

Quantifying in-paddock variation of soil organic carbon and pH: And does it pay?

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At a glance...

- Soil pH varied significantly across the four pasture and four cropping project paddocks, with some areas showing areas of high soil acidity, both in the topsoil and the subsoil.
- Soil organic carbon (SOC) per cent varied within each of the paddocks, with surface (0–10 cm) values ranging from 0.5–3.3 per cent. These results suggest that within this climatic zone and these soil types, there may be capacity to increase SOC values, based on an understanding of what is driving the differences in high versus low SOC zones.
- Regular soil testing to at least 20 cm, will offer a clear picture of the chemical profile and associated health of the soil and changes in that profile over time.
- Estimates of SOC stocks (t/ha) were used to calculate values for the Federal Government's Emission Reduction Fund and it was found that an increase of 0.5 per cent SOC at the 0–10 cm soil layer may equate to about \$55 per hectare. But this calculation did not account for reductions in this value due to on-farm emissions, or the costs of sampling, auditing and reporting.

Across Australia's vast and varied farmlands – and particularly in north-east Victoria and southern NSW – soil pH and soil organic carbon (SOC) are two soil properties that influence soil health and productivity in a significant way.

Soil pH plays an important role in governing the chemical environment in the soil. While some soils in north-east Victoria and southern NSW are naturally acidic, due to their parent material, others are becoming more acidic due to agricultural production. The ongoing use of nitrogen (N) and the off-farm export of agricultural produce (all of which extract calcium (Ca), magnesium (Mg) and other cations from the soil), result in net soil acidification.

Soil organic carbon (SOC) is a key component of soil organic matter (SOM) and plays many important roles in maintaining soil health, including supporting microbial activity, nutrient cycling, improved infiltration and water holding capacity, as well as maintaining soil structure.

With soil pH and SOC being critical to soil health and productivity, regular soil testing is critical to establish accurate soil pH and SOC values and understand how they change over time.

While 0–10 cm transect sampling has traditionally been the preferred method for soil sampling (where soil samples are collected along a line through a paddock, with all samples combined into the one sample for analysis), this approach is likely to mask any in-paddock soil pH and SOC variability. For this reason, incremented GPS-referenced soil sampling was used in this project to provide a more comprehensive understanding of paddock conditions and to enable these conditions to be monitored over time.

Soil organic carbon contributes much to our soil and farming systems and mechanisms are now in place, through the Federal Government Emission Reduction Fund, to pay farmers to maintain an increase in SOC, via the *Carbon Farming Initiative* (a voluntary carbon offsets scheme that allows land managers to earn carbon credits by changing land use or management practices to store carbon or reduce greenhouse gas emissions).



Soil sampling is key to understanding soil pH and soil carbon levels. (PHOTO: Riverine Plains)



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Riverine Plains Inc is an independent farming systems group dedicated to improving the productivity of broadacre farming systems in north-east Victoria and southern NSW. The group specialises in farmer-driven research and extension that delivers on-the-ground benefits to farmers.

The recently completed research project discussed in this article, sought to provide further information for growers looking to understand more about this process.

Why we did the project

The project aimed to quantify the baseline variance in soil pH and SOC across four cropping paddocks and four pasture paddocks in north-east Victoria, in order to understand the degree to which these parameters may vary in paddocks that appear relatively uniform.

Because the calculation of carbon stocks (for carbon trading) is more difficult in practice than in theory, and because there is a lack of regionally relevant reference data available for growers, the collection of soil samples using protocols from the *Carbon Farming Initiative* also aimed to provide a regionally relevant example of how to conduct this work, as well as a guide to likely local SOC stocks.

The project also aimed to calculate the benefit that could be ascribed to an SOC increase of 0.5 per cent (within a 25-year contracted period), using data collected for one of the project paddocks.

How we did it

Eight paddocks were selected across north-east Victoria, consisting of four paddock 'pairs'. Each pair included a paddock with a long-term cropping history and a paddock about to transition from pasture to crop production. These paddock pairs are referred to as "Yarrowonga 1", "Yarrowonga 2", "Springhurst" and "Violet Town".

The four pasture paddocks were soil sampled (GPS referenced) immediately before being prepared

for the cropping phase, with future soil sampling to be completed in order to track SOC and soil pH values. This will provide long-term information for both the continuous cropping and pasture-to-cropping paddocks to help understand the impact of practice change on SOC and soil pH.

Groundcover on the cropped paddocks at the time of sampling comprised retained stubble and volunteer species, while groundcover on the pasture paddocks ranged from annual grasses and broadleaf species, through to high-quality perennial ryegrass pastures.

As per the *Carbon Farming Initiative* methods, 20 GPS-located sampling points were selected in each paddock. Each paddock was assigned into polygons

(sub-areas of similar properties) to enable carbon stocks to be calculated within each sub-area.

All soil sampling was carried out during March, 2020. While 0–10 cm is the traditional depth for SOC and soil pH sampling, the likely presence of subsoil acidification and the need to quantify SOC stocks down to 30 cm means soil cores were taken to a depth of 30 cm, in cremented at 0–10 cm, 10–20 cm and 20–30 cm.

Soil cores were analysed for soil carbon (as per *Carbon Farming Initiative* methods, including bulk density and gravel determination) and soil pH (CaCl_2) at the Environmental Analysis Laboratory, Southern Cross University.

Determination of carbon stocks – reported as tonnes of soil organic carbon per hectare (t C/ha) – was done using the *Carbon Farming Initiative* methodology.

What we found

Soil organic carbon

Calculation of SOC stocks from SOC% and other soil parameters showed the SOC stocks (t C/ha) across the eight paddocks were relatively similar, ranging from 27 to 45 t C/ha (Figure 1). But there was large in-paddock variation, which reflected changes in soil type, clay content and cation exchange capacity (CEC) within individual paddocks.

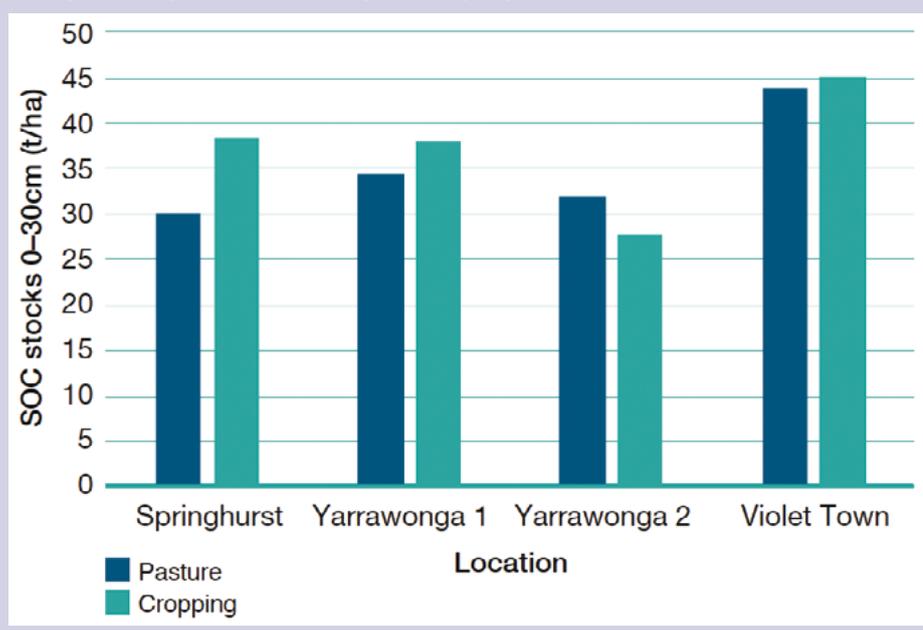
The total SOC stocks measured (0–30 cm) were similar between the pasture and cropping paddocks, with the Violet Town paddocks in the higher rainfall zone having the highest values (43.77–44.9t C/ha) (Figure 2). Generally, most of the SOC in these soils was present in the top 10 cm (up to 79 per cent), however, at some of the sites with lower SOC values, the proportion present in the top 10 cm dropped to as low as 20 per cent.

The relationship between SOC stocks (t C/ha) and SOC per cent suggests a SOC stock value of 45 t/ha may equate to 2.2 per cent SOC (0–10 cm).

This, along with the other results, indicates the possible range of SOC stocks for soils in north-east Victoria (keeping in mind this relationship changes if there is greater SOC accumulation below 10 cm depth).

For the cropped paddocks, average SOC values within the 0–10 cm increment ranged from 1.2 per cent in the Yarrowonga 2 paddock to 2.2 per cent in the Violet Town paddock (Figure 2). While average values of 1.2 per cent would be considered quite acceptable for cropped paddocks, spatial sampling also showed the upper values of SOC

Figure 1: Weighted average soil organic carbon stocks at the 0–30 cm depth for each paddock pair, from 20 sample sites per paddock



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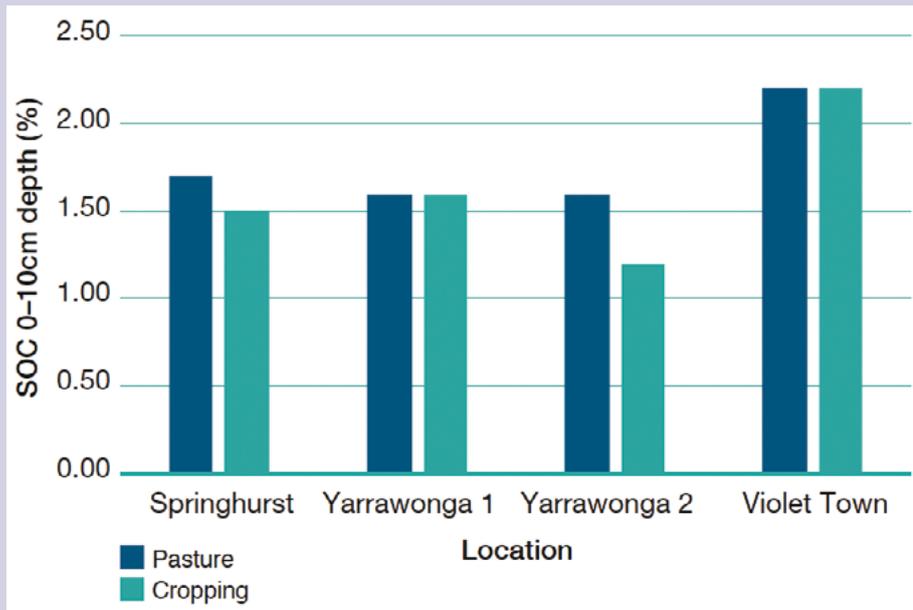
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Figure 2: Average soil organic carbon percentage for the 0–10 cm depth increment for each paddock pair, sampled from 20 sites per paddock*



*Note: SOC% (as described in a normal soil test) is used to calculate SOC stocks (t C/ha); the SOC% presented in Figure 2 (0–10 cm) may relate to the SOC stocks (0–30 cm) presented in Figure 3.

measured in those paddocks ranged between 1.6 per cent (Yarrowonga 2) to 3.3 per cent (Violet Town paddock).

Individual SOC results varied significantly within each paddock, with the greatest variation in the Violet Town pasture paddock, where sampling points ranged from 0.5–3.2 per cent SOC (0–10 cm). If a conventional transect method had been used for the Violet Town paddock (with all samples bulked together), the SOC would have been 2.2 per cent, with the in-paddock variance acting to dilute, or mask, the impact of any changes in SOC over time.

As such, when looking to monitor the SOC value over time to determine the impact of paddock management on SOC values, a more detailed GPS-located sampling approach (in increments to a depth of at least 20 cm), is recommended.

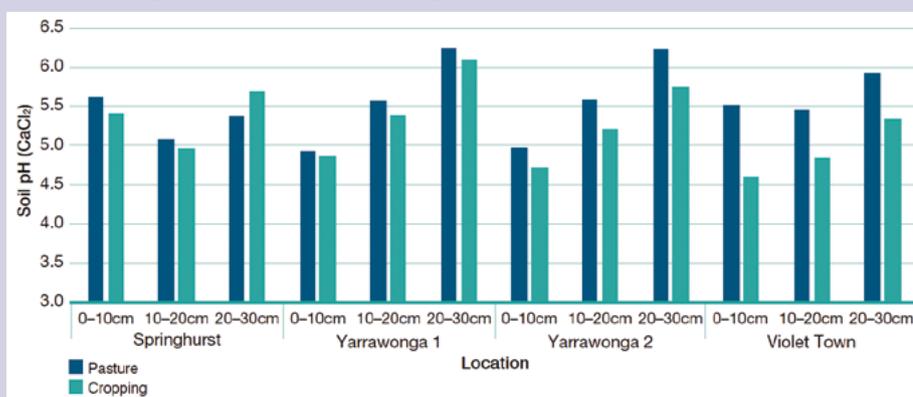
While the GPS-located approach may not reflect

the full range in SOC across the entire paddock, even if only one or two sampling points are used over time, any changes in SOC at these sampling points should be able to be measured more easily.

As the range in SOC values corresponds well to other readily available satellite imagery (including satellite-derived radiometrics [gamma-ray spectrometric methods], NDVI [greenness index] and other datasets including EM surveys and yield monitor data), one of the first steps towards increasing SOC in paddock may include identifying the likely high and low SOC locations in the paddock.

This could be done using remote sensing methods, EM or yield monitor information and by then sampling these points for a range of soil chemistry attributes to help identify the factors responsible for the difference. This would help in

Figure 3: Average soil pH values at depths of 0–10, 10–20 and 20–30 cm for long-term cropping and pasture-to-cropping paddocks at each location



whole-paddock management to support an increase in those factors of value.

The four pasture paddocks were sampled just before being cultivated prior to cropping, with a high potential for SOC loss during this transition through soil disturbance and associated carbon mineralisation (loss to the atmosphere as CO₂). Therefore, the baseline soil sampling and follow-up monitoring over the next 12–24 months (and potentially longer) will be of high value in understanding the flux of SOC over this time.

Soil pH (CaCl₂)

Soil pH values varied significantly across each paddock, both on the surface and at depth (Figure 3). Figure 3 also indicates soil acidity is a significant problem in the paddocks, with results as low as pH 4.61 in the 0–10 cm increment and pH 4.84 in the 10–20 cm increment (Violet Town cropping).

Generally, soil pH was higher (more alkaline) in the pasture paddocks than in the long-term cropping paddocks. The images in Figure 4 indicate the presence of some highly acid soils in the monitored paddocks.

The greatest range in 0–10 cm pH values was in the Yarrowonga 1 cropping paddock, where values ranged from pH 4.55–6.56. While low pH values were most common in the surface samples, there were also several highly acid (pH 4.8–5.1) 10–20 cm depth samples, with the Springhurst cropping paddock also being more acid at the 10–20 cm than 0–10 cm.

While the average soil pH values shown in Figure 3 indicate a number of paddocks with pH values higher than 5.0 (and which would be considered acceptable for agricultural use), the range in pH values measured across the paddocks include highly acid locations, which would be limiting productivity.

To help identify regions of low productivity in a paddock, as well as to measure soil pH variance, remotely sensed data (satellite NDVI etc) and yield maps could be used to select GPS located sampling sites. Additionally, soil sampling in 10 cm increments to a depth of at least 20 cm will provide a clearer picture of the soil’s chemical profile at depth.

For paddocks with a history of broadcast lime application with no incorporation, sampling at 0–5, 5–10 and 10–20 cm increments will provide a clearer picture of how far down the profile the lime has moved.

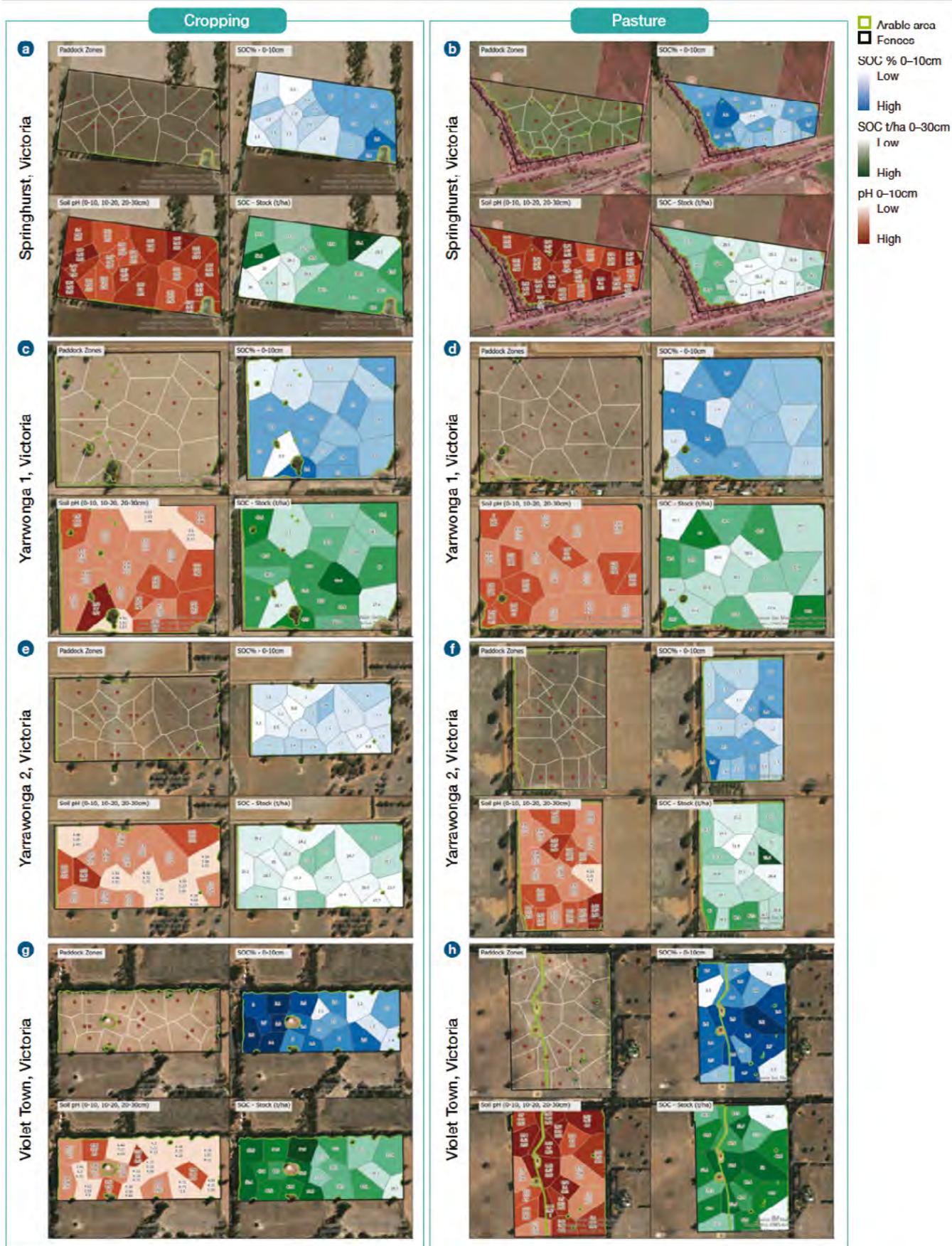
When the range of soil pH values is known, appropriate rates of lime can be applied to offset both surface and subsurface acidity, with some incorporation required – the depth of which will depend on soil conditions.

Interaction between SOC and soil pH

The interactions between SOC and soil pH are relatively complex, with soil pH being a key parameter driving the soil’s capacity to increase SOC.

As shown in the Violet Town cropping paddock (where SOC was 2.2 per cent despite pH 4.6–4.8 in the 0–10 and 10–20 cm depth increments), SOC can be retained under acidifying conditions.

Figure 4: These images a through h demonstrate the variance in SOC and pH within and between each paddock pair



Note images on the left are cropping paddocks, images on the right are pasture paddocks about to transition to cropping.

But the ability to increase SOC under such acid conditions is limited because microbial activity and function is reduced (bacteria prefer conditions between pH 5–9, with optimum activity at pH 7).

Reduced microbial function in acid soils also affects the bacterial legume inoculants (*Rhizobium* species) and is a key reason why legumes do not persist well under acidic conditions. Fungal activity is also important for increasing SOC, and while some fungi can function down to pH 2 (CaCl₂), optimum activity occurs at pH 5.

It follows that if soil microbes cannot function well under acid conditions, they cannot efficiently convert plant residues into SOM. This means more of this material is inefficiently converted into carbon dioxide (CO₂) gas and lost to the atmosphere.

Many plant species cannot grow well under acid conditions. In a pasture system, this means productive, deep-rooted perennials, such as phalaris (which can deposit significant levels of carbon through their root systems at depth) and clovers (which improve soil fertility) are outcompeted by annual grasses and broadleaf weeds. Annual grasses and broadleaf weeds are of little productive value and also produce less residue for recycling into SOM.

In cropping systems, areas of low pH can produce low-vigour crops with reduced biomass and yield. Acidic soils can also increase abiotic stresses on sensitive crops, which can lead to the crop being outcompeted by weed species or subject to increased pest and disease pressure. This can further reduce biomass turnover on top of the limits already imposed by reduced microbial activity.

Maintaining soil pH values above pH 5 (and preferably 5.2), will improve the productivity of the system while also improving the microbial function of the soil, both of which are important in increasing SOC values.

Carbon sequestration

The process and calculation

A key part of this project was to understand the practicalities of sampling for SOC using *Carbon Farming Initiative* approved methods and the estimated Australian Carbon Credit Unit (ACCU) value of any increase in SOC.

In order to be eligible for consideration for ACCUs through the Australian Emission Reduction Fund program, the following actions are required:

- Initial baseline soil sampling to 30 cm depth is to be carried out, according to approved sampling designs, with qualified contractors (subject to commercial arrangement).
- An independent contractor is to be engaged to develop a land management plan, to demonstrate 'additionality' (i.e. not be something that you would do anyway).
- A third-party audit of the land management plan is carried out.
- The practice change is to be set up (i.e. the 'new' change or practice that will lead to carbon sequestration).

- Soils are to be resampled after five years (first sampling period) and an independent audit of the results paid for.
- Where a measurable increase in SOC is observed, land owners/managers may then apply for consideration into the Emission Reduction Fund (ERF) auction. They can choose to hold onto ACCUs, or cash them in at current auction price.
- A carbon broker can also be engaged to assist in registering baseline sampling results and going through the ACCU auction process.

See the accompanying scenario for a calculation of estimated financial benefit from applying for carbon credits.

To sum up

Given the importance of soil pH and SOC on soil health and productivity, it is important to soil test regularly to measure soil pH and SOC values and better understand how they change over time, with incremented GPS-located sampling being the preferred method for sampling.

Soil pH can affect a soil's ability to increase SOC and the results from this project suggest that within the climatic zone and soil types of north-east Victoria, there may be capacity to use remote sensing data to understand differences in high versus low SOC areas.

This could then be used to increase SOC values by identifying the factors responsible for the difference and managing the whole paddock to support an increase in those factors of value.

Measuring carbon stocks for trading using the ACCU and the Australian Government's Emissions Reduction Fund may be of interest to some local growers. While such a program appears highly attractive, it relies on detailed soil sampling protocols to understand baseline carbon stock values, with further sampling also required over time to measure any increase in carbon stocks. The method for calculating carbon stocks, as indicated

by the *Carbon Farming Initiative*, is somewhat complex and may present challenges to those seeking to understand what it involves, and the relative gains to be made.

Further monitoring of the paddock pairs over time will provide valuable information on the rate of change in soil pH and SOC occurring under cropping systems, and the change in soil pH and SOC occurring upon the conversion of pasture paddocks into cropping.

The full report can be found at riverineplains.org.au or contact Jane McInnes, (03) 5744 1713; E: jane@riverineplains.org.au

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Applying for carbon credits: A scenario

The following scenario covers the key cost points of applying for ACCUs, based on publicly available information (as at December, 2020):

It is a financial benefit calculation for a 0.5 per cent increase in SOC over a 25-year period (contracts are available for either 25 or 100-year periods).

Using the Springhurst pasture paddock as an example (which had a baseline starting SOC of 1.7 per cent and carbon stock of 30 t C/ha), and maintaining all gravel and bulk density calculations, increasing the 0–10 cm depth soil carbon value by 0.5 per cent resulted in an extra 6.18 t C/ha over an initial five-year sampling period, within a 25-year contract.

The calculations and application process are quite complex, but using Springhurst this starting figure, the net financial benefit of applying for

ACCUs (carbon credits) after the first five years (first monitoring period) is estimated at about \$55 per hectare (\$11 per hectare per year).

It is important to consider that all soils have a threshold of soil carbon, based on their climate, soil type and management. Therefore, it is highly likely the rate of carbon increase over the second five-year sampling period will be considerably less than the first five-year period (due to the law of diminishing returns).

Also, if anything happens to the land during the 25-year ACCU contract period that results in a net loss of carbon (i.e. due to drought, flood, fire, pest animals etc), the farmer will need to pay back the loss.

Finally, if the land is sold during the contracted 25-year period, the new owner must either sign up to the committed contract, or pay it out.