Root turnover and microbial biomass in cotton farming systems

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Abstract

Crop rotation is claimed to be one management system whereby rates of decline of soil organic carbon can be reduced. The objective of this study was to quantify the contribution of cotton (*Gossypium hirsutum* L.) roots and microbial activity to soil carbon stocks in an irrigated Vertosol. A study was carried out in an on-going experiment at Myall Vale near Narrabri, NSW, Australia to compare the effects of some cotton-based rotations on root production and turnover, soil microbial biomass, microbial activity, and soil organic carbon. The rotations, implemented since 2002, were; cotton-vetch in which vetch stubble was retained (CV), continuous cotton (CC), cotton-wheat in which wheat stubble was incorporated (CW), cotton-wheat-vetch in which both wheat and vetch stubble were retained as surface mulch (CWV). Cotton root dynamics and below ground carbon production were measured using a minirhizotron, core break and root washing methods. The chloroform fumigation-extraction (CFE) method and Ninhydrin reactive N were used to measure microbial biomass. Microbial activity was measured by soil respiration (CO_2) using the NaOH trap method. Root growth rates, root numbers and root length were highest at 72 days after sowing in the CW rotation. Microbial biomass at this time was also highest in the CW rotation (10-20cm) indicating that high root growth and possibly root exudations, and incorporation of wheat residues were most favourable to microbial populations. Both cotton-based rotations that included wheat produced the highest root mass throughout the season and hence, the largest amounts of carbon in their root systems. There were no differences in microbial activity between rotations, suggesting that soil carbon losses through CO_2 respiration could be similar for all treatments. Therefore, the two cotton-based rotations incorporating a wheat phase (CW and CWV) may return the largest amount of carbon into the soil through their roots. Lint yields were also highest in rotations CWV and CW suggesting that the inclusion of a wheat phase in the rotation can improve cotton yield.

Key Words

Cotton; Soil organic carbon; Root growth; Microbial biomass; Microbial activity

Introduction

Historically, cotton was often grown as a monoculture in New South Wales and southern Queensland with intense land preparation. Soil organic carbon levels have been declining in these cotton producing regions of Australia due to multiple tillage operations and the practice of burning stubble residues. Minimum tillage and crop rotation are claimed to be management systems whereby rates of soil organic carbon decline can be reduced (Hulugalle *et al.* 1997). Minimum tillage also has the potential to enhance soil carbon sesquestration (Wright *et al.* 2004). While several recent studies have quantified the amounts of above-ground dry matter returned to soil, and hence, to soil organic carbon stocks under differing cotton-based rotation systems (McVay and Rice 2002), few have been able to do the same for below-ground activity. Root production is an important aspect of plant productivity, as the root system is responsible for anchorage as well as the extraction of water and minerals from the soil (McVay and Rice 2002). Roots are therefore vital to cotton fruit production and play an important role in the final yield. When roots grow, they produce exudates that support soil microbial populations. Similarly, when cotton roots turnover or decompose, microbial populations use this carbon source as a form of energy (Read *et* *al.* 2002). The objective of this study was to quantify the contribution of cotton roots and microbial activity to soil carbon stocks in an irrigated Vertosol.

Methods

Field experiment - rotations

A study was carried out in an on-going experiment in field D1 at the Australian Cotton Research Institute (ACRI) (30°S, 151°E) near Narrabri, NSW, Australia to compare the effects of some cotton-based rotations on root production and turnover, soil microbial biomass, microbial activity, and soil organic carbon stocks. The rotations, implemented since 2002, were; (1) cotton- vetch in which vetch stubble was retained as a surface mulch (CV), (2) continuous cotton (CC), (3) cotton- wheat in which wheat stubble was incorporated into the beds with a disc-hiller (CW), (4) cotton- wheat- vetch in which both wheat and vetch stubble were retained as surface mulch (CWV). Tillage in all treatments was limited to slashing cotton stalks, root cutting of cotton and incorporating cotton stubble and reforming beds with a disc-hiller. Depth of tillage did not exceed 10 cm. The cotton (*Gossypium hirsutum* L.) used in this study was sown on 27 November 04, and the layout was a randomised complete block design with four replications.

Data collection and measurements

Cotton root dynamics and below ground carbon production were measured using a minirhizotron (Jose *et al.* 2001), core break and root washing methods during the 2004/2005 growing season. The core break and root washing analysis were conducted on 07 Jan and 25 Feb 05 from 100 mm diameter, 1 m long soil cores extracted from three random locations in each plot, to calibrate and ground-truth the minirhizotron measurements. In the core break method, the soil cores were separated into 10 cm depth intervals and the numbers of live roots visible on both faces were counted and an average calculated. After counting, the cores from each depth intervals were placed into plastic bags and stored at 4°C prior to root washing. These cores were soaked in warm water containing a 2:1 solution of 10% sodium hexametaphosphate: 1 M sodium hydroxide for 4-12 h, washed using a 0.2 mm sieve, and the remaining organic material was stained with 0.1% Congo red solution for 2-4 h, followed by washing in 95% ethanol. The live roots were stained red and root length was measured using a line interception method (Jose *et al.* 2001). These roots were then weighed after drying at 80°C, and analysed for carbon (C) and nitrogen (N). The minirhizotron provided a non-destructive, in-situ method for observing root production and mortality. Transparent PVC tubes (1.2 m long and 5.1 cm inner diameter) were installed into the root zone at a 45° angle and two images 180° apart were taken by a digital camera at 10 cm intervals. The live root images were stored in a computer using BTC I-CAP Image Capturing System and exported to Rootracker? software for further analysis of root dimensions (volume/area/length). Root growth dynamics were calculated using a combination of the minirhizotron images from Rootracker?, core break, root washing and C and N analysis. Chloroform fumigation-extraction (CFE) and Ninhydrin reactive N were used to measure soil microbial biomass on 04 Jan and 15 Feb 05 (Martens 1995). Soil microbial activity was measured on four occasions during the season by soil respiration (CO_2) using the NaOH trap method (Tiessen *et al.* 1981). The data were analysed by analysis of variance (ANOVA) using Genstat release 8.

Results and Discussion

Root growth dynamics

Cotton root growth rates at 72 days after sowing (DAS) in CW and CWV were higher ($P<0.05$) than in the CV and CC rotations (Fig. 1a). This increased root growth could be due to macropores that have been created or left behind by previous wheat crops (Nakamoto 2000). However, growth rates were not different ($P>0.05$) at the other three sampling dates. There was a general trend towards a net loss of roots in the last two sampling dates which coincided with the reproductive phase. This corresponds to the cotton plants' tendency to turnover roots during the fruiting stage to direct more of its carbon and energy into boll development. Overall, the average root growth/turnover was slightly higher in rotations including wheat, CW (3.27 mg/cm^2/day) and CWV (3.26 mg/cm^2/day) compared to CC (3.23 mg/cm^2/day) and CV (3.23 mg/cm^2/day). Root numbers and root length showed similar trends and were all highest at 72 DAS in the CW rotation. Both cotton-based rotations that included wheat, CWV (330 g/m^2) and CW (216 g/m^2) produced the highest net root mass throughout the season (Fig. 1b) and hence, the largest amounts of carbon (27.1% w/w carbon in roots as measured in the C root analysis) in their root systems.

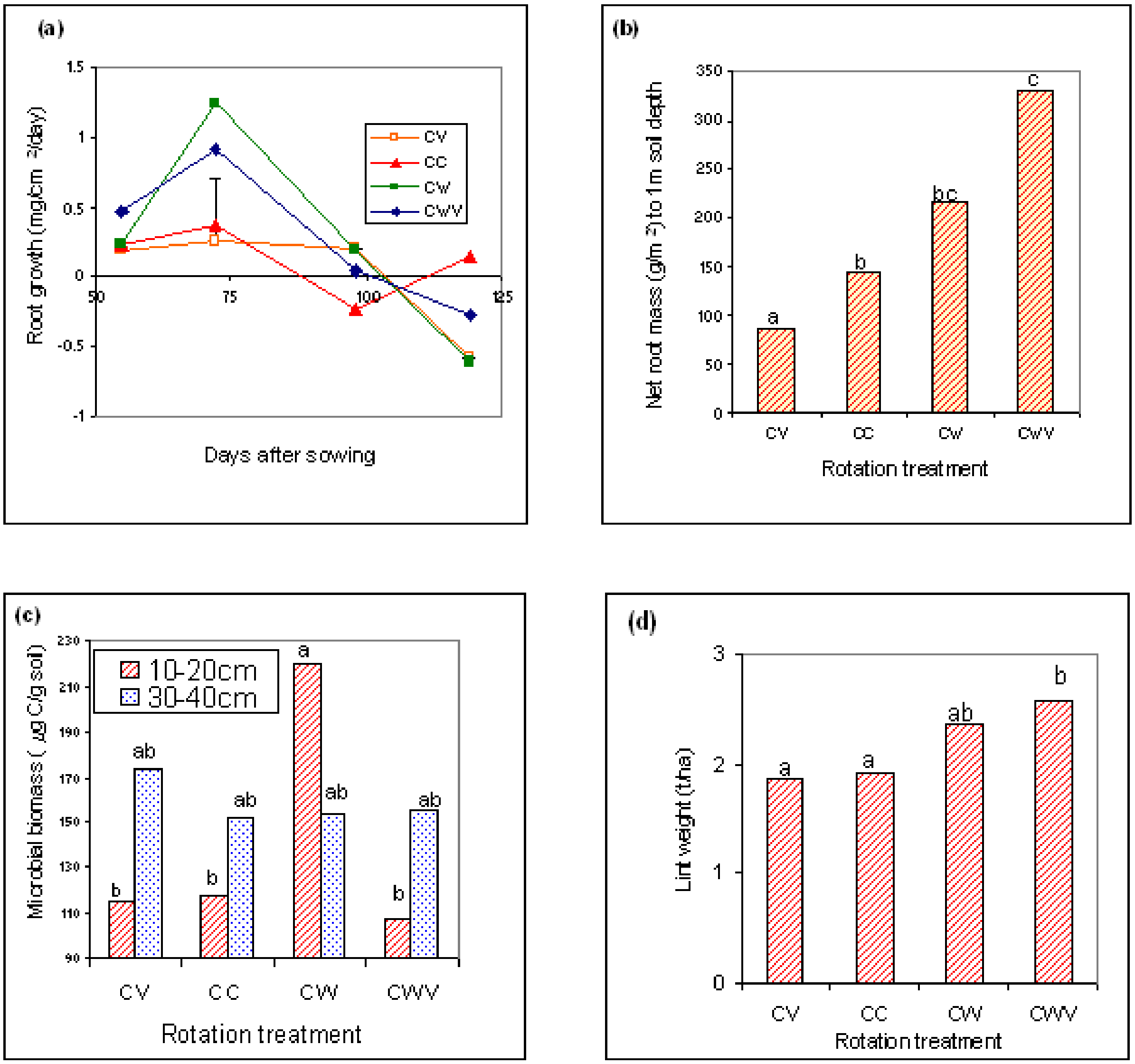

Fig. 1. (a) Cotton root growth rates (mg/cm^2/day) and (b) net root mass (g/m^2) measured using the minirhizotron, (c) soil microbial biomass (?g C/ g soil) measured using the Ninhydrin reactive N technique on 4 Jan 05 at 10-20 cm and 30-40 cm depth intervals and (d) cotton lint yield (t/ha) of the cotton-vetch (CV), continuous cotton (CC), cotton-wheat (CW) and cotton-wheat-vetch (CWV) rotations during the 2004/2005 growing season. Means with the same letters are not significantly different at *P*=0.05. Vertical bar represents l.s.d. at *P*=0.05 at 72 days after sowing in (a).

Microbial biomass and activity

Microbial biomass was highest (P<0.05) in the CW rotation (220 ?g C/g soil at 10-20 cm) during the first sampling on 4 Jan, while the other rotations, CV, CC and CWV had similar levels (108-118 ?g C/g soil, Fig 1c). This coincided with the high cotton root growth rates in CW at 72 DAS (Fig 1a). It may be possible that increased root exudations due to increased root mass, and/or the incorporation of wheat residues was favourable to microbial populations (Lal and Mishra 2002; Lu *et al.* 2002; Rees *et al.* 2005). The microbial biomass in the 30-40 cm depth interval in the second sampling on 15 Feb was lower (P<0.05) than at the 10-20 cm depth interval, but there were no consistent differences between rotations (Data not shown). There were no consistent differences (P>0.05) in microbial activity between rotations throughout the season (Data not shown). This suggested that soil carbon losses through CO_2 respiration could be similar for all treatments. However, due to the vulnerability of microbial functions to environmental conditions such as soil moisture and temperature, it was difficult to use this sampling technique in the field (Lee and Jose 2003).

Cotton yield

The CWV (2.58 t/ha) rotation had higher (P<0.05) lint yields than both CV (1.87 t/ha) and CC (1.92 t/ha), and CW (2.37 t/ha) was also slightly higher than both CV and CC (Fig. 1d). Cotton seed weight in CWV (3.64 t/ha) and CW (3.42 t/ha) was also higher (P<0.05) than CV (2.64 t/ha) and CC (2.57 t/ha).

Conclusion

Cotton root growth rates were high during the vegetative phase but declined with increasing root turnover during the reproductive phase in all rotations. Microbial biomass was also highest in CW, coinciding with the time when root growth rates were highest. This increased level of microbial population may have been encouraged by increased root exudates and the incorporation of wheat residue. The two cotton-based rotations incorporating a wheat phase (CW and CWV) produced the highest net root mass, and hence, may return the largest amount of carbon (27% w/w) into the soil through their roots. Since carbon losses through soil microbial respiration did not differ between rotations, these cotton-based rotations incorporating a wheat phase could potentially sequester and return the most soil carbon when roots turnover. Lint yields were also highest in rotations CWV (2.58 t/ha) and CW (2.37 t/ha) suggesting that the inclusion of a wheat phase in the rotation can also improve cotton. The higher net root mass may have increased the plants' ability to absorb nutrients and water, which could have contributed to the higher lint and seed yields.

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