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Research Paper

# Root biomass in cereals, catch crops and weeds can be reliably estimated without considering aboveground biomass

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ABSTRACT

Reliable information on belowground plant biomass is essential to estimate belowground carbon inputs to soils. Estimations of belowground plant biomass are often based on a fixed allometric relationship of plant biomass between aboveground and belowground parts. However, environmental and management factors may affect this allometric relationship making such estimates uncertain and biased. Therefore, we aimed to explore how root biomass for typical cereal crops, catch crops and weeds could most reliably be estimated. Published and unpublished data on aboveground and root biomass (corrected to 0–25 cm depth) of cereal crops (wheat and barley), catch crops and weeds were collected from studies in Denmark. Leave one out cross validation was used to determine the model that could best estimate root biomass.

Root biomass varied with year, farming system (organic versus conventional) and cereal species. Shoot and root biomass of catch crops were higher than for weeds (sampled in late autumn), and farming system significantly affected root biomass of catch crops and weeds. The use of fixed root biomass based on the most influential factors (farming system and species) provided the lowest error of prediction for estimation of root biomass, compared with the use of fixed allometric relations, such as root/shoot ratio. For cereal crops, the average root dry matter in organic farming systems was 218 g $m^{-2}$ (243 and 193 g $m^{-2}$ for wheat and barley, respectively), but in conventional systems only 139 g $m^{-2}$ (142 and 129 g $m^{-2}$ for wheat and barley, respectively). For catch crops and weeds, the root dry matter in organic farming systems were around 127 and 35 g $m^{-2}$, and in conventional farming systems 75 and 28 g $m^{-2}$, respectively.

In conclusion, the present analysis indicates that root biomass in cereals, catch crops and weeds can be reliably estimated without considering aboveground biomass, and it may be better estimated using fixed values based on species and farming systems than using fixed allometric ratios.

## 1. Introduction

Soil fertility in agricultural systems is sustained through inputs of organic matter from plant residues and from applied manure and compost (Lal, 2004a,b). These inputs contribute to carbon (C) storage and sequestration in soils, which in some cases may help to mitigate other greenhouse gas emissions (Powlson et al., 2011). The plant inputs of C from both aboveground and belowground components are generally calculated from their plant biomass by multiplying with specific transfer (humification) coefficients (Chirinda et al., 2012; Kätterer et al., 2011). However, unlike aboveground plant biomass, root biomass is difficult to sample and quantify. The C originating from roots can represent an important source for soil C storage (Warembourg and Paul, 1977), not least because they may contribute more to stable soil organic C (SOC) pools than aboveground inputs (Kätterer et al., 2011). Such considerations suffer from the fact that the amount of belowground C inputs is mostly not well quantified under field conditions (Smucker, 1984; Taylor, 1986). The difficulties in measuring belowground C inputs means that other approaches have to be taken to estimate this component. Therefore, simple estimation methods have been proposed for estimating belowground C inputs, and these are used for accounting purposes and in many cases also for soil C modelling (Keel et al., 2017).

Allometric estimation of root C inputs, where a certain (often constant) proportion of plant dry biomass is allocated to the root, is a commonly used method, for instance in national inventories of soil C changes (Johnson et al., 2006). Estimating root biomass using fixed allometric ratios is based on the assumption that for specific species and environmental conditions, growth of roots and shoots are closely

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associated (Pearsall, 1927; Poorter and Nagel, 2000). This assumes that the biomass allocated to roots is proportional to shoot biomass with a ratio determined by plant species and environmental conditions. As a consequence, the proportion is often a key parameter to estimate root biomass of crops under similar conditions. However, the ratio between the root and aboveground biomass varies between species and depends on environmental conditions (Bolinder et al., 1997, 2007; Campbell et al., 2000).

Many studies have shown that the proportion of the net primary productivity that is allocated to the belowground part is sensitive to the environmental conditions, e.g. nutrient and water availability and tillage (Hodge et al., 2000; Muñoz-Romero et al., 2009). Increasing N application will increase the growth of shoots, while N fertilisation has little effect on root biomass (Jenkinson, 1981; Anderson, 1988; Huggins and Fuchs, 1997). Thus shoots and roots respond differently to particular environmental conditions. Even though the allometric ratio has been shown to vary considerably (Johnson et al., 2006; Gyldenkærne et al., 2007), it is widely used to estimate root biomass, e.g. in models of soil carbon inputs (Kätterer et al., 2011; Berti et al., 2016). Although there is some evidence showing that root biomass seem to be constant for a certain species in a particular environment rather than varying if estimated from shoot biomass using a fixed allometric relationship (Chirinda et al., 2012), this assumption has not been thoroughly tested.

Given the large uncertainties in current methods for estimating root C inputs, our objective was to compare methods for root biomass estimation, in particular the fixed allometric functions versus fixed root biomass. In this analysis we also explore which environmental and management factors affected shoot and root biomass of cereals, catch crops and weeds.

## 2. Methodology

Published and unpublished shoot and root biomass data from several field experiments in Denmark were collected. Mean values of each treatment were used to obtain statistically equal weight between treatments, and the data covered both cereal crops (Table 1) and catch crops and weeds (Table 2).

### 2.1. Cereals

#### 2.1.1. Description of experiments

Data for cereal crops (winter and spring wheat (*Triticum aestivum* L.) and spring barley (*Hordeum vulgare* L.)) was collected from studies conducted at Foulum (56°30′N, 09°35′E) in western Denmark. Organic and conventional farming systems at Foulum showed no overall differences in topsoil (0–25 cm) properties, which was loamy sand soil (Typic Hapludult) with clay content of 88 g kg$^{-1}$. The soil pH was 6.5. Organic matter content was 38 g kg$^{-1}$. Soil bulk density was 1.42 g cm$^{-3}$. Average annual temperature and precipitation during 1961–1990 were 7.3 °C and 704 mm. More information on soil properties was provided by Olesen et al. (2000).

Data from 2008 and 2010 were sampled in a long-term crop rotation experiment initiated in 1997 (Olesen et al., 2000). Briefly, the experiment included two rotation systems, one inorganic fertiliser-based conventional system and one organically managed system in two replicates. All treatments were ploughed (Table 1). More information on field management is given in Chirinda et al. (2012).

Data from 2013 and 2014 were sampled in a field experiment established in 2002 under conventional management with four replicates. Generally, there were two factors: nitrogen fertiliser rates and tillage (ploughing and no tillage) (Table 1). In 2013, nitrogen rates were 50 and 250 kg N ha$^{-1}$, while in 2014 they were 65 and 265 kg N ha$^{-1}$ for the same sub-plots. More details on the experiment are given in Munkholm et al. (2008) and Hansen et al. (2011).

The mean climatic conditions during the spring period (March to May) are shown for these experimental years in Table 3. The potential evapotranspiration was calculated using a modified Makkink method (Hansen, 1984) using temperature and global radiation as determining

**Table 1**
Shoot dry matter at maturity and root dry matter at anthesis in field studies with cereals at Foulum, Denmark.

| Species | Shoot (Maturity) (g m$^{-2}$) | Root (Anthesis) (g m$^{-2}$) | Sampling depth (cm) | Root corrected to 0–25 cm g m$^{-2}$ | Root/(Shoot + Root) 0–25 cm | Year | Seeding time | Farming system | N applied (kg ha$^{-1}$) | Tillage | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Wheat | 1907 | 204 | 30 | 194 | 0.09 | 2008 | Autumn | Conventional | 165 | Ploughed | Chirinda et al. (2012) |
| | 838 | 213 | | 203 | 0.19 | | | Organic | 0 | | |
| | 1271 | 249 | | 236 | 0.16 | | | | 102 | | |
| | 1145 | 291 | | 277 | 0.19 | | | | 108 | | |
| | 1482 | 251 | | 239 | 0.14 | | | | 108 | | |
| | 1124 | 156 | 30 | 148 | 0.12 | 2010 | Spring | Conventional | 110 | | |
| | 1350 | 187 | | 177 | 0.12 | | | | 110 | | |
| | 1093 | 322 | | 306 | 0.22 | | | Organic | 102 | | |
| | 1171 | 211 | | 201 | 0.15 | | | | 102 | | |
| | 1175 | 116 | 20 | 124 | 0.10 | 2013 | Autumn | Conventional | 50 | Ploughed | Sharif et al. (Submitted) |
| | 1571 | 86 | | 92 | 0.06 | | | | 250 | | |
| | 1226 | 123 | | 131 | 0.10 | | | | 50 | No-tillage | |
| | 1613 | 99 | | 106 | 0.06 | | | | 250 | | |
| | 1283 | 154 | 20 | 165 | 0.11 | 2014 | | Conventional | 65 | Ploughed | |
| | 1673 | 148 | | 159 | 0.09 | | | | 265 | | |
| | 1266 | 128 | | 137 | 0.10 | | | | 65 | No-tillage | |
| | 1614 | 120 | | 129 | 0.07 | | | | 265 | | |
| Barley | 1135 | 153 | 30 | 146 | 0.11 | 2008 | Spring | Conventional | 130 | Ploughed | Chirinda et al. (2012) |
| | 965 | 238 | | 226 | 0.19 | | | Organic | 0 | | |
| | 772 | 200 | | 190 | 0.20 | | | | 57 | | |
| | 1043 | 236 | | 224 | 0.18 | | | | 57 | | |
| | 1271 | 240 | | 228 | 0.15 | | | | 57 | | |
| | 1267 | 140 | 30 | 133 | 0.09 | 2010 | | Conventional | 120 | | |
| | 1251 | 113 | | 108 | 0.08 | | | | 120 | | |
| | 982 | 162 | | 154 | 0.14 | | | Organic | 62 | | |
| | 987 | 142 | | 135 | 0.12 | | | | 62 | | |