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Short term effects of thinning on soil organic carbon fractions, soil properties, and forest floor in Cunninghamia lanceolata plantations

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Forest management impacts on the soil carbon pool and soil properties. This study analyzed the changes of soil organic carbon (SOC) fractions, soil properties, and forest floor in a Chinese fir (Cunninghamia lanceolata) plantation after two years of thinning in Eastern China. The experiment consisted of three thinning treatments: unthinned, moderate thinned (stand stem density reduced by approximately 21%), and heavy thinned (stand stem density reduced by approximately 36%) stands. Concentrations of soil dissolved organic carbon (DOC), light fraction carbon (LFOC), and total SOC in the topsoil (0 to 20 cm) increased in the heavy thinned stands, and no significant effect for heavy fraction carbon (HFOC) was detectable in the soil profile. Some soil properties were also altered after thinning, which included a decrease in soil bulk density (BD), and an increase in soil temperature (ST), soil organic matter (SOM), total nitrogen (TN), available nitrogen (AN), available phosphorus (AP), available potassium (AK), and pH. The change of these soil properties mainly occurred in the topsoil layers (0 to 20 cm) in the heavy thinned treatment. The SOC and soil labile carbon fractions were positively correlated with ST, TN, AN, AP, and AK. Moreover, the increase of SOC fractions and the availability of soil nutrients maybe due to the increased input from an abundant well-decomposed forest floor after thinning. These results suggest that a 36% of thinning operations had a marked impact on the soil labile carbon pool and soil fertility in the topsoil in a Chinese fir plantation during a short-time period. Thus, changes to soil carbon stability and soil fertility should be considered when developing forest management plans.

Key words: Thinning, soil organic carbon fraction, soil nutrient, soil carbon stability.

INTRODUCTION

Thinning is a common silvicultural practice in forest management. It reduces tree density and improves the growth rate of the remaining trees for increasing timber production (Zhou et al., 2013). Thinning changes the canopy structure, and will affect the microclimate within the modified stand, and also impact on forest floor decomposition, soil carbon sequestration, and soil properties (Selig et al., 2008; Hoover, 2011).

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Some studies have reported that thinning increased soil organic carbon (SOC) stock after one or two years of treatment (Brais et al., 2004; Asaye and Zewdie, 2013). However, other studies have indicated that thinning had no significant impact on SOC in mineral soil during a short-term period (Hu, 2000; Kim et al., 2009). These different results may relate to variables such as thinning intensity and thinning method, as well as differences in the sampling time after thinning (Jónsson and Sigurðsson, 2010; Clarke et al., 2015). Therefore, more research is needed to explore the relationship between thinning and SOC. Moreover, most works have previously focused on total SOC changes, therefore, less experimental evidence is available for the effect of thinning on SOC fractions in the mineral soil.

Density fractionation, which based on physical fractionation method, was commonly used to study the changes of soil labile and stable fractions (Wäldchen et al., 2013). The light fraction of SOC contains partly decomposed plant and animal residues, is readily influenced by the disturbance, and has a rapid turnover (Bremer et al., 1994). The heavy fraction composed of SOC adsorbed on the mineral surfaces or encrusted with small mineral particles, is stable and slow turnover (Six et al., 2002; Crow et al., 2007). Thinning influences the forest environmental conditions, and changes the inputs of forest floor. Thus, thinning might produce a substantial impact on the light and heavy fractions of SOC. Understanding the changes of SOC fractions after thinning is more important in evaluating SOC pool stabilization.

Forest floor is a primary source for SOC and soil nutrients. Meta-analyses by Nave et al. (2010) showed that carbon of the forest floor is more susceptible to forest harvest method (including thinning) than soil, which is affected by tree species composition, soil type, and harvest intensity. Therefore, forest floor and soil conditions after thinning may directly or indirectly affect the concentrations of SOC and its fractions. Furthermore, soil carbon fractions could be related to the changes of soil properties, while few information is available on soil properties of Chinese fir (*Cunninghamia lanceolata*).

Chinese fir is native to China, Northern Vietnam, and Laos, and is one of the most important timber species in Southern China (Xu, 2006). Chinese fir has been widely planted in China over 1000 years (Zhang et al., 2013), and its area was approximately 9.11 million hectares (Lei, 2005). A number of studies on stand management have concentrated mainly on Chinese fir growth and timber production (Yu, 2006; Lei, 2005; Zhang et al., 2006; Xu et al., 2014).

Several studies have reported the effect of thinning on SOC stocks and soil properties in the top soil (0 to 20 cm) (Zhang, 2001; Zhou et al., 2015). However, how thinning intensity affects SOC fractions and soil properties in different soil depths after short-term thinning treatment is still unclear. The purposes of this study were to:

(1) Assess the short-term (two years) changes of the SOC and its fractions in the soil profile after a pre-commercial thinning; and
(2) Determine how thinning intensities influence forest floor nutrients and soil physical, and chemical variables concentrations; and
(3) Analyze the effect of forest floor and soil properties on soil carbon fractions.

MATERIALS AND METHODS

Site descriptions

The experiment was carried out at the Kaihua Forest Farm (118°25′ E, 29°09′ N), in the southwest of Zhejiang Province, China. The forest coverage rate of Kaihua County was 80.54% in 2013, and the plantation area of Chinese fir was over 90, 000 ha, covering almost 50% of the total forest area. In the study area, the average annual temperature is 16.4 °C, the average annual precipitation is 1814 mm. The slopes of the experimental area were 18%, and the soil is silt loam in texture with a pH of 4.0 to 4.9.

Experimental design

This experiment included three thinning treatments:

(1) No thinning (CK)
(2) Moderate thinning (stand density reduced by approximately 21%, MT), and
(3) Heavy thinning (stand density reduced by approximately 36%, HT).

In March 2011, nine 20 m × 20 m plots were established in a Chinese fir plantation planted in 1996, and the initial planting stand density was 2500 trees ha-1. There were three replicates (plots) for each treatment.

Growth measurements

The tree height and diameter at breast height (DBH) of each plot were measured. Stand volume was estimated by the formula: $V = 0.000101614 \times D^{1.939021819} \times H^{0.736582360}$ (V is volume, m^3 ha^{-1}; D is DBH, cm; and H is tree height, m). Canopy coverage was estimated with a tracing radiation and architecture of canopies (TRAC) plant canopy analyzer (3rd Wave Engineering, Ontario, Canada). Nine subplots of 1 m × 1 m were randomly set in each plot, and shrub and herbs within each subplot were harvested. At the same time, the forest floor in each subplot was also collected. The subsamples of the understory vegetation and forest floor were dried at 70°C for 48 h, and the dry biomass was calculated. Total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP), and total potassium (TK) in the forest floor were measured using the method described by Bao (2005). The basic stand characteristics in 2012 are shown in Table 1.

Soil sampling and measurements

In each plot, soil samples were randomly collected from six points (0 to10 cm, 10 to 20 cm, 20 to 40 cm, and 40 to 60 cm soil layers) using a soil auger (ø 4 cm) in October 2012, and the samples from the same soil layer were mixed into one composite sample. Thus, 36 samples were collected from the nine plots. Each sample was

Table 1. Basic stand characteristics of the three thinning treatments. n = 3, mean ± SD.

Thinning treatment	CK	MT	HT
Tree density (tree ha^{-1})	1775±119	1408±131	1114±106
Canopy coverage (%)	96.2±1.8	87.5±3.5	75.1±4.6
Tree height (m)	14.5±0.8	14.8±0.6	14.9±0.4
DBH (cm)	17.6±0.5	18.5±0.8	19.1±0.8
Stand volume (m^3 ha^{-1})	344.3±18.8	312.7±21.5	276.9±17.3
Understory vegetation biomass (t ha^{-1})	1.49±0.43	1.98±0.91	2.36±0.65

sieved (2-mm mesh) and was divided into two parts. One part was used to measure soil dissolved organic carbon (DOC), and the other part was air-dried and determined light fraction soil organic carbon (LFOC), heavy fraction soil organic carbon (HFOC), total SOC, and other soil nutrients.

To determine the soil dissolved (cold-water-soluble) organic carbon, a fresh soil sample was extracted with deionized water, centrifuged, and then filtered (Liu et al., 2012). The water extracted organic carbon was measured by TOC-Vcph (Shimadzu, Japan). The light fractions and heavy fractions were separated by flotation on a NaI solution (1.70 g cm^{-3}) (Janzen et al., 1992). The concentrations of the light and heavy fractions, and total SOC were determined by the K2Cr2O7 method (Bao, 2005). SOM was determined by SOC × 1.724 (Waksman and Stevens, 1930). TN, available nitrogen (AN), TP, available phosphorus (AP), TK, and available potassium (AK) were measured according to the method described by Bao (2005). Soil pH was determined in a dilution of soil (soil: water is 1:2.5) by a glass electrode potentiometer (Mettler Toledo Instruments, Shanghai, China) (Bao, 2005).

Soil physical properties were determined by stainless steel cylinders (Zhang et al., 1999). Soil water content (SWC, %) was measured by drying fresh soil (Zhang et al., 1999). EC-300 portable digital soil temperature meter (Aquaterr, USA) was used to measure soil temperature (ST) in each plot at 5, 15, 30 and 50 cm soil depth. Soil particle size distribution, based on FAO criterion, was determined by laser analyzer (Mastersizer 2000, Malvern Instruments).

Data analysis

The differences of the SOC fractions, soil physical and chemical properties, and forest floor among the different thinning treatments were examined by a one-way analysis of variance (ANOVA), and then performed post hoc Duncan's test. The Pearson's correlation was used to test correlate relationship between the SOC fractions and soil properties. The significant level was set $P < 0.05$. All data were analyzed by the statistical package for social sciences (SPSS) software (SPSS 17.0, IBM SPSS Statistics).

RESULTS

Soil organic carbon fractions

The concentrations of SOC increased with an increase in thinning intensity in 0 to 10 cm and 10 to 20 cm soil layers. There was no significant difference among the three thinning treatments below 20 cm ($P > 0.05$) (Figure 1a). The DOC was significantly enhanced in the 0 to 10 cm soil layer in the HT plots when compared to the CK ($P < 0.05$), it exhibited no significant difference among the three thinning treatments below the 10 cm soil layers ($P > 0.05$) (Figure 1b). The concentrations of the LFOC were also significantly higher in only the 0 to 20 cm soil layers in the HT treatment than those in the CK ones ($P < 0.05$), and no significant difference was observed between the MT and CK plots ($P > 0.05$) (Figure 1c). The HFOC was not statistically significant among the three treatments in each soil layer ($P > 0.05$) (Figure 1d). The ratio of DOC: SOC increased with depth for the three thinning treatments, and showed no significant difference among the three thinning treatments in each soil layer ($P > 0.05$) (Figure 2a). The values of the LFOC:HFOC ratio in 0 to 20 cm soil layers were significantly higher in the HT plots than in the CK plots ($P < 0.05$), and no significant differences were detected among the three treatments below a depth of 20 cm ($P > 0.05$) (Figure 2b).

Soil physical and chemical properties

The BD in the 0 to 10 cm soil layer decreased with increasing thinning intensity ($P < 0.05$), and no marked difference was observed among the three thinning treatments below a 10 cm depth ($P > 0.05$) (Table 2). The average ST in the 0 to10 cm and 10 to 20 cm soil layers significantly increased with an increase in thinning intensity ($P < 0.05$), and showed less difference among the three thinning treatments below a 20 cm depth ($P > 0.05$). No significant difference in SWC and soil particle composition was observed among the three treatments ($P > 0.05$) (Table 2). The concentrations of SOM in the 0 to 10 cm and 10 to 20 cm soil layers significantly increased in the HT plots when compared to the CK plots ($P < 0.05$), and no significant difference was found between the MT and CK treatments ($P > 0.05$) (Table 3). The concentration of TN in the 0 to 10 cm soil depth was markedly higher in the HT treatment than that in the CK treatment ($P < 0.05$). TP and TK showed no difference among the three treatments ($P < 0.05$). However, the concentrations of AN and AP were markedly higher in the thinned treatments compared to the unthinned treatment (no difference in the 40 to 60 cm layer for AP) ($P < 0.05$) (Table 3). Compared to the CK treatment, the AK concentration of the 0 to 20 cm soil layer significantly

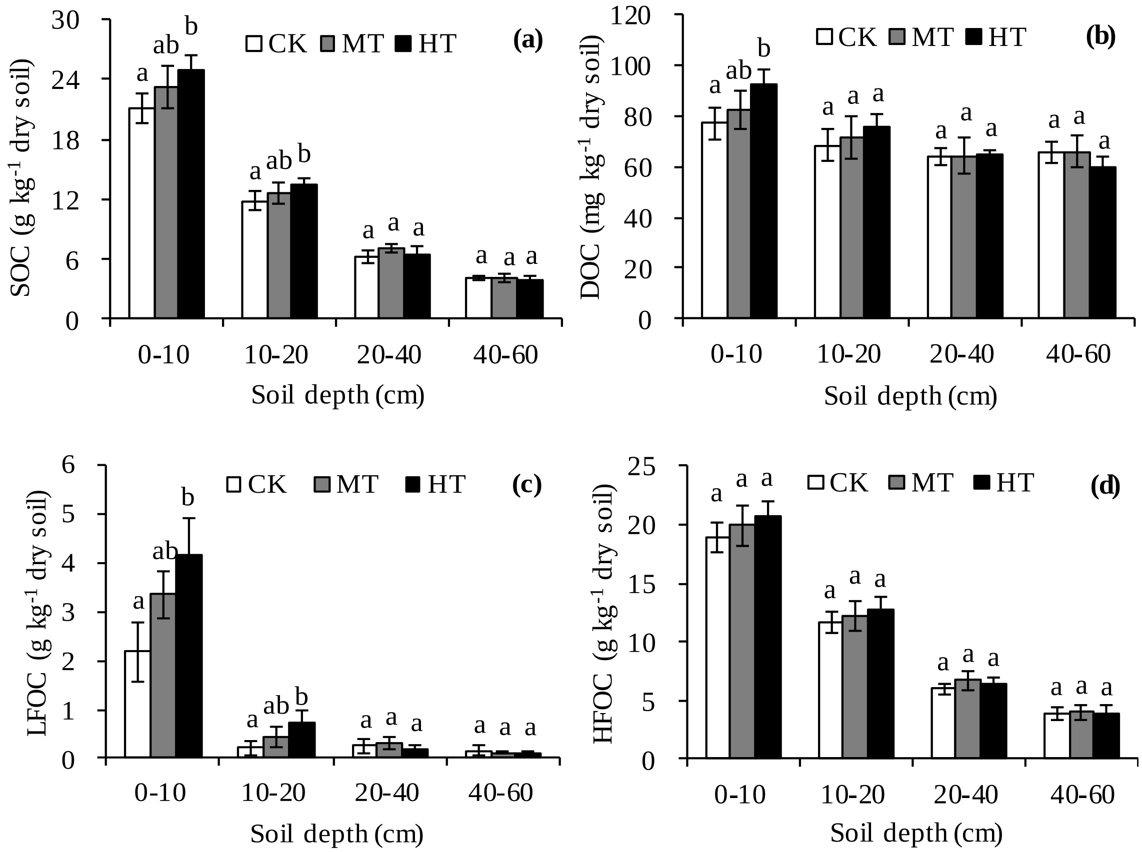

Figure 1. SOC (a), DOC (b), LFOC (c) and HFOC (d) concentrations of the three thinning treatments at different soil depths. Different letters indicate a significant difference between the treatments at the same soil layer ($P < 0.05$); n = 3, mean ± SD.

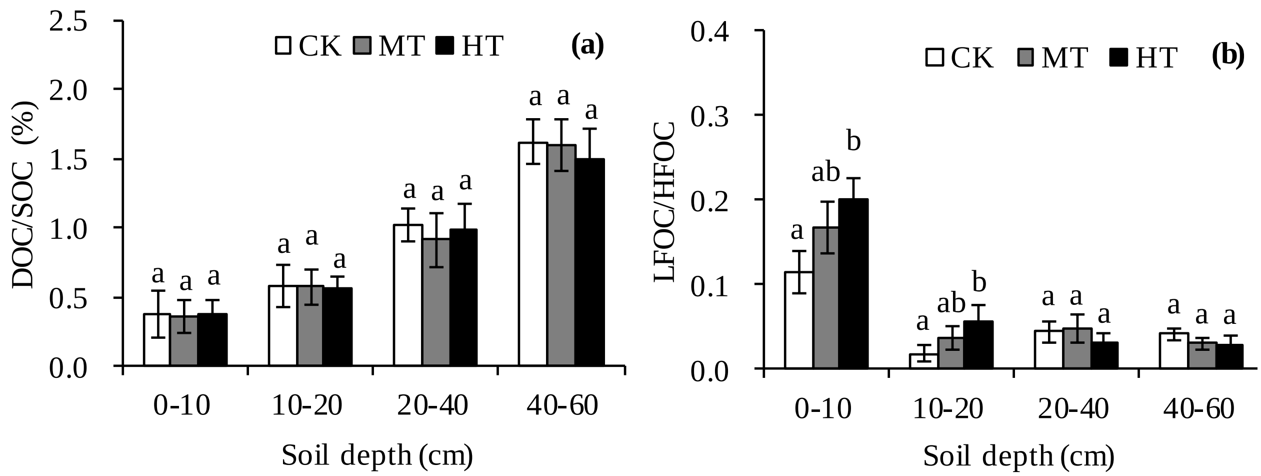

Figure 2. DOC:SOC(a) and LFOC:HFOC (b) of the three thinning treatments at different soil depths. Different letters indicate a significant difference between treatments at the same soil layer ($P < 0.05$); n = 3, means ± SD.

increased in the HT treatment ($P < 0.05$). The pH in the soil profile was significantly enhanced in the HT treatment when compared to the CK treatment ($P < 0.05$), and showed no difference between the MT and CK

Table 2. Soil physical properties in different thinning treatments. BD: bulk density, ST: soil temperature, SWC: soil water content; n = 3, mean ± SD.

Soil depth (cm)	Treatment	BD ($g \cdot cm^{-3}$)	ST (°C)	SWC ($cm^3.cm^{-3}$)	Clay (%)	Silt (%)	Sand (%)
0–10	CK	1.23 ± 0.04^{a}	23.1 ± 2.8^{b}	18.6 ± 3.2^{a}	2.4 ± 0.1^{a}	61.7 ± 1.2^{a}	35.9 ± 0.9^{a}
	MT	1.22 ± 0.05^{ab}	25.3 ± 3.2^{ab}	19.3 ± 3.5^{a}	2.6 ± 0.2^{a}	62.7 ± 1.5^{a}	34.7 ± 1.1^{a}
	HT	1.17 ± 0.04^{b}	26.7 ± 2.5^{a}	20.4 ± 4.1^{a}	2.3 ± 0.2^{a}	60.4 ± 2.3^{a}	37.3 ± 1.6^{a}
10–20	CK	1.31 ± 0.03^{a}	22.7 ± 2.1^{b}	18.9 ± 2.6^{a}	2.6 ± 0.1^{a}	62.8 ± 1.3^{a}	34.6 ± 1.1^{a}
	MT	1.27 ± 0.04^{a}	24.6 ± 2.5^{ab}	20.2 ± 2.8^{a}	2.7 ± 0.1^{a}	63.5 ± 2.1^{a}	33.8 ± 0.6^{a}
	HT	1.29 ± 0.02^{a}	26.1 ± 2.4^{a}	21.8 ± 2.5^{a}	2.5 ± 0.1^{a}	62.5 ± 0.7^{a}	35.0 ± 0.9^{a}
20–40	CK	1.31 ± 0.04^{a}	21.6 ± 1.5^{a}	21.1 ± 1.9^{a}	2.9 ± 0.2^{a}	62.6 ± 0.8^{a}	34.5 ± 0.4^{a}
	MT	1.35 ± 0.04^{a}	22.8 ± 1.4^{a}	20.9 ± 2.1^{a}	3.0 ± 0.1^{a}	64.0 ± 1.3^{a}	33.0 ± 0.9^{a}
	HT	1.28 ± 0.04^{a}	23.9 ± 1.7^{a}	22.0 ± 1.5^{a}	2.7 ± 0.1^{a}	63.8 ± 1.3^{a}	33.5 ± 0.5^{a}
40–60	CK	1.35 ± 0.03^{a}	20.7 ± 0.4^{a}	22.4 ± 1.2^{a}	3.4 ± 0.1^{a}	63.5 ± 1.9^{a}	33.1 ± 0.8^{a}
	MT	1.30 ± 0.03^{a}	20.9 ± 0.5^{a}	22.3 ± 1.5^{a}	3.9 ± 0.2^{a}	66.2 ± 0.8^{a}	29.9 ± 0.3^{a}
	HT	1.36 ± 0.03^{a}	21.0 ± 0.8^{a}	23.1 ± 1.0^{a}	3.3 ± 0.2^{a}	66.1 ± 0.9^{a}	30.6 ± 0.6^{a}

treatments ($P > 0.05$).

Forest floor dry biomass and nutrients

The forest floor dry biomass decreased with an increase in thinning intensity, and was only significantly reduced in the HT treatment when compared to the CK treatment ($P < 0.05$) (Table 4). The concentrations of TOC, TP, and TK in the forest floor showed no difference among the three treatments ($P > 0.05$). TN concentration was markedly reduced in the HT treatment ($P < 0.05$).

Correlation between soil carbon fractions and soil properties

The soil carbon fractions had a markedly positive correlation with ST, SOM, TN, AN, AK, AP, and no significant correlation with the TP and pH (Table 5). There were significant and negative correlations between the soil carbon fractions and BD (except for the DOC), SWC (except the DOC and LFOC), and TK.

DISCUSSION

DOC and light fraction are labile SOC components, which are easily influenced by forest management practices. In this study, only the heavy thinning treatment increased DOC and LFOC concentrations in the top soil (0 to 20 cm soil layer) after two years of thinning treatment. This indicated that thinning intensity had a great impact on the DOC and LFOC in the topsoil during a short-term period. The increase of these labile SOC fractions might be explained by the soil condition.

The DOC and LFOC were positively correlated with the ST, AN, AK, and AP. The higher ST and soil nutrient availability might stimulate soil microorganism activities. Soil enzyme activities in the 0 to 20 cm soil layer were significantly enhanced in the heavy thinning treatment at the experimental site (Cheng et al., 2014). Moreover, the LFOC was controlled by the intermediate products of the decomposition of litter and roots (Laik et al., 2009; Bu et al., 2012).

The forest floor dry biomass decreased with the increase in thinning intensity. This implied that more carbon from the forest floor input soil. Furthermore, this study results were consistent with some other studies that showed that an increase of thinning intensity reduced forest floor carbon stocks in field studies in New Zealand, Denmark, and the USA (Wollum and Schubert, 1975; Carey et al., 1982; Vesterdal et al., 1995). These results indicated that thinning (temporarily) could accelerate forest floor decomposition, increase soil temperature and nutrient availability, and enhance the amount of labile carbon fractions in the topsoil.

In the present study, we did not find marked changes in the HFOC concentrations among the three thinning treatments after two years. Previous studies showed that the soil stable carbon was not influenced by soil disturbance and management in a short time. Huang et al. (2011) reported no difference between the soil carbon mass in the heavy fraction (0 to 5 cm soil depth) in the stem only harvest stands and the forest floor removal stands at year 5 in the Pinus radiata plantations in New Zealand. Song et al. (2012) showed that the HFOC (0 to 10 cm) and SOC were not affected by increased precipitation or warming after six years of treatments in a temperate steppe in China. These results demonstrated

Table 3. Soil chemical properties in different thinning treatments. SOM: soil organic matter, TN: total nitrogen, TP: total phosphorus, TK: total potassium, AN: available nitrogen, AK: available potassium, AP: available phosphorus; n = 3, mean ± SD.

Soil depth (cm)	Treatment	SOM ($g \cdot kg^{-1}$)	TN ($g \cdot kg^{-1}$)	TP ($g \cdot kg^{-1}$)	TK ($g \cdot kg^{-1}$)	AN ($mg \cdot kg^{-1}$)	AK ($mg \cdot kg^{-1}$)	AP ($mg \cdot kg^{-1}$)	pH
0–10	CK	36.34±1.13^{b}	1.64±0.21^{b}	0.33±0.03^{a}	11.61±0.63^{a}	129.02±6.42^{c}	58.10±4.05^{b}	2.18±0.05^{b}	4.05±0.02^{b}
	MT	40.10±1.67^{ab}	1.78±0.24^{ab}	0.34±0.04^{a}	11.42±0.51^{a}	170.05±7.29^{b}	63.30±5.31^{ab}	3.07±0.08^{a}	4.16±0.04^{ab}
	HT	42.84±1.83^{a}	1.96±0.21^{a}	0.27±0.03^{a}	10.93±0.32^{a}	185.07±6.35^{a}	74.40±4.76^{a}	3.02±0.07^{a}	4.29±0.03^{a}
10–20	CK	20.43±0.65^{b}	1.05±0.10^{a}	0.27±0.04^{a}	12.67±0.29^{a}	82.21±4.28^{b}	42.80±2.31^{b}	0.92±0.03^{c}	4.06±0.03^{b}
	MT	21.71±1.36^{ab}	1.09±0.15^{a}	0.29±0.03^{a}	12.55±0.32^{a}	83.13±3.56^{ab}	39.70±3.26^{b}	1.23±0.05^{b}	4.09±0.03^{b}
	HT	23.21±1.27^{a}	1.08±0.19^{a}	0.26±0.02^{a}	13.11±0.36^{a}	90.15±4.03^{a}	49.20±3.87^{a}	1.38±0.04^{a}	4.28±0.02^{a}
20–40	CK	10.78±0.24^{a}	0.72±0.12^{a}	0.31±0.03^{a}	14.53±0.48^{a}	41.09±2.19^{b}	27.70±1.87^{a}	0.37±0.03^{b}	4.11±0.03^{b}
	MT	12.08±0.73^{a}	0.76±0.08^{a}	0.32±0.01^{a}	14.81±0.78^{a}	48.95±1.63^{a}	29.90±3.02^{a}	0.59±0.04^{a}	4.07±0.02^{b}
	HT	11.24±0.89^{a}	0.80±0.15^{a}	0.28±0.03^{a}	14.45±0.51^{a}	52.85±2.97^{a}	31.65±3.65^{a}	0.56±0.04^{a}	4.32±0.04^{a}
40–60	CK	7.05±0.21^{a}	0.60±0.05^{a}	0.30 ± 0.01^{a}	15.38±0.87^{a}	21.90±1.31^{b}	20.90±2.13^{a}	0.54±0.04^{a}	4.08±0.02^{b}
	MT	7.13±0.55^{a}	0.59±0.13^{a}	0.39 ± 0.03^{a}	15.98±0.64^{a}	23.50±1.25^{b}	25.60±2.17^{a}	0.56±0.05^{a}	4.11±0.03^{b}
	HT	6.86±0.21^{a}	0.64±0.09^{a}	0.28 ± 0.03^{a}	16.06±0.82^{a}	35.20±2.36^{a}	25.10±1.08^{a}	0.43 ± 0.05^{a}	4.32 ± 0.05^{a}

Table 4. Forest floor biomass and nutrient concentrations in different thinning treatments (FL: forest floor dry biomass, TOC: total organic carbon, TN: total nitrogen, TP: total phosphorus, TK: total potassium; n = 3, mean ± SD).

Treatment	FL/$10^3 kg \cdot ha^{-1}$	TOC/$g \cdot kg^{-1}$	TN/$g \cdot kg^{-1}$	TP/$g \cdot kg^{-1}$	TK/$g \cdot kg^{-1}$
CK	7.79±0.48^{a}	450.75±20.51^{a}	10.46±0.20^{a}	0.49±0.01^{a}	1.98±0.14^{a}
MT	6.76±0.69^{ab}	459.53±19.80^{a}	9.42±1.46^{ab}	0.43±0.05^{a}	1.53±0.43^{a}
HT	6.34±0.25^{b}	453.50±19.12^{a}	8.80±0.62^{b}	0.44±0.04^{a}	1.82±0.43^{a}

that the HFOC was relatively stable to forest management practices (for example, thinning) during a short-term period.

The total SOC concentrations increased with increasing thinning intensity in the topsoil (0 to 20 cm). The study result was consistent with that of Asaye and Zewdie (2013), who found thinning (after 1.5 years of thinning treatment) significantly increased the SOC in the 0 to 20 cm soil layer in a Cupressus lusitanica stand. However, Kim et al. (2009) reported that the SOC concentration in a 0 to 50 cm soil layer was minimally affected by thinning in a red pine (Pinus densiflora) stand after a one-year treatment.

Akburak and Makineci (2016) also showed that thinning had no significant effect on SOC concentration in a coppice-originated European hornbeam (*Carpinus betulus* L.) stand in Turkey over a two year period. The increase of SOC after thinning during the short term may be explained by an increase in decomposition rates of forest floor. Moreover, the SOC accretion in the thinned treatments was the result of a higher fine root turnover (Asaye and Zewdie, 2013).

Previous studies have demonstrated that thinning operations influenced soil environment (Jandl et al., 2007; Clarke et al., 2015). In the current study, the heavy thinned treatment led

Table 5. Pearson correlation between soil organic carbon fractions and soil properties.

Variable	SOC	DOC	LFOC	HFOC	DOC:SOC	FLOC:HLOC
BD	–0.901**	0.915**	–0.884**	–0.886**	0.743**	–0.848**
ST	0.781**	0.816**	0.678*	0.788**	–0.827**	0.666*
SWC	–0.738**	–0.540	–0.520	–0.770**	0.824**	–0.462
Clay	–-0.778**	–0.661*	–0.589*	–0.804**	0.927**	–0.549
Silt	–0.779**	–0.767**	–0.689*	–0.783**	0.790**	–0.669*
Sand	–0.800**	0.763**	0.684*	0.809**	–0.843**	0.659*
SOM	1.000**	0.939**	0.922**	0.996**	–0.875**	0.891**
TN	0.995**	0.939**	0.944**	0.986**	–0.848**	0.913**
TP	–0.097	–0.112	0.012	–0.119	0.287	0.036
TK	–0.957**	–0.877**	–0.801**	–0.972**	0.947**	–0.755**
AN	0.989**	0.942**	0.942**	0.979**	–0.858**	0.914**
AK	0.986**	0.955**	0.918**	0.980**	–0.867**	0.885**
AP	0.974**	0.951**	0.964**	0.955**	–0.764**	0.947**
pH	0.049	0.156	0.182	0.019	0.026	0.188

* Significant correlation at 0.05 levels; ** Significant correlation at 0.01 levels.

to a decrease of BD in the surface soil, and an increase of ST in the topsoil; the SOM and AN, AK, and AP in the topsoil was also markedly enhanced in the thinned stands. Less difference in soil properties were found between the moderate thinned and unthinned stands. The increase of ST in the thinned treatment was attributed to the removal of a certain number of trees and led to a reduction in canopy cover, thus enhancing the light condition within the modified stand (Clarke et al., 2015).

The increase in availability of primary essential elements might be a result of more nutrients input from forest floor decomposition (Jandl et al., 2007). Although thinning reduced forest floor accumulation, an increase of understory vegetation biomass may compensate for losses (Table 1). Zhang et al. (2001) reported that thinning (two years later) increased soil fertility, microbial quantity and enzyme activity, and reduced soil bulk density in 0 to 20 cm soil layers in *Cunninghamia Lanceolata, Pinus massoniana, Fokienia hodginsii, Cryptomeria fortunei, and Schima superba* plantations in Southern China.

In a Mediterranean natural forest, Baena et al. (2013) found that SOM concentration was reduced in the thinned plots when compared to the unthinned plots over four years of treatment, and total phosphorus and pH also reduced after six years of treatment. While SOM, TP, and pH increased in the thinned plots when compared to the unmanaged plots in a regenerated forest at the same site after two years of treatment. The difference in results indicated that the effect of thinning on soil properties was dependent on vegetation type and site condition.

Heavy thinning increased soil nutrients release and light fraction of SOC concentration, it was beneficial to the retained tree's growth. However, the increase of temporarily labile SOC fraction would accelerate soil carbon loss by soil respiration (Luan et al., 2013), this was detrimental to soil carbon sequestration. In terms of forest ecosystem carbon sequestration, moderate thinning had less disturbance on soil environments and SOC fractions. Therefore, forest thinning should take into account management objectives and ecosystem functional changes.

This study only investigated the changes of SOC fractions and soil physical, and chemical properties after two years of thinning treatment. Understanding the dynamics of SOC fractions and soil properties are more important when evaluating the effect of thinning on carbon pool stability and soil fertility. Furthermore, previous studies on soil labile carbon fractions have mainly focused on microbial biomass (Chen et al., 2015; Akburak and Makineci, 2016), while other SOC fractions based on physical and chemical methods were less studied. Therefore, further study on the variations of SOC fractions and soil microbial diversity in response to short-term and long-term thinning is needed.

Conclusions

This study showed that thinning intensity had a great effect on SOC, labile carbon fractions, and soil physical and chemical properties over a short-term period. The SOC, DOC and LFOC, ST, and nutrient availability were significantly enhanced in the heavy thinned plots when compared to the unthinned plots; however, these variables showed no significant difference between the moderate thinned and unthinned plots. Moreover, the changes of labile carbon fractions, and most of the soil properties occurred in the topsoil (0 to 20 cm), except for pH, and less variations were found below a 20 cm depth. The increase of soil labile carbon fractions and soil nutrient availability might be attributed to nutrient release from forest floor rapid decomposition after thinning.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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