

# Have agronomic field trials provided sufficient data to predict soil carbon sequestration rates?

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## Abstract

As nations debate whether and how best to include the agricultural sector in greenhouse gas pollution reduction schemes, the role of soil organic carbon as a potential large carbon sink has been thrust onto centre stage. Results from most agricultural field trials indicate a relative increase in soil carbon stocks with the adoption of various improved management practices. However, the few available studies with time series data suggest that this relative gain is often due to a reduction or cessation of soil carbon losses rather than an actual increase in carbon stocks. Based on this observation, we argue here that stock change data from agricultural field trials may have limited predictive power when the state of the soil carbon system is unknown and that current IPCC accounting methodologies based on these trial results may not properly credit these activities.

## Key Words

Carbon sequestration, greenhouse gases, soil organic matter, IPCC.

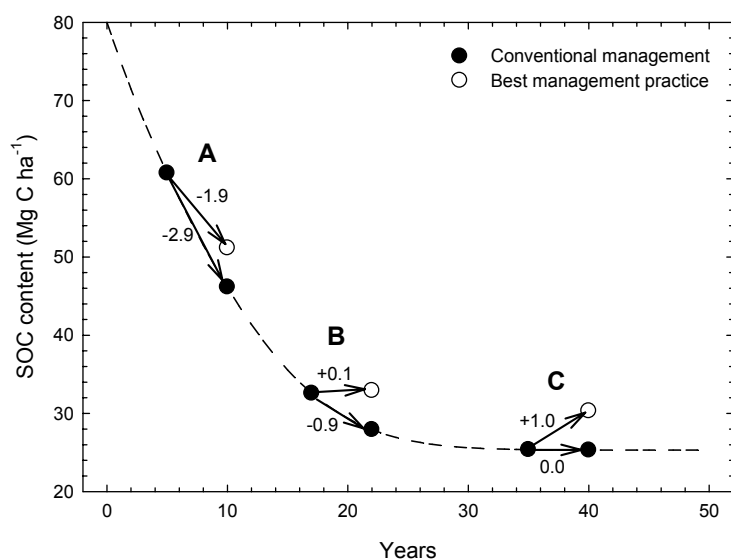
## Introduction

Improved management of agricultural land has the potential to both greatly reduce net greenhouse gas (GHG) emissions (Smith *et al.* 2008) and to act as a direct CO<sub>2</sub> sink through soil carbon sequestration (Lal 2004). The recognition that agricultural soil carbon sequestration could be a successful “win-win” or “no regrets” policy, simultaneously reducing atmospheric GHG levels and increasing food security through improved soil health has thrust the issue onto numerous national political agendas. Existing agricultural field trials represent one of the greatest immediately available resources for the study of management impacts on soil carbon sequestration. These data sets have both informed soil carbon modelling efforts (i.e. Parton *et al.* 1987; Skjemstad *et al.* 2004) and formed the basis for the stock change factors used in current IPCC accounting guidelines (IPCC 2006). The measurement of soil organic carbon (SOC) content at the onset of a trial provides a baseline from which to calculate the impact of imposed management treatments on rates of SOC change. Initial SOC measurements can also be useful to verify that starting SOC values are similar between treatments, which are of critical importance for paired-plot studies where greater concern over spatial heterogeneity between sites exists. Unfortunately, the great majority of these studies were designed to define the influence of agricultural management practices on plant dry matter production, grain yields and other agronomic properties. Few long-term trials accurately measured SOC stocks at the onset of experimentation. Useful data on SOC stock changes have been and can still be gathered without the aid of the baseline data. However, without time series data, results from these trials have restricted predictive power and current IPCC accounting methodologies based on these trial results may not properly credit these management activities.

## Discussion of typical results

As noted, only a small number of studies have actually followed a change in management through time, the remainder have compared SOC stocks in contrasting management practices after a defined number of years of implementation. Without the baseline data at the inception of a trial or a temporal sequence of measurements, it is impossible to determine whether or not a current measured difference in SOC between two treatments has resulted in a net sequestration of atmospheric CO<sub>2</sub>-C. A second consideration involved in defining the influence of applied management practices on soil carbon change and carbon sequestration is whether SOC has stabilised at a new steady state value indicative of the applied management practice or is still changing and progressing towards a new equilibrium value. Evidence suggests that the imposition of agriculture on previously undisturbed soil will result in a 20-60% loss of SOC (Mann 1986; Davidson and Ackerman 1993; Lal 2004) with the rate of loss being greatest initially and then diminishing with time (dashed line in Figure 1). If two management practices (conventional (CP) and best management practice (BMP) in terms of SOC accumulation) are initiated at different times after clearing (points A, B and C)

different SOC sequestration outcomes are obtained (Figure 1). Results from replicated field trials with time series data in Australia indicate that Australian agricultural soils are typically somewhere between scenario A and B in **Error! Reference source not found.** The relative change between treatments consistently showed a large net gain in SOC, but this was due to the conventional practice typically losing SOC and the conservation or BMP losing SOC but at a smaller or insignificant rate.



**Figure 1. Results from a hypothetical field trial comparing CMP and BMP initiated at three times (A, B and C) after initial clearing. If the initial conditions were unknown, all 3 trials would show a relative gain of 5 Mg C/ha in the BMP over the 5-year trial period. The actual rate of change in SOC stocks (given next to each arrow) is entirely dependent upon the initial state of the system: A) the soil is still responding to the initial land clearing and is losing SOC at a rapid rate and both management scenarios result in a net emission of CO<sub>2</sub>; B) the rate of SOC loss has moderated and little net change in SOC is noted in the BMP while the conventional management system continues to lose SOC; and C) the soil has reached steady state with respect to the CMP and the BMP results in a net sequestration compared to the SOC content present at the time the experiment was initiated.**

### Predictive value of these results?

Does the observed difference in a paired-site study or single point-in-time measurements in a trial translate to the case of adopting the new management? If the CMP trial was at steady state at the beginning of the trial (e.g. point C in Figure 1), then we can reasonably assume that the difference was due to increased soil carbon stocks under the BMP system and adoption of this practice at some point in the future will result in these gains. However, if the CMP trial was not at steady state and was continuing to lose SOC (i.e. **Error! Reference source not found.** and points A and B in Figure 1) and the relative gain in the BMP trial was really due to a reduction or cessation of losses, then it is uncertain whether this data will give us an answer to the posed question because the accumulation and loss of SOC may not be symmetrical processes.

There is evidence from both mechanistic and modelling studies that SOC is typically lost more rapidly than it is gained. First, the formation of stable aggregates that retard SOC decomposition may be much slower than their destruction during tillage (Jastrow *et al.* 1996; Six *et al.* 2000), thus SOC stocks may not build nearly as rapidly as they appear to be lost (Balesdent *et al.* 2000). This concept of hysteresis was nicely demonstrated by Pankhurst *et al.* (2002) by switching management practices after 14 years of a trial and then re-sampling 3 years later. Applying tillage to the previously no-till plots resulted in large losses of C from the upper 10 cm of soil, however, applying no-till to previously tilled plots resulted in non-significant SOC changes after 3 yrs (Pankhurst *et al.* 2002). In a second example, studies of rangeland management have shown that re-establishment of healthy, diverse and productive plant communities takes much longer (up to 5-10 times longer) than the degradation of these systems (Harrington *et al.* 1984; McKeon *et al.* 2004) leading to potential rapid loss of SOC but gradual gains (Hill *et al.* 2006). Third, most multiple-pool soil carbon models will show greater loss rates than sequestration rates when modelling input changes over decadal timescales because changes typically take on the order of a century to fully propagate through all the various SOC pools. These examples all suggest that reducing SOC loss rates may be easier than actually increasing stocks.

## Accounting implications

Carbon emissions and removals for Article 3.4 of the Kyoto Protocol (UNFCCC 1992) activities most pertinent to the agricultural sector need to be accounted for on a “net-net” basis; meaning that net emissions and removals from activities during a commitment period are to be compared to net emissions and removals in a base year (Schlamadinger *et al.* 2007). Accounting for net uptake or release of CO<sub>2</sub> from soils presents a unique challenge for the AFOLU (Agriculture, Forestry and Other Land Uses) sector because accurate measurements are extremely difficult, thus necessitating monitoring changes in SOC stocks instead of net emissions. While the net change in SOC stocks will give a measure of the overall emissions or removals during a commitment period, comparing stocks only in 2 years does not yield any information on whether or not the net emissions rate has changed throughout the commitment period. Currently, the agreed-upon IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006) outline accounting methodology into a 3 tiered system depending on the level of desired detail and availability of suitable information.

*Tier I & II Accounting.* In these accounting approaches, SOC stock changes are calculated by multiplying a reference stock value (IPCC default values for Tier I and country/region specific values for Tier II) by a series of stock change factors, which are assumed to have linear effects for 20 years before reaching a new equilibrium (IPCC 2006). The stock change factors, which essentially represent the relative difference between two management practices, have been derived from data sets composed of primarily paired-site studies (i.e. West and Post 2002; Smith *et al.* 2008). As discussed earlier, these data cannot distinguish between sequestration and avoided emissions, with the result being that a country would get credit for an activity regardless of the actual SOC outcome. An advantage of this accounting methodology is that nations will correctly get credits for avoided emissions regardless of whether the actual SOC trajectory was more like scenarios A or B versus C in Figure 1. However, these credits may be artificially high in many situations because of the hysteresis problem outlined in the previous section.

Additionally, under a stock change factor accounting system, a change in land-use, management or inputs is needed to induce a SOC stock change. Thus, a farm that has been steadily increasing SOC stocks due to continuous good management since the baseline year would not get any credits for these activities despite actually decreasing the atmospheric burden of CO<sub>2</sub> on an annual basis. Furthermore, this accounting methodology makes no consideration for when the change in management occurred, as long as it occurred between the accounting year and the baseline year, with the result being all land area that falls within one management change category will get the same amount of credits.

*Tier III Accounting.* The highest order accounting system is a spatially explicit detailed modelling- or inventory-based system (IPCC 2006). From a modelling standpoint, knowledge of only the relative difference between management wouldn't be good enough to predict actual SOC stock changes. In the case of scenarios A and B, we would also need to know if the baseline, if projected into the commitment period, is changing which would be extremely difficult to verify let alone model. In a Tier III national inventory-based approach, SOC stocks would only be followed through time so the relative SOC gains (i.e. emission reductions) found in many field trials would not be “seen” and only the actual change in stocks over time will be reported.

Thus, under current IPCC recommended accounting guidelines, there may be a perverse situation where Tier I and II approaches will yield emissions reduction credits for all management shifts regardless of whether the shift results in net sequestration or simply a reduction in SOC losses, while SOC accounting under the more detailed Tier III approach would result in net liabilities for a country if the change in management only resulted in a reduction in SOC loss rate. Given that even a reduction in the loss rate of SOC is of value in terms of meeting GHG abatement targets and is consistent with the goals of net-net accounting (Schlamadinger *et al.* 2007), this analysis suggests that inventory-based accounting methods, while being able to correctly track changes in SOC stocks, may not be the most appropriate choice for emissions inventories and efforts should perhaps be focused on improving the stock change factor and modelling approaches.

## Conclusions

Results from agronomic field trials generally show a relative gain in carbon stocks with implementation of management practices that return or retain more of the carbon captured by growing plants. However, much of the data used to support such a conclusion has been derived from point-in-time measurements which are

ambiguous as to whether the relative difference was due to net sequestration or simply a cessation of losses during the trial (i.e. an avoidance of emissions). While most field trial evidence suggests a real net benefit to GHG abatement, we have argued here that 1) the predictive power of results from most agronomic field trials to alternative situations where these management practices have been implemented is questionable without detailed knowledge of the state of the soil carbon system; and 2) the current recommended IPCC accounting methodologies may not properly credit these activities and may indeed result in contradictory results when accounted for using Tier I or II versus Tier III approaches.

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