Potential contribution by cotton roots to soil carbon stocks in furrow-irrigated Vertisols of NW New South Wales, Australia

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ABSTRACT

Historically, soil organic carbon dynamics in Australian Vertisols have been analysed in terms of inputs from above-ground crop residues but not by roots. Potential contribution by cotton roots to soil carbon stocks was evaluated between 2002 and 2008 in two experiments near Narrabri, north-western NSW. Experiment 1 consisted of cotton monoculture sown either after conventional tillage or on permanent beds and a cotton-wheat rotation on permanent beds, and Experiment 2 consisted of four rotation systems sown on permanent beds: cotton monoculture, cotton-vetch, cotton-wheat and cotton-wheat-vetch. A Roundup-Ready™ cotton variety was sown until 2005, and a Bollgard™ II-Roundup Ready™-Flex™ variety thereafter. 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 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}). Average C_{total} ranged between 0.5 and 4 t/ha, with C_{lost} contributing 25-70%. C_{total}, C_{lost} and C_{root} were reduced by cool/wet seasons, cotton monoculture, high insect pest numbers and Bollgard II varieties, but increased by warm/dry seasons, non-Bollgard II varieties and wheat rotation crops. Permanent beds increased C_{root}.

INTRODUCTION

Soil organic carbon stocks in the surface 0.6 m of Australian cotton (*Gossypium hirsutum* L.)-growing Vertisols generally range from 60-100 t/ha under irrigation to 40-60 t/ha under rainfed condition (Hulugalle and Scott, 2008). SOC dynamics have been primarily analysed in terms of inputs of above-ground material. 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). Estimates of C contained in cotton roots, and hence, potential contribution to SOC, is relatively low, with higher values (~1 t/ha) being reported from clay-rich Vertisols and between 0.1 and 0.25 t/ha in sandy Ultisols and Entisols (Hulugalle *et al*., 2009). Direct measurements of intra- and post-seasonal contributions to SOC stocks are, however, absent from the scientific literature. The objective of this study, therefore, was to determine the contribution of cotton roots to SOC stocks in irrigated Vertisols, both through root turnover during the growing season and decay of root systems thereafter. Measurements were made from 2002 to 2008 in two long-term experiments using a combination of soil cores and minirhizotron observations.

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 were classified as fine, thermic, smectitic, Typic Haplusterts (Soil Survey Staff, 2006). Particle size distribution in the 0-1 m depth of both experiments was similar: 64% clay, 11% silt and 25% sand. Roundup-Ready™

cotton was sown from the 2002-2003 until the 2005-06 growing seasons, and Bollgard™ II-Roundup-Ready™-Flex™ cotton thereafter. Cotton was sown in October and picked during late April/early May after defoliation. Both experiments were furrow irrigated with 100 mm of water when 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 (Field C1): A cotton monoculture was sown either 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) or on permanent beds (slashing of cotton plants after harvest, followed by root cutting, incorporation of cotton stalks into beds, and bed renovation with a disc-hiller), and a cotton-wheat (*Triticum aestivum* L.) rotation on permanent beds in a 4RCB design. The wheat stubble was retained as *in-situ* mulch into which the following cotton crop was sown. Individual plots were 190 m long and 36-44 rows wide.

Experiment 2 (Field D1): The experiment consisted of four rotations sown on permanent beds: cotton monoculture, cotton-vetch (*Vicia villosa* Roth.), cotton-wheat where wheat stubble was incorporated into the beds after harvest with a disc-hiller, and cotton-wheat-vetch where wheat stubble was retained as an *in-situ* mulch into which vetch was sown. The vetch in cotton-vetch and cotton-wheat-vetch rotations was killed and the residues retained as *in situ* mulch into which cotton was sown. The experiment was laid out as a 3RCB design. Individual plots were 165 m long and 20 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 and root weight, and the root weight in each core was estimated. Relative root length (root length/root weight) 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. 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. Measurements were made during vegetative, flowering, boll initiation/filling and boll filling/opening 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 carbon at end of season, C_{root} (2) Root carbon added to the soil during season, C_{lost}, and (3) Root carbon which could be potentially added to soil organic carbon stocks = (1) + (2), C_{total}. Data were analysed after $\log_e$ transformation with an analysis of variance for a split-plot design where treatment was designated as main- and season as sub-plot treatments. Seasonal root carbon indices for both experiments were also evaluated with multiple linear regression analysis after pooling of data. Models were selected using best subset regression for a range of management and climatic variables such as tillage system, cropping system, rotation crops, cotton varieties, insect stress, seasonal rainfall and cumulative day-degrees. Significant variables were selected using Mallow's C_p, adjusted R^2, and the difference between Akaike's Information Criteria for a candidate model, AICC, and the model with the lowest value, AICC(min). The selected model was analysed with least squares linear regression.

RESULTS AND DISCUSSION

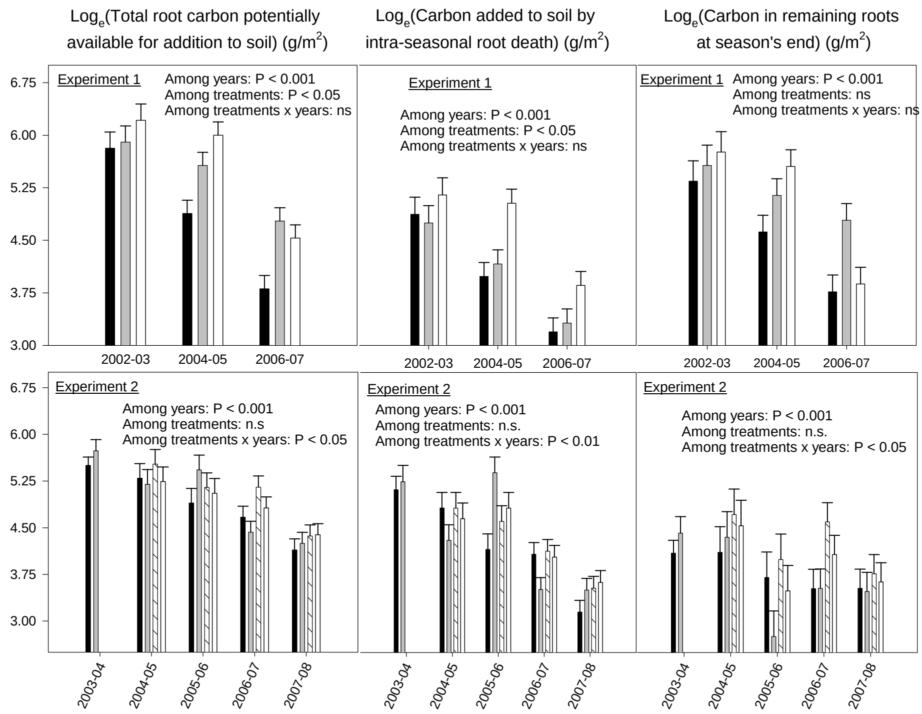

Figure 1. Effect of rotations and tillage system on root C indices. Experiment 1: Black, cotton monoculture after conventional tillage; Grey, cotton monoculture on permanent beds; White, cotton-wheat rotation on permanent beds. Experiment 2: Black, cotton-vetch; Grey, cotton monoculture; White with black diagonal stripes, Cotton-wheat; White, cotton-wheat-vetch. Vertical bars are SEM's.

In Experiment 1 (Field C1), C_{total}, C_{lost} and C_{root} were, generally, highest ($P < 0.05$) with cotton wheat (Fig. 1). Compared with 2002-03 and 2004-05, seasonal values of the previously-mentioned indices were significantly lower ($P < 0.001$) during 2006-07. Average C_{total} was 4 t/ha during 2002-03, 2.8 t/ha during 2004-05 and 0.7 t/ha during 2006-07. Similarly mean C_{lost} was 1.1 t/ha during 2002-03, 0.7 t/ha during 2004-05 and 0.2 t/ha during 2006-07. Mean C_{root} was of the order of 2.6 t/ha during 2002-03, 1.6 t/ha during 2004-05 and 0.5 t/ha during 2006-07. Relative to other years, differences among treatments were small or absent during 2006-07. These data also suggest that carbon addition to soil through C_{lost} was small compared with C_{root}; *viz.* 29% in 2002-03, and 25% in both 2004-05 and 2006-07.

In Experiment 2 (Field D1), except for 2005-06, C_{total}, C_{lost} and C_{root} were in the order of cotton-wheat > cotton-wheat-vetch > cotton-vetch > cotton-winter fallow, although differences were small during 2007-08 (Fig. 1). Between 2004 and 2008, C_{total} ranged from 0.85 to 3 t/ha. These values are similar to those previously reported in the literature (Hulugalle *et al.*, 2009). During 2005-06 a large proportion of total root C was derived from intra-seasonal root death (averaged among all treatments it was of the order of 70% in comparison with other years when it ranged from 44-50%), and may be related to the damage caused by the high *Helicoverpa* numbers

(Sadras, 1996). Insect damage may, therefore, influence root functions such as water and nutrient extraction (de Kroon and Visser, 2003). Overall, the values of intra-seasonal additions to soil C through root death were very much greater than those in Experiment 1. The higher root mortality rate in Experiment 2 may be related to the poorer structure and higher ESP in the sub-soil, which can increase root mortality through a combination of high soil strength and low oxygen concentration (de Kroon and Visser, 2003). The soil in Experiment 1 had an ESP of 10 in the 0.6-1.2 m depth whereas in Experiment 2 it was 15 in the same depth.

In both experiments, the abovementioned root C indices were higher ($P < 0.001$) with non-Bollgard II cotton varieties compared with Bollgard II varieties. Although these differences were undoubtedly due in part to variation in climatic factors, these results do suggest that the root mass and turnover of Bollgard II varieties are less than those of non-Bollgard II varieties, presumably because of a larger sink for carbon in the above-ground organs such as the bolls of the former.

Multiple linear regression analyses of pooled data indicated that by either sowing a non-Bollgard II variety or a wheat rotation crop seasonal root C indices such as C_{total} and C_{lost} were increased ($P < 0.001$), but were decreased ($P < 0.001$) by either insect damage and sowing a Bollgard II variety. These same root indices were also positively related ($P < 0.001$) to climatic variables such as cumulative day degrees and seasonal rainfall. C_{root} was increased by permanent beds but decreased by conventional tillage ($P < 0.05$). Leguminous rotation crops such as vetch did not significantly affect seasonal root carbon indices.

CONCLUSIONS

C_{total} ranged between approximately 0.5 and 4 t/ha, with C_{lost} contributing 25-70%. These values are approximately 10 to 60% of that contributed by above-ground crop residues. Seasonal root C indices were reduced by cotton monoculture and Bollgard II varieties, and increased by non-Bollgard II varieties and wheat rotation crops. Seasonal factors such as stress caused by high insect numbers reduced root C whereas cumulative day degrees and seasonal rainfall were positively related to seasonal root C.

REFERENCES

de Kroon, H., Visser, E.J.W. (eds.). 2003. Root Ecology. Heidelberg: Springer-Verlag.

Drew, M.C., Saker, L.R. 1980. Assessment of a rapid method, using soil cores, for estimating the amount and distribution of crop roots in the field. Plant Soil, 55, 297-305.

Duke University. 2001. RooTracker: Software for Root Image Analysis – User Guide version 2.0. http://www.biology.duke.edu/rootracker. Accessed 4 August 2008.

Hulugalle, N.R., 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. Aust. J. Soil Res. 42, 173-190.

Hulugalle, N.R., Weaver, T.B., Finlay, L.A., Luelf, N.W., Tan, D.K.Y. 2009. Potential contribution by cotton roots to soil carbon stocks in irrigated Vertosols. Aust. J. Soil Res., 47, In Press.

Sadras, V.O. 1996. Population-level compensation after loss of vegetative buds: interactions among damaged and undamaged cotton neighbours. Oecologia 106, 417-423.

Smit, A.L., Bengough, A.G., van Noordjwijk, M., Pellerin, S., van de Geijin, S.C. (eds.) 2000 Root Methods: A Handbook. Heidelberg: Springer-Verlag.

Soil Survey Staff. 2006. Keys to Soil Taxonomy, 10th ed. Washington, DC: USDA-Natural Resources Conservation Service.