Particulate and mineral-associated organic carbon fractions as influenced by corn residue incorporation and simulated tillage

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Abstract
Vegetable production systems rely on frequent tillage to prepare beds and manage weeds. These cultivations disrupt soil aggregates leading to a loss of soil organic carbon (SOC) and decline productivity. Crop residue incorporation could be a way to counteract such negative impacts. This hypothesis was examined using two contrasting soils, a Vertosol and a Chromosol, sweet corn (*Zea mays* var. *rugosa* L.) residue either incorporated or not and soils sieved/disturbed or not to simulate tillage in an incubation experiment. The treated soils were dispersed and fractionated to determine concentrations of particulate organic carbon (POC) and mineral-associated organic carbon (MOC). POC and MOC were affected by soil type and residue incorporation but not by simulated tillage. Vertosol and '+' residue had significantly higher POC and MOC. On average, the POC and MOC accounted for 23% and 77% of total organic carbon (TOC) for Chromosol and 17% and 83% of TOC for Vertosol, respectively. The limited effect of simulated tillage is possibly due to low intensity and frequency of sieving. The residue amended soils had 15% and 10% higher TOC for Chromosol and Vertosol, respectively. Residue incorporation could help improve SOC in the intensively cultivated vegetable soils. The mineral-associated fraction has a greater SOC stabilising capacity in clayey Vertosols than in sandy Chromosols due to the sorption mechanism of carbon particles on organo-mineral surfaces. Sorption of carbon particles on organo-mineral surfaces may be responsible for the increased MOC in residue amended treatments.

Key words
Sieving, soil disturbance, carbon stabilization, organo-mineral complexes, sorption

Introduction
Vegetable production systems rely on tillage to prepare beds and manage weeds and insects. The tillage operations disrupt soil aggregates exposing the physically protected soil organic matter (SOM) leading to loss of soil organic carbon (SOC) (Angers *et al*., 1993) and decline in soil productivity. The CO_2 fixed in plant biomass by photosynthesis is returned to soil forming SOM, some of which is lost due to tillage (Jarecki and Lal, 2003; Johnson *et al.*, 2007). Crop residue incorporation could be one way to counteract this loss and to improve SOC levels. We examined our hypothesis that vegetable systems could be made more resistant to the effects of tillage by including a high-residue grain crop like sweet corn (*Zea mays* var. *rugosa* L.) in the rotation through an incubation experiment.

Materials and methods
The treatments consisted of two contrasting soils (Chromosol or Vertosol) ± ground (< 4mm) corn residue incorporated (RES or -RES) and ± sieved to create soil disturbance (< 4mm) to simulate tillage (+Till or –Till), making a 2^3 factorial design. The layout was completely randomized with four replicates. The two contrasting soils (Table 1) used were a Black Vertosol and a Brown Chromosol (Isbell, 2002) from two sites in Armidale, NSW. The soils were air-dried, sieved through <2-mm sieve and homogenised by mixing. Five hundred (Vertosol) and 600 (Chromosol) grams of soil (oven-dried basis) were weighed into 8.6 cm diameter polythene pots to a depth of ~0.1 m.

The entire experiment including four months pre-incubation was conducted in growth cabinet with temperature maintained at 25°C except when the soils were taken out for sieving. Lights were maintained continuously for 12 hours and 12 hours of dark each day. The residue was incorporated at a rate of 15 tonnes/ha (dry weight basis) with an average C:N ratio of 34:1 and pre-incubated four months to allow decomposition of the applied residue. Water was applied once in two weeks for Vertosol and once every six days for Chromosol to raise soil moisture levels from wilting point (-1500 kPa) to field capacity (-33 kPa) during pre-incubation and after two simulated tillage events. The irrigation schedule resulted in 11 and 25 wetting/drying cycles in Vertosol and Chromosol, respectively. Particle size distribution of the two soils enabled their hydraulic characteristics to be estimated with the pedotransfer functions of Vervoort *et al.* (2006) for Vertosols and Minasny (2006) for Chromosols. Soils were sieved twice to simulate tillage (Calderon *et al.* 2000; Kristensen *et al.* 2003) with a <4mm screen to disturb soil and the second sieving was done 15 days after the first. Sieving was done when the soil moisture level dropped close to wilting point to avoid smearing and for practical convenience.

Table 1: Selected soil properties for 0-0.1 m depth with means (*n* = 4).

Soil property	Chromosol	Vertosol
Carbon (g/100g)	1.28	2.47
Nitrogen (g/100g)	0.12	0.21
pH (H_20) $_{1:5}$	6.0	5.8
Bulk density (Mg/m^3)	1.47	1.22
Sand content (g/100g)	67.9	24.4
Silt content (g/100g)	17.8	13.9
Clay content (g/100g)	14.3	61.7

Briefly, 10 g of air dry treated soil (<2mm) was weighed out in 50 mL centrifuge tube, filled to 45 mL mark with potassium hexa-meta phosphate solution (5g/L) and tumbled overnight. The duplicate soil samples were used for Vertosol and triplicate for Chromosol based on the estimate of recoveries. The dispersed soil in potassium hexa-meta phosphate solution was fractionated using 50 µm sieve into >50 µm fraction which consisted particulate organic matter (POM) + sand and <50 µm fraction of mineral-associated organic matter (MOM). An automated wet sieving technique (FRITSCH Vibratory Sieve Shaker Analysette 3 PRO) was implemented for a minimum of three minutes with amplitude of 2.5 mm and time interval of 20 seconds (Sanderman *et al*., 2011). From >50 µm fraction, POM and sand were separated by flotation. Dry weights of POM and MOM were recovered from water by oven drying at 70 ^{o}C for 72 hours. The two fractions were analysed for carbon and nitrogen to determine concentrations of particulate organic carbon (POC), mineral-associated organic carbon (MOC), nitrogen in POM (POM-N) and nitrogen in MOM (MOM-N). The total organic carbon (TOC) was estimated by summation of the POC and MOC and similarly total nitrogen (TN) by summation of POM-N and MOM-N. Approximately 0.3000 g of finely ground (<0.5mm) sample was weighed out into tin cups and analysed by a complete combustion method at 950^{o}C furnace (TruSpec Carbon and Nitrogen Analyser, LECO Corporation).

Analysis of variance (ANOVA) was used to assess the effects of residue, simulated tillage and soil type on POC, MOC, TOC, POM-N, MOM-N and TN on the equivalent soil mass basis using the R version 2.9.1 (R Development Core Team 2010). All ANOVA models were evaluated for normality and homogenous variances. All statistical significant differences referred to are $P \leq 0.05$, unless otherwise specified.

Results

No significant interactions were found between the main factors of soil, residue and simulated tillage with respect to POC fraction. The individual main factors of soil and residue had highly significant ($P \leq 0.001$) effects on both POC and MOC but simulated tillage did not. However, three-way interaction between soil × residue × simulated tillage was significant ($P \leq 0.05$) for MOC. The influence of the four treatments on the POC and MOC fractions in each soil type on the equivalent soil mass basis is presented in Figure 1. Residue incorporated treatments resulted in significantly higher levels of POC and MOC (Figure 1 A and B). The TOC showed similar results as MOC except that the two-way interaction between residue × simulated tillage had a significance at P=0.10. On average, the POC and MOC accounted for 23% and 77% of TOC for Chromosol and 17% and 83% of TOC for Vertosol, respectively. Similar to POC, no interactions were significant on POM-N and MOM-N. The only factor that was significant for POM-N ($P \leq 0.001$) was residue. Soil and residue had highly significant ($P \leq 0.001$) influence on MOM-N, but simulated tillage had no significant influence (Figure 2 A and B). As for TOC, both soil and residue had highly significant ($P \leq 0.001$) influence on TN.

Discussion

Incorporating crop residues increased levels of both the POC and MOC fractions due to carbon addition from the incorporated residue. POC is a labile fraction sensitive to recent management (residue incorporation) of soil. A major part of POC would be lost within few months due to microbial action, whereas MOC is a more stable fraction that is physically held on organo-mineral complexes of silt and clay particles (Lützow *et*

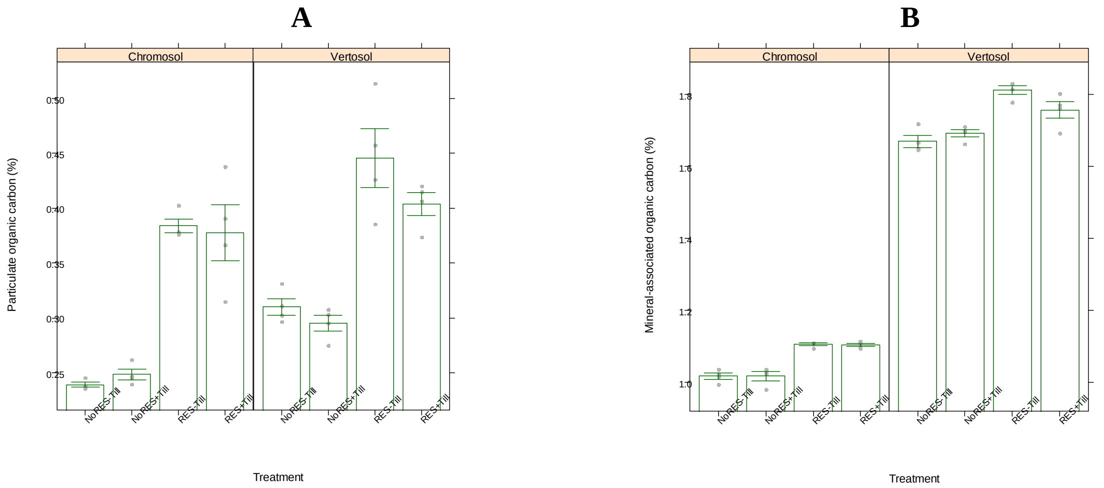

Figure 1: Particulate organic carbon in two soils (A) and mineral-associated organic carbon in two soils (B); Vertical bars are standard errors of means; noRES±Till = no residue treatments with or without sieving; RES ± Till = residue incorporated treatments with or without sieving.

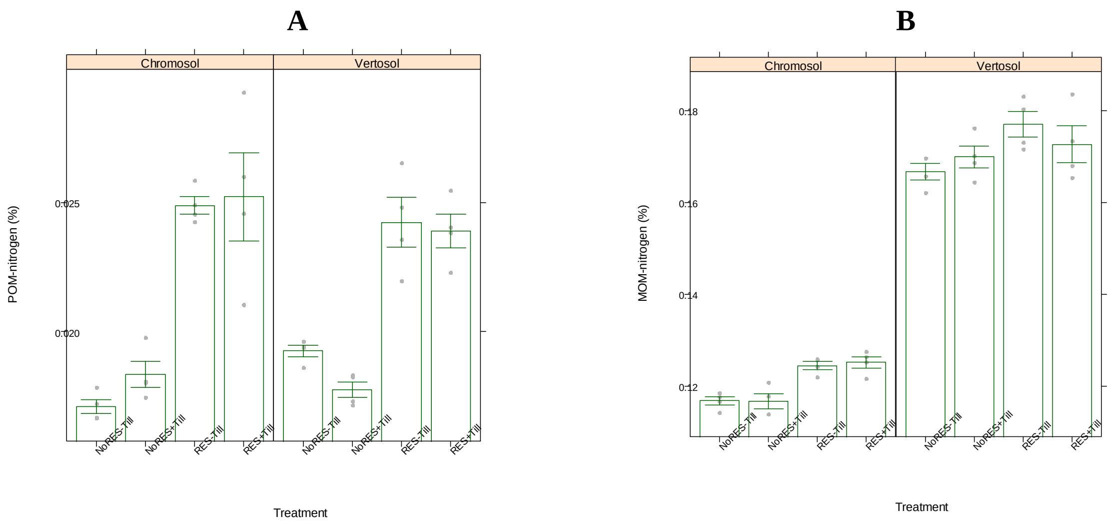

Figure 2: POM (particulate organic matter)-nitrogen in two soils (A) and MOM (mineral-associated organic matter)-nitrogen in two soils (B); Vertical bars are standard errors of means, noRES±Till = no residue treatments with or without sieving; RES ± Till = residue incorporated treatments with or without sieving.

al., 2006). The simulated tillage had limited effect both fractions presumably due to low intensity (<4 mm sieve) and frequency of twice only. However, there was a detectable evidence that simulated tillage (P=0.10) had an effect on TOC at the least. In agreement with our findings, Calderón *et al.* (2000) and Kristensen *et al.* (2003) have reported the limited effect of simulated tillage on mineralisation of soil carbon and nitrogen. Under field conditions too, no significant differences between tilled and no-till in five years period is reported in a meta-analysis of 69 paired sites experiments in terms of SOC (Luo *et al*., 2010) which may explain our results. The CO_2-C fluxes of this experiment at different sampling times after the simulated tillage showed significant interaction between residue × simulated tillage (Bajgai *et al.,* 2011) highlighting the role of residue and simulated tillage on stimulating microbial activities.

The three-way interaction between soil × residue × simulated tillage was significant ($P \leq 0.05$) on MOC. This may be attributed to: 1) higher levels in residue incorporated treatments, 2) initial differences between two the soil types and 3) difference between simulated tillage treatments of the residue incorporated (RES±Till) Vertosol soil. The two-way interaction, residue × simulated tillage impacted significantly on MOC levels due to lower and easily decomposable average C:N ratios (8.79 for Chromosol and 10.11 for Vertosol) as compared with higher C:N ratios (14.49 for Chromosol and 17.00 for Vertosol) of POC. The residue incorporated soils had 15% and 10% higher TOC for Chromosol and Vertosol, respectively, compared with the treatments without residue. The microaggregates (250-50 µm) that stabilise SOC through physical protection (Six *et al*., 2000) were dispersed in this experiment to examine the extent of POC and MOC. Fine textured Vertosol showed greater percentage of MOC owing to its higher carbon enrichment capacity (Christensen, 2001) compared to sandy Chromosol. The sorption mechanisms of carbon particles on the organo-mineral surfaces may be attributed for the enrichment and thus stabilisation of carbon (Christensen, 2001, Lützow *et al*, 2006).

Conclusion

Residue incorporation improved SOC and soil nitrogen in the intensively cultivated soils of vegetable production that are subjected to regular disturbance. The two simulated tillage events (by < 4mm sieve) did not affect the POC and MOC fractions, but residue incorporation did. The residue × simulated tillage impacted significantly on MOC levels due to lower and easily decomposable average C:N ratios. The mineral-associated fraction has a greater SOC stabilising capacity in clayey Vertosols than in sandy Chromosols.

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