Short report

Carbon inputs by irrigated corn roots to a Vertisol

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Abstract: Row crops commonly grown under irrigation in the Vertisols of north-western New South Wales, Australia, include summer crops such as corn (*Zea mays* L.) and cotton (*Gossypium hirsutum* L.). Soil organic carbon (SOC) and residue (SOR) dynamics in these farming 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 and SOR stocks either in the form of roots dying and decaying during and after the crop's growing season may, however, be significant. Carbon inputs by roots of irrigated corn to an irrigated Vertisol were evaluated in an experiment near Narrabri, Australia, where 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_{total}). C_{total} averaged 5.0 Mg ha^{-1} with cotton-corn and 9.3 Mg ha^{-1} with corn monoculture, with average C_{lost} accounting for 11%. Intra-seasonal root death from corn made only a small contribution to soil carbon stocks. L_A of corn was higher with corn monoculture than with cotton-corn.

Keywords: haplustert, image analyses, irrigation, minirhizotron, rotation, Vertisol,

Introduction

Row crops commonly grown under irrigation in north-western New South Wales, Australia, include summer crops such as sorghum (*Sorghum bicolor* Moench.), cotton (*Gossypium hirsutum* L.) and corn (*Zea mays* L.). Soil organic carbon (SOC) and residue (SOR) dynamics in these farming 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 and SOR stocks either in the form of roots dying and decaying during and after the crop's growing season may, however, be significant (Laurenroth and Gill 2003 2003). Hulugalle et al. (2009) reported that when root death during the cropping season is accounted for, potential contribution by cotton roots to SOR in Vertisols ranged between 0.5 and 4 Mg C ha^{-1}year^{-1}. The potential contributions to SOC and SOR 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 Mg C ha^{-1}year^{-1}. None of the papers reviewed by these authors accounted for C contributed by root death during the cropping season. Estimates made from data collected from long-term experiments and national crop yield data bases in the United States suggest that depending on tillage system and fertiliser rates, carbon inputs from irrigated and rainfed corn roots could range from 2.7 to 6.3 Mg C ha^{-1}year^{-1} (Allmaras et al. 2004, Wilts et al. 2004, Johnson et al. 2006). Similar estimates were made by Balesdent and Balabane (1996) in France, who reported a value of 5.4 Mg C ha^{-1}year^{-1} for a corn crop grown under cool temperate zone conditions. Both the US and French estimates were derived from modelling and not from direct measurements. The objective of this study, therefore, was to determine by direct measurements, carbon inputs by roots of irrigated corn to a Vertisol, both through root turnover during the growing season and decay of root systems thereafter.

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Materials and Methods

Corn root growth was measured in an experiment 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, BSh (Kottek et al. 2006). The hottest month is January (mean daily maximum of 35°C and minimum of 19°C) and July the coldest (mean daily maximum of 18°C and minimum of 3°C). Mean annual rainfall is 593 mm and potential evaporation, 1997 mm. The soil in the experimental site was a Vertisol (fine, thermic, smectitic, Typic Haplustert (Soil Survey Staff 2006)). Particle size distribution in the 0-1 m depth was 530 g kg^{-1} clay (< 2 μm), 230 g kg^{-1} silt (2-20 μm) and 240 g kg^{-1} sand (20-2000 μm).

The experiment 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. 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. The experiment was 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. Corn root growth was measured only in the corn monoculture and cotton-corn rotation. Cotton roots were not monitored in this experiment.

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 (Oliveira 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 2010). The video camera part of the minirhizotron was inserted into clear, plastic acrylic minirhizotron tubes (50 mm diameter) installed within each plot, 30° from the vertical. The operating and measurement procedures used were those described by Johnson et al. (2001). Measurements of corn roots were made during early/mid vegetative growth, tasselling, silking, and 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° 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} = Sum of net changes in root carbon between times of measurement in all depths where, for individual depths and between times of measurement, the net change in root carbon was calculated as: Net change in root length x Relative root length x Root carbon concentration) (3) Root carbon added to the soil during season, C_{lost} = Sum of root carbon added to soil due to root death between times of measurement in all depths where, for individual depths and between times of measurement, root carbon added to soil was calculated as: Length of roots which died x Relative root length x Root carbon concentration; (4) Root carbon which could be potentially added to SOR, C_{total} = C_{root} (2) + C_{lost} (3). Data were analysed after $\log_e$ transformation with analysis of variance.

Results and Discussion

Corn root densities, particularly towards the latter part of the growing season, were generally higher with corn monoculture than with cotton-corn rotation (Fig. 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 (~6-7 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 cot-

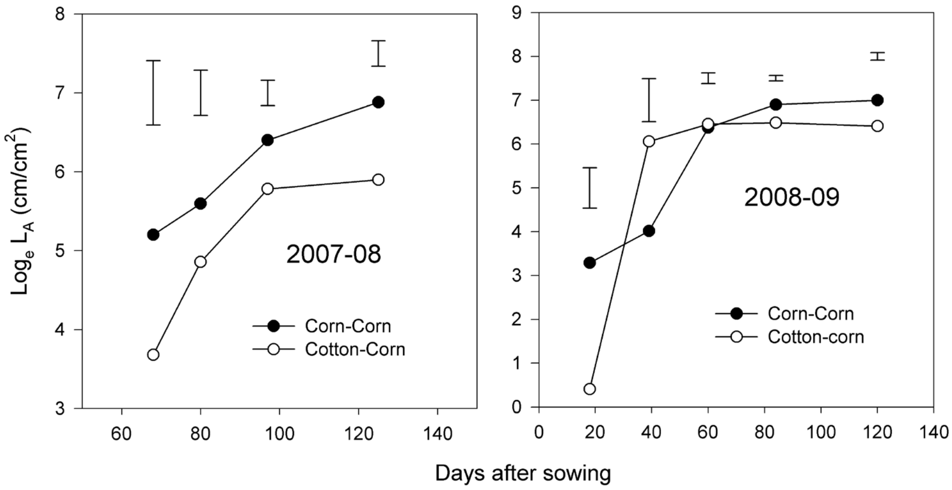

Fig. 1. Effect of corn monoculture and cotton-corn rotation on root length per unit area, L_A, of corn to a depth of 1 m. Vertical bars are standard errors of the means. (1 cm cm^{-2} = 10^2 m m^{-2}).

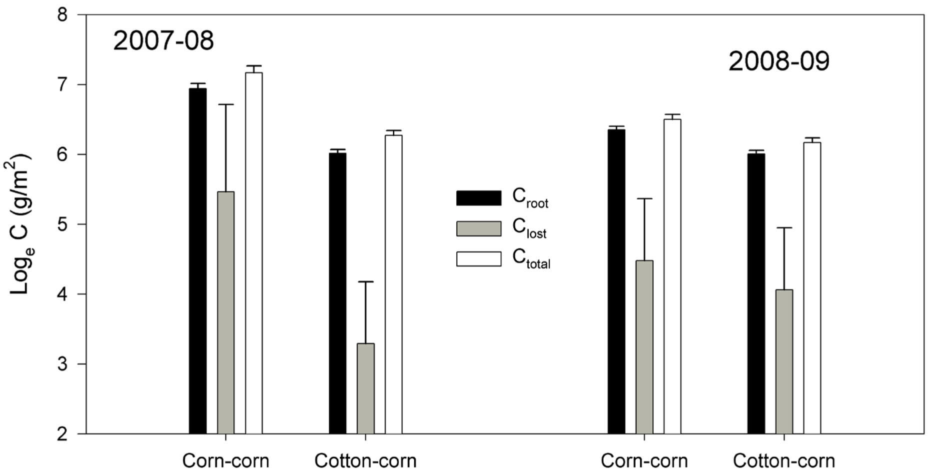

Fig. 2. Effect of corn monoculture and cotton-corn rotation on root C indices. C_{root}, root carbon at end of season; C_{lost}, root carbon added to the soil during season; C_{total}, root carbon which could be potentially added to soil organic carbon stocks = C_{root} + C_{lost}. Vertical bars are standard errors of the means.

ton-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 (Fig. 2). Average corn C_{total} with monoculture was 930 g m^{-2} yr^{-1} (9.3 Mg ha^{-1} yr^{-1}) and with cotton-corn was 503 g m^{-2} yr^{-1} (5.0 Mg ha^{-1} yr^{-1}), and average C_{root} with corn monoculture was 770 g C m^{-2} yr^{-1} (7.7 Mg C ha^{-1} yr^{-1}) and with cotton-corn was 409 g m^{-2} yr^{-1} (4.1 Mg ha^{-1} yr^{-1}). Among both cropping systems mean C_{lost} was of the order 76 g m^{-2} yr^{-1} (0.8 Mg ha^{-1} yr^{-1}). These data also suggest that carbon addition to SOR 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 where this experiment was located and in other locations, 43-50% in healthy crops and up to 70% in crops which had been severely damaged by insect attack (Hulugalle et al. 2009).

Although measurements were not made during our study, it is likely that contribution to SOC stocks by C_{lost} was negligible as most of it may have been converted into CO_2 during the growing season. This assumption is supported by a study in the United States, which indicated that only 5% of plant carbon inputs by corn was converted into SOC (Allmaras et al. 2004). The above figure of 5% suggests that contributions to SOC stocks through C_{lost} in our study may have been of the order of 0.04 Mg ha^{-1} yr^{-1}.

Conclusions

C_{total} averaged 5.0 Mg ha^{-1} yr^{-1} with cotton-corn and 9.3 Mg ha^{-1} yr^{-1} with corn monoculture, with average C_{lost} accounting for 11%. Intra-seasonal root death may, therefore, have contributed only a very small amount to soil carbon stocks and was speculated to be of the order of 0.04 Mg ha^{-1} yr^{-1}. L_A of corn was higher with corn monoculture than with cot ton-corn.

Acknowledgements

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