Cotton yield and soil carbon under continuous cotton, cotton-corn, cotton-vetch-corn and cotton-wheat rotations

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Abstract

The quality of soil organic carbon (SOC) in Vertosols sown with cotton-based rotations has been little studied. This paper reports soil microbial biomass, SOC fraction (light and occluded), cotton root density and yield changes in four cotton-based rotations during the 2006/07 season in two experiments located near Narrabri, NSW, Australia. The rotations were cotton–corn (CCo), cotton–vetch–corn (CVCo), continuous cotton (CC) and cotton–wheat (CW). Experiment 1 included the CCo and CVCo rotations, while experiment 2 included the CC and CW rotations. Experiment 1 started in September 2005, while experiment 2 started in September 2002. SOC, as determined using the Walkley-Black oxidation method showed no differences between rotations at the start of the season. During the season, there was a slight decline in SOC in all rotations due to carbon mineralisation. The light and occluded carbon fractions were determined using sodium iodide (NaI) density separation of the particulate organic carbon. The light fraction was highest in the rotations which included corn, while the occluded fraction did not differ among treatments. Microbial biomass estimated using the Ninhydrin reactive N method was the highest in the CCo and CVCo rotations, while CC was lower than the CW rotation. Total root density was highest in the CCo and CVCo rotations. Plant mapping throughout the season showed that boll numbers in the CW rotation were higher than in CC, but there were little differences between CCo and CVCo. The CW rotation had the highest yield, but the light fraction of the organic carbon was lower for CW compared with CCo and CVCo. There was a high correlation between root density and microbial biomass ($R^2 = 0.70$), root density and labile carbon ($R^2 = 0.51$) and between microbial biomass and labile carbon ($R^2 = 0.68$). Cotton-based rotations which included corn had higher light fraction carbon levels, root densities and microbial biomass. Generally, changes in the light fraction tended to influence SOC while the occluded fraction remained fairly constant. Measurements will need to be made over several seasons to better understand carbon fraction dynamics under these long-term rotations.

Key Words

Cotton, Corn, Crop rotations, Soil organic carbon, Particulate organic carbon, Microbial biomass

Introduction

Thirty years ago, cotton (*Gossypium hirsutum*) was cropped in a monoculture leading to a decline in soil organic carbon (SOC) from intensive tillage and a lack of inputs (Hulugalle and Scott 2008). The most common rotation at present is two years cotton and one year wheat followed by a nine month fallow. Minimum tillage and rotations with crops such as wheat (*Triticum aestivum*), woolly pod vetch (*Vicia villosa*) and corn (*Zea mays*) are claimed to be management systems that can reduce SOC decline (Hulugalle and Scott 2008). SOC can be categorised into two main fractions, light (labile) carbon and occluded (stable) carbon. Light carbon is readily oxidised and free from soil particles making it more beneficial to short-term soil health, while the occluded carbon is bound or within soil particles and is seen as a long term carbon source (Conteh *et al.* 1997). Soil microbial biomass forms part of the light carbon fraction. Although it makes up less than 5% of SOC, it is important for supplying roots with nutrients and is a good indicator of soil health (Wright *et al.* 2004). Little research has been done on the comparative effects of crops such as corn, wheat and vetch sown in rotation with cotton on light (including microbial biomass), and occluded carbon fractions and cotton yield, although cotton-wheat sequences are reported to have a higher proportion of more decomposable organic matter (Conteh *et al*. 1998).

The aim of this study was to evaluate cotton yield and SOC fraction changes in four cotton-based rotations, cotton–corn (CCo), cotton–vetch–corn (CVCo), continuous cotton (CC) and cotton–wheat (CW) in an irrigated Vertosol during the 2006/07 cotton-growing season. It tested the hypothesis that inclusion of corn and wheat in cotton-based rotations increased SOC, light and occluded carbon fractions, soil microbial biomass and cotton yield compared with a cotton monoculture.

Methods

Field experiment - rotations

Plant and soil samples were taken from two on-going experiments, located in a furrow irrigated grey Vertosol (60% clay, 15% silt, 25% sand), at the Australian Cotton Research Institute (ACRI) (30.11?S, 149.37?E), near Narrabri, NSW. Experiment 1, implemented in 2005, consisted of two rotations: (1) cotton – winter fallow – corn (CCo) and (2) cotton – vetch – corn (CVCo). Both corn and cotton phases in each rotation were sown every year. Experiment 2, established in 2002, included: (1) continuous cotton (CC) and (2) cotton – wheat – summer and winter fallow-cotton (CW), in which wheat stubble was incorporated into the beds with a disc-hiller. Both wheat and cotton phases of the rotation were sown every year. Tillage in all treatments was limited to slashing cotton stalks, cotton root cutting and incorporating cotton stubble and reforming beds with a disc-hiller. Depth of tillage did not exceed 10 cm. The cotton cultivar Sicala 43BRF was sown on 16 Oct 06 and harvested on 26 Apr 07, and the field layouts were randomised complete block designs with four replicates in Experiment 1 and three replicates in Experiment 2.

Data collection and measurements

SOC, carbon fractionation and microbial biomass were measured in soil cores (100 mm diam.) sampled from the root zone three times during the season (28 Nov 06, 22 Jan and 20 Feb 07) at the depths of 0-10 cm and 10-30 cm. The core break and root washing methods (described in Luelf *et al.* 2006) were also conducted on soil cores sampled on 15 Dec 06, 5 and 20 Feb 07 and used to calculate root number and density. Three cores were taken per plot. SOC was determined using the Walkley-Black titration method (Walkley and Black 1934), and the light and occluded carbon fractions were measured by sodium iodide (NaI) density separation of the particulate organic carbon (Sohi *et al.* 2001; Ghosh 2007). For the light fraction, soil samples were ground to <2 mm and 15 g soil was added into a 125 mL tall glass containing 75 mL NaI (Unilab reagent, 1.6 g/cm^3), mixed by tipping the glass jar five times and allowed to settle for two days. The supernatant was filtered through filter paper (Whatman glass fibre, 55 mm diam.) under suction and the light fraction left on the paper was dried at 60?C overnight, scraped off onto a Petri dish and weighed. For the occluded fraction, another 75 mL NaI (1.6 g/cm^3) was added to the soil solid left after extracting the light fraction. The solution was sonicated for 15 min using a 75 mm tip at full power at a soil:water ratio of between 1:5 and 1:10, and mixed by tipping the glass jar five times. After standing for two days, the solution was centrifuged for 5 min at 3000 rpm and the supernatant poured through a pre-weighed glass fibre filter paper, dried at 60?C overnight and weighed (Ghosh 2007). Soil microbial biomass was measured using the chloroform fumigation-extraction (CFE) and Ninhydrin reactive N method (Luelf *et al.* 2006). Plant mapping was conducted by measuring node numbers, internode length, square and boll numbers and plant height every two weeks. A 1 m^2 sample from each plot was taken for biomass harvest which was weighed after being oven dried at 70?C for two days. The cotton was harvested using a cotton picker, ginned at ACRI Narrabri and lint and seed yields estimated. The data was analysed by analysis of variance (ANOVA) and REML using Genstat v.10. The two experiments could not be statistically compared due to different locations and starting times.

Results and discussion

Carbon fractions and microbial biomass

SOC for all rotations was maintained from 0.75% to 0.95% (Fig. 1a and 1b). The light carbon fraction increased from 0.4% to 0.8% for both CCo and CVCo from Nov 05 to Nov 06 (Fig. 1a). This increase can be attributed to the large above and below ground biomass from incorporated corn residue. The occluded fraction was stable at approximately 0.15% in all rotations. Rotations with corn (CCo and CVCo, 800 μgC/g) had approximately four times more soil microbial biomass than CC and CW (200 μgC/g) (Fig. 2a and 2b). CCo and CVCo (0.16 mg/cm^3) had approximately twice the density of roots compared with CC and CW (0.08 mg/cm^3) (Fig. 2c and 2d). Microbial biomass increased linearly as root density increased ($y = 594x + 15.6$, $R^2 = 0.70$, $P<0.001$). The root density increased linearly as the light carbon fraction increased ($y = 0.284x + 0.071$, $R^2 = 0.51$, $P<0.01$). Microbial biomass also increased with increasing light fraction ($y = (0.091 + 1534x^{39.3})/ (0.00023 + x^{39.3}$, $R^2 = 0.68$, $P<0.05$).

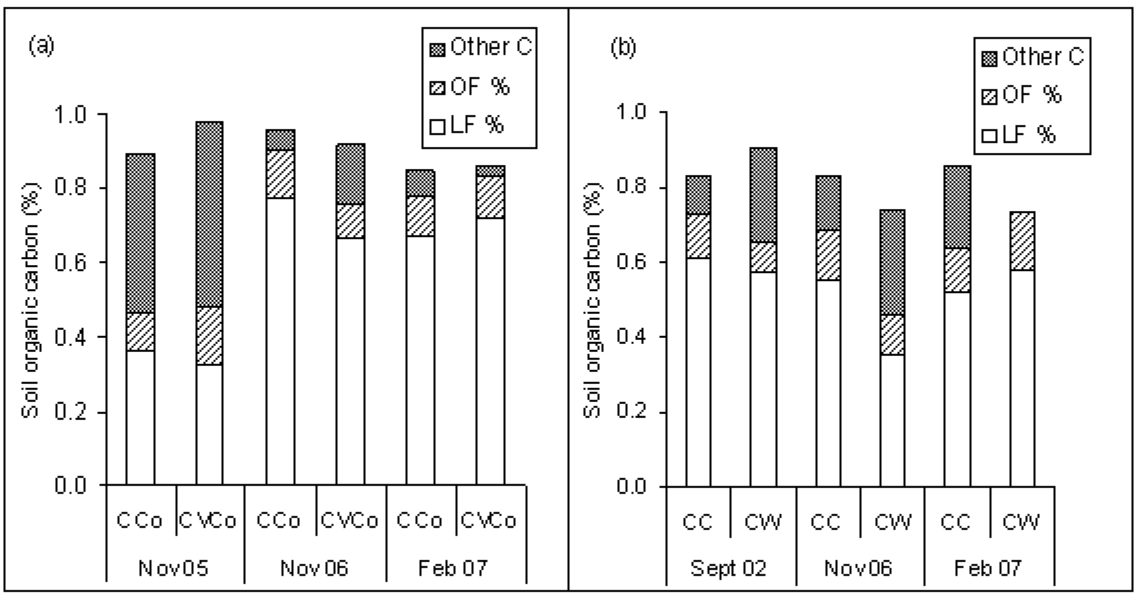

Figure 1. The percentage contribution to SOC of the light and occluded carbon for (a) CCo and CVCo and (b) CC and CW rotations at 0 -10 cm soil depth. The November 05 sample for CCo and CVCo was taken at 0-30 cm depth.

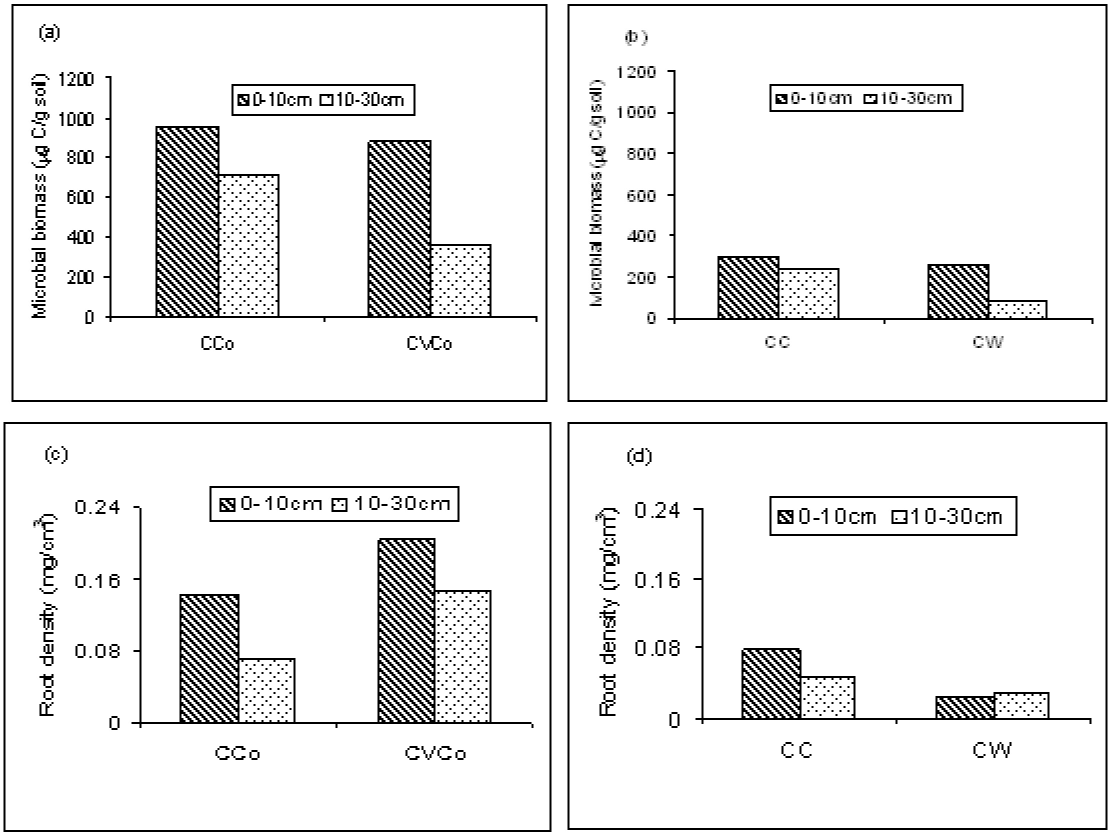

Figure 2. Microbial biomass for (a) Experiment 1 (CCo and CVCo, l.s.d. = 2.69) and (b) Experiment 2 (CC and CW, l.s.d. = 2.75) sampled on 28 Nov 06. Root density (mg/cm^3) for (c) Experiment 1 (CCo and CVCo l.s.d. = 0.152) and (d) Experiment 2 (CC and CW, l.s.d. = 0.067) sampled on 15 Dec 06. There were no significant differences between the means of microbial biomass and root density in either experiment.

Microbial biomass, root density and light carbon fraction appeared to be dependent on each other as shown through correlation. Other researchers have also found that the change in SOC correlated with the final live fine root length density and fine root surface area density possibly due to exudation of organic compounds and soil carbon stabilisation by microbial processes in the rhizosphere (Guo *et al.* 2005). The increased cotton root density in CCo and CVCo could be due to a macropore network that had been created or left by previous corn crops. Root exudation has an important role in the input of soil carbon and could possibly have increased microbial biomass, but it is difficult to measure (Lal and Mishra 2002; Ghosh 2007). The separate effects of roots exudates and light carbon fraction on microbial biomass can only be determined if there is an additional rotation treatment where the corn residue is incorporated with no cotton crop growing in it. Measurements will need to be made over several seasons to understand carbon fraction dynamics better under these long-term rotations. The mean vetch biomass incorporated during the 2006 winter for CVCo was 0.67 t/ha, fixing approximately 30 kg N/ha. The mean corn biomass (after corn cobs were removed) incorporated in CCo and CVCo was approximately 11.4 t/ha.

Yield and plant mapping

There were approximately 20 more bolls/m^2 for CW than CCo and CVCo at the end of the season. Lint yields for CW (2.31 t/ha) were higher than CC (1.79 t/ha) (l.s.d. = 0.28, P<0.05). Lint yields for CCo (1.87 t/ha) and CVCo (1.73 t/ha) were similar to CC.

Conclusion

The light carbon fraction, microbial biomass and root density in the soil were highest in cotton-based rotations which included corn (CCo and CVCo) possibly due to the higher corn residue biomass added to the soil. This suggests that corn residue may improve soil organic carbon and long term sustainability. The higher soil microbial biomass implies better soil health and increased nutrient availability. Hence, corn and wheat sown in rotation with cotton in the Australian cotton industry could potentially improve soil organic carbon and nutrient cycling.

Acknowledgements

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References

Conteh A, Blair GJ, Macleod DA, Lefroy RDB (1997) Soil organic carbon changes in cracking clay soils under cotton production as studied by carbon fractionation. *Australian Journal of Agricultural Research* **48**, 1049-1058.

Conteh, A. Blair GJ, MacLeod DA,Whitbread AM (1998). Soil organic matter changes in Vertisols under cotton rotations in Australia. Proceedings of the 1998 National Soils Conference, 27-29 April 1998, pp. 341-344. (ASSSI, Brisbane, Qld.)

Ghosh S (2007) Effect of organic amendments on soil quality and profitability in cotton farming systems. PhD thesis, University of New England.

Guo LB, Halliday MJ, Siakimotu SJM, Gifford RM (2005) Fine root production and litter input: its effects on soil carbon. *Plant and Soil* **272**, 1-10.

Hulugalle NR, Scott F (2008) A review of the changes in soil quality and profitability accomplished by sowing rotation crops after cotton in Australian Vertosols from 1970 to 2006. *Australian Journal of Soil Research* **46**, 173-190.

Lal JK, Mishra B (2002) Effect of recycling of crop residues in situ on soil fertility and crop yield. *Journal of Research* **14**, 181-185.

Leulf N, Tan DKY, Hulugalle NR, Knox O, Weaver TB, Field D (2006) Root turnover and microbial biomass in cotton farming systems. “Ground-breaking stuff”. Proceedings of the 13th Australian Agronomy Conference, 10-14 September 2006. (Eds. Turner NC, Acuna T and Johnson RC) (Australian Society of Agronomy, Perth) http://www.regional.org.au/au/asa/2006/concurrent/soil/4545_tandky.htm

Sohi SP, Mahieu N, Arah JRM, Powlson DS, Madari BT, Gaunt JL (2001) A procedure for isolating soil organic matter fractions suitable for modelling. *Soil Science Society of America Journal* **65**, 1121-1128.

Walkley A, Black IA (1934) An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* **37**, 29-38.

Wright AL, Hons FM, Matocha Jr JE (2004) Tillage impacts on microbial biomass and soil carbon and nitrogen dynamics of corn and cotton rotations. *Applied Soil Ecology* **29**, 85-92.