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Soil organic carbon stocks in three Canadian agroforestry systems: From surface organic to deeper mineral soils

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ABSTRACT

Our understanding of the effect of agroforestry systems on soil organic carbon (SOC) is largely limited to the upper layer of the mineral soil, while LFH (litter, partially decomposed litter and humus) and deeper soil layers are poorly studied. In this study, the effects of three different agroforestry systems (hedgerow, shelterbelt, and silvopasture) and their component land-cover types (treed area and adjacent herbland) on SOC stock in LFH and mineral soil layers (0–75 cm) were investigated across 36 sites in central Alberta, Canada. The SOC stock of mineral soil (0–75 cm) was not affected by agroforestry systems but by land-cover type. The treed area had greater ($p < 0.001$) SOC in the 0–75 cm mineral soil (25.5 kg C m^{-2}) than the herbland (19.4 kg C m^{-2}), driven by the greater ($p < 0.001$) SOC level in the top 0–30 cm rather than that in the deeper layers (30–75 cm). Within the treed area, the silvopasture system that was dominated by broad-leaf deciduous trees had 56–70% more SOC in the 0–10 cm soil than in the hedgerow and shelterbelt systems. The SOC stock in the 0–10 cm layer was positively ($p = 0.025$) related to the C stock of the overlying LFH layer in the silvopasture system. These results together with the 22–24% higher dissolved organic carbon (DOC) concentration in the silvopasture than in the other systems suggest that the greater SOC stock in the 0–10 cm mineral soil could be attributed to the higher rates of translocation of DOC from the LFH in the silvopasture than that in shelterbelt or hedgerow. We conclude that SOC stock in the top mineral soil (e.g., 0–30 cm) is more responsive to changes in land-cover type and the LFH layer plays an important role in increasing SOC stock in the surface mineral soil of the agroforestry systems in central Alberta.

1. Introduction

Agroforestry is a land-use system that combines perennial vegetation such as trees and shrubs (referred to as "treed area" hereafter) with annual crops and/or grazed pasture (herbland area) on the same land unit (Montagnini and Nair, 2004; Nair et al., 2009). In Alberta, three agroforestry systems (hedgerow, shelterbelt, and silvopasture) are common, and each of them consists of two land-cover types: a treed area with trees and understory vegetation (shrubs, forbs and other plant species), and a herbland comprised of annual crops or grazed grassland (Baah-Acheamfour et al., 2015). The hedgerow system typically consists of a 3–5 m wide strip of natural vegetation containing trees, shrubs and grasses along the edge of the cropland (Van Vooren et al., 2017). In the shelterbelt system, trees are planted to protect soils, crops, and animals from wind (Kort and Turnock, 1998). The silvopasture is a system that contains a mosaic of open grassland and natural forest with understory for livestock grazing (Abbas et al., 2017).

Agroforestry systems may sequester more soil organic carbon (SOC) than annual cropping systems because perennial woody vegetation continuously returns plant litter to the soil and tree removal occurs less frequently than annual crop harvesting (Paul et al., 2002; Montagnini and Nair, 2004; Oelbermann et al., 2004; Lenka et al., 2012; Abbas et al., 2017). For example, treed areas in Florida silvopasture contained 33% more SOC than adjacent open herblands (Haile et al., 2008). In our previous studies (Baah-Acheamfour et al., 2014, 2015), up to 30% more SOC was found in the 0–30 cm layer of mineral soil in the treed area

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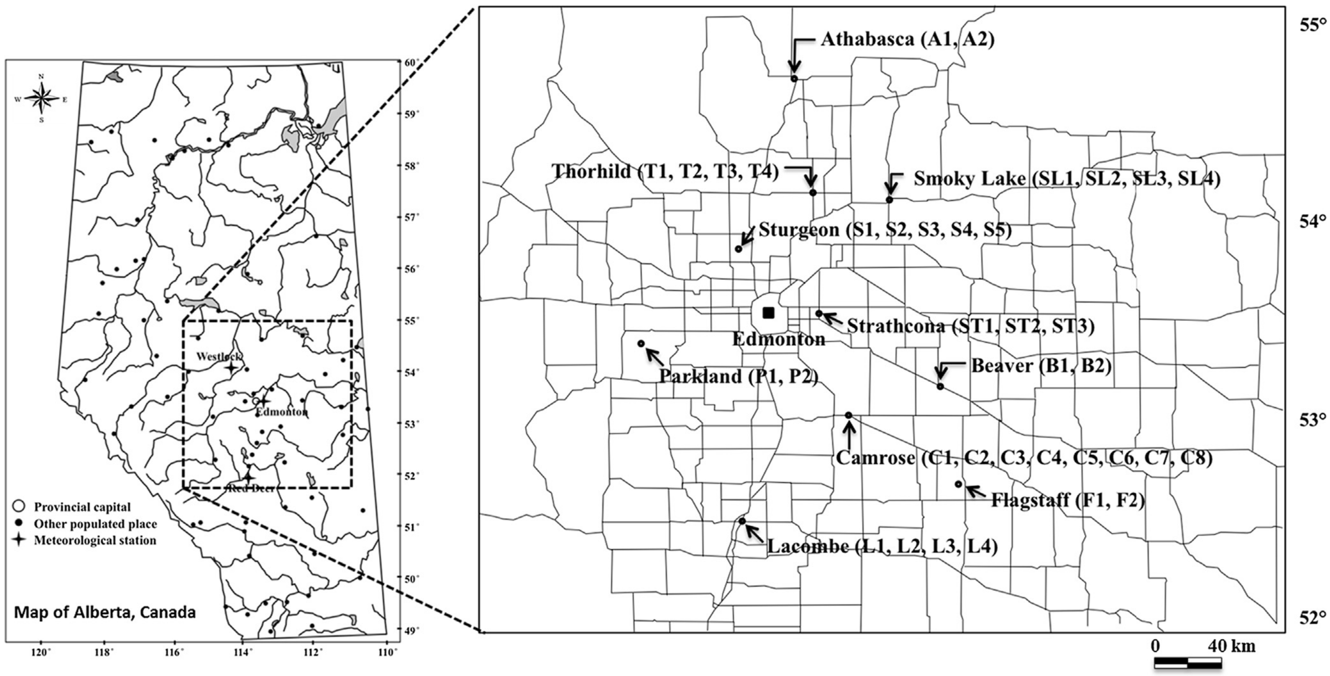

Fig. 1. Soil sampling locations across central Alberta, Canada. Detailed information about county and agroforestry system types of the location codes are provided in Table S1.

compared to the cropland in western Canada. However, in these studies, SOC stock in soil layers below 30 cm depth has rarely been considered. Though studies investigated deeper soil layers are available, these studies are limited to a certain agroforestry system such as silvopasture (Haile et al., 2008, 2010; Upson and Burgess, 2013; Upson et al., 2016; Cardinael et al., 2017, 2018) or hedgerow systems (Cardinael et al., 2015; Thiel et al., 2015). Therefore, our overall understanding of the effect of different types of agroforestry systems on SOC sequestration is limited to the top mineral soil layers (typically 0–30 cm), and it remains unclear if the observed trends in SOC extend to deeper soil layers. The SOC in deeper layers may be particularly important for treed areas as compared with herblands because of the deep-rooting habit of woody plants (Batjes, 1996; Jobbagy and Jackson, 2000), even though the majority of the roots are found in the upper 30 cm of soil in boreal forests (Jackson et al., 1996).

The surface organic soil layer (LFH, the litter, partially decomposed litter and humus) has also rarely been considered in studying SOC stock in agroforestry systems largely due to the LFH being susceptible to loss by fire and other surface disturbances (Baah-Acheamfour et al., 2015). Nevertheless, where present the LFH can represent about 10% of the total C in forested area (Birdsey et al., 1993) and is an important source of SOC for mineral soils, although it is possible for some for agroforestry systems to have little LFH due to a low tree density or fast litter decomposition. Due to the difference in litter quantity and quality between tree species (Prescott et al., 2000), the contribution of LFH to SOC stock in mineral soil could differ between deciduous vs. coniferous dominated agroforestry systems. In our previous studies (Baah-Acheamfour et al., 2014, 2015), agroforestry systems (e.g., hedgerow and silvopasture) containing deciduous trees were found to have higher SOC stock in mineral soil than that dominated by conifer trees (e.g., shelterbelt). This difference in SOC stock in the mineral soil was attributed to deciduous trees generating a large amount of high-quality litter (i.e., less recalcitrant, and thus more likely to be stabilized in the mineral soils via microbial processes), while coniferous trees produce a lower quantity of litter with more recalcitrance to microbial processes (Miltner et al., 2012; Cotrufo et al., 2013). However, we still do not understand how LFH influences the SOC stock in the mineral soil of agroforestry systems containing functionally different trees. One possible mechanism is the vertical migration of SOC into the surface mineral soil in the form of dissolved organic C (DOC) following a partial decomposition of surface organic matter in the LFH (Neff and Asner, 2001; Chantigny, 2003); however, patterns of DOC concentration in the soils of agroforestry systems have rarely been investigated.

This study was conducted to investigate (1) the effect of different agroforestry systems (hedgerow, shelterbelt, and silvopasture) and their land-cover types (treed area and herbland) on SOC stock across the LFH and the 0–75 cm soil layers and (2) the difference in DOC concentration in the top mineral soils among different agroforestry systems. We hypothesized that (1) the SOC benefit of agroforestry would be greater when deeper soil layers are accounted for due to the deep-rooting habit of trees and the contribution of deep roots to SOC stock and (2) DOC concentrations would be greater for agroforestry systems dominated by deciduous trees (e.g., hedgerow and silvopasture) than that for systems with coniferous trees (e.g., shelterbelt) due to more readily decomposability of deciduous litter than coniferous litter as well as the greater quantity of litter of the first than that of latter as mentioned previously.

2. Materials and methods

2.1. Site description

This study is part of a larger project investigating soil physicochemical and microbiological properties, including the SOC stock size and its stability in different agroforestry systems and land-cover types in central Alberta, Canada (Baah-Acheamfour et al., 2014, 2015; Banerjee et al., 2016). We selected 12 sites for each of the three common agroforestry systems (total of 36 sites): hedgerow, shelterbelt, and silvopasture, along a 270-km long north-south soil/climatic gradient (54° 60′ N to 52° 33′ N latitude; 111° 52′ W to 114° 42′W longitude and 533–850 m above mean sea level), spanning the prairie and parkland regions (Fig. 1; Table S1). Temperature and precipitation data were obtained from 26 Environment Canada climate stations adjacent to the study sites. During the past 30 years (1984–2013), annual precipitation varied from 448 to 463 mm, and mean annual temperature ranged from 1.9 to 2.4 °C (Environment Canada, 2014). Dominant soils were Black Chernozems in the southern, Dark Gray Chernozems in the central, and Gray Luvisols in the northern parts of the study area (Soil Classification Working Group, 1998).