to break it up and lay the stubble on the ground. We also fully retain all our legume stubbles.

Ideally we would like to cut all of our cereal stubbles at 'beer-can height' and retain them all. We strategically burn our windrowed header tailings where we have weed issues.

Q What soil carbon values do you have across your property, on average (0–10cm depth)?

Our OC results range from around 0.8 to 1.9% We run as a minimum-till operation and slowly but surely we are improving these levels.

We focus on soil health and in particular increasing our root biomass, which we believe is also having a positive effect on soil carbon. We are also getting a boost in OM from sowing earlier and using longer-season winter wheats.

Q What value do you place on maintaining/improving soil carbon in your cropping system?

I think we need to maintain OC and increase the cation exchange capacity (CEC) of the soil to make nutrients more available to plants. The increased mineralisation means we can better capitalise on organic nitrogen. As such it is a high priority for us.

Q Are you trying to improve your soil carbon values?

Soil health, and by association, OC, is always front of mind. Our focus is on improving the health of our soils so increasing OC (by incorporating more OM) plays a huge role in that.

We are actively trying to sow earlier to increase the size of our root systems and to provide our crops with a better plant structure so they are more resilient during a dry spring.

In terms of risk management, improving soil health ticks many boxes and improves productivity and profitability.

We value the role legumes play in our system and a positive by-effect of that is we are also increasing our OC levels.

Q Are you likely to change your management practices to attempt to improve soil carbon?

At the moment I'm pretty comfortable with the steps we are taking to improve OC, so I don't have immediate plans to change much in the near future.

Q Would you consider adding fertiliser to stubble post-harvest as a viable option for improving soil carbon?

I'm not convinced the mechanical breakdown of stubble is effective without sufficient (and early) summer rainfall. This is actually where I'd like to see sheep become part of the discussion again. Sheep grazing stubbles have been shown to enhance cycling so if we can get stubble breakdown to happen more quickly through sheep then I think that would be a better alternative.

7 | Trial details — soil carbon

Soil carbon measurements were taken from each site in 2012 before the field trial was established, with sampling carried out within each treatment during August–September 2013 and 2014 to determine the effects of the treatments imposed. Soil samples were taken at 0–10cm, 10–20cm and 20–30cm depth to identify the distribution of soil carbon through the profile (Figure 14) and how the various stubble and fertiliser treatments influenced the amount of soil carbon remaining in the soil.

7.1 Field site: Rutherglen

While some variation in total SOC was measured at the Rutherglen site across treatments and time, no statistically significant differences were found. The average SOC values at each depth were: 1.40% at 0–10cm, 0.83% at 10–20cm and 0.42% at the 20–30cm depth increment (Figure 14 to Figure 16). The results show the percentage of SOC was almost halved at each depth increment, with the highest proportion of carbon in the 0–10cm layer (as would be expected).

In the 0–10cm depth increment there were non-significant trends of declining SOC seen in the nil fertiliser treatments in the standing stubble, mulched and burnt treatments, with the 2014 values being slightly lower than the 2013 values. Additional soil sampling was conducted at the Rutherglen site in 2015, the season after the project treatments were completed, to determine if there were any residual effects of treatments on SOC in the 0–10cm depth only (Figure 14).

Figure 14. Total soil carbon values for the stubble and post-harvest fertiliser treatments at 0-10cm during 2012 (before applying treatments), 2013 and 2014 at Rutherglen. Additional sampling was also carried out at this site in September 2015, after the project was completed

Bars are measures of standard error.
Values are expressed as a percentage (g/100g).
Not corrected for equivalent soil mass.

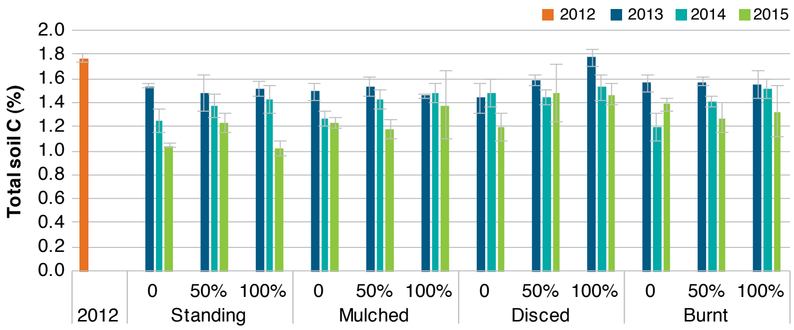


Figure 15. Total soil carbon values for the stubble and post-harvest fertiliser treatments at 10–20cm during 2012 (before applying treatments), 2013 and 2014 at Rutherglen

Bars are measures of standard error.
Values are expressed as a percentage (g/100g).
Not corrected for equivalent soil mass.

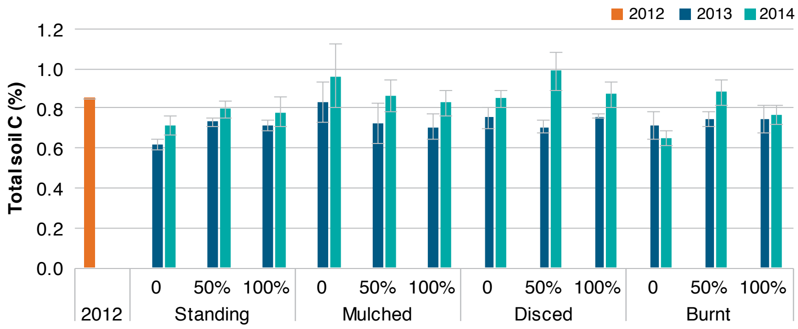
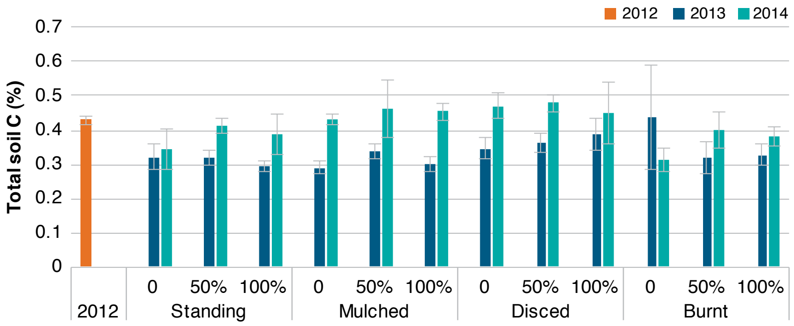


Figure 16. Total soil carbon values for the stubble and post-harvest fertiliser treatments at 20–30cm during 2012 (before applying treatments), 2013 and 2014 at Rutherglen

Bars are measures of standard error.
Values are expressed as a percentage (g/100g).
Not corrected for equivalent soil mass.



While there appeared to be trends, these were non-significant, with the 2015 results further highlighting the inherent variability in sampling for SOC.

The 10–20cm depth was characterised by high variability, and no trends were evident (Figure 15).

The 20–30cm depth increment showed a stronger trend towards increasing SOC during 2014 in the standing stubble, mulched and disced treatments, compared with 2013, although this was not significant (Figure 16). The increase was most likely due to the movement of water-soluble SOC to depth due to the water-logged conditions of early 2014. Water soluble SOC is not likely to contribute to on-going sequestration as it is readily decomposable by soil microbes, however it may benefit plant roots growing through this zone.

7.2 Field site: Culcairn

There was no effect of stubble or fertiliser treatment on SOC values at the Culcairn site over the two years of treatments for the 0–10cm, 10–20cm or 20–30cm depth increments (Figure 17 to Figure 19). The average SOC values across the site with depth were 1.64% at 0–10cm, 0.68% at 10–20cm and 0.34% at 20–30cm, with SOC levels nearly halving at each depth increment.

This site was characterised by high variability in total SOC, which makes it difficult to identify any significant treatments effects.

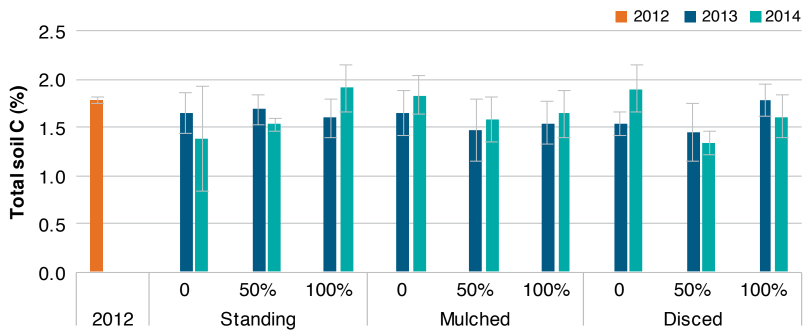


Figure 17.
Total soil carbon values for the stubble and post-harvest fertiliser treatments at 0–10cm during 2012 (before applying treatments), 2013 and 2014 at Culcairn
Bars are measures of standard error.
Values are expressed as a percentage (g/100g).
Not corrected for equivalent soil mass.

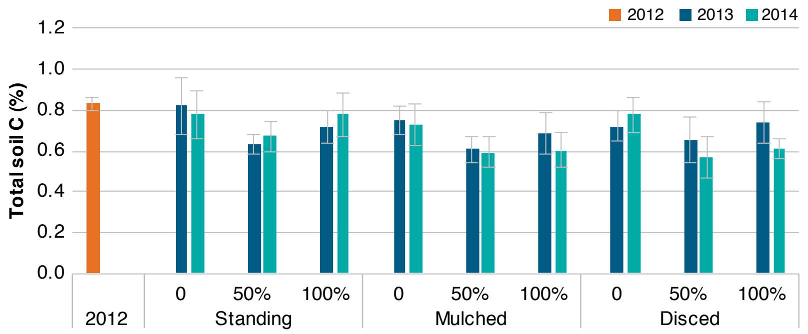


Figure 18.
Total soil carbon values for the stubble and post-harvest fertiliser treatments at 10–20cm during 2012 (before applying treatments), 2013 and 2014 at Culcairn
Bars are measures of standard error.
Values are expressed as a percentage (g/100g).
Not corrected for equivalent soil mass.

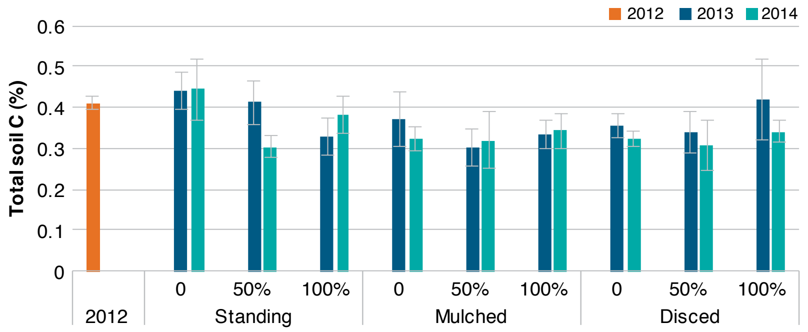


Figure 19.
Total soil carbon values for the stubble and post-harvest fertiliser treatments at 20–30cm during 2012 (before applying treatments), 2013 and 2014 at Culcairn
Bars are measures of standard error.
Values are expressed as a percentage (g/100g).
Not corrected for equivalent soil mass.

7.3 Field site: Tocumwal

The surface SOC values at the Tocumwal site were lower than at Rutherglen or Culcairn, with an average of 0.97% at the 0–10cm depth in 2014 (Figure 20). This relatively low SOC value is likely due to the site's irrigation history.

Maintaining higher soil moisture during warmer months (through irrigation) will stimulate microbial activity, which will break down OM more rapidly. This results in larger losses of carbon from the soil to the atmosphere as carbon dioxide gas (CO_2). This makes it more difficult to build, or even maintain, higher SOC levels under irrigated systems.

At the Tocumwal site, SOC values did not decrease with depth as sharply as the Rutherglen and Culcairn sites (where the soil carbon reading for each 10cm depth increment almost halved). The average SOC values at Tocumwal were 0.67% (10–20cm depth), and 0.53% (20–30cm depth) in 2014. This compares with 0.83% at Rutherglen and 0.68% at Culcairn (10–20 cm depth) and 0.34% at Rutherglen and 0.53% at Culcairn (20–30cm depth) in 2014. This may be due to leaching of water-soluble SOC to depth, and the breakdown of larger root systems, both of which would be aided by long-term irrigation.

There were no statistically significant changes in SOC levels across the different stubble and fertiliser treatments, or with time (Figure 20 to Figure 22) at Tocumwal over the course of the project. This may be due to the high spatial variability at this site, which is discussed on page 24.

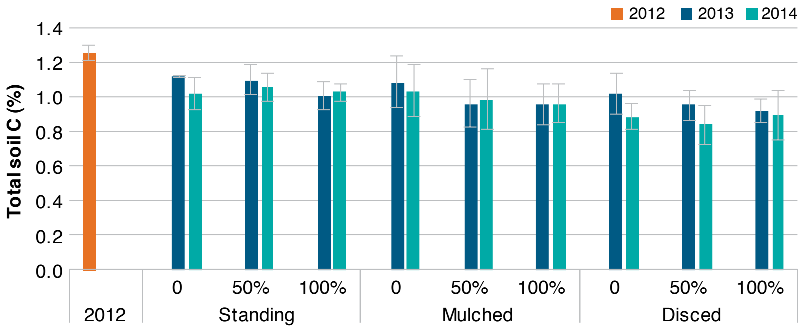


Figure 20. Total soil carbon values for the stubble and post-harvest fertiliser treatments at 0–10cm during 2012 (before applying treatments), 2013 and 2014 at Tocumwal

Bars are measures of standard error.
Values are expressed as a percentage (g/100g).
Not corrected for equivalent soil mass.

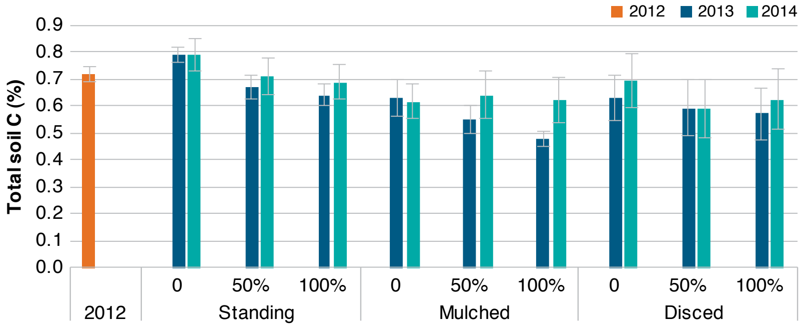


Figure 21. Total soil carbon values for the stubble and post-harvest fertiliser treatments at 10–20cm during 2012 (before applying treatments), 2013 and 2014 at Tocumwal

Bars are measures of standard error.
Values are expressed as a percentage (g/100g).
Not corrected for equivalent soil mass.

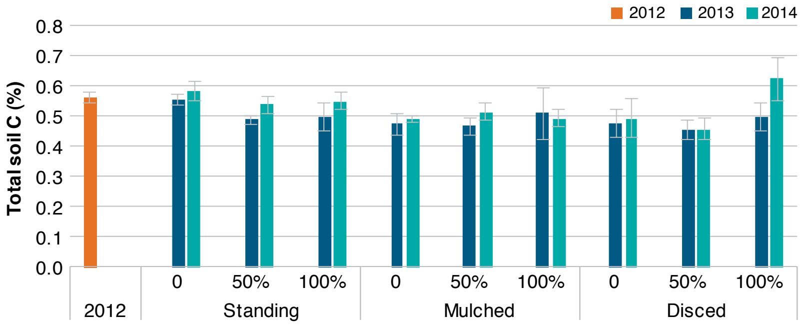


Figure 22. Total soil carbon values for the stubble and post-harvest fertiliser treatments at 20–30cm during 2012 (before applying treatments), 2013 and 2014 at Tocumwal

Bars are measures of standard error.
Values are expressed as a percentage (g/100g).
Not corrected for equivalent soil mass.

7.4 Measuring soil carbon fractions at Rutherglen in 2014 — were there any differences?

During 2014 at Rutherglen, a selection of soils was sampled to identify the quantity and types of carbon present in the stubble treatments. The tests measured the amount of **particulate organic carbon** (POC), **humus organic carbon** (HOC), and **recalcitrant organic carbon** (ROC), present in the soil under the various treatments.

Samples were taken only from plots that received the 100% or 0% post-harvest fertiliser treatments, to identify the potential range of values (while acknowledging changes in soil carbon fractions are unlikely to occur in such a short time-frame).

These results showed no statistical differences in carbon fractions between any of the treatments (Table 12).

This project was designed to look at changes in SOC due to management changes within a particularly short timeframe (three years), with carbon fraction sampling occurring after only two years of management change.

The absence of statistically-significant results over this short period suggests longer periods of change and measurement might be required to determine if applying post-harvest fertiliser to increase stable SOC is a valid approach in north east Victoria.

Looking generally at the results, the proportions of OC in each fraction are relatively stable across the treatments, with about 2.1g/kg of POC, 8.6g/kg of HOC and 3.7g/kg of ROC (Table 12).

The variation associated with these values is relatively small (shown as the LSD value), which suggests within a soil type/location, eliciting a significant treatment effect would take time and require drastic management changes.

7.5 Summary of soil carbon results across sites — key points

Stubble management (standing, mulching, discing or burning) and the impacts on soil carbon values in the short term

Across all the trial sites, and over the three-year life of this project, there were no clear differences in SOC values that could be attributed to the different stubble management practices (Figure 14 to Figure 22).

As stubble breakdown is most effective when stubble is in contact with soil microbes, the discing treatment could have reasonably been expected to have accelerated stubble breakdown compared with the other treatments (and therefore deliver higher levels of soil carbon), especially in the 0–10cm surface soil layer.

Conversely, it would also have been reasonable to expect the burnt treatment at the Rutherglen site (with its lower levels of crop residue available for breakdown) to have measurably decreased SOC in the 0–10cm layer relative to the other treatments.

Neither of these expectations proved true under statistical analysis. While there was a trend for declining SOC in the nil fertiliser treatment under stubble burning, this was not significant.

Table 12.
Soil carbon fractions from selected high and low post-harvest fertiliser treatments at the Rutherglen site during 2014

		Soil carbon fraction (g/kg soil)		
Stubble treatment	Post-harvest fertiliser	Particulate organic carbon (POC)	Humus organic carbon (HOC)	Recalcitrant organic carbon (ROC)
Standing	100%	2.3	8.7	3.6
	0%	2.1	8.3	3.5
	LSD (p<0.05)	*0.3*	*0.8*	*0.4*
Mulched	100%	2.0	8.5	3.8
	0%	1.9	8.4	3.7
	LSD (p<0.05)	*0.4*	*0.7*	*0.5*
Disced	100%	2.3	8.9	3.8
	0%	2.0	8.7	3.7
	LSD (p<0.05)	*0.3*	*0.8*	*0.4*
Burnt	100%	2.4	9.1	3.8
	0%	2.1	8.7	3.7
	LSD (p<0.05)	*0.3*	*0.6*	*0.4*
LSD (p<0.05) between stubble treatments		*0.3*	*0.7*	*0.4*

The failure of stubble management technique to impact significantly on SOC levels may be due to several factors, including the high variability across sites, and/or insufficient summer and early autumn rainfall to optimise microbial breakdown of stubble. It is also possible there was insufficient time to detect measurable changes in SOC between treatments or that equally, stubble management has only a limited impact on **total** SOC, as discussed in the introduction.

Limitations of using post-harvest fertiliser as a means to increase soil carbon values in the short term

While previous experiments under controlled conditions have demonstrated the potential for post-harvest fertiliser addition to increase the HOC fraction of SOC, only limited large-scale validation of this concept has previously been attempted. In undertaking this project, Riverine Plains Inc identified three key factors that have most likely limited the potential increase in stable, HOC within the constraints of the field trials:

Water

Microbes require three things in order to function efficiently: air, nutrients and **water**. Even if microbes have access to all the nutrients they require, without adequate moisture they cannot function efficiently. Applying fertiliser to stubble during summer can only aid microbial activity if moisture levels are sufficient for microbes to operate. If conditions are too hot and dry, microbes will function more slowly, doing less until conditions improve. While fertiliser can be applied during summer to provide additional time for stubble breakdown, it may be that microbial activity doesn't increase until autumn, when there is adequate moisture.

In theory, irrigated sites should have a greater opportunity to convert stubble into SOC with the addition of fertiliser during summer — irrigation could potentially keep soil microbes operating in an optimum, moist environment. In reality however, it would not be economically feasible to spend money on irrigation water to support microbial activity in preference to crop growth. Given this outlook, the Tocumwal irrigated site was not watered during summer, which perhaps was a missed opportunity to look more closely at microbial activity during this time.

Site variability

Each trial site was surveyed via EM38 mapping to identify the 'more uniform' areas of the paddock suitable for the SOC trial work. Despite the pre-trial surveying, the within-site SOC variability was high at each of the three trial sites. Every paddock has some degree of variability, which must be accounted for when soil sampling — usually the greater number of soil samples, the more comprehensive the information returned. However, because the natural variability in SOC was so high at each site, an enormous change in SOC levels (due to management) would have been required to achieve a statistically significant change in SOC across the treatments. This is why achieving (and measuring) a change in SOC at the paddock scale is so difficult, even when you think you are doing everything right.

Time

The three-year time frame for this project was likely too short to determine whether any of the treatments applied had the potential to change SOC levels at each trial site, or the lack of measured change could in fact have been a true reflection of what might happen over a longer time period. Long-term monitoring over 10^{+} years would be recommended in order to develop a more definitive answer on the impact of stubble management and post-harvest fertiliser on the amount and form of SOC stored in local soils.

Andrew Godde

Business name	**Location**	**Farm size**	**Soil types**
Godde Farms Pty Ltd	Culcairn/Henty	1500ha owned and 500ha leased	Heavy clays to red loams

Q Describe your farming enterprise.

Mixed farming (sheep and cropping), with around two-thirds cropping and one-third sheep.

Q What is your cropping sequence/rotation?

On our own country, the rotation is usually wheat/wheat/lupins/canola. On our leased area, we usually go with a wheat/wheat/canola rotation. Lupins are our only legume at present, but I am considering faba beans for the future.

We have recently increased the amount of lucerne we grow to cater for the increased size of our sheep enterprise. We can usually get five years out of our lucerne stands before moving back into something else. We don't have permanent pasture as such — we use grazing wheats and oat varieties for early feed, and also graze our crop stubbles.

Q How do you manage your stubbles within your cropping system?

We currently burn about 50% of our crop area and retain the other 50%. We tend to burn in front of canola or lupins, which helps us better manage problem pests, like slugs.

We usually retain wheat stubbles when sowing wheat on wheat, but this doesn't always work with heavy stubble loads or if we have other issues. When we burn we always do so as late as we can to keep the soil covered for as long as possible. We also windrow burn our canola and lupin header trails to manage ryegrass weed seeds.

Q What soil carbon values do you have across your property, on average (0–10cm depth)?

Our organic carbon (OC) percentage results vary across our area. It ranges from as low as 1.1% to 2.1% — but they average around the 1.5% mark.

I've been managing the cropping side of the business for about five years and this is when we first started soil testing — our results have slightly increased since then.

Q What value do you place on maintaining/improving soil carbon in your cropping system?

It's something that we are conscious of because of the flow-on benefits, so where we can easily change our practices to improve our soil OM percentage (and associated OC percentage), then we will. We have a number of priorities within our farming operation at the moment, and while it's not a top priority it is certainly something we are mindful of.

Q Are you trying to improve your soil carbon values? If so, how?

We would like to see an increase in soil carbon, particularly in our lower-range soils. We do our best to retain stubble and don't burn unless there is a real need.

We are also looking to upgrade our seeder so it can handle greater volumes of stubble, which will further reduce the need to burn.

For a long time our rotation was wheat/wheat/canola, and we are now trying to put more emphasis on legumes in the rotation, especially now we have increased scale of our sheep operation.

Q Are you likely to change your management practices to attempt to improve soil carbon?

While we are happy to make easy changes to our system, to do more requires the practice to be economic. For instance, I would consider adding fertiliser to stubbles to aid stubble breakdown, however fertiliser is expensive and I question the value of applying it during anything other than a wet summer. If it's going to be applied, the fertiliser should really be on early in January, which can also be a bit of a challenge with family holidays a priority after harvest and Christmas.

8 | Nitrogen gas emissions — does post-harvest fertiliser increase emissions?

The project aimed to determine if additional nitrogen applications would generate nitrous oxide (N_2O) emissions beyond those considered current best practice. To this end, N_2O emissions were measured at the Rutherglen and Culcairn sites (using specialised gas collection chambers) in the stubble-disced treatments only, from January 2014 for more than 12 months. The stubble-disced treatments were chosen for monitoring because they were considered to have maximum contact between the soil and post-harvest fertiliser for microbial activity.

The results from this monitoring showed substantially higher emissions of N_2O on plots with post-harvest fertiliser compared with no post-harvest fertiliser.

8.1 Field site: Rutherglen 2014

The Rutherglen site showed high N_2O emissions, even from the nil post-harvest fertiliser treatments. Saturated, warm soil conditions favour N_2O emissions, and the wet, often waterlogged, conditions experienced between April and June 2014 (Figure 23) provided ideal conditions for elevated N_2O emissions. These conditions, when combined with post-harvest fertiliser applications, significantly increased N_2O emissions and resulted in an extra 1.2% of the total applied nitrogen being lost as N_2O. This was above the 0.6% lost with standard farmer fertiliser practice.

To offset this increase in emissions, an additional **0.03%** of SOC would need to be captured, or sequestered, each year to offset the increase in greenhouse gases (GHG). While this does not seem a large amount; it is what is needed just to **maintain** the current balance of GHG emissions vs SOC stored if post-harvest fertiliser applications are to continue. Based on the lack of change in SOC observed throughout this project, the likelihood of achieving such an increase every year would be considered low.

8.2 Field site: Culcairn

Because the soil at the Culcairn site did not become as wet as the Rutherglen soil during 2014, the rates of N_2O emissions at Culcairn were much lower than at Rutherglen, even with the post-harvest fertiliser treatment (Figure 24).

This means the carbon sequestration required to offset the N_2O emissions from the post-harvest fertiliser applications at the 100% rate at this site during 2014 was low, requiring only an additional **0.002%** SOC to be captured each year (assuming seasonal conditions as for 2014).

As discussed previously, no increase in SOC has been demonstrated within the three-year project time-frame by applying post-harvest fertiliser. If future research should show statistically significant increases could be measured over a longer period, then the total cost (and emissions) associated with increasing SOC over that period, prior to change being measured, must be considered.

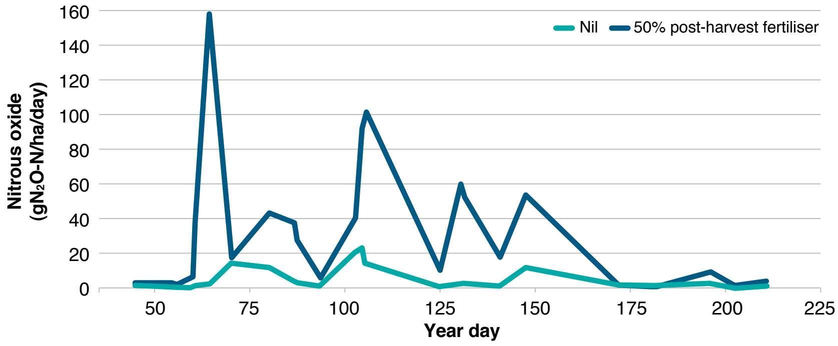


Figure 23.
Cumulative nitrous oxide emissions from the disced treatment at the Rutherglen site, starting January 2014

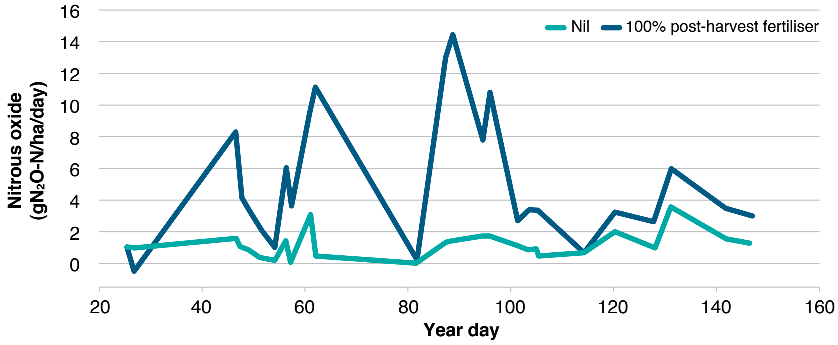


Figure 24.
Cumulative nitrous oxide emissions from the disced treatment at the Culcairn site, starting January 2014

9 | Soil nitrogen

Considering the amount of nitrogen fertiliser applied through this project, the fate of the nitrogen applied to the different treatments was determined. Soil sampling for mineral nitrogen (nitrate + ammonium) was carried out at increments to a depth of 80cm during September 2014 at the Rutherglen site only. Only the nitrate-nitrogen results are reported due to the variability in ammonium under wet conditions.

There was a general trend of increased nitrate concentrations at depth, which was due to the high amount of rainfall during 2014 and the waterlogged conditions through winter. The decreased nitrate measured in the 10–30cm zone may indicate plants have actively extracted nitrogen from this depth.

Within each stubble treatment, there was increased movement of nitrate-nitrogen to depth, with the addition of 100% post-harvest fertiliser, which was significant in the burnt, disced and mulched treatments (Figure 25). As all other fertiliser applications through the season were consistent, this showed the fertiliser applied before sowing may still have contributed to in-crop nitrogen as it moved into the rootzone; however, plants may not have accessed this nitrogen, due to poor root growth under waterlogged conditions.

A comparison of the different stubble treatments at the 100% post-harvest fertiliser rate shows the capacity for nitrate storage and movement under high nitrogen supply (Figure 26). The increased nitrate accumulated at depth in the disced treatment may relate to the physical disturbance, which occurred in the disced treatment. The disturbance of the soil and increased contact between the stubble and soil, which occurred with discing, is likely to have increased the potential for microbial conversion of organic nitrogen to mineral nitrogen.

These results have highlighted the movement of plant-available nitrogen through the soil that can occur during a wet winter. Similar results have been measured at other sites in the region, showing the capacity of nitrate to leach. These results are certainly in contrast to those generally measured after non-waterlogged winter conditions, when there would be stratification of nitrate, with accumulation in the surface horizons.

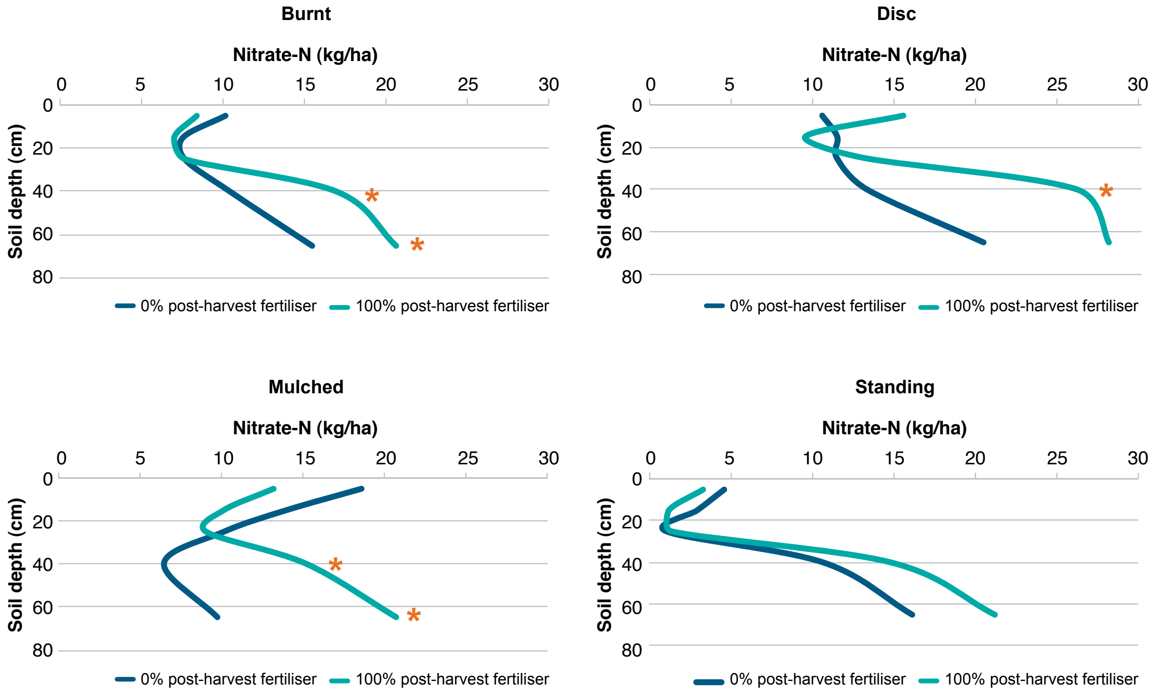


Figure 25.
Mineral nitrogen at depth under the four different stubble management treatments at the Rutherglen site, measured September 2014

Note: Only the nil (0%) or 100% post-harvest fertiliser rates are shown. The asterisks (*) on each graph show the depth at which there was a significant difference between the 0% and 100% post-harvest fertiliser treatments.

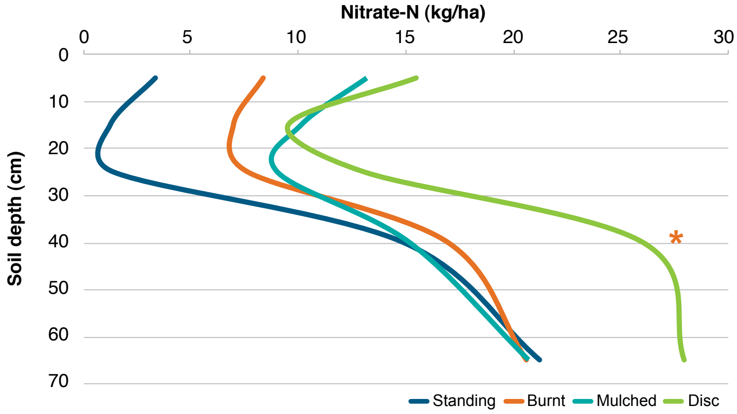


Figure 26.
Mineral nitrogen at depth, compared across the four different stubble management treatments at the Rutherglen site, measured in September 2014

Note: Only the 100% post-harvest fertiliser rate is shown. The asterisk (*) show the depth at which there was a significant difference between the disced treatment and the other different stubble management treatments.

Nitrogen Fertiliser	kg N/ha	Date
Pre-sowing fertiliser	101	15 Feb
Sowing fertiliser	0	26 May
Aerial spray	28	15 July
Ground spray	46	30 Aug
Total Nitrogen	175	

10 | Cost of applying post-harvest fertiliser

For carbon sequestration to be financially viable, we must also consider the cost of applying post-harvest nitrogen, phosphorus and sulphur. In this cost analysis, only the cost of nitrogen and phosphorus fertiliser has been compared between post-harvest applied fertiliser and standard farmer practice (for 2014). The spreading cost has also been included as this is an additional operation that would not normally be incurred.

The comparison is between the highest rate of post-harvest fertiliser and the standard rate of in-season fertiliser applied by the farmer at each site. As demonstrated in Table 13, the additional fertiliser required to increase the nitrogen, phosphorus and sulphur concentrations in the stubble residue to stimulate microbial decomposition and facilitate humus formation cost **$285/ha** at Rutherglen, **$177/ha** at Culcairn and **$249/ha** at Tocumwal during 2014.

If nitrogen could be supplied through fixation by legume crops, then the cost of applying the additional phosphorus and sulphur could be as low as $60/ha. This could be a more feasible option, but would require additional work to consider the overall agronomic and economic value of including the legume phase, including validation work on whether inclusion of a legume phase can contribute to any increase in stable HOC.

As described earlier, there were some significant differences in yield observed between the nil and 100% post-harvest treatment rates at some sites in some stubble treatments. In these instances, some of the additional cost of applying the additional post-harvest fertiliser were recouped through increased yield and therefore increased per-hectare returns. The increased yields indicated the applied post–harvest fertiliser remained available to the subsequent crop and may have contributed to improved fertility at particular sites. However, this may not be the case across all years, as rainfall (timing and amount received) will have a bearing (either positive or negative) on the response to the additional fertiliser applied.

Table 13.

Total cost of applying nitrogen, sulphur and phosphorus fertiliser to stubble residue at the Rutherglen, Culcairn and Tocumwal sites during 2014

Site	Fertiliser treatment (%)	Total fertiliser applied Granuloc 15 (kg/ha)	In-season fertiliser applied as urea or MAP (kg/ha)	Total cost of fertiliser @$380/t ($/ha)	Cost of spreading fertiliser @$40/t ($/ha)	Total cost of applying fertiliser ($/ha)	Additional cost of applying fertiliser onto stubbles ($/ha)
Rutherglen	100	736	287	385	37	402	**285**
	0	0	287	109	8	117	
Culcairn	100	421	167	223	22	245	**177**
	0	0	167	63	5	68	
Tocumwal	100	592	407	380	36	416	**249**
	0	0	407	154	13	167	

Peter Campbell

Business name	**Location**	**Farm size**	**Soil types**
Petal Partnership	Henty	2000ha	Red brown earths and yellow podzolics

Q Describe your farming enterprise.

Mixed farming (sheep and cropping), based on about 75% cropping and 25% pasture.

Q What is your cropping sequence/rotation? Are there any pastures/legumes in the system?

Usually canola/wheat/lupins/wheat. We usually have seven years of cropping, then five years of pasture. Our pastures are usually a clover/lucerne mix; but we also have perennial grass pastures.

Q How do you manage your stubbles within your cropping system.

We retain our stubbles.

Q What soil carbon values do you have across your property, on average (0–10cm depth)? Have these improved, stayed the same, or decreased compared with previous years?

They vary across the farm from 1.4–2.2% and have gradually improved since we started looking to increase our soil carbon levels.

Q What value do you place on maintaining/improving soil carbon in your cropping system?

While it's not the most pressing issue we are facing, I always keep it in the back of my mind. The higher the amount of soil carbon we have, the greater the amount of soil nitrogen mineralisation we have. With more nitrogen available to the crop, the less we have to apply as fertiliser.

Q Are you trying to improve your soil carbon values? If so, how?

We've been trying to improve our soil carbon values for 20 years — but it's a gradual process. We are aiming for 2% soil carbon.

The first thing we did was stop cultivating our soils, then we moved to a full no-till, stubble-retained system. We are also actively using our pasture phase to increase our soil carbon levels.

Q Are you likely to change your management practices to attempt to improve soil carbon?

While we already feel like we are doing a fair bit, there is more we can do. But how much extra we can do all depends on the economics of the situation. For example, adding fertiliser to accelerate stubble decomposition might be something we consider in the future, but only if it is economical.

11 | Conclusions

Although applying post-harvest fertiliser provided relatively high rates of nitrogen fertiliser to certain plots (up to 103kg N/ha) the response to either the fertiliser applied post-harvest or the fertiliser applied at sowing was sporadic across the three sites.

The Rutherglen site responded to the applied nitrogen whereas both Culcairn and Tocumwal did not respond, despite high soil fertility at all sites before treatment application.

Measurements taken during this project did not demonstrate any significant change in SOC stocks after applying fertiliser nitrogen, phosphorus and sulphur onto stubble residues, where stubble residues were either left standing, mulched, disced or burnt.

An extended period of research (at least 5–10 years) is needed to determine if an increase in SOC is possible with these practices in this region.

The cost of achieving a change in SOC stocks over a three-year period (equivalent to the project duration) would be at least $738/ha (average cost of fertiliser across sites at $246/ha/yr) for the nitrogen and phosphorus fertiliser alone. Even if the SOC could be increased by 0.02% per annum over a continuous period of five years to achieve an increase of 1t/ha of SOC, the resultant cost of fertiliser required to achieve this increase would be $1230/ha. Therefore, the value of SOC from a carbon trading perspective would then need to be at least $1230/t just to cover the cost of applying additional fertiliser.

Measurements of the greenhouse gas N_20 showed an additional 1.4kg N_2O-N/ha/yr at the Rutherglen site and 0.2kg N_2O-N/ha/yr at the Culcairn site lost with additional post-harvest fertiliser additions.

These results demonstrate that in regions where soils drain well and dry out over summer, such as at Culcairn, it may be more feasible to consider post-harvest fertiliser application compared with regions where soils remain wet and saturated for long periods of time, such as at the Rutherglen site.

At the Rutherglen site these emissions were large compared with standard farmer practice and represent a significant increase in the emissions factor from 1%[1] default for wheat crops in temperate zones) to 1.8% during 2014. In contrast, the fertiliser application rates as standard farmer practice produced low N_20 emissions (0.6% Rutherglen and 0.2% Culcairn) compared with international default figures. This indicates farmers in the high-rainfall cropping regions of Australia produce emissions that are still below international rates of N_20 emissions.

The nitrogen sampling component of this project highlights the potential for soil nitrogen to be highly stratified. This is not captured in the conventional 0–60cm sampling carried out in grain production systems. Although the data are only preliminary they show substantial stores of nitrogen may be underutilised in some crop systems representing a significant cost to production and the potential for further reductions in emissions of N_2O in future years.

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[1] United Nations Framework Convention on Climate Change (UNFCCC).

12 | Summary

The two questions asked at the start of this project were:

a. Is it possible to retain more of the carbon in stubble, and so increase our soil carbon values?

b. Is it worth the effort?

In answer to a), a project dependent on field trial information always has its challenges. Between frosts and flooding, it was difficult to determine if the results obtained were reflective of a 'typical' year. Given the additional challenges of large plot sizes, in-paddock variability and hot, dry summers, the value of adding post-harvest fertiliser to increase SOC values is not clear cut.

However, what we do know is at least during the first few years of application, post-harvest fertiliser addition does not have a statistically measurable impact on SOC, nor on the fractions thereof (HOC, POC and ROC).

If the challenges encountered in this project of in-paddock variability and lack of reliable summer rainfall to optimise microbial cycling are extrapolated across a property in the Riverina region of northern Victoria – southern NSW, the chance of achieving measurable gains in sequestered SOC in the short term are low.

If the approach was to continue applying post-harvest fertiliser in the hope that after 5–10 years there might be a positive result, the monetary value of that stored SOC would have to be significant in order to recoup all of the costs involved in achieving it.

In addition, the *actual* physical stability of that sequestered SOC is unknown. While it is postulated that the SOC will be within the stable humus fraction (HOC) and so have a long residence time, it is just as likely it may become accessible for microbial breakdown, with SOC values again dropping after the post-harvest fertiliser regime stops.

This short-term project has not clearly demonstrated that more of the carbon in stubble can be retained through post-harvest fertiliser addition, and that SOC values have not significantly increased.

In answer to b), this project has not clearly identified any unequivocal benefits to post-harvest fertiliser application. However, it has demonstrated that post-harvest fertiliser application leads to greater emissions of N_20 (a potent greenhouse gas), increased potential for nitrogen loss through leaching, and significant costs in fertiliser purchase and spreading.

While there may be some immediate financial gain in managing SOC for sequestration, there are many greater benefits in continuing to focus on maintaining soil cover and SOM. Even if SOC values do not increase, maintaining high microbial activity will have a multitude of soil physical, chemical and biological benefits that go beyond the actual SOC value.

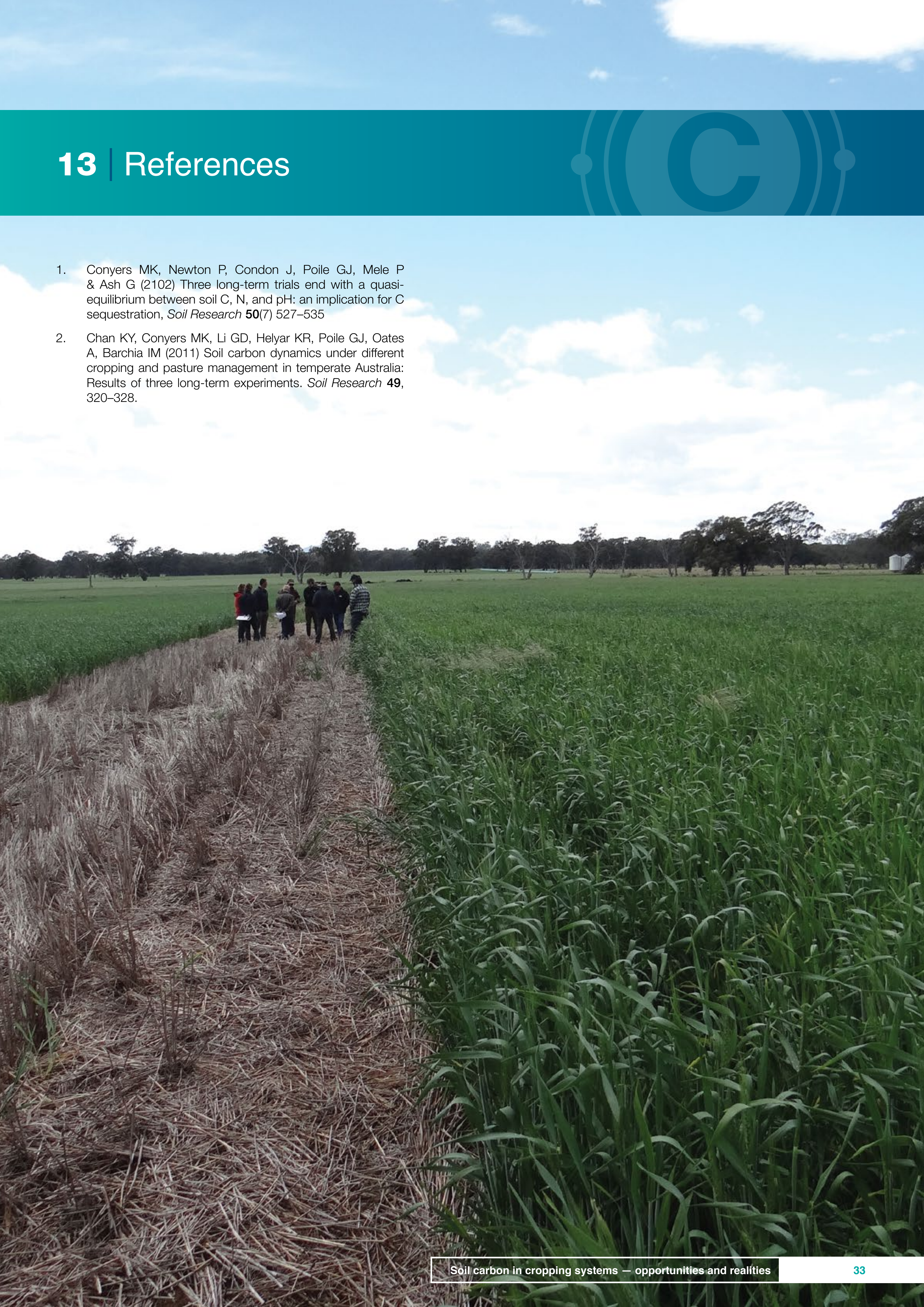
So, is it worth the effort… not yet.

However, research in this area is ongoing. Scientists from CSIRO and collaborating agencies are continuing to carry out field trials to understand the conditions under which nutrient addition to stubble may show value in building soil carbon and reducing stubble loads in the subsequent crop.

While the short-term field trials held under this project showed little benefit, it is hoped trials carried out over a longer time frame may present a clearer picture of the relative benefits and costs of applying fertiliser post-harvest onto stubble. So, stay tuned.

13 | References

1. Conyers MK, Newton P, Condon J, Poile GJ, Mele P & Ash G (2102) Three long-term trials end with a quasi-equilibrium between soil C, N, and pH: an implication for C sequestration, *Soil Research* **50**(7) 527–535
2. Chan KY, Conyers MK, Li GD, Helyar KR, Poile GJ, Oates A, Barchia IM (2011) Soil carbon dynamics under different cropping and pasture management in temperate Australia: Results of three long-term experiments. *Soil Research* **49**, 320–328.



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