Catena 123 (2014) 99–105

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Root and soil carbon distribution at shoulderslope and footslope positions of temperate toposequences cropped to winter wheat

Ngonidzashe Chirinda [a,*], Svenja Doreen Roncossek [b], Goswin Heckrath [b], Lars Elsgaard [b], Ingrid Kaag Thomsen [b], Jørgen Eivind Olesen [b]

[a] Centro Internacional de Agricultura Tropical (CIAT), A. A. 6713, Cali, Colombia
[b] Department of Agroecology, Aarhus University, Blichers Allé 20, DK-8830 Tjele, Denmark

ARTICLE INFO

Article history:
Received 6 March 2014
Received in revised form 18 June 2014
Accepted 21 July 2014
Available online 12 August 2014

Keywords:
Root biomass
Slope
Soil bulk density
Soil organic carbon
Soil erosion

ABSTRACT

Crop root residues are an important source of soil organic carbon (SOC) in arable systems. However, the spatial distribution of root biomass in arable systems remains largely unknown. In this study, we determined the spatial distribution of macro-root and shoot biomass of winter wheat at shoulderslope and footslope positions from four cultivated slopes within an arable field in western Denmark. In addition, soils from the shoulderslope and footslope positions of four slopes were characterized for physical and chemical properties. Root biomass dry matter (DM) was marginally higher ($P = 0.06$) at footslope (1.2 Mg DM ha^{-1}) than at shoulderslope positions (0.9 Mg DM ha^{-1}), in particular in the subsoil. Likewise shoot biomass was higher ($P = 0.03$) at footslope (10.3 Mg DM ha^{-1}) compared to shoulderslope (7.1 Mg DM ha^{-1}) positions. Soil bulk density increased with depth at shoulderslope positions, but was more variable with depth at footslope positions. Root C was significantly correlated with SOC in shoulderslope soils ($r = 0.98$), but not in footslope soils. We conclude that, at shoulderslope positions, SOC originated mainly from root residues whereas at footslope positions, SOC was derived from both root residues and likely soil redistribution processes. Management practices that increase C input at shoulderslope positions potentially enhance soil carbon storage and increase crop productivity, which would probably not be the case for C rich footslope soils. These findings imply that models used to simulate or predict C dynamics and crop productivity should consider topography-controlled variations in root C input and SOC redistribution as well as their effects on soil properties, root growth and crop productivity.

1. Introduction

Soils globally store an estimated stock of 2344 Pg organic carbon and represent a major potential source or sink in the carbon cycle (Stockmann et al., 2013). In croplands, soil organic carbon (SOC) is mainly derived from root and shoot residues, as well as livestock manure applied as fertilizer, with a high importance of root C input for accumulation of SOC (Rasse et al., 2005). In-field variation in crop growth and residue distribution and retention may, over time, lead to uneven distribution of SOC. Such variation is a factor contributing to uncertainty in the estimation of cropland SOC stocks. Topographical characteristics (e.g., slope, surface curvature and elevation) contribute to spatial variation in crop growth as they influence factors such as soil water content (Hanna et al., 1982), nutrient retention (Verity and Anderson, 1990), erosion, subsurface water movement, canopy temperature and humidity (e.g., Heckrath et al., 2005; Hook and Burke, 2000; Knapp et al., 1993; Si and Farrell, 2004). Thus, topographical variations may directly influence crop growth and yield, and thereby influence the SOC stocks through varying inputs and retention of root and shoot residues (Avilés-Hernández et al., 2009). Also, topography is an important driver for lateral soil and SOC redistribution by water and tillage erosion creating distinct spatial patterns of SOC stocks on undulating arable land (Van Oost et al., 2005).

Several studies have quantified the influence of field elevation on aboveground crop growth (e.g., Boling et al., 2008; Si and Farrell, 2004), but the influence of elevation on root biomass has been largely ignored. In forest ecosystems, a few studies have compared root biomass at upland and lowland positions without documenting statistically significant differences (Avilés-Hernández et al., 2009; Ehrenfeld et al., 1992). However, whether this would apply also to different topographic positions in arable landscapes is poorly known. To our knowledge only Slobodian et al. (2002) have studied the effect of topography on root biomass distribution with a focus on shoulderslope and footslope positions in arable landscapes. Slobodian et al. (2002) reported that belowground biomass was 29% higher for soils from footslope positions (294 g m^{-2}) than for convex shoulderslope positions (228 g m^{-2}).

The depth profile of root growth and biomass is affected by soil factors including soil bulk density (BD) and derived physical properties (e.g., Bengough et al., 2011). For instance, Zhang et al. (2012) observed

* Corresponding author. Tel.: +57 2 4450000.
E-mail address: n.chirinda@cgiar.org (N. Chirinda).

http://dx.doi.org/10.1016/j.catena.2014.07.012
0341-8162/

a strong influence of BD on root growth for winter wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) grown in the North China Plain with greater root growth at low BD. Differences in BD at shoulderslope and footslope positions may be caused by soil erosion at shoulderslope positions leading to exposure of denser soils than at footslope positions (Van Oost et al., 2005). Accordingly, Ebeid et al. (1995) observed high BD at moderately and severely eroded field positions in a farm-scale study conducted in western Ohio. These findings imply that higher BD is potentially an impediment to root growth at eroded compared to depositional positions which in turn may affect the resultant root biomass and incorporation of SOC particularly in deeper soils layers.

The significance of root biomass in SOC sequestration is due to the biochemical properties of root biomass and its physico-chemical protection through interactions with soil minerals which increase the residence time of root-derived C (Mendez-Millan et al., 2010; Rasse et al., 2005). In addition, root decomposition influences aggregate formation and formation of particulate organic C (Puget and Drinkwater, 2001). Consequently, if root biomass depends on landscape positions, this would imply a spatially driven difference in root C input, distribution of SOC and crop productivity. The aim of the present study was to quantify the differences in macro-root biomass of winter wheat grown at different slope positions of an arable field in order to assess the effect of topographic position on root biomass. In addition, we explored the relationships between root biomass, SOC and BD and hypothesized that differences in soil properties would lead to lower macro-root biomass at the shoulderslope compared to footslope positions.

2. Material and methods

2.1. Field site and management history

The study site was an arable field situated in western Denmark (56°22.5′N; 09°33.6′E). Mean annual rainfall at the site was 704 mm and the mean annual air temperature was 7.3 °C (Djurhuus and Olesen, 2000). The dominant soil textural classes at the field site were loamy sand and sandy loam developed on glacial till from the Weichelian glaciation.

The selected field had been under continuous intensive cropping for more than 100 years with crop rotations dominated by spring barley (*Hordeum vulgare* L.), grass (primarily ryegrass, *Lolium perenne* L.), and fodder beet (*Beta vulgaris* L.) before the 1970s and since then by winter wheat, spring barley and winter oilseed rape (*Brassica napus* L.). Straw has generally been removed following harvest. The field has regularly received livestock manure, prior to 1975 predominantly as farmyard manure and thereafter as pig slurry. Typical slurry rates have been 20–30 Mg ha^{-1} with about 3–4 kg total N per Mg slurry. Mineral N fertilizer has been applied since the 1950s. Based on general fertilization practice in Denmark the estimated average rates declined from about 210 kg N ha^{-1} yr^{-1} in the late 1980s to presently about 170 kg N ha^{-1} yr^{-1} for a typical crop rotation of winter oilseed rape, two times winter wheat followed by winter barley. Soil pH has been maintained between 6.5 and 7.5 by intermittent liming. The field has been mouldboard-ploughed typically once a year to a nominal depth of 20–25 cm from the mid-1950s to 2008. Hereafter reduced tillage was introduced, working the soil to a depth of ca. 8 cm with a tine bar cultivator. Winter wheat was grown in 2011/2012, when this study was conducted. Winter wheat was sown at a seed rate of 180 kg ha^{-1} with a pneumatic seeder fitted with broadcast injectors. There were no gaps between seed bands resulting in a rather uniform plant stand.

2.2. Soil sampling and characterization

Four short toposequences (referred to as slopes 1, 2, 3 and 4) were selected at the field site; two slopes (1 and 2) were facing eastward, and the other two (3 and 4) were facing westward (Fig. 1). The mean steepness of slopes 1, 2, 3 and 4 was 16, 17, 22 and 13%, respectively, and the shoulderslope and footslope positions were 25, 20, 30 and 31 m apart, respectively. Slope 1, referred to as the main slope, had five sampling positions (A to E) at different positions along the catena; samples for slopes 2, 3 and 4 were only taken at the shoulderslope (A) and footslope (E) positions (Fig. 1).

Soil samples for SOC analyses (0–100 cm) and intact soil cores for BD and soil texture (at 5, 40 and 80 cm depth) were sampled on 20 June 2012. A 1-m long soil auger (2-cm diameter) was used to collect soil samples from 0 to 20, 20 to 40, 40 to 60, 60 to 80 and 80 to 100 cm depths. On the main slope (slope 1), soil was sampled in five replicate points (i–v) along a 1.5 m contour line at each of the five slope positions (A to E). Soil samples (i–v) from each slope position were pooled to give a composite sample from each of the five depth intervals. For slopes 2, 3 and 4 the sampling procedure was the same but samples were only collected at shoulderslope (A) and footslope (E) positions. The total of 55 composite soil samples were air-dried, passed through a 2-mm mesh sieve and pulverized for analysis of total soil C concentrations using a LECO dry combustion system (LECO Corporation, St Joseph, MI, USA). There were no detectable calcium carbonates in the soil samples; therefore total C was equivalent to SOC. Soil C stocks were calculated from the SOC concentration, sampling depth and BD—having accounted for the stone content (Syswerda et al., 2011).

At the shoulderslope (A) and footslope (E) position of each of the four slopes, a 1-m^2 pit was dug at a central position relative to the five sampling points (i–v). From each pit, five intact 100-cm^3 cores (~6 cm diameter; 3.5 cm high) were taken at depths ca. 5, 40 and 80 cm. The soil cores were characterized for BD and particle size distribution using sieve-hydrometer methods (Gee and Bauder, 1986). The amount of non-complexed clay (NCC) was estimated using the equation proposed by Dexter et al. (2008) and tested for Danish soils (Arthur et al., 2012; Schjønning et al., 2012):

$$NCC = \begin{cases} Clay - 10 \times SOC; \; if \; 10 \times SOC < Clay \\ 0; \; if \; 10 \times SOC > Clay \end{cases} \quad (1)$$

where clay and SOC represent the amount of clay and SOC (g kg^{-1}) in the soil sample. In June 2012, soil profile descriptions were done on the shoulderslope and footslope positions for all four slopes.

2.3. Aboveground and root biomass of winter wheat

At the beginning of anthesis (18 June 2012) above-ground shoot samples from slope 1 were collected from five 0.25 m^2 areas at each of the five sampling positions (A to E) (Fig. 1). On slopes 2, 3 and 4, shoot samples were collected from the five points at shoulderslope (A) and footslope (E) positions. To determine dry matter (DM) content, all shoot samples ($n = 55$) were oven-dried to constant weight at 80 °C for at least 18 h.

Also at anthesis, a 1-m long soil auger (10-cm diameter) was used to collect soil samples at all the slopes to determine root biomass. As there were no distinct plant rows, coring was done randomly, including over plant stubbles. Sampling positions were adjacent to those for SOC determination. Each soil core was subdivided into 0–20, 20–40, 40–60, 60–80 and 80–100 cm depth segments. All soil segments ($n = 275$) were stored at −18 °C until further processing (i.e., quantification of root biomass), which took place within two months after sampling.

To process the samples, the soils were first thawed at 10 °C. Then the soil was washed with tap water to separate roots from mineral particles, and the root material was collected on a sieve with a mesh size of 0.425 mm. The collected material was placed in a tray, where living roots were separated from dead organic matter based on color and physical appearance (Muñoz-Romero et al., 2010). Subsequently, the living roots were dried at 80 °C for at least 24 h and root DM and ash content were determined as described by Chirinda et al. (2011). Root DM biomass was calculated on soil surface-area basis (Oliveira et al., 2000) and root length was calculated from root DM biomass by