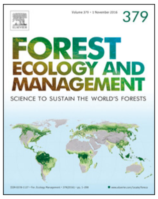
Forest Ecology and Management 424 (2018) 62–70

Contents lists available at ScienceDirect

Forest Ecology and Management

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



A multi-site approach toward assessing the effect of thinning on soil carbon contents across temperate pine, oak, and larch forests

Seongjun Kim[a], Choonsig Kim[b], Seung Hyun Han[a], Sang-Tae Lee[c], Yowhan Son[a,*]

[a] *Department of Environmental Science and Ecological Engineering, Graduate School, Korea University, Seoul 02841, South Korea*
[b] *Department of Forest Resources, Gyeongnam National University of Science and Technology, Jinju 52725, South Korea*
[c] *Forest Practice Research Center, National Institute of Forest Science, Pocheon 11186, South Korea*

ARTICLE INFO

Keywords:
Effect size
Larix kaempferi
Pinus densiflora
Quercus species
Thinning intensity
Time after thinning

ABSTRACT

Large divergence of the post-thinning change in soil carbon contents has impaired the evaluation of the thinning effect on forest carbon storage reported in previous case studies. In this context, the present study used a multi-site approach to assess the effect of thinning on forest floor and mineral soil carbon contents. The sites included four pine (*Pinus densiflora* Sieb. et Zucc.), five oak (*Quercus* spp.), and four larch (*Larix kaempferi* (Lamb.) Carr.) forests under the temperate climate, each of which included un-thinned control, intermediate thinning (15–30% basal area reduction), and heavy thinning (30–50% basal area reduction) treatments. Forest floor and mineral soil (0–10, 10–20, and 20–30 cm depths) carbon contents were determined 0–1, 3–4, and 6–7 years after thinning. The average forest floor and mineral soil (0–30 cm) carbon contents (Mg C ha^{-1}) were 6.7 and 54.1 under the control, 6.6 and 60.7 under the intermediate thinning treatment, and 6.0 and 64.7 under the heavy thinning treatment, respectively. There was a slight decrease in forest floor carbon contents but an increase in mineral soil carbon contents under the thinning treatments, although the magnitude and direction of the thinning effect were site-specific. The magnitude of the thinning effects was stronger under the heavy thinning treatment than under the intermediate thinning treatment. However, the effect of thinning was unrelated to time after thinning and forest type. Topography (altitude and slope), soil properties (soil water content, pH, and total nitrogen concentration), diameter at breast height and height of remaining trees, and the percentage of removed basal area explained approximately 45% of variance in the thinning effect, indicating that differences in the environment are important in the divergence of the thinning effect on soil carbon contents across multiple sites. Our results suggest that designing thinning practices to foster forest carbon sequestration should consider the contribution of thinning intensity and environmental conditions to variation in the thinning effect on soil carbon contents.

1. Introduction

Soil is a major component of forest carbon storage, and contains approximately 44% of the carbon contained in the world's forests (Pan et al., 2011). Carbon stored in forest soil significantly contributes to carbon sequestration as the largest form of carbon storage in forest ecosystems (Lal, 2005). Accordingly, the Intergovernmental Panel on Climate Change and other agencies have recommended measuring soil carbon contents for the quantification and assessment of forest carbon storage (James and Harrison, 2017).

Thinning to harvest deformed and poorly growing trees has diverse impacts on the storage of soil carbon. Post-thinning reduction of tree density decreases litter production from remaining trees at the stand scale (Navarro et al., 2013; Segura et al., 2017), and allows more light and rainwater to reach the soil surface (Chase et al., 2016; Sun et al., 2017). Thinning also produces unharvested residue and root litter (Kim et al., 2018; Shen et al., 2017), and elevates the growth of remaining trees and understory vegetation (Lee et al., 2018; Zhou et al., 2016). These changes can result in substantial shifts in microclimate, microbial activity, organic matter decomposition, and carbon efflux (Akburak and Makineci 2016; Bastida et al., 2017; Gliksman et al., 2018; Lei et al., 2018), which would be expected to alter soil carbon contents in forest ecosystems.

As a principal management intervention, the effect of thinning was recently evaluated in several meta-analyses (Achat et al., 2015; James and Harrison 2017; Kalies et al., 2016; Lee et al., 2015; Zhou et al., 2013). These studies confirmed that thinning generally decreases carbon contents in aboveground biomass but increases understory carbon contents (Zhou et al., 2013). Furthermore, the effects of thinning can be a function of thinning intensity and time after thinning

---

* Corresponding author.
E-mail address: yson@korea.ac.kr (Y. Son).

https://doi.org/10.1016/j.foreco.2018.04.040
Received 20 March 2018; Received in revised form 19 April 2018; Accepted 20 April 2018

across individual case studies (Kalies et al., 2016; Zhou et al., 2013). However, the post-thinning change in soil carbon contents is unconfirmed because it can differ markedly in magnitude and direction with environmental factors, such as the soil depth, soil type, forest type, and climate of each site, rather than thinning intensity and time after thinning (Achat et al., 2015; James and Harrison, 2017; Lee et al., 2015; Zhou et al., 2013).

Only a few studies have addressed the different effects of thinning on soil carbon contents across multiple sites. For example, Powers et al. (2012) observed no significant effect of thinning on soil carbon contents in *Pinus resinosa* Sol. Ex Aiton forests along the chronosequence. In addition, Boerner et al. (2008) and Kim et al. (2016a) found no general effect of thinning on soil carbon contents over a network of multiple sites; however, they did detect significant changes in soil carbon contents in a few individual sites. Inagaki et al. (2011) found a general decrease in forest floor carbon contents following intensive thinning of *Chamaecyparis obtusa* Endlicher forests. Nevertheless, factors influencing the magnitude and direction of the effects of thinning on soil carbon contents across multiple sites remain unidentified in the forest ecology.

The present study aimed to elucidate the effect of thinning on soil carbon contents over multiple pine, oak, and larch forests, which are principal tree species in temperate climate zone. Although several studies have investigated forest carbon storage for these species at a single stand level (Hwang and Son, 2006; Kim et al., 2009; Kim and Lee, 2017; Mu et al., 2013), the absence of multi-site studies assessing soil carbon contents in thinned forests has limited our understanding of the consequences of management interventions for these forest ecosystems. We hypothesized that (1) the effect of thinning on soil carbon contents would be related to thinning intensity and time after thinning, and (2) differences in the effect of thinning across individual sites would occur due to variation in environmental conditions such as forest type, topography, and soil property, according to previous findings (Achat et al., 2015; James and Harrison, 2017; Zhou et al., 2013). In the present study, four pine, five oak, and four larch forests receiving two thinning intensities and diverse environmental conditions were investigated to assess general or site-specific patterns related to these factors. The effect of thinning on soil carbon contents was determined in three different times after thinning to test changes over the elapsed time. Considering the large heterogeneity among study forests, the effects of thinning in each study forest at different times after thinning were compared using a standardized effect size that has been widely used as a meta-analytical approach (Nakagawa and Cuthill, 2007).

2. Materials and methods

2.1. Study forests

The study forests included four pine (*Pinus densiflora* Sieb. et Zucc.; GNP, JSP, JJP, and SCP), five oak (*Quercus* spp.; HCO, YYO, HSO, SCO, and HYO), and four larch (*Larix kaempferi* (Lamb.) Carr.; GNL, IJL, MFL, and MSL) forests throughout South Korea (Table 1). Of them, GNP, JSP, HCO, YYO, HSO, GNL, and IJL were in central Korea, whereas JJP, SCP, SCO, HYO, MFL, and MSL were in southern Korea. The climate of the study forests was temperate with cold, dry winters and hot, humid summers. The study forests were 31–60-year-old (Table 1); this age group accounts for approximately 87% of the nation's forest area (Korea Forest Service, 2016). The study forests represented a range of topography and soil properties, ensuring the potential applicability of any findings of the present study. For example, the altitude and slope ranged from 140 m and 13° to 930 m and 32°, respectively (Table 1). The soil pH, gravimetric water content, and nitrogen concentration were 4.3–5.3, 10.7–34.0%, and 0.4–5.0 g kg^{-1}, respectively (Table 1). The soil of the study forests was dominated by a dry brown forest soil type (B1), according to the South Korean forest soil classification (Korea Forest Research Institute, 2011), which typically has dry and acidic soil properties and occurs on mountain ridges. The soil texture of the study forests was generally a sandy loam in the central forests, and a loamy sand or a loam in the southern forests. Information regarding understory vegetation for several study forests has been presented previously (Kim et al., 2015, 2016b, 2018).

Each study forest contained three stands receiving un-thinned control, intermediate thinning, and heavy thinning treatments, respectively, except for one pine forest (JJP). Because the intermediate thinning stand was clearcut to prevent pine wilt disease, JJP had the control and heavy thinning stands only. Each stand within a study forest included three circular permanent plots with a 9–12 m radius. To reduce potential edge effects and spatial heterogeneity, all plots within each study forest were enclosed by at least a 5-m wide buffer strip and installed on areas with similar pre-thinning tree density and topography. The intensities of the intermediate and heavy thinning treatments were 15–30 and 30–50% according to the removed basal area (Table 1). Thinning of the study forests included the logging of deformed and poorly growing trees, and involved the subsequent removal of stems only. Trees were cut with a chainsaw instead of a heavy machinery to minimize disturbance of the soil surface. Thinning treatments were conducted for pine, oak, and larch forests in 2008, 2010, and 2011, respectively, except for two southern oak forests (SCO and HYO), which were thinned in 2007.

2.2. Sample collection and carbon content determination

Forest floor and mineral soil were sampled three times from each study forest (indicated as the first, second, and third measurement periods), representing 0–1, 3–4, and 6–7 years after thinning, respectively, except for three of the study forests (SCO, HYO, and IJL). As SCO and HYO were thinned 3 years earlier than the other oak forests, the first, second, and third measurement periods for these forests corresponded to 3–4, 6–7, and 9–10 years after thinning. Data were only available for 3–4 and 6–7 years after thinning for IJL, which was included in the present study after completion of the first measurement period. During each sampling period, forest floor and mineral soil samples were collected from three randomly located soil pits at each plot within each treatment, except for the first measurement period for GNP, JSP, HCO, YYO, and HSO, where samples were obtained in one plot per treatment using five soil pits.

A sample was taken from the forest floor with a 900 cm^2 square frame on each soil pit (Korea Forest Research Institute, 2010). Forest floor samples included humus, fallen leaves, and twigs (smaller than 7 cm in diameter) on the mineral soil surface. After removing the forest floor, a mineral soil sample was taken with a 10-cm long corer (407 cm^3) at 0–10, 10–20, and 20–30 cm depths near each soil pit (Korea Forest Research Institute, 2010). Forest floor and mineral soil samples were each placed into zipper storage bags and brought to the laboratory for further analyses.

Dry mass of forest floor samples was measured after oven-drying at 85 °C. Mineral soil samples were air-dried and passed through a 2-mm sieve to separate coarse rocks and roots from mineral soil samples. Soil particles and fine roots penetrating the sieve were treated as the mineral soil in the present study. Soil bulk density and coarse rock content were estimated as the proportion of dry mass of all mineral soils to the volume of the corer and the ratio between the dry mass of coarse rocks and all mineral soils, respectively, both of which were based on the mass remaining after oven-drying at 105 °C. Forest floor and mineral soil carbon concentrations were determined using an elemental analyzer (vario Macro, Elementar Analysensysteme GmbH, Germany). Forest floor carbon contents were calculated using the dry mass and carbon concentration, while mineral soil carbon contents at 0–10, 10–20, and 20–30 cm depths were calculated using bulk density, coarse rock content, and carbon concentration (Korea Forest Research Institute, 2010).

Soil properties including soil pH, soil gravimetric water content, and