Effect of alternative cropping management on soil organic carbon

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Abstract

Concerns about declining soil organic carbon (SOC) and increased greenhouse gas emissions due to practices such as intensive tillage and bare fallows have encouraged the adoption of practices such as no-tillage, crop rotations and residue retention. However, whilst no-till farming is suited for broadacre crops, it has not been widely adapted for most vegetable production systems. Vegetable production systems, especially organic ones, routinely use tillage to prepare beds and manage weeds. These tillage operations break soil structure and aggregates, which is known to accelerate losses of SOC stocks. Despite requiring multiple tillage operations, the vegetable systems are also characterised by little or no crop residue input, potentially further reducing SOC stocks. The effect of sweet corn (*Zea mays* L. var. *rugosa*) residue management (RM; i.e. incorporation or removal) in a corn-cabbage (*Brassica oleracea* L.) rotation on SOC parameters in two soil management systems (SMS; i.e. organic and conventional) was examined because crop residue incorporation and application of organic fertilisers could be ways to counteract loss of SOC due to tillage in vegetable systems.

The principal aim of this thesis was to examine the effect of RM in the two SMS on soil total carbon (TOC) concentrations and stock, soil carbon fractions and microbial biomass carbon (MBC) through a field experiment of a corn/cabbage rotation over two years. A laboratory experiment was performed to separate the confounding factors of SMS in the field experiment, i.e. herbicide and mineral fertilisers in the conventional SMS, and cultivation and organic fertilisers in the organic SMS. To supplement the field experiment, another laboratory experiment focused on how two potentially opposing determinants of TOC, residue incorporation and simulated tillage (sieving), influence the emission of CO_2-C. Although, the research objectives of this thesis are focused on SOC, agronomic and fertility parameters, the essential components of a crop production system, were also considered.

The field experiment was conducted from December 2009 to December 2011 in a completely randomised layout with a factorial design (2 RM × 2 SMS × 2 soil types with 4 replications) near Armidale, New South Wales, Australia. Two laboratory experiments were also conducted using factorial designs (completely randomised with 4 replications) from January to June 2011 in the University of New England, Armidale. All field and laboratory experiments of this thesis were conducted on Vertosol and Chromosol, two common agricultural soils in Australia. Yield components of corn and cabbage crops and weed

biomasses and nutrient uptake by corn stover and cabbage; and TOC and its fractions, SOC stocks and soil macro-nutrients were also analysed for the field experiment. In the laboratory experiments, TOC and its fractions and CO_2-C emissions were the main chemical analyses.

Corn and cabbage yields and nutrient uptake by corn stover (except P) and cabbage head were not influenced by RM or SMS. Yields of both crops under the organic SMS were not lower than the conventional SMS, possibly due to the equivalent N, P and K nutrients applied and also soil nutrient status might not have reached the limiting level after imposition of the treatment. Exchangeable K, but not Colwell P was significantly increased by residue incorporation. Residue incorporation and the organic SMS increased the average total N by 7% and 4% compared to the treatments without residue and the conventional SMS, respectively, indicating the longer-term fertility gains of these treatments. Residue incorporation reduced weed biomass in the cabbage crop by 22% in 2010 and by 47% in 2011. Corn residue-induced inhibitions on weed biomass may be exploited as a supplementary tool to mechanical weed control for the organic SMS potentially reducing the negative impacts of cultivation on SOC.

In the field experiment, TOC concentration increased significantly by 6.5 % in the 0-0.1 m depth by incorporating shredded residue; however the effect of SMS was inconsistent. The laboratory experiment confirmed that the use of atrazine and mineral fertiliser in the conventional SMS in the field experiment had no significant effect on TOC, whereas both the organic fertiliser and simulated tillage significantly increased TOC, as expected in the organic SMS scenario. Organic fertiliser application in the field may, therefore, balance the C lost through tillage. Soil basal respiration and MBC data showed that the soil's biological fertility could be improved by incorporating residues and by combining residue incorporation with organic fertiliser. Evaluation of the SOC stock determined that residue incorporation at about 15 Mg/ha per year (oven-dry equivalent) in soil accumulated an average of 0.96 and 1.22 Mg C/ha for Chromosol and Vertosol, respectively, in the field trial after 2 years.

With regard to TOC fractions, residue incorporation increased particulate organic C (POC) by 32% in the field experiment and 48% in the laboratory experiment. Mineral-associated organic C (MOC) and TOC were positively impacted by residue incorporation and soil type in both field and laboratory experiments alike. These results indicate that residue and the soil type were key determinants of POC and MOC fractions. MOC was the major pool of TOC in both experiments, i.e. $\geq$ 83% in the Vertosol and $\geq$ 73% in the Chromosol. The increase in the

stable form of C, not just in the labile forms, indicates the potential for longer term C sequestration in soil through physicochemical stabilisation in vegetables systems, if not through aggregation. Simulated tillage (sieving) had a limited impact on POC, MOC and TOC, suggesting that hand hoeing (cultivation) to control weeds in organic SMS in the field might have only a minor effect on the rate of SOM mineralisation in the short-term.

On average, residue incorporated and simulated tillage treatments emitted 2.3 and 1.5 times more CO_2-C in comparison to unamended and undisturbed treatments, respectively, across the two soil types. This suggests that C availability and form could be more important for CO_2-C emission than physical disturbance in cropping soils. Both residue incorporated and sieved treatment (organic scenario) not only emitted more CO_2-C but also had 16% and 11% higher level of SOC in Chromosol and Vertosol, respectively, compared with the treatment that was neither incorporated with residue nor sieved (conventional scenario). This confirms the observation that an organic system might retain more soil C than a conventional system. Since the CO_2-C emitted is usually a minute fraction in relation to SOC, the C lost by soil disturbance is more than compensated by incorporation of residue.

Between soil types, the clayey Vertosol conserved higher levels of soil nutrients, had better soil structural stability, had higher levels of TOC, MOC and MBC concentration and stored more SOC stock compared to the sandy Chromosol. However, SOC-rich Vertosol also emitted more CO_2-C than the SOC-poor Chromosol.

In conclusion, the observed short-term gains have the potential to translate into longer-term C sequestration and soil fertility gains, if sweet corn is rotated with vegetable crops and shredded residue is incorporated into soil. However, the effect of SMS was inconsistent because the longer time interval (8 months) between organic fertiliser incorporation and soil sampling led to loss soil C possibly due to easily decomposable C:N ratios ($\leq$ 5.4) of the organic fertilisers. Though shredding of residue may not be practical for growers, the results highlight the potential for increasing soil C using crop residues. Moreover, these practices may be an option to counteract the loss of C due to multiple tillage operations that vegetable systems, especially organic ones, routinely use. The increase in the stable form (MOC), not just in the labile forms (POC and DOC), indicates the potential for longer term C sequestration in soil through physicochemical stabilisation.

Publications arising from this thesis

Journal articles

Bajgai, Y., Kristiansen, P., Hulugalle, N. and McHenry, M. 2011. A laboratory study of soil carbon dioxide emissions in a Vertisol and an Alfisol due to incorporating corn residues and simulating tillage. *Journal of Organic Systems*. 6(3): 20-26.

Bajgai, Y., Kristiansen, P., Hulugalle, N. and McHenry, M. in press. Effect of residue management and conventional and organic soil management systems on crop yields and weed biomass. *Acta Horticulturae*.

Bajgai, Y., Hulugalle, N., Kristiansen, P. and McHenry, M. Under review. Soil carbon changes and CO_2 emissions due to incorporating corn residues and simulating tillage – A laboratory study. Paper submitted to *Soil Use and Management*.

Bajgai, Y., Kristiansen, P., Hulugalle, N. and McHenry, M. Under review. Effect of corn residue incorporation and soil management systems on soil carbon fractions: Results of field and laboratory experiments. Paper submited to *Soil Research*.

Bajgai, Y., Kristiansen, P., Hulugalle, N. and McHenry, M. Under review. Influence of corn residue incorporation in organic and conventional soil management systems on crop yields, nutrient uptakes, weed biomass and soil nutrients. Paper submitted to *Renewable Agriculture and Food Systems*.

Bajgai, Y., Hulugalle, N., Kristiansen, P. and McHenry, M. In preparation. Effect of alternative cropping management on soil carbon concentration and stock and soil microbial biomass carbon.

Conference papers (= peer-reviewed)*

*Bajgai, Y., Kristensen, P., Hulugalle, N. and McHenry, M. 2012. Particulate and mineral-associated organic carbon fractions as influenced by corn residue incorporation and simulated tillage. In: Yunusa, I. (Ed.) *Capturing Opportunities and Overcoming Obstacles in Australian Agronomy: Proceedings of the 16th ASA Conference, 14-18 October 2012*. Australian Agronomy Society, Armidale, Australia. pp. online.

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Bajgai, Y., Kristiansen, P., Hulugalle, N. and McHenry, M. 2011. Preliminary findings - Effect of alternative cropping management on soil organic carbon. In: Cowie, A. (Ed.) *Rural Climate Change Solutions Symposium, 3-4 May 2011*. University of New England, Armidale. pp. 58-59.

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