Relationship between organic matter retention and soil carbon in irrigated mixed farming systems

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Abstract
Understanding the relationship between farming systems and long-term trends in soil organic carbon (SOC) levels is of significant current interest, both for improving soil health and estimating the potential for sequestering greenhouse gases. This relationship was investigated for the mixed irrigated cropping and pasture farming systems in NW Victoria and southern New South Wales, Australia, using a sample of 13 paired paddocks, each with a high and low organic matter retention history. At each paddock, the annual average organic matter (OM) produced and not removed was estimated over the previous 10 year period. The difference in this value at each paired site was compared to the current difference in SOC at each paired site. This relationship showed that 70% of the variability in the difference in SOC at each paired site could be explained by the difference in the estimated average annual amount of OM remaining on or in the soil over the preceding ten year period.

Key Words
Soil carbon, soil organic matter, soil health, carbon sequestration

Introduction
Soil organic matter (SOM) has long been considered central to soil health and maintaining soil productivity (Magdoff and van Es, 2000). The soil also holds a vast stock of carbon (C) and agriculture is often considered to have run down these stores releasing significant quantities of greenhouse gases. For these reasons there is considerable debate about the role that farming systems plays in increasing or decreasing soil organic carbon (SOC) levels. The study of SOC dynamics is difficult because trends in SOC occur slowly, while actual measurements can be quite inconsistent due to spatial variability and short-term climate effects.

For these reasons short-term trials are not good indicators of long-term soil C trends, but indicate dynamics in more labile pools. Long-term experiments provide the best information on C trends, although such experiments are rare and often do not have management systems relevant to current farmer practices. The development of new long-term trials is important, but they will only be able to include a limited quantity of farmer practices, and it will take a decade or more before firm conclusions can be drawn. Paired sites have been used for a number of SOC studies (e.g. Harms and Dalal, 2003). This approach is useful as it enables comparison of a wide range of possible farming systems without the delays involved in establishing new experiments. However, as with many other methodologies, considerable care and scientific understanding is required in applying paired site studies if misleading conclusions are to be avoided. Conclusions from paired-site studies, as with any experimental data, also need to be contextualised for the conditions that applied, and the results not extrapolated to other situations.

Ensuring all conditions, as far as is reasonable, are the same in both parts of a paired site, except the parameter to be investigated, is of paramount importance in any paired site study. The definition of the population to be studied also needs to be clearly defined, and sites where the hypothesised relationship is expected to be different need to be excluded from the population, or a variable included as a covariate. This is particularly true of soil texture properties in the study of SOC dynamics, as both the rate of C accumulation and the SOC equilibrium value are expected to be different as textures range from sandy to clay. Climate conditions and soil water are also important variables.

This study has taken the approach of using a sample of 13 paired paddocks, each with a 'high' and 'low' organic matter retention history, to develop the relationship between the differences in the estimated average annual amount of OM remaining on or in the soil over a preceding ten year period, to the current difference in SOC at each paired site.

Methods

This study is based on a sample of thirteen paired paddocks that were selected by district agronomists to represent the irrigated mixed farming industry of northern Victoria and southern NSW. Paired paddocks were required to be adjacent and agronomists were requested to only select sites where there were no apparent differences in soil type or land form for a reasonable distance on each side of the adjoining boundary. The assumption in this analysis is of near homogeneity at each paired site of all other factors (e.g. soil texture) and variables except those being studied. Site consistency was reasonably supported by measurement of particle size analysis from three bulked samples on each paddock.

Each paired site was chosen by the agronomists, following discussion with the growers, to represent one paddock with a history of higher average annual amount of OM remaining on or in the soil over the preceding ten year period (referred to as 'High OM Scenario') relative to the corresponding paddock in each pair (referred to as the 'Low OM Scenario'). Rotation and approximate yield histories were collected from the grower for the past 10-20 years. This data was converted into an estimated annual quantity of OM retained at the paddock (including roots) using published data on the harvest index and root to shoot index that most closely reflected the site and farming system. Rotations included OM input practises such as subterranean clover dominant pasture or lucerne and low OM input practises such as annual cropping with residues burnt. Other rotations and management used in the study include winter cropping (wheat, barley, oats, faba beans, canola), double cropping (combinations of oaten hay/maize, soybeans/barley, soybeans/sub clover silage), summer cropping (maize, rice, soybeans), orchards (apples), stubble retention versus stubble burnt or bailed, and the application of composted pig manure. All sites used in the study were predominantly irrigated systems.

Soils were sampled at three locations and three depths (0-10, 10-20, 20-30 cm) in each paddock. Sampling sites were selected to be reasonably close to the adjoining paddock to minimise any soil differences, but avoided any edge effects. Total carbon was determined using a high frequency induction furnace and infrared detection (LECO CR12 analyser). The various relationships were assessed using linear regression. Where the regression analysis indicated the presence of outliers these were removed and regression analysis on the remaining data indicated that the regression assumptions of constant variance and normal distribution for the residuals were reasonably satisfied by the data.

Results

Soil textures for the paired sites are plotted on a soil texture triangle in Figure 1. The lines link the High and Low OM Scenario paddocks at each site. Soil texture differences were negligible within most paired paddocks, although at three paired sites (labelled in orange) slightly larger texture differences were found. Carbon modelling of the sites suggests that difference in soil texture, for the clay range found (20 – 50%), will be expected to have only a small impact on C sequestration rate (data not shown). At each paired site, the estimated annual OM retained at the paddock (from above and below ground sources), averaged over the 10 years prior to the soil measurements, was higher in the High OM Scenario paddocks compared to the corresponding Low OM Scenario paddocks (Figure 2). The sites included a wide range of differences in OM retained, possibly reflecting the difficulty agronomist had in predicting the quantity of OM retained. However this enabled a wide range of values for the regression analysis.

Across all 24 paddocks, the value of estimated annual OM retained at the paddock (from above and below ground sources), averaged over the 10 years prior to the soil measurements explained 58% of the variability in measured SOC values (Figure 3). Unexplained variability in this relationship is likely to reflect previous rotation history prior to the ten years considered, and other climatic, site and management factors, and any inaccuracies in estimation of OM retained or SOC measurement.

Although soil C is constantly in flux due to changes in OM inputs and climatic condition, and can take many decades to reach an equilibrium level, provided there exists a cause and effect relationship between OM retained and SOC, this medium term (i.e. 10 year) average annual OM input relationship (Figure 3) provides an indication of the rate of OM input in these systems required to maintain a specific SOC level. For example, for these soil types to maintain SOC levels at around 1%, OM retained needs to be maintained at approximately 4 to 5 t/ha per year, whereas to maintain SOC levels at 2.5%, OM retained needs to be approximately 11 t/ha per year. This OM input includes all plant residues (roots and shoot), manures or any other organic material.

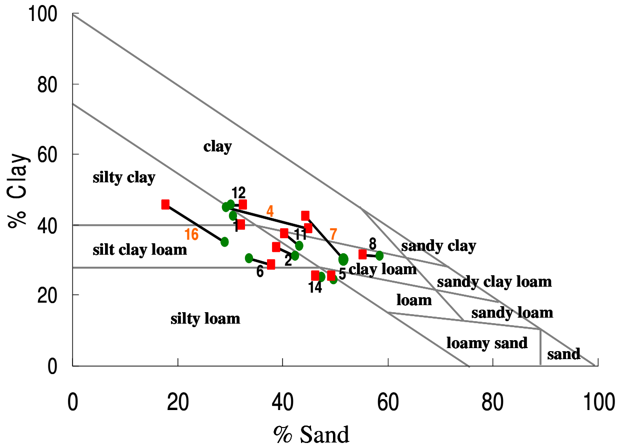

Figure 1. Australian Soil Texture Classification Triangle showing soil textures (0-10 cm) of High (●) and Low (■) OM Scenario paddocks in the paired paddock study (paddocks 13 and 15 not included because measurements not taken). Numbers on diagram refer to the site code. Clay and sand components are graphed, while the silt content is the unaccounted for component from 100% after clay and sand is accounted for.

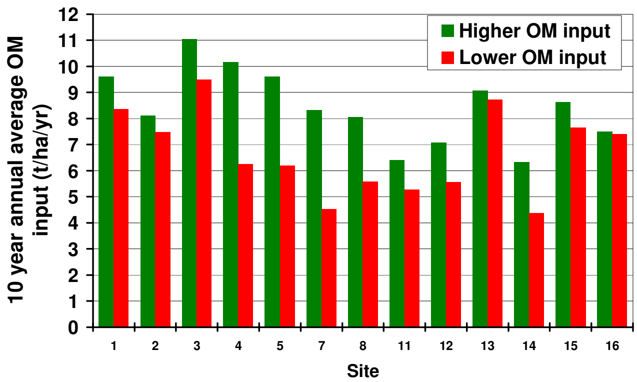

Figure 2. Average annual OM input over a ten year period, versus TOC (%, 0-10 cm) for 13 paired paddocks. Green bars are High OM Scenario paddocks; Red bars are Low OM Scenario paddocks.

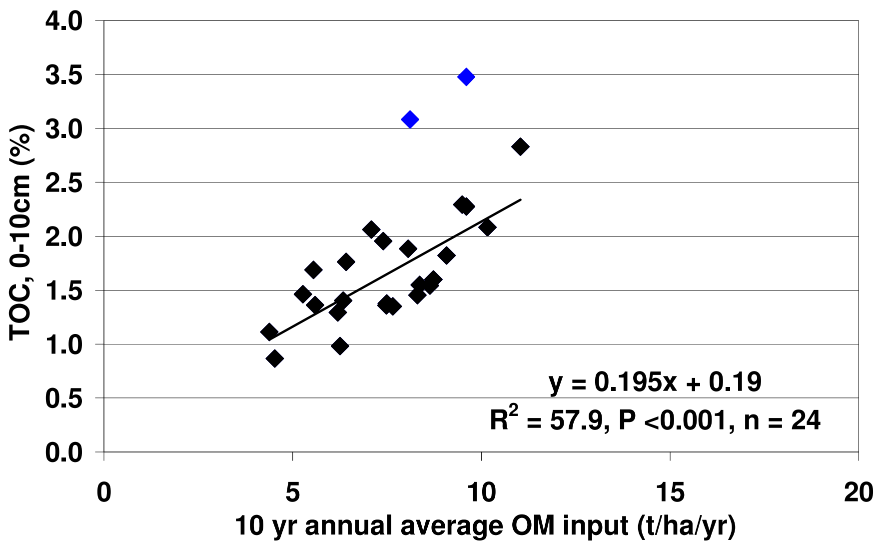

Figure 3. Average annual OM input for ten years, versus TOC (%, 0-10 cm) for 26 paired paddocks. Blue points represent paddocks 1H and 2H (outliers), not included in the analysis.

To remove from the analysis variability caused by differences between the various paired sites, the relationship has been developed between the differences in estimated average annual OM retained over the past 10 years between the paddocks at each paired site, and the corresponding current differences in measured SOC values (0-10 cm) between the paddocks at each paired site. This relationship shows that 70% of the variability in the measured difference in SOC can be explained by the difference in estimated 10 year average annual OM retained (Figure 4). If there exists is a cause and effect relationship between SOC and OM input, then this relationship suggests a useful rule of thumb for these sites. This is that for every extra 1 t/ha/year of organic matter retained that is continued for at least 10 years, it can be expected that SOC values after 10 years will be approximately 0.28% higher than they would have been otherwise.

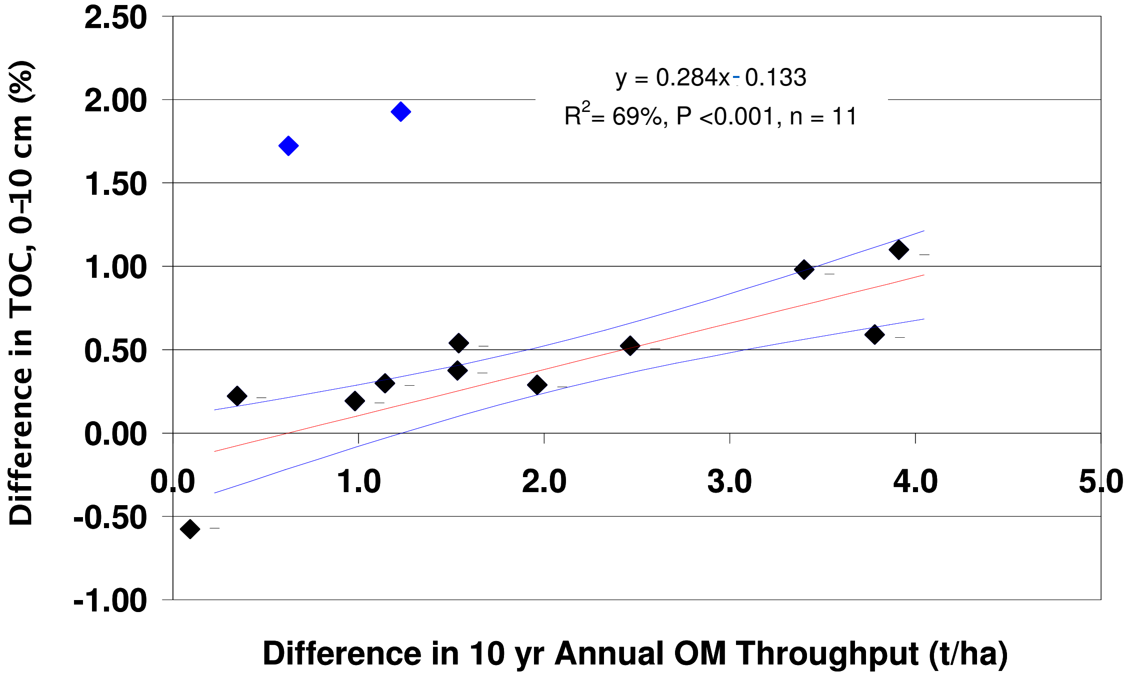

Figure 4. The difference in estimated average annual OM retained (over a 10 year period) between High and Low OM Scenario paddocks at each paired paddock, versus the current measured difference in TOC between High and Low OM Scenario paddocks. Two outliers (sites 1 and 2 shown as blue points) are not included in the regression. 95% confidence intervals are shown as blue lines.

Conclusion

The study of SOM dynamics is difficult and many different methodological approaches, such as short- and long-term experiments, modelling, and paired site studies, are all required to obtain a full picture of the issues involved. This project took the approach of using farmers' paired paddocks to develop the relationship between the estimated quantity of OM retained over a 10 year period, and C-sequestration. Despite the complexity of the factors affecting the amount of OM required to increase TOC levels, this study has shown a positive relationship between the difference in the estimated amount of OM retained and the difference in measured SOC level. However this relationship is only applicable to the irrigated mixed farming systems within the study region.

Considering the various difficulties in all approaches to studying soil carbon dynamics, using strategically selected paired sites to develop the relationships between differences in organic matter retained on site and the corresponding change in soil carbon, for specific agroecological zones, soil types and management, may provide a useful methodology to support other soil carbon monitoring techniques.

References

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