Quantifying in-paddock variation of soil organic carbon and pH in north-east Victoria

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Key points

- 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 (0–10cm) 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 a depth of at least 20cm, using GPS-located sample points, based on available spatial data (including yield maps, EM surveys, NDVI images or radiometric maps) 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 completed and 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 0–10cm soil layer may equate to about $55/ha (as measured after the first five-year sampling period). Calculations did not account for reductions in this value due to on-farm emissions (both historically and within the sampling period), or the costs of sampling, auditing and reporting.
- Comprehensive baseline soil pH and SOC information was collected from eight paddocks in north-east Victoria. Monitoring these paddocks 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 upon converting pasture paddocks into cropping paddocks.

Project background

In north-east Victoria and southern NSW, two soil properties influence soil health and productivity in a significant way — soil pH and soil organic carbon (SOC).

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 0–10cm 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). This project sought to provide further information for growers looking to understand more about this process.

Aims

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% (within a 25-year contracted period), using data collected for one of the project paddocks.

Method

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 pairs are referred to as the "Yarrawonga 1", "Yarrawonga 2", "Springhurst" and "Violet Town" paddock pairs (Figure 1).

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 (by a Latin Hypercube analysis of spatial variance in satellite-derived radiometric data). 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 0–10cm is the traditional depth for SOC and soil pH

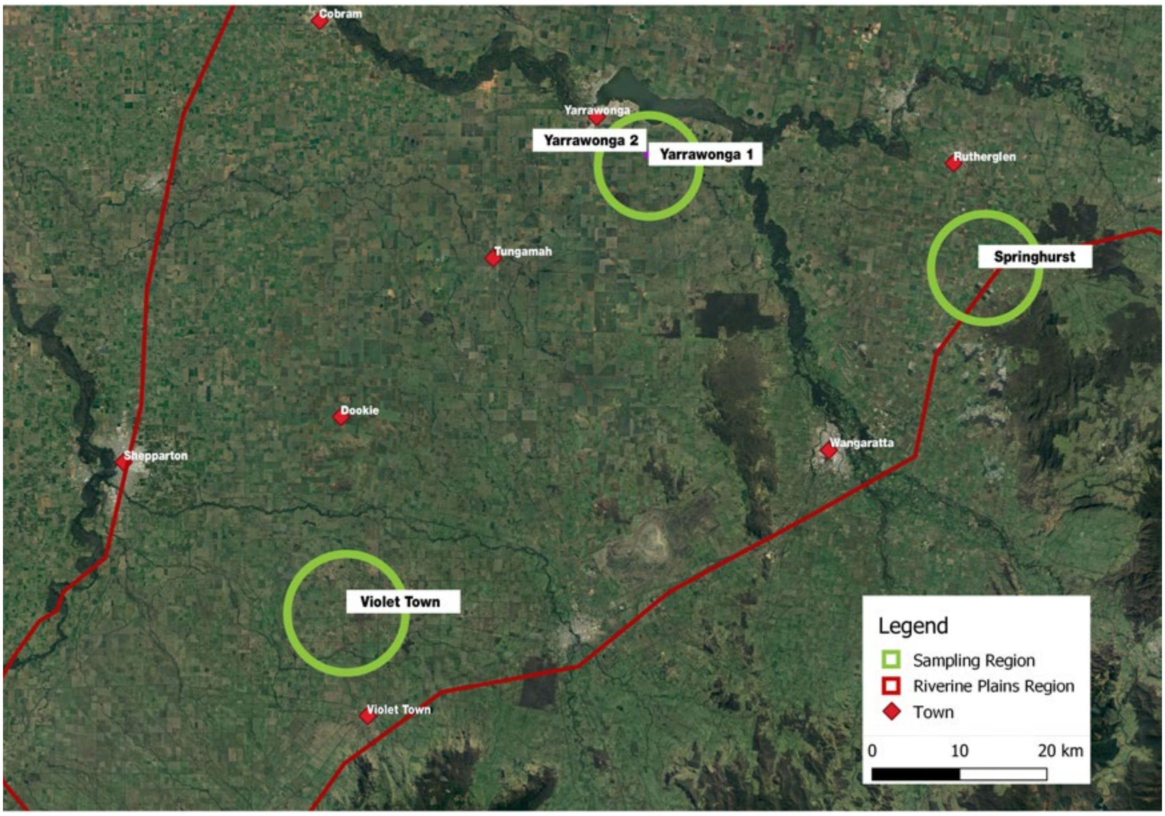

FIGURE 1 General location of each paddock pair, with a pair consisting of a paddock with a long-term cropping history and a paddock transitioning from pasture to crop production

sampling, the likely presence of subsoil acidification and the need to quantify SOC stocks down to 30cm means soil cores were taken to a depth of 30cm, incremented at 0–10cm, 10–20cm and 20–30cm.

The *Carbon Farming Initiative* methods specify one soil core per sampling point with an inner cutting diameter of 3.8cm, however this was not available in the region. Therefore, two soil cores with an inner cutting diameter of 2.6cm were collected at each sampling point and bulked.

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 Environmental Analysis Laboratory, Southern Cross University.

Determination of carbon stocks (reported as tonnes of soil organic carbon per hectare [t C/ha]) was done according to the calculations described in the Carbon Credits Methodology Determination 2018 (*Carbon Farming Initiative — Measurement of Soil Carbon Sequestration in Agricultural Systems*), and the Supplement version 1.0 — January 2018.

Carbon stocks (t C/ha) were calculated from SOC% and other parameters as follows;

Carbon stock calculations:

SOC (%) adjusted for gravel = SOC (%) – [SOC x (% gravel ÷ 100)]

SOC (t/ha) per depth = ((SOC% adjusted for gravel x 10) x total soil mass (kg/ha)) ÷ 1,000,000

Total SOC stocks (0–30cm) (t/ha) = SOC (0–10cm) + SOC (10–20cm) + SOC (20–30cm)

Total SOC stocks (0–30cm) were assigned to each polygon based on area.

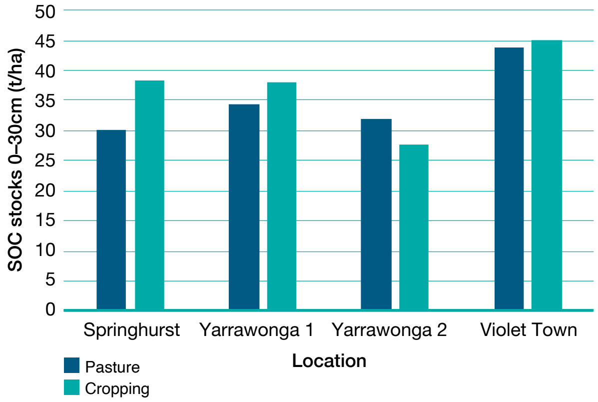

FIGURE 2 Weighted average SOC stocks at the 0–30cm depth for each paddock pair, from 20 sample sites per paddock and accounting for the different area in each polygon

Results and discussion

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 27–45t C/ha (Figure 2). However, 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 (0–30cm) 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 10cm (up to 79%), however, at some of the sites with lower SOC values, the proportion present in the top 10cm dropped to as low as 20%. The relationship between SOC stocks (t C/ha) and SOC% is presented in Figure 4, which shows a SOC stock value of 45t/ha may equate to 2.2% SOC (0–10cm). 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 10cm depth).

For the cropped paddocks, average SOC values within the 0–10cm increment ranged from 1.2% in the Yarrawonga 2 paddock to 2.2% in the Violet Town paddock (Figure 3). While average values of 1.2% would be considered quite acceptable for cropped paddocks, spatial sampling also showed the upper values of SOC measured in those paddocks ranged between 1.6% (Yarrawonga 2) to 3.3% (Violet Town paddock).

Individual SOC results varied significantly within each paddock, with the greatest variation in the Violet Town pasture paddock, where sampling points ranging from

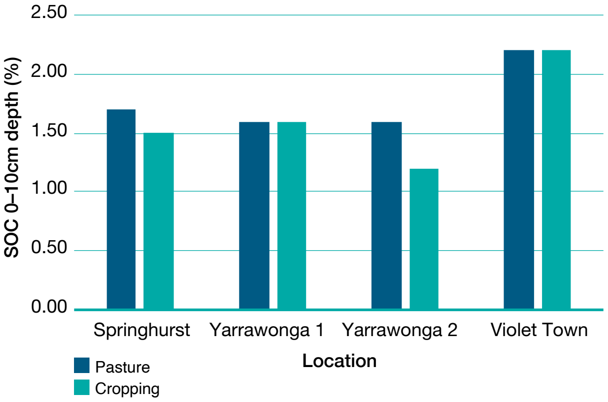

FIGURE 3 Average SOC % for the 0–10cm depth increment for each paddock pair, sampled from 20 sites per paddock*

*Note: SOC% (as described in a normal soil test) is used to calculate SOC stocks (t C/ha); the SOC% presented in Figure 3 (0–10cm) may relate to the SOC stocks (0–30cm) presented in Figure 4.

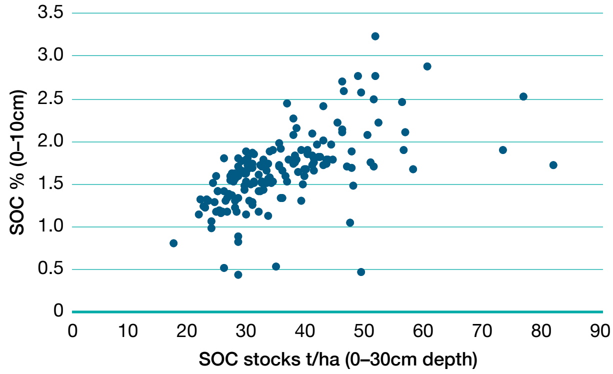

FIGURE 4 The relationship between commonly measured SOC % at 0–10cm and what this looks like in regards to SOC stocks at 0–30cm (quantified as t C/ha)

0.5–3.2% SOC (0–10cm). 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%, 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 20cm), is recommended.

While the GPS-located approach may not reflect the full range in SOC across the entire paddock, even if only 1 – 2 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 or 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 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 CO_2). 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 ($CaCl_2$)

Soil pH values varied significantly across each paddock, both on the surface and at depth (Figure 5). Figure 5 also indicates soil acidity is a significant problem in the paddocks, with results as low as pH 4.61 in the 0–10cm increment and pH 4.84 in the 10–20cm 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 6 (page 5) indicate the presence of some highly acid soils in the monitored paddocks.

The greatest range in 0–10cm pH values was in the Yarrawonga 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) 10–20cm depth samples, with the Springhurst cropping paddock also being more acid at the 10–20cm than 0–10cm.

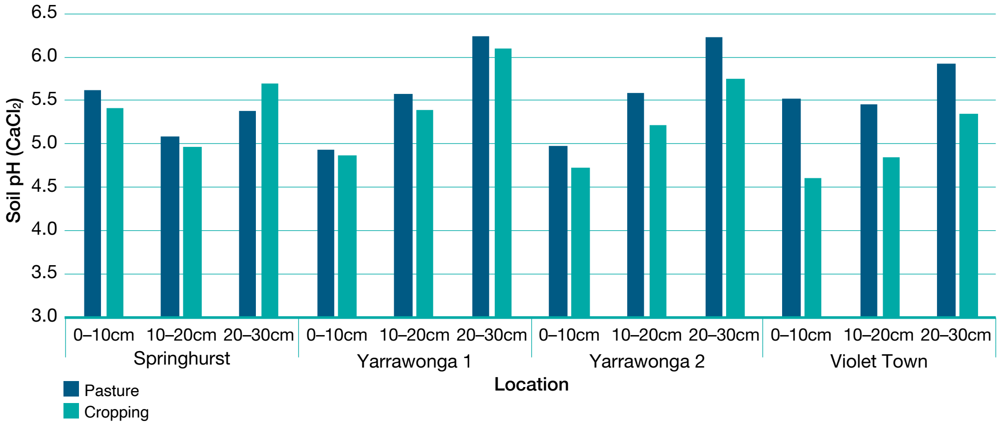

FIGURE 5 Average soil pH_{Ca} values at depths of 0–10, 10–20 and 20–30cm for long-term cropping and pasture-to-cropping paddocks at each location

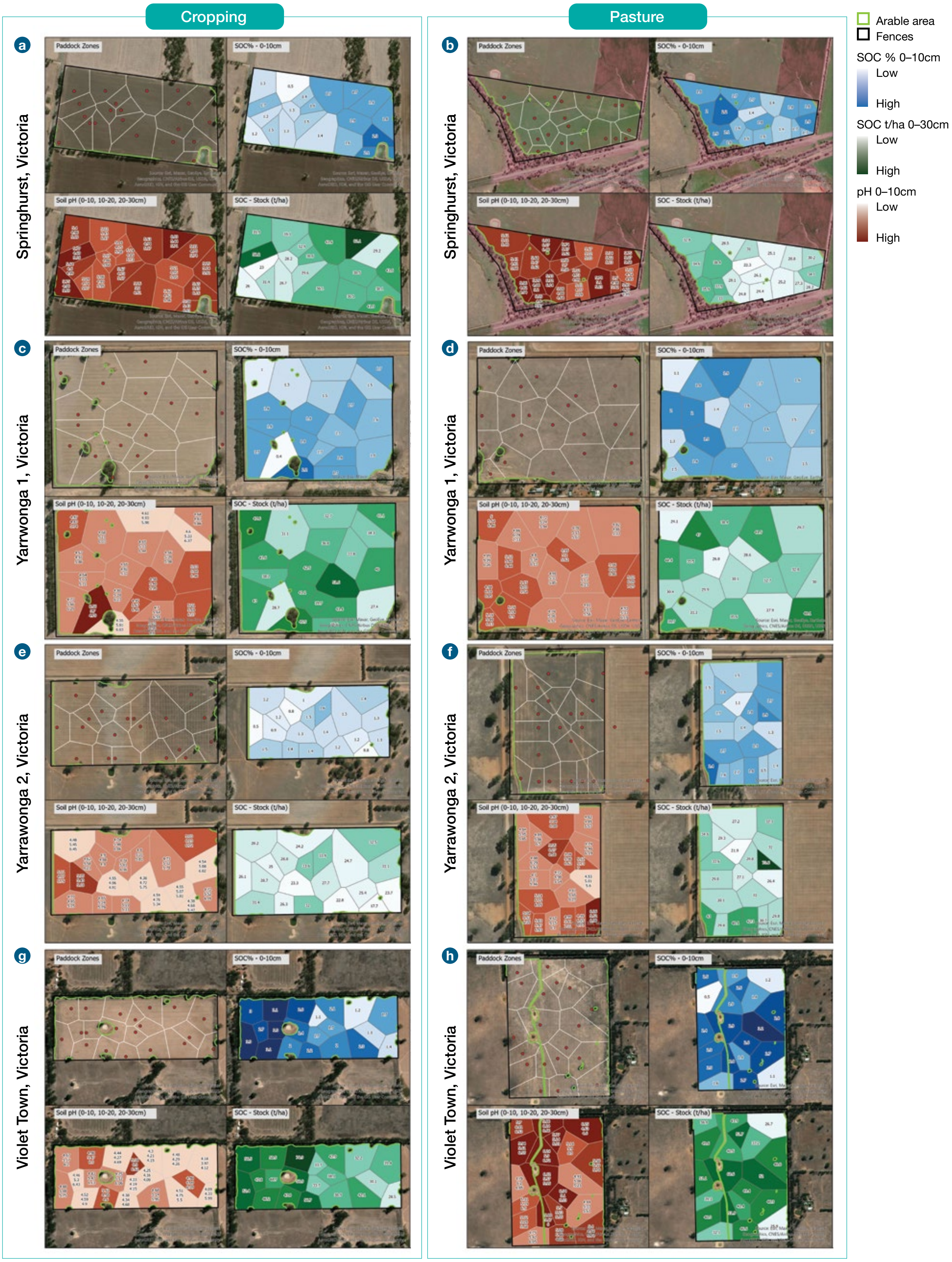

FIGURE 6 A–H demonstrate the variance in SOC and pH within and between each paddock pair

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

While the average soil pH values shown in Figure 5 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 10cm increments to a depth of at least 20cm 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 10–20cm 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 illustrated in the Violet Town cropping paddock (where SOC was 2.2% despite pH 4.6–4.8 in the 0–10 and 10–20cm depth increments), SOC can be retained under acidifying conditions. However, 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 (CO_2) 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;

1. Initial baseline soil sampling to 30cm depth is to be carried out, according to approved sampling designs, with qualified contractors (subject to commercial arrangement).
2. 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).
3. A third-party audit of the land management plan is carried out.
4. The practice change is to be set up (i.e. the 'new' change or practice that will lead to carbon sequestration).
5. Soils are to be resampled after five years (first sampling period) and an independent audit of the results paid for.
6. 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.
7. A carbon broker can also be engaged to assist in registering baseline sampling results and going through the ACCU auction process.

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

Financial benefit calculation for a 0.5% increase in SOC over a 25-year period (contracts 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% and carbon stock of 30t C/ha), and maintaining all gravel and bulk density calculations, increasing the 0–10cm depth soil carbon value by 0.5% resulted in an extra **6.18t C/ha over an initial five-year sampling period, within a 25-year contract.**

Using this starting figure, the financial benefit of applying for ACCUs (carbon credits) after the first five years (first monitoring period) can be described by the following process:

1. ACCUs are based on carbon dioxide equivalents (CO_2e values), not on SOC values. Therefore, the **6.18t C/ha *is equivalent* to 22.63 t CO_2e/ha**.
2. An estimation should be made of baseline emissions over the 10 years leading up to the baseline sampling including: methane (CH_4) from livestock, nitrogen (N) fertiliser, fuel, lime and other input emissions. The starting CO_2e value is therefore **22.63t CO_2e/ha *less emissions from the previous 10 years***. (Not calculated in this example, therefore this CO_2e value is higher than it should be.)
3. Discount of 5% (applied to all projects considered for ACCUs to account for uncertainty) = **21.50t CO_2e/ha**
4. Discount of 25% applied for a 25-year contract (NB not discounted for 100-year contracts) = **15.84t CO_2e/ha**
5. Discount of further 50% applied as all soil carbon projects have a 50% deferral from the first monitoring period (five years after baseline) and the second period = **4.53t CO_2e/ha**
6. Assuming an average ACCU value of **$16.14** (as per the Emission Reduction Fund auction on 25/26 March 2020 — Auction #10) = 73.06 ACCUs/ha (= $73/ha at current pricing)
7. Emissions over the five-year monitoring period also need to be considered, so growers need to assume the value of **$73/ha** will decrease further due to emissions that offset any carbon gains.
8. Based on current pricing, a carbon broker may charge 25% of the total ACCU value, which further decreases the value to **$54.8/ha. This is equivalent to $11/ha/year for the first five-year monitoring period. (Note: this value does not take into account any further discounts due to estimated emissions during the sampling period, which would further reduce any carbon value).**

While the above calculations provide an example financial return from carbon trading on a local soil, it is important to also 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.

Conclusion

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.

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