Potential contribution by corn and Bollgard II cotton roots to soil carbon stocks in a furrow-irrigated Vertisol

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Abstract
Potential contribution by roots of corn and genetically-modified Bollgard II cotton to soil carbon stocks was evaluated in two experiments near Narrabri, north-western NSW. In one experiment a Bollgard™ II-Roundup Ready™-Flex™ variety was compared with a Roundup Ready™-Flex™ variety, and in another, corn grown as a monoculture was compared with corn sown in rotation with cotton. Root growth in the surface 0.10 m was measured with the core-break method, and that in the 0.10 to 1.0 m depth with a minirhizotron and I-CAP image capture system. These measurements were used to derive root length per unit area (L_A), root C added to soil through intra-seasonal root death (C_{lost}), C in roots remaining at end of season (C_{root}) and root C potentially available for addition to soil C (C_{total}). C_{total} averaged 5.0 t/ha with cotton-corn and 9.3 t/ha with corn monoculture, with average C_{lost} accounting for 11%. In contrast, C_{total} with genetically-modified cotton ranged from 0.6 to 0.9 t/ha with C_{lost} contributing 43%. Intra-seasonal root death makes a significant contribution to soil carbon stocks by cotton roots whereas only a small proportion was contributed through this pathway by corn. L_A was higher with corn monoculture than with cotton-corn, and was higher in Bollgard II cotton which was resistant to the *Helicoverpa* moth larvae than in cotton which did not possess the Bollgard II gene.

Key Words
Minirhizotron, Haplustert, image analyses, rotation, genetically-modified organisms.

Introduction
Row crops commonly grown under irrigation in north-western New South Wales, Australia, include summer crops such as cotton (*Gossypium hirsutum* L.) and corn (*Zea mays* L.). SOC dynamics in such cropping systems have been analysed primarily in terms of inputs of above-ground material and root mass towards the end of a growing season. Addition of root material to SOC stocks either in the form of roots dying and decaying during and after the crop's growing season may, however, be significant (de Kroon and Visser 2003). Hulugalle *et al.* (2009) reported that when root death during the cropping season is accounted for potential contribution by cotton roots to SOC in Vertisols ranged between 0.5 and 4 t/ha. The statistical models developed by these authors also suggested that in comparison with non-Bollgard cotton varieties, Bollgard varieties may contribute less carbon due to a more sparse root system. Direct comparison of the two cotton types were not, however, undertaken in their study. The potential contributions to soil C by corn roots in irrigated Vertisols do not appear to have been quantified, although Amos and Walters (2006) in a review of 45 studies estimated that in a range of climates and soil types, corn roots could contribute between 1.5 and 4.4 t C/ha. None of the papers reviewed by these authors accounted for C contributed by root death during the cropping season. The objective of this study, therefore, was to determine the potential contribution by roots of corn and Bollgard II™ cotton to SOC stocks in irrigated Vertisols, both through root turnover during the growing season and decay of root systems thereafter.

Materials and methods
Cotton root growth was measured in two experiments at the Australian Cotton Research Institute, near Narrabri (149°47'E, 30°13'S) in New South Wales, Australia. Narrabri has a sub-tropical semi-arid climate with a mean annual rainfall of 593 mm. The soils in both experiments were Vertisols and classified as fine, thermic, smectitic, Typic Haplusterts (Soil Survey Staff, 2006). Particle size distribution in the 0-1 m depth of Experiment 1 (corn experiment, see below) was 53% clay, 23% silt and 24% sand, and in Experiment 2 (cotton experiment, see below), 61% clay, 11% silt and 28% sand. In northern NSW, cotton is sown in October and picked during late April/early May after defoliation and corn, is sown between September and December and harvested between February and April. Both experiments were sown after good spring rains,

but were furrow irrigated with 100 mm of water when in-crop rainfall was insufficient to meet evaporative demand. The rows (beds) were spaced at 1-m intervals with vehicular traffic being restricted to the furrows. Experiment 1 consisted of four cropping systems: Cotton monoculture, corn monoculture, cotton-wheat (*Triticum aestivum* L.) and cotton-corn rotations sown during the growing seasons of 2007-08 and 2008-09 in plots 20 m long and 8 rows wide. The experiment was designed such that both phases of the rotation were sown every year in the rotation treatments. Corn root growth was measured only in the corn monoculture and cotton-corn rotation. Cotton roots were not monitored in this experiment. In Experiment 2, two cotton varieties, Sicot 80BRF (a Bollgard II™/Roundup-Ready™-Flex™ variety) and Sicot 80 RRF (a Roundup-Ready™-Flex™ variety) were sown during the growing season of 2008-09 after conventional tillage (slashing of cotton plants after harvest, followed by disc-ploughing and incorporation of cotton stalks to 0.2 m, chisel ploughing to 0.3 m followed by bed construction) in a cotton-wheat rotation. The experimental design was 2RCB and individual plots were 200 m long and 4 rows wide.

Root growth in the surface 0.10 m was measured with the core-break method (Drew and Saker 1980). The live roots in a sub-sample of the cores were separated from the dead material after washing, and length measured using a modified Newman's line interception method (Smit *et al.* 2000). These root samples were then oven-dried, weighed and. carbon concentration measured by combustion with a LECO CHN 2000 analyser. Relationships were derived between root number, root length and root weight, and the root length and weight in each core estimated. Relative root length (root weight /root length) was also calculated. Root growth in the 0.10 to 1.0 m depth was measured at 0.10 m depth intervals with a "Bartz" BTC-2 minirhizotron and I-CAP image capture system (Bartz Technology Corporation, 2007). The video camera part of the minirhizotron was inserted into clear, plastic acrylic minirhizotron tubes (50 mm diameter) installed within each plot, 30^{o} from the vertical. The operating and measurement procedures used were those described by Johnson *et al.* (2001). Measurements of cotton roots were made during vegetative growth, flowering, boll initiation/filling and boll filling/opening, and of corn roots during early/mid vegetative growth, tasselling, silking, grain filling/maturity between early December and late March. Root images were captured in two orientations, left and right side of each tube, at each time of measurement and analysed with RooTracker 2.03 (Duke University 2001) to estimate selected root growth indices. The data for each orientation and over the entire measured profile were summed to assess root growth over a 360^{o} plane of vision. The indices evaluated were the length and number of live roots at each time of measurement, number and length of roots which died (i.e. disappeared between times of measurement) and net change in root numbers and length. The above, together with the previously-described relative root lengths and root C concentrations were used to calculate several other indices of root growth; *viz*. (1) Root length per unit area to a depth of 1 m, L_A; (2) Root carbon at end of season, C_{root} (3) Root carbon added to the soil during season, C_{lost}, and (4) Root carbon which could be potentially added to soil organic carbon stocks = (2) + (3), C_{total}. Data were analysed after $\log_e$ transformation with analysis of variance.

Results and discussion

In Experiment 1 (corn experiment), corn root densities, particularly towards the latter part of the growing season, were generally higher with corn monoculture than with cotton-corn rotation (Figure 1). Values of L_A (cm/cm^2) at crop maturity under corn monoculture ranged from 975 at 125 days after sowing (DAS) during the 2007-08 season to 1097 at 120 DAS during the 2008-09 season. L_A values for corn in the cotton-corn rotation at the same time were 365 and 606 during the 2007-08 and 2008-09 seasons, respectively. This may be related to the greater amount water stored in the soil after corn than with cotton (Devereaux *et al.* 2008). The shorter growing season of the corn (5-6 months) results in a longer fallow period between corn crops whereas the longer growing season of the cotton (~6 months) results in a shorter fallow. Subject to late summer, autumn and winter rainfall, more water is therefore, likely to be stored under a corn monoculture than with a cotton-corn rotation.

C_{total} and C_{root} of corn differed significantly ($P < 0.05$) between rotations and seasons. Significant ($P < 0.05$) interactions also occurred between years and seasons. C_{lost} of corn was not significantly affected by seasons or years. C_{total} and C_{root} were higher ($P < 0.05$) with corn monoculture (Figure 2). Average corn C_{total} with monoculture was 930 g/m^2 (9.3 t/ha) and with cotton-corn was 503 g/m^2 (5.0 t/ha), and average C_{root} with corn monoculture was 770 g/m^2 (7.7 t/ha) and with cotton-corn was 409 g/m^2 (4.1 t/ha). Among both cropping systems mean C_{lost} was of the order 76 g/m^2 (0.8 t/ha). These data also suggest that carbon addition to soil through C_{lost} was small with corn; *viz*. averaging 11% of C_{total} in both years. This is much lower than that of cotton, which ranged from 25-29% in the same field (Hulugalle *et al.* 2009).

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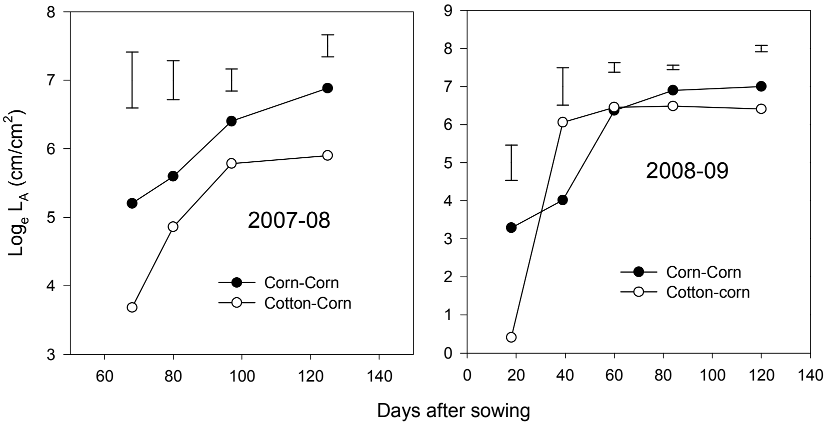

Figure 1. Effect of corn monoculture and cotton-corn rotation on root length per unit area, L_A, of corn to a depth of 1 m. Vertical bars are SEM's.

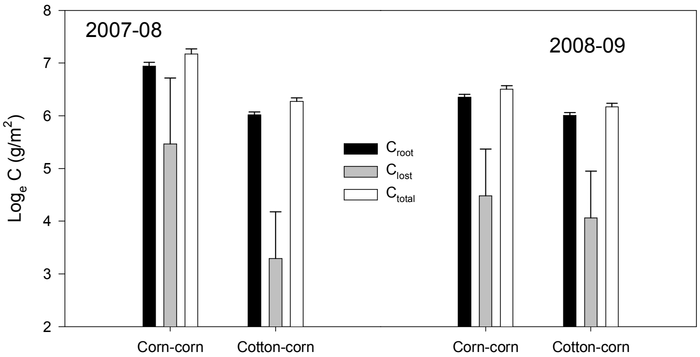

Figure 2. Effect of corn monoculture and cotton-corn rotation on root C indices. C_{root}, carbon at end of season; C_{lost}, root carbon added to the soil during season; (3) C_{total}, root carbon which could be potentially added to soil organic carbon stocks = C_{root} + C_{lost}. Vertical bars are SEM's.

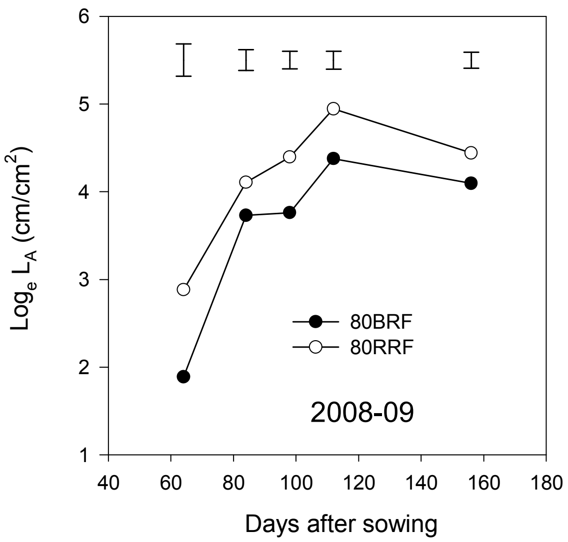

Figure 3. Effect of cotton variety on root length per unit area, L_A, to a depth of 1 m. Vertical bars are SEM's.

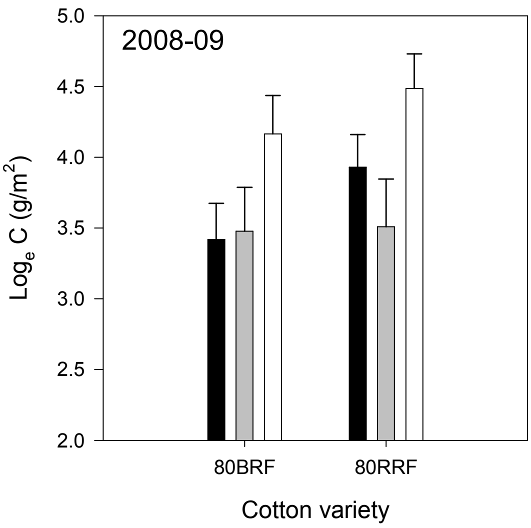

Figure 4. Effect of cotton variety on root C indices. C_{root}, root carbon at end of season; C_{lost}, root carbon added to the soil during season; (3) C_{total}, root carbon which could be potentially added to soil organic carbon stocks = C_{root} + C_{lost}. Vertical bars are SEM's.

In Experiment 2 (cotton experiment), root densities were higher ($P < 0.01$) with 80RRF than with 80BRF. Values of L_A (cm/cm^2) at crop maturity under Sicot 80RRF was 60 cm/cm^2 and 85 cm/cm^2 under Sicot 80BRF (Figure 3). Hulugalle *et al.* (2009) have suggested that this may be related to the higher boll retention in Bollgard II cotton, and thus a higher carbon and nutrient demand by above-ground organs. Carbon and other nutrients may therefore, be distributed preferentially to above-ground organs relative to roots in Bollgard II varieties, resulting in a lower rate of root initiation and consequently, lower root densities. Significant differences were absent between the two varieties with respect to the root carbon indices. C_{total} was 64 g/m^2 (0.6 t/ha) with Sicot 80BRF and 89 g/m^2 (0.9 t/ha) with Sicot 80RRF. Similarly, C_{root} was 31 g/m^2 (0.3 t/ha) with Sicot 80BRF and 51 g/m^2 (0.5 t/ha) with SicotRRF. C_{lost} was 33 g/m^2 (0.3 t/ha) with both varieties. These values are similar to the lower range of values previously reported by Hulugalle *et al.* (2009). At the same time, carbon addition to soil through C_{lost} was relatively high; viz. averaging 43% of C_{total}.

Conclusions

C_{total} averaged 5.0 t/ha with cotton-corn and 9.3 t/ha with corn monoculture, with average C_{lost} accounting for 11%. In contrast, C_{total} with genetically-modified cotton ranged from 0.6 to 0.9 t/ha with C_{lost} contributing 43%. Intra-seasonal root death makes a significant contribution to soil carbon stocks by cotton roots whereas only a small proportion was contributed through this pathway by corn. L_A was higher with corn monoculture than with cotton-corn, and was higher in Bollgard II cotton which was resistant to the *Helicoverpa* moth larvae than in cotton which did not possess the Bollgard II gene.

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