High root biomass for cereal crops increases carbon sequestration in organic arable systems

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Key words: Carbon sequestration; Root biomass

Abstract

In agroecosystems, soil organic carbon (C) inputs come from applied manures, plant roots and retained shoot residues. Several reasons, associated with root measurements, limit current knowledge on root C input.This study aimed at evaluating root responses to nutrient management and fertility building measures (e.g. catch crops). We made use of one inorganic fertilizer-based and two organic systems in an 11-year-old field experiment on sandy loam soil. At anthesis, soil cores (5 cm dia.) were sampled from 0-30 cm depth within and between rows of winter wheat and spring barley. Roots were separated from soil and washed with tap water, the dry matter (DM) biomass was determined. Dry matter biomass was also measured in shoots.The spring barley root DM was at least 30% higher in the organic compared to the inorganic fertilizer-based system. The organic system that included catch crops had 17% higher spring barley root DM than where catch crops were absent. In the inorganic fertilizer-based system, the biomass shoot-to-root ratio for spring barley was double that in the comparable organic system. High root DM biomass in organic compared to the inorganic fertilizer-based systems, implies higher C sequestration in the former, especially considering the slow decomposition rate of root residues.

Introduction

In agroecosystems, soil C inputs are mainly from applied manures, organic material released from growing roots (i.e. root exudates, lysates, mucilages, sloughed cells), plant shoot and root residues. Basically, the organic material released from growing roots are mainly easily decomposible in soil, which is unlike root residues that are more lignified and have lower biodegradability (Rasse *et al.* 2005). The SOC stocks reflect the balance between C input and C mineralization (Wong *et al.* 2010). Therefore, notwithstanding the mineralization of organic material, cropping systems with different C inputs influence soil C content differently. In particular, high-input crop production systems fertilized with inorganic fertilizer tend to have high shoot biomass and large quantities of crop residues. On the other hand, due to presence of more resilient C, applied animal manure could enhance C sequestration in low-input organic systems. Whereas C input from manure and shoot residues have been extensively studied, root contributions to soil C have been estimated from root biomass towards the end of the growing season (Hulugalle *et al*. 2010). However, the scarcity of literature on root C input is partly due to the costs associated with most current methodologies (Izzi *et al*. 2008). Consequently, the knowledge gap causes increased uncertainty in assessing the potential for C sequestration within arable systems. This

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is despite the fact that an accurate assessment of plant rooting is essential for understanding the role of roots in soil C storage and ecosystem functioning. In addition, a combination of higher chemical resistance of root molecular structures to decomposition and physico-chemical protection through interactions with soil minerals doubles the residence time of root-derived C over shoot C (Rasse *et al.* 2005). Notwithstanding limited literature on root studies, we are not aware of studies that compared root C inputs between organic and inorganic fertilizer-based systems; which was the main objective of the current study.

Materials and methods

Field site

This study used plots in a crop rotation experiment initiated in 1997 at Foulum in western Denmark (Olesen *et al.* 2000). The soil is a Typic Hapludult, sandy loam.

Experimental structure

The experiment has a factorial design comprising three factors and two replicate blocks (Olesen *et al*. 2000). The present study used organic crop rotations (O4) fertilized with manure; with and without undersown catch crops (CC) in the cereal and pulse crops in addition to an inorganic fertilizer-based (C4) crop rotaion (Table 1).

Table 1: Structure of the three selected four-year crop rotations

Rotation course	O4/+M/+CC	O4/+M/−CC	C4/+IF/−CC
1	s. barley^{CC}	s. barley	s. barley
2	Faba bean^{CC}	Faba bean	Faba bean
3	Potato	Potato	Potato
4	w. wheat^{CC}	w. wheat	w. wheat

spring (s), winter (w), catch crop (cc), Manure (M), inorganic fertilizer (IF)

Results presented here are from samples collected in 2007/08 from soils under winter wheat and spring barley. The catch crops in the organic cropping systems were either pure stands of perennial ryegrass or various mixtures of perennial ryegrass, chicory and clover species (Olesen *et al*. 2009).

Management

Winter wheat and spring barley had inter-row distances of ca. 12.5 cm, and sown at rates of ca.181 and 170 kg ha^{-1}, respectively. On average crops in the C4 rotation received approximately 109 kg total N ha^{-1} y^{-1} while organic rotations received pig slurry at rates corresponding to 70 kg total N ha^{-1} y^{-1}. Weeds in O4 and C4 systems were controlled mechanically and chemically, respectively.

Plant measurements

At anthesis, above-ground plant material sampled from areas of 1 m^2 areas was dried in an oven set at 80 ^{o}C for 18 h. Three seperate soil cores (5 cm dia.) were collected from within and between crop rows (0−30 cm depth; where 90% of ceral roots are found). Soil cores from similar sampling positions were pooled. The roots were washed with tap water to remove mineral matter and collected on a sieve with a mesh size of 0.425 mm. The collected roots and debris were placed in a tray where live roots were separated from dead organic matter based on colour and physical appearance as described by Gregory (2006). The live roots were then dried in an oven at 70 ^{o}C for 48 h. Upon removal from the oven, root dry matter was recorded before a portion was weighed, oven-dried again and placed in a muffle furnace set at 650 °C for 5 h. This was done to determine root ash content. (Chirinda *et al.* 2011a). Shoot and ash-free root DM biomass were used to determine DM biomass shoot-to-root (S/R) ratios. It is important to highlight that at cereal anthesis catch crops had just begun to germinate hence their roots were an insignificant part of measured biomass.

Statistical analyses
A mixed model was used to test the response of different plant attributes to cropping system. Differences of Least Squares Means were used to compare treatment means.

Results

Results in Table 2 indicate that root DM biomass for winter wheat showed a tendency (P = 0.07) to be lower in C4/+IF/−CC compared to the organic O4/+M/−CC system. For spring barley, the difference in root DM biomass between the C4/+IF/−CC and the O4/+M/−CC system was significant (P < 0.001).

Table 2: Cereal shoot and root biomass (g DM m^{-2}) and biomass shoot-to-root (S/R) ratios

System	Shoot	Root	S/R
winter wheat			
C4/+IF/−CC	1121^{a}	206^{a}	5.4^{a}
O4/+M/−CC	870^{a}	292^{a}	3.0^{a}
O4/+M/+CC	976^{a}	250^{a}	3.9^{a}
spring barley			
C4/+IF/−CC	576^{a}	154^{a}	3.7^{a}
O4/+M/−CC	375^{b}	201^{b}	1.9^{b}
O4/+M/+CC	565^{a}	236^{c}	2.4^{b}

Values with different letters for same crop and column are significantly different (P<0.05)

The organic rotation that included manure and catch crops had higher (P < 0.01) root DM biomass for spring barley compared to where catch crops were excluded. The biomass S/R ratio for the inorganic fertilizer-based system was significantly higher for spring barley (P < 0.001) and marginally higher for winter wheat (P = 0.06) than in the comparable organic system. The organic system that included manure and catch crops had marginally higher (P = 0.06) spring barley biomass S/R ratios than the organic system were catch crops were excluded.

Discussion

High nutrient availability in the inorganic fertilizer-based system probably led to the generally higher cereal shoot biomass compared to the organic systems. Besides, the low shoot biomass in organic systems may have been due to poor synchrony between crop nutrient demand and supply. Significantly higher spring barley root DM biomass for the O4/+M/−CC compared to the C4/+IF/−CC indicate a potential for enhanced root C input in organic compared to inorganic fertilizer-based systems. Similar tendencies for winter wheat, though not statistically significant, supports this finding. This suggests that in low input systems root exploration of soil to meet plant nutrient demands and overcome the low nutrient availability leads to higher root biomass compared to high-input systems. Therefore, root C input from cereals grown in organic fertilizer-based systems are higher than those grown in inorganic fertilizer-based systems. Considering the longer residence time of root C (Rasse *et al.* 2005), low-input organic systems may therefore have substantial below-ground contributions to C sequestration. Moreover, in a recent study, Kong and Six (2010) observed that the relative contribution to stable soil organic matter of root C compared to shoot C was greater in the organic than conventional system.

The differences in cereal biomass S/R ratios in manure and inorganic fertilizer-based systems result from a high shoot biomass and low root biomass in the latter. These findings corroborate with the hypothesis that plants establish different biomass S/R functional equilibriums in response to soil and climatic conditions (Bolinder *et al.* 2002). This implies that, in agroecosystem under different management regimes, estimating root biomass from fixed biomass S/R ratio values may further increase uncertainties in estimation of below-ground C inputs and lead to biases when comparing different cultivation systems.The findings reported in the current study were corraborated by those from a follow-up study conducted at the same site in 2010 (Chirinda *et al*. 2011b).

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