Forest Ecology and Management 328 (2014) 131–139

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Trees increase soil carbon and its stability in three agroforestry systems in central Alberta, Canada

Mark Baah-Acheamfour [a], Cameron N. Carlyle [b], Edward W. Bork [b], Scott X. Chang [a,*]

[a] Department of Renewable Resources, University of Alberta, 442 Earth Science Building, Edmonton, Alberta T6G 2E3, Canada
[b] Department of Agricultural, Food and Nutritional Science, University of Alberta, 410 Agriculture/Forestry Centre, Edmonton, Alberta T6G 2H1, Canada

ARTICLE INFO

Article history:
Received 3 March 2014
Received in revised form 12 May 2014
Accepted 20 May 2014
Available online 14 June 2014

Keywords:
Nitrogen
Physical fractionation
Hedgerow
Shelterbelt
Silvopasture

ABSTRACT

Agroforestry land-use systems have significant potential for increasing soil carbon (C) storage and mitigating increases in atmospheric greenhouse gas (GHG) concentrations. We studied the impact of three agroforestry systems (hedgerow, shelterbelt, and silvopasture) on soil organic C (SOC) and nitrogen (N) in the 0–10 cm mineral layer, by comparing SOC and N distributions in whole soils and three particle-size fractions (<53, 53–250, 250–2000 μm) to assess the potential role of physical protection on soil C and N storage. We assessed thirty-five sites (12 hedgerows, 11 shelterbelts and 12 silvopastures), each comprised of 2 paired plots (forest and adjacent agricultural herbland), that were distributed along a 270 km long north–south soil/climate gradient in central Alberta, Canada. Across all sites, 48.4%, 28.5%, and 23.1% of SOC was found in the fine (<53 μm), medium (53–250 μm) and coarse fractions (250–2000 μm), respectively. Mean SOC in the whole soil was 62.5, 47.7 and 81.3 g kg^{-1} in hedgerow, shelterbelt and silvopasture systems, respectively. Soil C in the more stable fine fraction was 34.3, 28.8 and 29.3 g kg^{-1} in the hedgerow, shelterbelt and silvopasture systems, respectively. Within each agroforestry system, the forested land-use consistently had greater total SOC and SOC in all size fractions than the agricultural component. Our results demonstrate the potential for trees to increase soil C sequestration in agroforestry systems within the agricultural landscape.

1. Introduction

In response to the increased global demand for food and other agricultural products, more land has been brought under agricultural cultivation. Agricultural practices such as conventional tillage are some of the main contributors to the increased concentrations of carbon dioxide (CO_2) and other greenhouse gases (GHGs), including methane (CH_4) and nitrous oxide (N_2O), in the atmosphere (Paustian et al., 2000). If GHG concentrations continue to increase, it is likely that global average temperature will rise further (IPCC, 2013). Removing atmospheric C and storing it within vegetation and soil pools in terrestrial ecosystems is one of the means to mitigate GHG emissions (IPCC, 2013).

Agricultural lands could be used to remove large amounts of C from the atmosphere if trees are reintroduced to the system and managed together with crops and/or animals (Nair et al., 2010; Sainju et al., 2012). Agroforestry (AF)—an approach to farming where trees and/or shrubs are deliberately combined with crops and/or livestock as a way of increasing diversity and sustainability—is believed to be an effective and low-cost method of sequestering atmospheric C into vegetation and soil pools (Albrecht and Kandji, 2003; Montagnini and Nair, 2004). Consequently, the importance of AF as a land-use system is receiving wider attention not only in terms of agricultural sustainability but also as a tool to minimize climate change (Oelbermann et al., 2004; Takimoto et al., 2009). However, a knowledge gap exists on the rate of C inputs from forest and agricultural components and their contribution to stabilizing soil C (Oelbermann et al., 2004).

Historically, shelterbelts are a common AF system practiced in western Canada; trees have been planted in shelterbelts for reducing soil erosion and protecting soils, crops, animals and farm yards from severe wind (Kort and Turnock, 1998). Modern agricultural practices, such as conservation tillage, are reducing the need to plant trees and even leading to their removal in some areas. Approximately 30% (20.6 million hectares) of Alberta's total land area is used for crop and livestock production (Alberta Agriculture and Rural Development, 2010), representing a substantial opportunity to sequester C if AF practices are adopted more widely. Conversely, removal of existing AF systems from the agricultural landscape would represent a potential source of C.

* Corresponding author. Tel.: +1 780 492 6375; fax: +1 780 492 1767.
E-mail address: sxchang@ualberta.ca (S.X. Chang).

http://dx.doi.org/10.1016/j.foreco.2014.05.031
0378-1127/

However, the net effects of land cultivation and forestry practices on soil C and nitrogen (N) pools, as well as the stability of these stores, have not been assessed for AF systems on regional scales in Alberta, although such studies have been undertaken to determine the amount of C held in the prairie shelterbelts of Saskatchewan (Kort and Turnock, 1998).

The complexities of land management practices applied to different land-use systems have a considerable impact on C storage in soils (Arevalo et al., 2009; Howlett et al., 2011). Forests can be significant sinks of atmospheric C compared to many row crop agricultural systems due to high C input associated with decomposing fine roots of trees and annual litterfall (Montagnini and Nair, 2004; Ayres et al., 2009). For example, Haile et al. (2008) reported that forested areas in silvopasture systems of Florida sequestered 33% more soil C than adjacent open pasture. Most studies have also estimated more than a 35% increase in soil C 50 years after the establishment of AF systems within temperate agricultural landscapes (e.g., Johnson, 1992; Howlett et al., 2011). On the other hand, land-use conversion from forest vegetation into cultivated agriculture has been reported to decrease total SOC (Takimoto et al., 2009). Cultivation reduces physical protection of soil organic matter from decomposition because of the destruction of soil structure, which enhances microbial decomposition of C (Costa and Foley, 2000; Johnson and Curtis, 2001). In addition, large amounts of biomass are physically removed from most agricultural fields, either through grain harvesting, straw removal, or both, further reducing the potential for C accumulation (Paustian et al., 2000).

Soil C is composed of fractions (pools) that have different rates of biochemical and microbial degradation, and land-use activity can influence the distribution of organic C and N among these SOC pools (Cambardella and Elliott, 1994; Teklay and Chang, 2008). Quantification of functional pool sizes may provide insight into the effects of land-use on SOC stabilization (d'Annunzio et al., 2008). Physical, chemical, and biological techniques are often used to separate SOC into fractions that differ in their functional roles such as C stabilization (Christensen, 2001; Six et al., 2002). Of these methods, physical fractionation of the whole soil into different components based on particle-size has routinely been used because the method is considered to be chemically less destructive and is better related to the function of soil C *in situ* (Creamer et al., 2011; Arevalo et al., 2012). With particle-size fractionation, soils can be separated into fine- (<53 μm), medium- (53–250 μm), and coarse (250–2000 μm) fractions. Particle-size fractionation allows us to consider the effect of different land-use practices on the process of soil aggregation, including how much C is contained in each fraction and an estimate of the residence times of SOC under different land-use systems (Six et al., 2000; Christensen, 2001; Gupta et al., 2009; Howlett et al., 2011). The C inside the coarse fraction (macroaggregates) is considered more labile than that associated with the fine fraction (microaggregates); C in the latter is better protected such that its decomposition rate is slower than those in the coarse fraction (Hassink, 1997; Six et al., 2000; John et al., 2005).

In this study, we determined SOC and N in different AF systems within the whole soil and particle-size fractions to: (i) assess the role of forested land areas in facilitating long-term C storage in the surface soil (0–10 cm), and (ii) identify the influence of different AF systems (hedgerow, shelterbelt, and silvopasture) and their land-use components (forest and agricultural land-uses) in facilitating SOC and N storage in the whole soil and different soil particle-size fractions in central Alberta, Canada. This study is expected to provide important baseline data on the amount of C and N in the whole soil and particle-size fractions in common AF systems, and highlight opportunities to increase C storage and reduce GHG emissions across the region.

2. Materials and methods

2.1. Study area

This study was conducted across a 270 km long north–south soil/climate gradient (from 54° 35′ N to 52° 28′ N), spanning the prairie and parkland ecoregions of central Alberta, Canada (Fig. 1). Climate normals for the study area, based on data for the last 30 years (1971–2000) from 35 Environment Canada climate stations, show that the northern part of the study area experienced 115–125 frost-free days, while the southern sites experienced 125–145 frost-free days. Mean annual air temperatures in the north and south were 1.9 and 2.4 °C respectively. Annual precipitation varies from 463 mm in the north to 448 mm in the south (Environment Canada, 2012). The area is characterized by three soil zones: Dark Gray Chernozemic and Gray Luvisolic soils (based on the Canadian system of soil classification) were predominant in the north, with the south was dominated by Black Chernozemic soils (Soil Classification Working Group, 1998).

We selected study sites that represent three common AF systems in the region: hedgerow, shelterbelt and silvopasture systems. Both the hedgerow and shelterbelt systems are boundary type AF practices. In both systems, strips of permanent vegetation (3–5 m wide) consisting of trees, shrubs and grasses are planted or managed around edges of agricultural lands. The hedgerow forests were 40- to 100-year-old broad-leaved deciduous stands dominated by *Populus tremuloides* Michx., *Betula papyrifera* Marsh., and *Populus balsamifera* L., whereas shelterbelt forests were made up of 20- to 50-year-old coniferous and deciduous trees dominated by *Picea glauca* Moench. Large areas were also devoted to extensive annual crop production in both systems. Most of the landowners practiced minimum tillage, applied fertilizers that include N (up to 120 kg ha^{-1} annually), and grow *Hordeum vulgare* L., *Triticum aestivum* L., or *Brassica napus* L. in rotation. The silvopasture was established by deliberately grazing existing understory vegetation in native aspen forests to provide alternative forage for livestock, particularly late in the growing season and during droughty periods. The trees in this system also provided shelter for the livestock grazing in this system. Both the grazed aspen forest and agricultural land-use (open pasture) components support livestock grazing in either rotational or season-long grazing systems. In this system, the size of the forests can vary depending on the amount of space available. Species composition and ages of the aspen forests were similar to the natural hedgerows. Open pastures contain a mix of grasses and forbs, including N-fixing legumes.

2.2. Sampling design

Because of the spatial arrangement of the components within the three AF systems, the experiment was based on a split-plot design. The three AF systems (hedgerow, shelterbelt, and silvopasture) were the main plots, with the two land-use types (forest and agricultural land-uses) as the subplots. We selected 35 sites (12 hedgerows, 11 shelterbelts and 12 silvopastures) along the soil-climate gradient. As much as possible, sites were randomly selected to cover the entire study area. One transect was established within each pair of forest and agricultural land-use subplots. Depending on the site condition, the length of the transect varied from 30 to 50 m. The transect in the forested land-use was established in the center of the forested sub-plot, while that in the agricultural land-use sub-plot was located at least one tree height (~30 m) from the nearest tree to reduce the immediate influence of trees on adjacent agricultural fields. As much as possible, we established the paired forest and agricultural transects on the same ecosite with similar landform, elevation, drainage and slope. Soil samples