Changes in soil properties in a low-quality broadleaf mixed forest after cutting strip reforms in a 9-year period in Northeastern China

Huiwen Guan, Xibin Dong , Tian Zhang, Yuan Meng, Jiafu Ruan, Zhiyong Wang

Key Laboratory of Sustainable Forest Management and Environmental Microorganism Engineering of Heilongjiang Province, Northeast Forestry University, Harbin, 150040, China

Correspondence to: Xibin Dong (xibindong@nefu.edu.cn)

Abstract. Strip reforms with widths of 6 m, 10 m, 14 m and 18 m were carried out in a low-quality broadleaf mixed forest in Greater Khingan Mountains. The influence of time on soil properties, including physical and chemical properties, were analysed on the basis of data of the soil components obtained from nine consecutive years (from 2010 to 2018). First, use the repeated measures ANOVA to distinguish the effects of various width of cutting strip and years. In the meantime, a principal component analysis was used to determine the weight of each soil indicator, and the fuzzy comprehensive index method was applied to provide further insight into the variation of soil quality. We found that most soil physical properties can be affected by strips while only two indicators can be affected by years. And half of the indicators can be affected by the interaction by strip and year. As for soil chemical properties, only two plant available elements (N and P) can be affected either strip or year. In addition, no indicator was changed by the interaction. Over the 9 years, soil physical properties displayed more differences than chemical properties across cutting strip widths. However, it's not enough for the properties to recover for 9 years unfortunately. In view of the current research years, the soil quality could not be restored in the 18-m harvesting zone within nine years. The cutting width of 10 m is more obvious than that of other transformation widths, so 10 m is the best width for cutting strips for the forest. The study provides reference for the production management of broadleaf mixed forests in the region and other similar areas. A larger width of the cutting strip should be forbidden for this type of forest here. Moreover, for forest soil conditions, we need to continue long-term observations.

1 Introduction

In regard to maintaining the productivity and sustainability of forests, soil is a vital factor. For one thing, soil provides the moisture and nutrients to tree growth and supports trees physically. For another, the litter generated by the growing trees can return a great amount of nutrients back to soil, through microbial decomposition. There are many ways to intervene in forests, including logging and planting, which usually affect soil nutrients. Cutting timber can heavily impact soil compaction, temperature and diurnal fluctuation, causing changes in soil (Camenzind et al., 2018; DeLuca and Aplet, 2008). Excessive cutting may result in serious consequences, such as forest degradation or soil erosion. In contrast, appropriate harvesting promotes soil nutrients through complex microbial decomposition (Jamroz et al., 2014; Ma et al., 2013; Zhou et al., 2015).

Many have done related work to reveal the relationship between timber cutting and forest soil (Guan et al., 2018; Gao et al., 2013). Recently, many researchers have attached great importance to understanding the impacts of cutting and soil (Arevalo-Gardini et al., 2015; Pang et al., 2011). Some studies have shown that harvesting not only deteriorate the physical properties of the soil, especially the soil water holding capacity and soil porosity, but also affects the chemical properties. (Caldato et al., 2016; Parfitt et al., 2014; Yang et al., 2016); the soil bulk density was increasing and soil was being eroded. (Gerke and Hierold, 2012; Hieke and Schmidt, 2013; Zhou et al., 2010); and organic matter, N (nitrogen), P (phosphorus), K (potassium), and other minerals were also reduced after cutting. (Ikurekong and Akpabio, 2005; Ong et al., 2012; Ozcan and Gokbulak, 2015).

Some others have found the change of forest stand structure after lumbering (De Nicola et al., 2017; Oyen and Nilsen, 2004; Zhirin and Knyazeva, 2012). Forest ecosystems can be disturbed by cutting heavily. Many trees have been taken away, and the composition of tree species also becomes different, such as the changes of dominant of tree species and spatial distribution structure. Some scientists have also tried to determine the effects of timber harvesting on biodiversity (Barna and Bosela, 2015; Dechene and Buddle, 2009; Okonogi and Fukuda, 2017). These studies have explored that high-intensity interference may adversely affect biodiversity, while low-intensity interference may benefit biodiversity for a long time. However, most of these studies focused on the short- or medium-term effects of plantation and timber harvesting, in part because of the lack of long-term data. In addition, most of them analyse the variability of individual property rather than from the perspective of the overall properties. Therefore, it is necessary to reveal the effects of wood harvesting in mixed forests over a longer period of time from the perspective of overall properties. The study aims to describe the impacts of timber cutting on selected physical and chemical soil properties throughout a nine year period in the broadleaf mixed forest located in the Daxing'anling mountain range, Northeast China. We try to reveal the change of soil quality in 3, 6 and 9 years after cutting in different width of strip on both physical and chemical properties. Focusing on the impacts of cutting strip reforms, we would like to enrich the existing literature basing on the impacts of cutting strip reforms, which is centred on cutting intensity in forest plantations over a certain time.

In addition, we use fuzzy mathematics and multivariate statistical analyses (such as PCA) to calculate the comprehensive index of combining soil physical with chemical properties and evaluate its soil quality by the value. Since cutting also changes several soil properties simultaneously and these properties usually interact mutually, it is crucial to collectively reflect the aggregation effect. At last, we explored the effects of various width of strips in broad-leaved mixed forests ranging from 0 m to 18 m with clear cutting. Consequently, our results and conclusion can help determine the optimal width of the cutting strip for the forests in the region. At the same time, our finding can also benefit other regions with similar forests given the geographic spread.

2 Study area and methods

2.1 Study area

The study area was set on the Yuejin Forest Centre, Jiagedaqi Forestry Bureau, Heilongjiang Province, Northeastern China (124°23'48″-124°24'35″E, 50°34'9″-50°34'32″N). The research plots were established in compartment 174. The elevation of the site ranges from 429 to 521 m with a slope of 6-10°. This area has a cold temperate land monsoon climate. The mean annual temperature is -1.3°C, and the annual precipitation is 494.8 mm. The frost-free period is approximately 85-130 days. According to United States Department of Agriculture (USDA) soil taxonomy, the soil on the study area is classified as brown earth. The thickness of soil is 15-30 cm.

The main tree species are *Quercus mongolica* Fisch. ex Ledeb., *Populus davidiana* Dode, *Betula dahurica* Pall., and *Betula platyphylla* Suk. Shrub species on the site are dominated by *Rhododendronea*, covering 12% of the area. Underground herbaceous and liana species are dominated by *Cyperus microiria* and *Pyrola dahurica*, respectively, covering 27% of the area.

2.2 Plot establishment and measurements

In March 2009, cutting strips were established in the low-quality broadleaf mixed forest with the widths of 6 m (S1), 10 m (S2), 14 m (S3), and 18 m (S4) (Figure 1), which are cutting plots. The length of the transformation zone was 300 m. When cutting the timbers, mature trees were cut down while the coniferous seedlings and rare tree species were preserved. Every cutting strip was divided into three parts (A, B, C) with lengths of 100 m, cultivating *Larix gmelinii* (Rupr.) Kuzen., *Pinus sylvestris* L.var. *mongolica* Litv., *Pinus koraiensis* Sieb. et Zucc., respectively. A, B, C are subplots. In Fig. 1, the blank parts show the harvesting area while the shadow parts show the reserved band with no cutting, and the bandwidth of the reserved band is the same as the bandwidth of the corresponding transformation band at 6 m, 10 m, 14 m and 18 m. The control plot was set up in the same forest without cutting near the transformation zone, with the distance of 20m, nearly having same original stand state as cutting plots (soil texture, slope, species composition, etc.)

The cutting operation consisted of chainsaw cutting, on-site delimbing and bucking, skidding by human shoulder, and collecting and utilizing branches >5 cm in diameter. This logging method is a common practice in the region, and the width is the most important difference between strips. In August 10, 2012 (3 years after the cutting), August 17, 2015 (6 years after cutting) and August 8, 2018 (9 years after the cutting), we measured the characters of the forest, such as the height and diameter at breast height (DBH). And soil was gathered in the subplots of different strips and did the experiment in laboratory. Because of the limitations of technical means and experimental conditions 10 years ago, we only set up a test area in Greater Khingan Mountains. This may lack the necessary sample repetition for the overall situation of the broadleaf mixed forest in the Greater Khingan Mountains. However, this experiment can reflect the soil changes of the current plot to a certain extent, and provide some reference for future research. In order to meet the statistical needs, in other words, to make the sampling point distribution as uniform as possible, we divided each treatment into three parts. In fact, these three parts have been replanted with three species, but this is not meaningful for this experiment. (In fact, these three subplots may have differences because replanted species. But in this paper, we neglect it because our main purpose is not that and after the mixture, the effects can be neutralized). We simply took soil samples from the three areas for the composite. The average and standard deviation of the soil physical and chemical properties of each treatment plot were obtained by analysing the results of multiple soil samples according to the random sampling of the soil. Unfortunately, we missed pre-cutting data, so we can't compare this with the data of 3, 6 and 9 years after cutting. Therefore, we looked for a non-cutting plot similar to the treatment site conditions and stand composition in the vicinity of the control plot as pre-cutting.

2.3 Soil sample measurement

Since the effect of cutting on soil is mostly on surface soil, only the surface soil layers between 0 and 10 cm and between 10 and 20 cm were gathered as sample and they were mixed directly. The sampling was implemented based on the national standard for gathering and handling soil samples in forest (Zheng et al., 2008). Soil samples to texting the soil properties are taken from the A, B, and C sections in each plot, with 5 samplings of each subplots. In order to test physical properties, undisturbed soil samples were held in their initial shapes by placing them into aluminium boxes to prevent them from being squeezed and becoming deformed. In order to analyse chemical properties of soil samples, disturbed samples were put inside plastic bags, sealed and labelled. Three soil samples from the A, B, and C sections in each plot were evenly mixed and air-dried and finally 5 samples per treatment.

The soil physical properties analysed here selected soil bulk density, soil maximum water-holding capacity, soil capillary water-holding capacity, soil non-capillary porosity, soil capillary porosity and soil total porosity. Soil bulk density is closely related to soil porosity, and is one of the important indicators reflecting soil physical properties. Soil bulk density is related to the development of soil and can reflect the permeability and water permeability of soil. Current studies show that soil bulk density is related to the compactness of soil. The smaller the soil bulk density, the looser the soil will be, which means there are more aggregates in the soil and the stronger the ability of water conservation of soil is. Soil porosity is also an important indicator of soil physical properties. Water, nutrients and air in soil are stored in soil pore. Among them, capillary porosity is particularly important. Most of the available water in soil is stored in the capillary porosity of soil. The larger the capillary porosity, the higher the content of available water stored in soil, thus providing more water for plant survival and promoting vegetation growth. Soil non-capillary porosity is related to soil permeability. The higher the non-capillary porosity is, the faster the infiltration rate of precipitation is, and the stronger the ability of water conservation and soil and water conservation is. Soil water-holding capacity is an important index reflecting soil hydrological performance and water conservation capacity of forest. The stronger water-holding capacity, the more water can be stored in soil, the more precipitation can be intercepted. To a certain extent, it can help to avoid the erosion and loss of soil and water. So because of the function of these indicators, we choose them to reflect the influence of year and strip to see if the erosion of soil and water can be managed. Meanwhile, indicators of soil chemical properties commonly, such as organic matter, total nitrogen (N), total phosphorus (P), total potassium (K), water-soluble nitrogen (N), rapidly avaliable phosphrous (P), and rapidly avaliable potassium (K) were also considered in this study.

According to the national standard/protocol, analyses of soil physical and chemical properties were done. (Zhang et al., 1984). The water holding capacity was analysed with the cutting ring method (LY/T1215-1999) (Forestry); organic matter was quantified with the potassium dichromate oxidation-external heating method (LY/T 1237-1999) (Forestry); total nitrogen was assessed via the perchloric acid-sulfuric acid digestion diffusion absorption method (LY/T 1228-1999) (Forestry); water-soluble nitrogen was extracted with the alkaline hydrolysis-diffusion absorption method (LY/T 1229-1999) (Forestry); total phosphorus was estimated with the perchloric acid-sulfuric acid-soluble Mo-Sb colorimetry method (LY/T 1232-1999) (Forestry); rapidly available phosphorus was gauged with the hydrochloric acid-ammonium fluoride extraction method (LY/T 1233-1999) (Forestry); total potassium was measured with the sodium hydroxide alkali fusion-flame photometry method (LY/T 1234-1999) (Forestry); and rapidly available potassium was tested with the ammonium acetate extraction-flame photometry method (LY/T 1236-1999) (Forestry).

2.4 Data analyses

The soil testing results got finally are the representative for the average value from the A, B, and C sections in each strip relatively. With the data derived from laboratory experiment and pre-processing, the change in soil physical and chemical properties was calculated under different cutting strip widths and different year by repeated measures ANOVA using SPSS. Because repeated measures is a term used when the same entities take part in all conditions of an experiments. In our study, we focus on same subplots testing for different years and strips so that it fits for the method. Besides, two-way repeated measures ANOVA was selected because two independent variables have been manipulated in the experiments, which are year and strip. It is appropriate because each plot does all of the conditions in the experiment, and provides a score for each permutation of two variables. Firstly, SPSS produces a text that look at whether the data have violated the assumption of sphericity. According to the Mauchly's test for these data, where the significance value is most important, if the value is less than 0.05, we must accept the hypothesis that the variances of the difference between levels were significantly different and a test statistics (F-ratio) that simply cannot be compared to tabulated values of the F-distribution, which means it needs to be corrected. There are three ways to adjust it in SPSS. The basic way is looking at the Greenhouse-Geisser estimate of sphericity (ε) in the SPSS handout. When $\varepsilon>0.75$ then use the Huynh-Feldt correction. When $\varepsilon<0.75$ then use the Greenhouse-Geisser correction. The specific results of the sphericity were not shown here but we adopted this method.

Actually, the aggregate effect of the cutting strip width was the results particularly interested in, which called for a multivariate analysis. Nevertheless, possible correlations among different variables in this model brought statistical complications (Melquiades et al., 2013). To overcome this challenge, we adopted fuzzy mathematics and a principal component analysis.

Because of different attributes and dimensions of diverse soil quality indicators, they must be processed before soil quality can be comprehensively evaluated. Data standardization is a statistical method to compare different dimensions and different types of set of indicators (Fan et al., 2015). In this study, first, the soil physical and chemical properties were standardized and transformed into dimensionless values between 0 and 1, to normalize the dimensions of the indicators. In data standardization, data are divided into 2 types: positive and negative effects. In this study, except for soil bulk density, the other indicators are positive effects. The positive and negative effects are calculated by Eq. (1) and Eq. (2) respectively. The method follows three principles: the relative difference of data within the same index remains unchanged, the relative difference between different indices remains unchanged, and the maximum value after standardization is equal.

$$F(X_i) = (X_{i\max} - X_{ij}) / (X_{i\max} - X_{i\min}) \quad (1)$$

$$F(X_i) = (X_{ij} - X_{i\min}) / (X_{i\max} - X_{i\min}) \quad (2)$$

That is, we computed $F(X_i)$, which is the membership value of soil property *i*, reflecting the evaluation as follows, where $X_{i\max}$ is the maximum measured value of soil property *i*; X_{ij} is the average value of the measured sample of soil property *i*; and $X_{i\min}$ is the minimum measured value of soil property *i*.

Because the importance of each factor is different, namely, the degree of impact on soil quality is diverse, it needs to be given distinct weights. In this study, SPSS is used to analyse the standardized data of 13 indicators using a principal component analysis, and the contribution rate and cumulative contribution rate of each factor are calculated. The load matrix is obtained by common factor rotation, and the common factor variance of the soil quality index is calculated to show its contribution to the variation of soil quality belonging to the soil physical and chemical properties. The proportion of the common factor variance of each index to the total common factor variance is taken as the weight of each index.

Based on the evaluation factors of membership degree and weight determination, using the weighted method and addition rule in fuzzy mathematics, we use Eq. (3) to calculate the soil quality of different cutting strip widths in these years. *F* is the comprehensive index of soil quality, and W_i is the weight of each soil factor, which reflects the importance of each evaluation index.

$$F = \sum W_i \times F(X_i) \quad (3)$$

3 Results

3.1 Impacts on soil physical properties individually

As shown in Table 1, all of these indicators showed a certain variation, indicating that soil physical properties could be at least influenced over time. However, some of these changes were not significant. Soil bulk density showed a decline from 6 to 9 years after the cutting in most cutting strips while the changes of other indicators seem to more complex. In different years, there were differences in the correlation between the changes of indices and the width of cutting strips. Three years after cutting, soil bulk density decreased and then increased with the increasing of the width of strip. The lowest mean value appeared in the 10m strip, which is 0.62. In 6 and 9 years after cutting, the mean value is decreasing as a whole, but the lowest value appeared in the width of 6m (0.57) and 10m (0.59). As for other indicators, the trends were hardly to describe, which have many waves and there was diversity in the turning points. So next, we tried to use repeated measures ANOVA to separate the effects of year and strip. Table 2 shows the results of the ANOVA (with corrected F values). The output was split into sections that referred to each of the effects in the model. Looking at the significance values in the table it was clear that there were significant differences (p<0.05) between various years in the indicators of soil bulk density and soil non-capillary porosity, and there are significant differences (p<0.05) between various strips in the indicators of soil maximum water-holding capacity, soil capillary water-holding capacity, soil non-capillary porosity and soil total porosity. As for the interaction between these two variables, there are significant differences (p<0.05) in the indicators of soil capillary water-holding capacity, soil non-capillary porosity and soil capillary porosity.

As shown in Table 3 and Figure 2, the mean effects of indicators that had significant differences about year were displayed. The value of soil bulk density was highest in 2012 (3 years after cutting). It had significantly decreased after 6 and 9 years after cutting. The value of soil non-capillary porosity was increased in 2015 and decreased in 2018. Only these two indicators of soil physical properties had significant differences during 9 years after cutting. As shown in Table 4 and Figure 3, the mean effects of indicators that had significant differences about strip were displayed. Except for the strip with width of 14m and 18m, the value of soil maximum water-holding capacity of the others cutting strip was higher than the control plot (non-cutting). The value of soil capillary water-holding capacity in control plot was the lowest. The value of soil non-capillary porosity in width of 14m was lowest, but the control plot was highest. The value of soil total porosity was highest in control plot and lowest in the width of 14m. As shown in Table 5 and Figure 4, when it comes to the interaction of year and strip, only three indicators have significant differences between the interactions, which are soil capillary water-holding capacity, soil non-capillary porosity and soil capillary porosity. This effect told us that the profile of ratings across dates of different levels of year was different for width of strips, which means the influence of strips was changing during the years after cutting.

Table 1. Soil physical properties in 3, 6 and 9 years after cutting

Cutting Strip Width	Soil Bulk Density ($g\cdot cm^{-3}$)	Soil Maximum Water-holding Capacity (%)	Soil Capillary Water-holding Capacity (%)	Soil Non-capillary Porosity (%)	Soil Capillary Porosity (%)	Soil Total Porosity (%)
			3 years after cutting			
6 m	0.63±0.09	92.63±18.61	81.25±13.47	7.41±2.20	52.9±8.83	60.31±12.15
10 m	0.62±0.13	96.56±18.74	84.10±10.24	7.03±2.31	55.45±8.38	62.48±10.79
14 m	0.66±0.13	89.51±16.06	79.99±12.57	8.22±2.93	52.03±7.58	60.25±10.39
18 m	0.72±0.21	75.36±18.24	58.06±12.56	13.13±2.39	44.08±8.80	57.21±7.84
Non-cutting	0.66±0.10	94.75±10.38	98.88±10.74	13.01±2.01	53.48±9.84	66.49±9.64
			6 years after cutting			
6 m	0.57±0.10	95.44±6.46	85.25±13.94	20.23±2.95	46.38±10.8	66.61±12.58
10 m	0.60±0.13	96.79±5.48	89.23±11.67	16.42±2.66	51.37±7.02	67.79±10.38
14 m	0.65±0.14	80.15±16.67	83.12±9.90	9.12±1.56	54.81±10.34	63.93±12.25
18 m	0.63±0.17	79.82±19.02	78.37±11.30	10.58±2.01	50.11±8.65	60.69±12.72
Non-cutting	0.64±0.12	96.84±5.59	89.64±11.21	15.29±2.01	49.89±8.89	65.18±9.93
			9 years after cutting			
6 m	0.61±0.12	98.06±4.33	85.21±15.67	13.97±1.65	52.47±7.85	66.44±8.86
10 m	0.59±0.13	97.65±5.26	88.47±14.82	11.29±2.42	54.13±8.08	65.42±12.32

14 m	0.62±0.12	86.08±15.50	81.26±12.82	9.87±2.00	53.14±9.98	63.01±9.37
18 m	0.69±0.16	79.68±17.90	80.12±13.06	10.13±1.72	48.35±9.62	58.48±12.07
Non-cutting	0.63±0.12	94.04±8.24	91.02±13.45	13.51±2.31	51.23±9.39	64.74±8.99

Note: The number in the table is "average ± standard deviation". Standard deviation is between strips of all years.

Table 2. Tests of within-subjects effects for soil physical properties

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Soil Bulk Density						
Year	Sphericity Assumed	0.02	2.00	0.01	9.82	0.01
Strip	Sphericity Assumed	0.06	4.00	0.02	2.97	0.05
Year * Strip	Sphericity Assumed	0.02	8.00	0.00	0.72	0.67
Soil Maximum Water-holding Capacity						
Year	Sphericity Assumed	28.99	2.00	14.50	0.16	0.85
Strip	Sphericity Assumed	3968.03	4.00	992.01	7.63	0.00
Year * Strip	Sphericity Assumed	357.75	8.00	44.72	0.66	0.72
Soil Capillary Water-holding Capacity						
Year	Sphericity Assumed	423.98	2.00	211.99	2.49	0.15
Strip	Sphericity Assumed	3013.22	4.00	753.30	17.24	0.00
Year * Strip	Sphericity Assumed	1263.39	8.00	157.92	5.78	0.00
Soil Non-capillary Porosity						
Year	Greenhouse-Geisser	262.23	1.00	261.07	36.76	0.00
Strip	Sphericity Assumed	247.70	4.00	61.93	38.35	0.00
Year * Strip	Sphericity Assumed	417.14	8.00	52.14	26.83	0.00
Soil Capillary Porosity						
Year	Greenhouse-Geisser	25.52	1.02	25.03	0.73	0.44
Strip	Sphericity Assumed	368.02	4.00	92.00	2.17	0.12
Year * Strip	Sphericity Assumed	299.45	8.00	37.43	2.46	0.03
Soil Total Porosity						
Year	Sphericity Assumed	157.00	2.00	78.50	1.66	0.25
Strip	Sphericity Assumed	463.28	4.00	115.82	4.89	0.01

Year * Strip	Sphericity Assumed	118.56	8.00	14.82	0.62	0.76

Table 3. Estimates of physical indicators which have significant difference in various years

Year	Mean	Std. Error	95% confidence Interval	
			Lower Bound	Upper Bound
		Soil Bulk Density		
2012	0.66	0.05	0.51	0.81
2015	0.62	0.06	0.46	0.77
2018	0.63	0.06	0.47	0.78
		Soil Non-capillary Porosity		
2012	9.76	0.94	7.15	12.37
2015	14.33	0.82	12.05	16.61
2018	11.75	0.77	9.62	13.88

Table 4. Estimates of physical indicators which have significant difference in various strips

Strip	Mean	Std. Error	95% confidence Interval	
			Lower Bound	Upper Bound
		Soil Maximum Water-holding Capacity		
6m	95.38	4.07	84.09	106.67
10m	97.00	3.97	85.98	108.02
14m	85.25	6.73	66.57	103.92
18m	78.29	7.21	58.27	98.31
CK	95.21	3.19	86.36	104.06
		Soil Capillary Water-holding Capacity		
6m	83.42	5.99	66.79	100.05
10m	86.26	5.40	71.26	101.26
14m	81.43	5.38	66.48	96.37
18m	72.18	5.79	56.11	88.26
CK	91.40	4.98	77.58	105.22
		Soil Non-capillary Porosity		
6m	13.87	0.97	11.17	16.57
10m	11.58	0.82	9.31	13.85
14m	9.07	0.84	6.75	11.40
18m	11.28	0.67	9.42	13.14
CK	13.94	0.88	11.51	16.37
		Soil Total Porosity		
6m	64.45	4.64	51.57	77.34
10m	65.23	3.99	54.16	76.30
14m	62.40	4.54	49.80	75.00

18m	58.79	4.72	45.68	71.91
CK	65.47	4.12	54.02	76.92

Table 5. Estimates of physical indicators which have significant difference in the interaction of year and strip

Year * Strip		Mean	Std. Error	95% confidence Interval	
				Lower Bound	Upper Bound
Soil Capillary Water-holding Capacity					
2012	6m	81.25	6.73	62.55	99.95
	10m	84.10	5.12	69.88	98.32
	14m	79.99	6.29	62.54	97.44
	18m	58.06	6.28	40.63	75.49
	CK	94.53	3.13	85.84	103.22
2015	6m	84.89	6.77	66.10	103.69
	10m	88.40	5.35	73.56	103.25
	14m	83.12	4.95	69.37	96.87
	18m	78.37	5.65	62.69	94.05
	CK	89.36	5.47	74.19	104.54
2018	6m	84.13	7.19	64.17	104.08
	10m	86.28	6.17	69.15	103.41
	14m	81.17	6.34	63.56	98.77
	18m	80.12	6.53	62.00	98.25
	CK	90.32	6.43	72.47	108.17
Soil Non-capillary Porosity					
2012	6m	7.41	0.98	4.68	10.14
	10m	7.03	1.03	4.16	9.90
	14m	8.22	1.31	4.58	11.86
	18m	13.13	1.07	10.17	16.09
	CK	13.01	0.90	10.52	15.50
2015	6m	20.23	1.32	16.56	23.90
	10m	16.42	1.19	13.11	19.73
	14m	9.12	0.70	7.19	11.05
	18m	10.58	0.90	8.09	13.07
	CK	15.29	0.90	12.79	17.79
2018	6m	13.97	0.74	11.93	16.02
	10m	11.29	1.08	8.29	14.29
	14m	9.87	0.90	7.39	12.35
	18m	10.13	0.77	7.99	12.27
	CK	13.51	1.03	10.64	16.38
Soil Capillary Porosity					

2012	6m	52.90	3.95	41.94	63.86
	10m	55.45	3.75	45.05	65.86
	14m	52.03	3.39	42.62	61.44
	18m	44.08	3.93	33.16	55.00
	CK	53.48	4.40	41.27	65.69
2015	6m	46.38	4.83	32.97	59.79
	10m	51.37	3.14	42.65	60.09
	14m	54.81	4.62	41.98	67.64
	18m	50.11	3.87	39.37	60.85
	CK	49.89	3.98	38.85	60.93
2018	6m	52.47	3.51	42.73	62.21
	10m	54.13	3.62	44.09	64.17
	14m	53.14	4.46	40.75	65.53
	18m	48.35	4.30	36.41	60.29
	CK	51.23	4.20	39.58	62.89

3.2 Impacts on soil chemical properties individually

As shown in Table 6, the trend of all indicators are not the same either by strip or by year. However, most of their values increased and then decreased with an increase in cutting strip with, which the peak value often was in 10m and 14m. But it seemed to not significant. On the other hand, by the year, the value of most indicators were decreased in 6 years after cutting compared with 3 years and basically remained unchanged in 9 years after cutting. To get more details about the effects of year and strip, the repeated measures ANOVA was applied.

Table 7 shows the results of the ANOVA (with corrected F values). The output was split into sections that referred to each of the effects in the model. Looking at the significance values in the table it was clear that there were significant differences (p<0.05) between various years in the indicators of water-soluble nitrogen and rapidly available phosphorus, and there are significant differences (p<0.05) between various strips in these two indicators. As for the interaction between these two variables, there are no significant differences (p<0.05) in all indicators of soil chemical properties.

As shown in Table 8 and Figure 5, the mean effects of indicators of soil chemical properties that had significant differences about year were displayed. The value of water-soluble nitrogen was highest in 2012, which was 524.53. It has significantly decreased after 6 and 9 years after cutting, which is the same as the trend of the value of rapidly available phosphorus. Only these two indicators of soil chemical properties had significant differences during 9 years after cutting. As shown in Table 9 and Figure 6, the mean effects of indicators of soil chemical properties that had significant differences about strip were displayed. The value of water-soluble nitrogen and rapidly available phosphorus in control plot was the lowest, and in width of 10m was highest. However, when it comes to the interaction of year and strip, no indicator of soil chemical properties has significant differences between the interactions, which told us that the profile of ratings across dates of different levels of year had no difference for width of strips, in other words that means the influence of strips weren't changing during the years after cutting.

Table 6. Soil chemical properties in 3, 6 and 9 years after cutting

Cutting Strip Width	Organic Matter ($g\cdot kg^{-1}$)	Total Nitrogen ($g\cdot kg^{-1}$)	Water-soluble Nitrogen ($mg\cdot kg^{-1}$)	Total Phosphorus ($g\cdot kg^{-1}$)	Rapidly Available Phosphorus ($mg\cdot kg^{-1}$)	Total Potassium ($g\cdot kg^{-1}$)	Rapidly Available Potassium ($mg\cdot kg^{-1}$)
3 years after cutting							
6 m	21.25±2.96	9.25±2.24	519.63±74.93	2.20±0.24	14.86±2.34	9.24±1.62	54.32±8.38
10 m	22.90±3.09	9.45±3.20	545.01±59.56	2.23±0.27	16.13±2.65	9.36±2.56	56.05±8.04
14 m	22.19±3.35	9.21±3.79	557.92±70.33	2.41±0.33	16.24±2.91	10.21±2.11	58.48±9.10
18 m	24.28±3.66	9.93±1.90	530.28±66.50	2.38±0.26	15.86±2.62	9.35±1.53	58.13±8.14
Non-cutting	20.95±1.89	8.58±1.38	469.81±67.51	2.13±0.25	13.90±1.38	9.11±2.37	55.87±7.72
6 years after cutting							
6 m	21.32±2.62	8.82±2.84	481.39±55.38	2.08±0.42	13.42±2.52	9.02±1.85	53.11±5.90
10 m	21.90±2.50	9.26±1.71	512.36±55.51	2.11±0.27	14.97±2.32	9.14±1.87	57.12±7.63
14 m	22.59±3.17	8.91±3.16	500.31±60.19	2.24±0.24	14.82±2.11	9.57±2.41	55.51±11.42
18 m	21.53±1.75	8.74±2.34	492.13±60.18	2.10±0.44	13.31±1.56	8.81±2.33	52.57±9.94
Non-cutting	21.61±2.50	8.76±2.71	468.24±74.78	2.07±0.37	13.81±1.90	8.86±2.79	54.12±10.65
9 years after cutting							
6 m	21.85±2.16	8.79±2.54	485.69±73.46	2.09±0.33	13.85±2.52	9.01±2.01	53.17±7.59
10 m	22.15±2.55	9.38±2.01	521.31±84.60	2.16±0.35	15.23±3.00	9.14±2.45	58.14±7.31
14 m	21.57±3.19	8.98±2.43	507.46±72.66	2.31±0.35	14.98±2.09	9.82±2.56	55.74±8.08
18 m	21.94±1.88	8.71±2.17	497.52±71.20	2.14±0.27	13.72±2.24	8.85±2.68	52.48±11.80
Non-cutting	21.38±2.53	8.79±2.79	471.21±70.50	2.12±0.30	13.94±2.68	8.92±2.00	55.46±6.75

Note: The number in the table is "average ± standard deviation". Standard deviation is between strips of all years.

Table 7. Tests of within-subjects effects for soil chemical properties

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Organic Matter						
Year	Sphericity Assumed	4.68	2.00	2.34	0.78	0.49
Strip	Sphericity Assumed	17.93	4.00	4.48	0.84	0.52
Year * Strip	Sphericity Assumed	24.88	8.00	3.11	1.08	0.40
Total Nitrogen						
Year	Greenhouse-Geisser	2.29	1.04	2.21	1.69	0.26

Strip	Sphericity Assumed	3.43	4.00	0.86	0.12	0.97
Year * Strip	Sphericity Assumed	3.68	8.00	0.46	0.21	0.99
			Water-soluble Nitrogen			
Year	Sphericity Assumed	16191.40	2.00	8095.70	10.21	0.01
Strip	Sphericity Assumed	30978.00	4.00	7744.50	8.64	0.00
Year * Strip	Sphericity Assumed	5188.12	8.00	648.52	0.35	0.94
			Total Phosphorus			
Year	Sphericity Assumed	0.30	2.00	0.15	3.98	0.06
Strip	Sphericity Assumed	0.44	4.00	0.11	2.36	0.10
Year * Strip	Sphericity Assumed	0.10	8.00	0.01	0.54	0.82
			Rapidly Available Phosphorus			
Year	Sphericity Assumed	24.69	2.00	12.34	30.62	0.00
Strip	Sphericity Assumed	32.76	4.00	8.19	11.30	0.00
Year * Strip	Sphericity Assumed	9.33	8.00	1.17	0.41	0.91
			Total Potassium			
Year	Greenhouse-Geisser	1.98	1.04	1.91	0.26	0.64
Strip	Sphericity Assumed	8.22	4.00	2.05	1.33	0.30
Year * Strip	Sphericity Assumed	0.46	8.00	0.06	0.05	1.00
			Rapidly Available Potassium			
Year	Sphericity Assumed	58.97	2.00	29.49	0.82	0.47
Strip	Sphericity Assumed	132.52	4.00	33.13	0.80	0.54
Year * Strip	Sphericity Assumed	97.02	8.00	12.13	0.59	0.78

Table 8. Estimates of chemical indicators which have significant difference in various years

Year	Mean	Std. Error	95% confidence Interval	
			Lower Bound	Upper Bound
		Water-soluble Nitrogen		
2012	524.53	24.12	457.57	591.49
2015	490.89	25.54	419.97	561.80
2018	496.64	28.86	416.50	576.78

Rapidly Available Phosphorus				
2012	15.40	0.79	13.20	17.59
2015	14.07	0.89	11.60	16.54
2018	14.34	0.95	11.70	16.99

Table 9. Estimates of chemical indicators which have significant difference in various strips

Strip	Mean	Std. Error	95% confidence Interval	
			Lower Bound	Upper Bound
Water-soluble Nitrogen				
6m	495.57	25.23	425.53	565.61
10m	526.23	24.18	459.08	593.37
14m	521.90	28.21	443.56	600.23
18m	506.64	28.24	428.25	585.04
CK	469.75	27.64	393.00	546.50
Rapidly Available Phosphorus				
6m	14.04	1.02	11.21	16.88
10m	15.44	0.89	12.97	17.92
14m	15.35	0.89	12.89	17.80
18m	14.30	0.83	11.98	16.61
CK	13.88	0.83	11.57	16.20

3.3 Impacts on Soil Physical and Chemical Properties comprehensively

3.3.1 Determining the Weights of Indices

Eq. (1) and Eq. (2) were used to standardize the data of 13 soil quality indicators, and then a principal component analysis (PCA) was used to calculate the contribution rate and cumulative contribution rate of each factor. The load matrix was obtained by the common factor rotation, the common factor variance of soil quality index was calculated, and the weight was calculated. The results of the principal component analysis and weight accounting of 13 soil quality indicators are shown in Table 10. According to Table 10, we can see that the eigenvalue of the first principal component is 6.72, which accounts for 51.71% of the total variance. The cumulative contribution rate of the three principal component factors extracted was 85.27%, which almost contained all the information of the original data and was in accordance with the condition that the cumulative contribution rate of principal component analysis was more than 80%.

Table 10. Rotated principal component matrix, communality and weight of each indicator

Index	Principal Component			σ^2 of common factor	Weight
	1	2	3		

Soil Bulk Density	-0.5668	0.5585	0.2208	0.6819	0.0615
Soil Maximum Water-holding Capacity	-0.6869	0.4754	0.4092	0.8652	0.0781
Soil Capillary Water-holding Capacity	-0.7444	0.5511	-0.1933	0.8952	0.0808
Soil Non-capillary Porosity	-0.5962	-0.1960	0.7170	0.9080	0.0819
Soil Capillary Porosity	-0.0617	0.7962	-0.5147	0.9027	0.0814
Soil Total Porosity	-0.7277	0.5516	0.3047	0.9266	0.0836
Organic Matter	0.7849	-0.1836	0.3795	0.7938	0.0716
Total Nitrogen	0.7950	0.1269	0.4835	0.8818	0.0796
Water-soluble Nitrogen	0.8592	0.3197	0.0383	0.8419	0.0759
Total Phosphorus	0.9322	0.1090	-0.0744	0.8864	0.0800
Rapidly Available Phosphorus	0.8615	0.4643	0.1417	0.9778	0.0882
Total Potassium	0.6960	0.4625	-0.1595	0.7238	0.0653
Rapidly Available Potassium	0.6357	0.5221	0.3507	0.7997	0.0721
Eigenvalue	6.72	2.68	1.68		
Proportion (%)	51.71	20.65	12.91		
Cumulative proportion (%)	51.71	72.36	85.27		

3.3.2 Soil Quality Index relating to Soil Physical and Chemical Properties

On the basis of determining the subordinate degree and weight of evaluation index factors, the comprehensive index of soil quality in different years and different widths of cutting strips was calculated by using the weighted synthesis method and the addition and multiplication rule in fuzzy mathematics. The method is shown in Formula 3. The transformation of soil quality with cutting width in different years is shown in Figure 7.

Soil quality has a great relationship with the width of the cutting strip, and the optimum cutting width has changed in different years. In the third year after cutting, the comprehensive index of soil quality showed the cutting width with 14 m (0.6280) > 10 m (0.6043) > 18 m (0.4844) > non-cutting (0.4195) > 6 m (0.4137). Except for the 6-m transformation zone, the soil quality of other transformation plots was better than that of the control plots, which may be due to the increase of soil nutrients caused by the decomposition of harvested residues. In the 6th year after harvesting, the comprehensive index of soil quality was 10 m (0.5913) > 14 m (0.4713) > 6 m (0.4071) > non-cutting (0.3689) > 18 m (0.2327), and the soil quality in the 18-m harvesting zone was significantly lower than that in other modified plots and the control plot. It was possibly that the soil nutrient loss caused by the wide harvesting width could not be restored within 6 years. Nine years after cutting, the relationship between the comprehensive index of soil quality and the cutting strip was basically consistent with that after six years of harvesting, which was 10 m (0.6148) > 14 m (0.4965) > 6 m (0.4071) > non-cutting (0.3689) > 18 m (0.2082). This indicated that the soil quality could not be restored in the 18-m harvesting zone within nine years. It may be that the cutting width is too wide for this experimental stand, or it may take longer to restore soil quality. In view of the current research years, the cutting width of 10 m is more obvious than that of other transformation widths.

4 Discussion

The results showed that the effect of bandwidth on the physical properties of the soil surface was more significant than the chemical nature. Schwendenmann, L. (2000) also believed removing vegetation had an effect on the physical soil properties. In our study, four of the six indicators of physical properties showed significant differences in the change of bandwidth, while only two of the chemical properties showed significant differences. This was because the physical properties here were mostly selected as indicators to reflect the capacity of the soil to hold water, and the soil erosion or loss in forests was closely related to human disturbances. This was also proved in Borrelli, P. et.al (2017) study said that about half of the soil loss (45.3%) was predicted for the logged areas in Italy. However, in chemical properties, there were only water-soluble nitrogen and rapidly available phosphorus having significant effects within various strips. This showed that the bandwidth harvesting was more affecting the growth of the remaining vegetation, the rate of absorption of elements in the soil changes, and the ionic activity in the soil was intensified. In fact, there have been many studies about it, however, the relationship between soil chemical properties and logging in different regions was various especially for the stand age (Schwendenmann, L., 2000). For us, in this stage, the influence of plant available elements effected by cutting of strip was more obvious. What's more, the effect of restoring years after cutting on the physical properties of soil surface seemed to be superior to chemical properties, but this was not supported by special theory, which was directly reflected from the number of indicators. There was no definitive answer of the recovery period to stand disturbances (Zang, R., and Ding, Y, 2009; Griffiths, P. et. al, 2014), but 9 years should not restore forest soil performance unfortunately.

Our results showed that the width of the cutting strip had a significant impact on soil physical and chemical properties comprehensively. In general, the soil bulk density decreases and then increases, but soil porosity and water holding capacity increase and then decrease as width increases after 9 years of cutting reform, echoing the results reported in the literature (Jennings et al., 2012; Lu, 2006; Makineci et al., 2007). Likewise, an increase in the width of the cutting strip, after 9 years of recovery in our study, could cause a recovery but then loss of soil nutrients (N, P, and K), which is parallel to the finding of existing studies (XU and WEI, 2013; Ying et al., 2012). In addition to confirming existing findings, our study shed new light on the aggregate impact of cutting strips on both soil physical and chemical properties. The results from PCA revealed that the first principal component was exclusively associated with soil chemical properties, which explained most variation in the impact of cutting strips, and the second principal component was mostly linked to soil physical properties. Therefore, people are most concerned about the loss of soil nutrients (especially phosphorus and potassium) due to the excessive width of cutting strips in the forest, which has difficulty recovering in a short time. Without nutrient supplementation, if not fertilized, soil nutrient loss will reduce long-term soil productivity and lead to forest degradation.

Moreover, a certain width of cutting strip can promote soil nutrients after a certain year. The recovery of soil properties impacted by most widths of cutting strips is a slow process. It would take longer for overall soil properties to recover as the width rises. This was not only because a wider of cutting strip would cause greater damage to soil properties but also because the recovery rate of soil properties would slow down sooner with an increase in the cutting strip width. Thus, additional time in our study may not be very helpful in restoring soil properties damaged by an excessive width of cutting. With even more years, soil quality could not be fully restored if the cutting strip is exceeds a normal range.

Given the rising demand for timber and the promotion of stand regeneration, appropriate harvesting from this forest seems necessary. With all the above impacts in mind, if timber harvesting from this forest has to continue to some extent, the width of cutting strip should be maintained at approximately 10 m. Moreover, it is feasible to supplement nutrients by applying appropriate fertilizers to help regenerate or restore forests in the region.

5 Conclusions

It was examined that the impact of cutting strip width on soil physical and chemical properties in a low-quality broadleaf mixed forest in northeastern China in 3, 6 and 9 years after cutting reform. We considered four treatments—6 m, 10 m, 14 m, and 18 m widths of cutting strips—with non-cutting as the control. We analysed the impacts of cutting intensity on both individual and comprehensive soil properties. After 9 years, in terms of impacts on individual soil properties, cutting strip reform caused a much greater impact on most soil physical properties, while the impact on soil chemical properties was augmented with an increase in cutting strip width. As for aggregate impacts on overall soil physical and chemical properties, the difference of strip width showed various impact on it.

These findings will make vital implications for sustainable ecological management to the mixed natural broadleaf forest in the study region and places similarly. First, Over 9 years after cutting, most soil physical properties displayed some differences across cutting strip widths, while most chemical properties didn't. Chemical properties needed more time to recover. In view of the current research years, the soil quality could not be restored in the 18-m harvesting zone within nine years. The cutting width of 10 m is more obvious than that of other transformation widths, so 10 m is the best width of cutting strip for the forest. Hence, a suitable width of the cutting strip can increase soil nutrients after certain years. However, it has a critical value, which means that if we apply wider cutting strip to a forest stand, the soil nutrients cannot be recovered or it takes a long time. Second, given the impacts of cutting strips on both individual and overall soil properties, a large width of the cutting strip in this type of forest in the region should be avoided. For forest soil conditions, we need to continue long-term observations.

The effects of cutting band width on soil physical and chemical properties and soil comprehensive quality were studied. In the future, we will explore the effects of cutting band width on stand regeneration and stand structure, not only on soil properties but also on forest productivity and forest resilience. In addition, the application of cutting zones to more tree species can help us explore the effects of other factors, such as tree species composition and environmental conditions. Finally, it is of great value for the sustainable development of forests to carry out continuous observations in the experimental area and to study the effects of more years of rehabilitation on forests.

Competing Interest. The authors declare no conflicts of interest.

Acknowledgements. This research was funded by the National Key R&D Program of China (2017YFC0504103) and the Fundamental Research Funds for the Central Universities (2572017AB20).

References

Arevalo-Gardini, E., Canto, M., Alegre, J., Loli, O., Julca, A., and Baligar, V.: Changes in Soil Physical and Chemical Properties in Long Term Improved Natural and Traditional Agroforestry Management Systems of Cacao Genotypes in Peruvian Amazon, Plos One, 10, 10.1371/journal.pone.0132147, 2015.

Barna, M., and Bosela, M.: Tree species diversity change in natural regeneration of a beech forest under different management, Forest Ecology and Management, 342, 93-102, 10.1016/j.foreco.2015.01.017, 2015.

Caldato, N., Forti, L. C., Camargo, R. D., Lopes, J. F. S., and Fourcassie, V.: Dynamics of the restoration of physical trails in the grass-cutting ant Atta capiguara (Hymenoptera, Formicidae), Revista Brasileira De Entomologia, 60, 63-67, 10.1016/j.rbe.2015.10.001, 2016.

Borrelli, P., Panagos, P., Märker, M., Modugno, S., and Schütt, B: Assessment of the impacts of clear-cutting on soil loss by water erosion in Italian forests: First comprehensive monitoring and modelling approach, Catena, 149, 770-781,2017.

Camenzind, T., Hattenschwiler, S., Treseder, K. K., Lehmann, A., and Rillig, M. C.: Nutrient limitation of soil microbial processes in tropical forests, Ecological Monographs, 88, 4-21, 10.1002/ecm.1279, 2018.

De Nicola, C., Fanelli, G., Testi, A., Costa, C., D'Angeli, D., and Pignatti, S.: Recovering ability of deciduous Oak Forest after different stages of tree cutting in Central Italy, Rendiconti Lincei-Scienze Fisiche E Naturali, 28, 53-64, 10.1007/s12210-016-0572-0, 2017.

Dechene, A. D., and Buddle, C. M.: Effects of experimental forest harvesting on oribatid mite biodiversity, Forest Ecology and Management, 258, 1331-1341, 10.1016/j.foreco.2009.06.033, 2009.

DeLuca, T. H., and Aplet, G. H.: Charcoal and carbon storage in forest soils of the Rocky Mountain West, Frontiers in Ecology and the Environment, 6, 18-24, 10.1890/070070, 2008.

Fan, S.F., Zhao, J.C., Su W,H, Yu, L and Yan, Y. Comprehensive evaluation of soil quality in Phyllostachys edulis stands of different stocking stocking densities. *Scientia Silvae Sinicae*, 51, 1-9, 2015 (in Chinese)

Forestry Industry Standards of China. Determination of Forest Soil Water-Related Physical Properties (LY/T 1215-1999); Chinese Academy of Forestry Sciences: Beijing, China, 1999.

Forestry Industry Standards of China. Determination of Organic Matter in Forest Soil and Calculation Carbon-nitrogen Ratio (LY/T 1237-1999); Chinese Academy of Forestry Sciences: Beijing, China, 1999.

Forestry Industry Standards of China. Determination of Total Nitrogen in Forest Soil (LY/T 1228-1999); Chinese Academy of Forestry Sciences: Beijing, China, 1999.

Forestry Industry Standards of China. Determination of Hydrolysable Nitrogen in Forest Soil(LY/T1229-1999); Chinese Academy of Forestry Sciences: Beijing, China, 1999.

Forestry Industry Standards of China. Determination of Total Phosphorus in Forest Soil (LY/T 1232-1999); Chinese Academy of Forestry Sciences: Beijing, China, 1999.

Forestry Industry Standards of China. Determination of Available Phosphorus in Forest Soil(LY/T1233-1999); Chinese Academy of Forestry Sciences: Beijing, China, 1999.

Forestry Industry Standards of China. Determination of Total Potassium in Forest Soil(LY/T1234-1999);Chinese Academy of Forestry Sciences: Beijing, China, 1999.

Forestry Industry Standards of China. Determination of Available Potassium in Forest Soil (LY/T 1236-1999); Chinese Academy of Forestry Sciences: Beijing, China, 1999.

Gerke, H. H., and Hierold, W.: Vertical bulk density distribution in C-horizons from marley till as indicator for erosion history in a hummocky post-glacial soil landscape, Soil & Tillage Research, 125, 116-122, 10.1016/j.still.2012.06.005, 2012.

Gao, M., Zhu, Y.J. and Dong X.B.: Effects of tending felling on soil chemical property of timber forest in Daxing'an Mountain, Journal of Northeast Forestry University, 41, 39-41, 76, 10.3969/j.issn.1000-5382.2013. (in Chinese)

Griffiths, P., Kuemmerle, T., Baumann, M., Radeloff, V. C., Abrudan, I. V., Lieskovsky, J. and Hostert, P.: Forest disturbances, forest recovery, and changes in forest types across the Carpathian ecoregion from 1985 to 2010 based on Landsat image composites, Remote Sensing of Environment, 151, 72-88, 2014.

Guan, H.W., Dong, X.B., Tang G.H., Zhang T., Qu H.F. and Ma X.B.: Spatial and temporal changes of soil nutrients to Quercus mongolica low-quality forest in Greater Khingan Mountains after induced transformation, Journal of Central South University of Forestry & Technology, 35, 1-10,22, 10.14067/j.cnki.1673-923x.2018. (in Chinese)

Hieke, F., and Schmidt, J.: The effect of soil bulk density on rill erosion - results of experimental studies, Zeitschrift Fur Geomorphologie, 57, 245-266, 10.1127/0372-8854/2012/0091, 2013.

Ikurekong, E. E. A., and Akpabio, E. M.: Rotational farming system and soil nutrient status in parts of south-eastern Nigeria, Tropical Agriculture, 82, 204-208, 2005.

Jamroz, E., Weber, J., and Debicka, M.: Trophic soil index of the rusty soils affected by clear-cutting in the Spala Forest District, Sylwan, 158, 669-674, 2014.

Jennings, T. N., Smith, J. E., Cromack, K., Sulzman, E. W., McKay, D., Caldwell, B. A. and Beldin, S. I.: Impact of postfire logging on soil bacterial and fungal communities and soil biogeochemistry in a mixed-conifer forest in central Oregon, Plant and soil, 350, 393-411, 2012.

Ma, Y. L., Geng, Y., Huang, Y. Y., Shi, Y., Niklaus, P. A., Schmid, B., and He, J. S.: Effect of clear-cutting silviculture on soil respiration in a subtropical forest of China, Journal of Plant Ecology, 6, 335-348, 10.1093/jpe/rtt038, 2013.

Makineci, E., Demir, M., Comez, A., and Yilmaz, E. J. J. o. T.: Effects of timber skidding on chemical characteristics of herbaceous cover, forest floor and topsoil on skidroad in an oak (Quercus petrea L.) forest, Journal of Terramechanics, 44, 423-428, 2007.

Melquiades, F., Andreoni, L., Thomaz, E. J. A. r., and isotopes: Discrimination of land-use types in a catchment by energy dispersive X-ray fluorescence and principal component analysis, Applied radiation and isotopes, 77, 27-31, 2013.

Okonogi, H., and Fukuda, K.: The effects of previous land-use to herbaceous vegetation in Quercus acutissima stands before and after clear-cutting, Journal of Forest Research, 22, 363-374, 10.1080/13416979.2017.1376732, 2017.

Ong, K. H., Chubo, J. K., King, J. H., Lee, C. S., Su, D. S. A., and Sipen, P.: Influence of soil chemical properties on relative abundance of arbuscular mycorrhiza in forested soils in Malaysia, Turkish Journal of Agriculture and Forestry, 36, 451-458, 10.3906/tar-1107-32, 2012.

Oyen, B. H., and Nilsen, P.: Growth and recruitment after mountain forest selective cutting in irregular spruce forest. A case study in Northern Norway, Silva Fennica, 38, 383-392, 10.14214/sf.406, 2004.

Ozcan, M., and Gokbulak, F.: Effect of size and surrounding forest vegetation on chemical properties of soil in forest gaps, Iforest-Biogeosciences and Forestry, 8, 67-72, 10.3832/ifor0940-007, 2015.

Pang, X. Y., Bao, W. K., and Wu, N.: The effects of clear-felling subalpine coniferous forests on soil physical and chemical properties in the eastern Tibetan Plateau, Soil Use and Management, 27, 213-220, 10.1111/j.1475-2743.2010.00324.x, 2011.

Parfitt, J. M. B., Timm, L. C., Reichardt, K., and Pauletto, E. A.: IMPACTS OF LAND LEVELING ON LOWLAND SOIL PHYSICAL PROPERTIES, Revista Brasileira De Ciencia Do Solo, 38, 315-326, 10.1590/s0100-06832014000100032, 2014.

Schwendenmann, L.: Soil properties of boreal riparian plant communities in relation to natural succession and clear-cutting, Peace River lowlands, Wood Buffalo National Park, Canada, Water, air, and soil pollution, 122(3-4), 449-467, 2000.

XU, Q., and WEI, X. J. F. R. M.: Effects of the Structure Readjustment of Mixed Stands of Ash and Larch on Physical and Chemical Properties of Soil in Ash Stand, 12, 2013.

Yang, J., Xu, X. L., Liu, M. X., Xu, C. H., Luo, W., Song, T. Q., Du, H., and Kiely, G.: Effects of Napier grass management on soil hydrologic functions in a karst landscape, southwestern China, Soil & Tillage Research, 157, 83-92, 10.1016/j.still.2015.11.012, 2016.

Ying, M., Zhou, L., and Yin, W. J. S. S. S.: Effects of Different Thinning Manners on the Soil Organic Carbon Content of Larix olgensis Plantations, 48, 170-173, 2012.

Zang, R., and Ding, Y: Forest recovery on abandoned logging roads in a tropical montane rain forest of Hainan Island, China, Acta Oecologica, 35(3), 462-470, 2009.

Zhang, W.R. Methods of Soil Location Study in Forestry; Forestry Publishing House: Beijing, China, 1984.

Zheng, L.F., Zhou, X.N., Wu, Z.L., Luo, C.J., Cai, R.T. and Lin, H.M. Analysis on soil physic-chemical properties of a natural forest 10 years after high intensity cutting. For. Res., 21, 106–109, 2018(in Chinese)

Zhirin, V. M., and Knyazeva, S. V.: Changes in the forest cover after intense logging in southern taiga of the russian federation, Contemporary Problems of Ecology, 5, 669-676, 10.1134/s1995425512070104, 2012.

Zhou, X. N., Zhou, Y., Zhou, C. J., Wu, Z. L., Zheng, L. F., Hu, X. S., Chen, H. X., and Gan, J. B.: Effects of Cutting Intensity on Soil Physical and Chemical Properties in a Mixed Natural Forest in Southeastern China, Forests, 6, 4495-4509, 10.3390/f6124383, 2015.

Zhou, Z. C., Gan, Z. T., Shangguan, Z. P., and Dong, Z. B.: Effects of grazing on soil physical properties and soil erodibility in semiarid grassland of the Northern Loess Plateau (China), Catena, 82, 87-91, 10.1016/j.catena.2010.05.005, 2010.

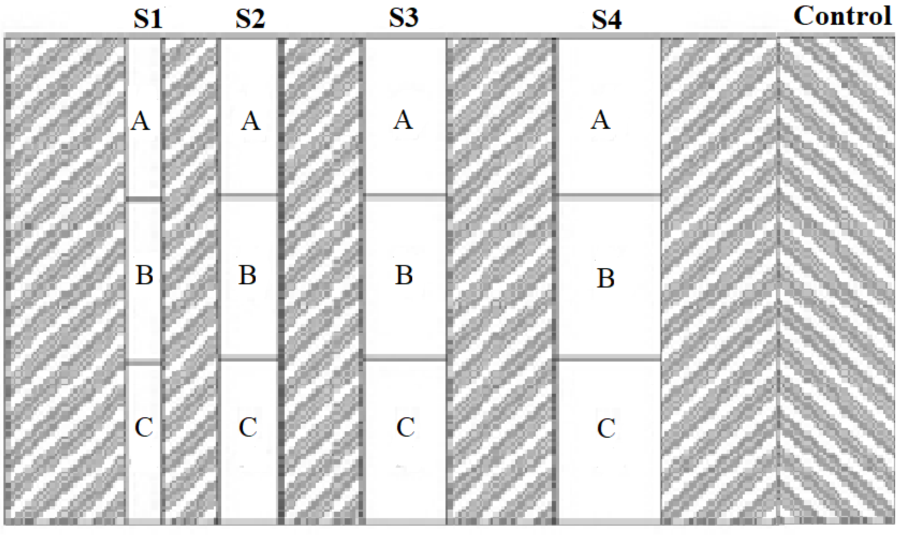


Figure 1: Strip plots settings. S1, S2, S3 and S4 show cutting strips with width of 6m, 10m, 14m and 18m respectively. A, B and C show that every strip is divided to 3 subplots with different planting seedlings. Control plot is set near the transformation zone, with the width of 20m.

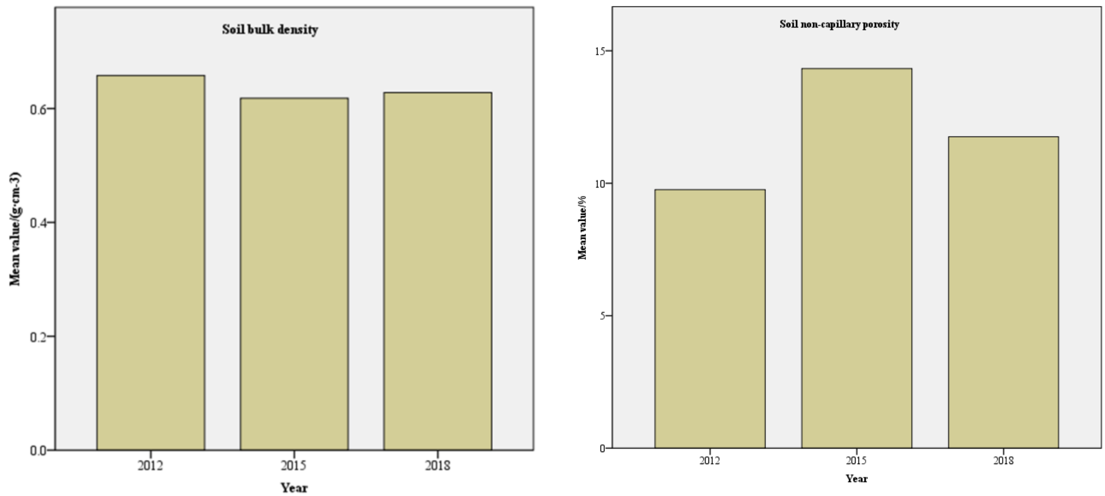
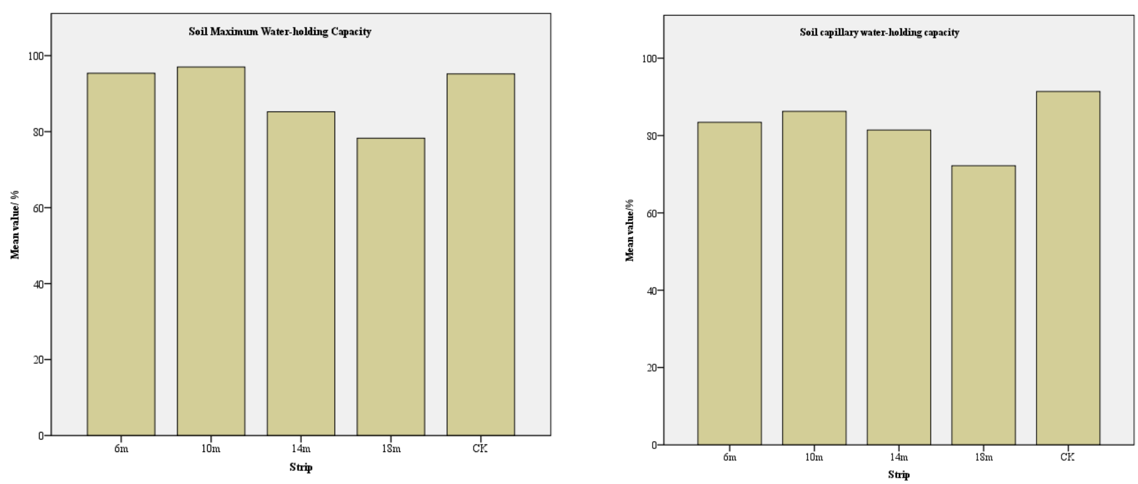


Figure 2. The mean value of physical indicators which have significant difference in various years



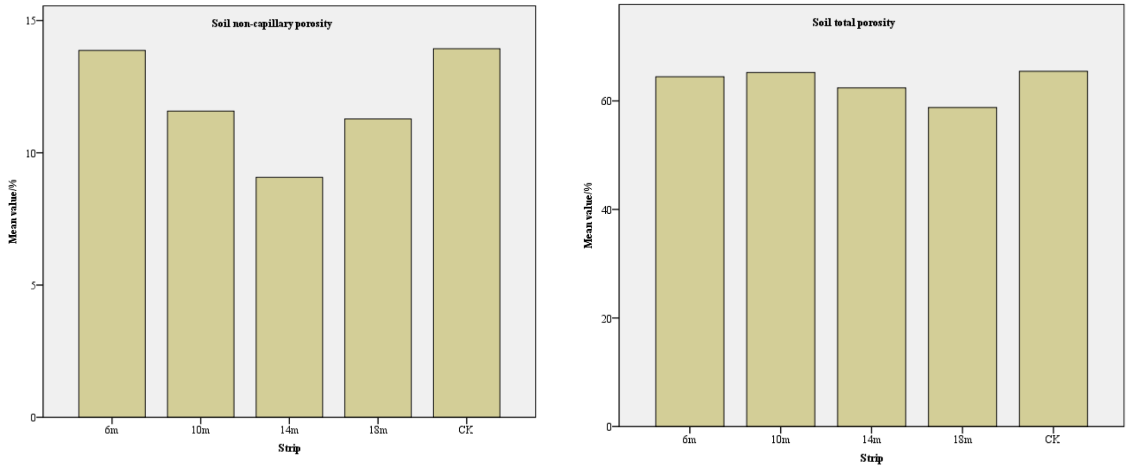
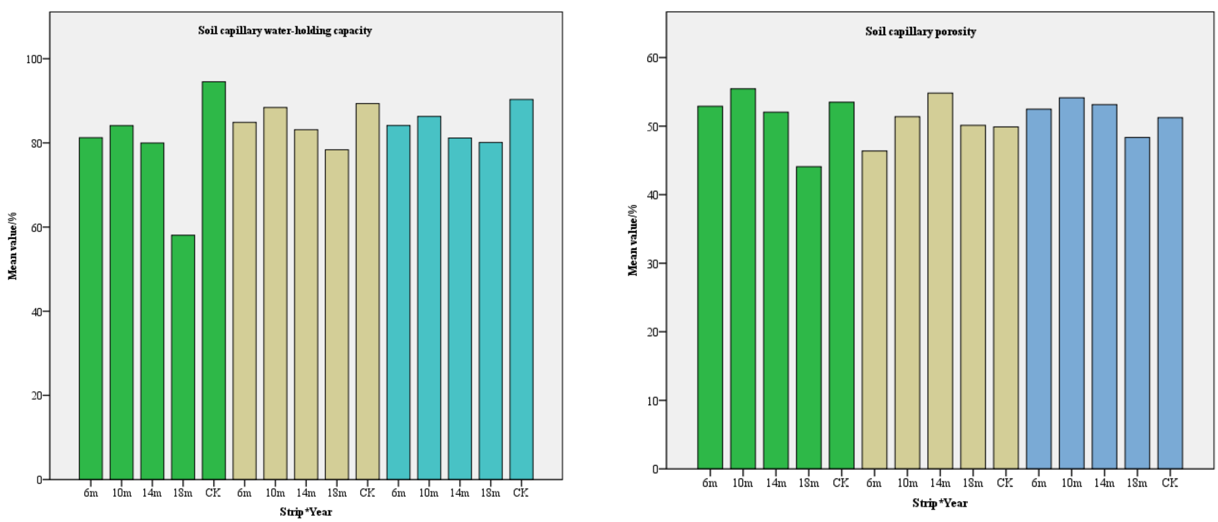


Figure 3. The mean value of physical indicators which have significant difference in various strips



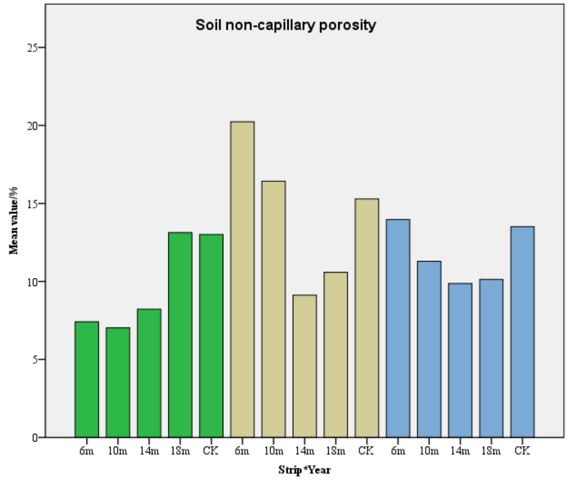


Figure 4. The mean value of physical indicators which have significant difference in the interaction of year and strip

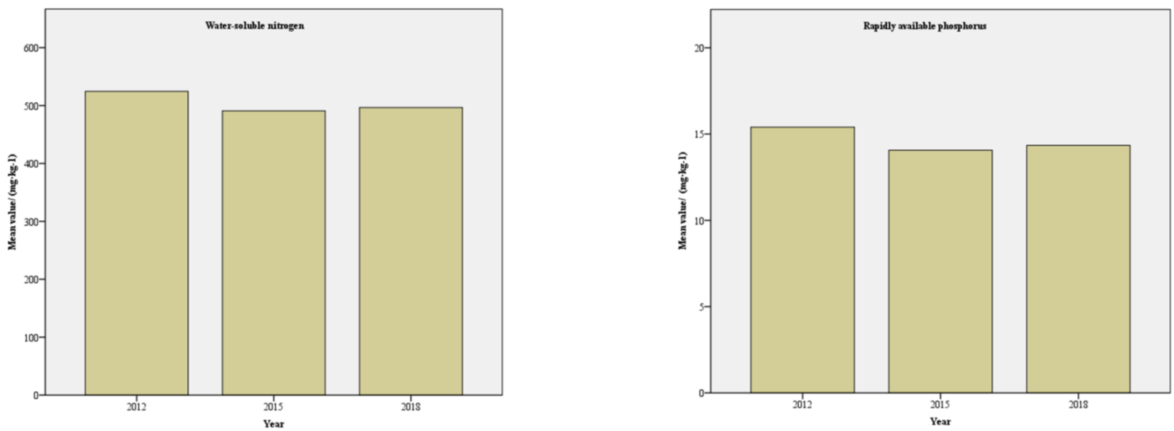


Figure 5. The mean value of chemical indicators which have significant difference in various years

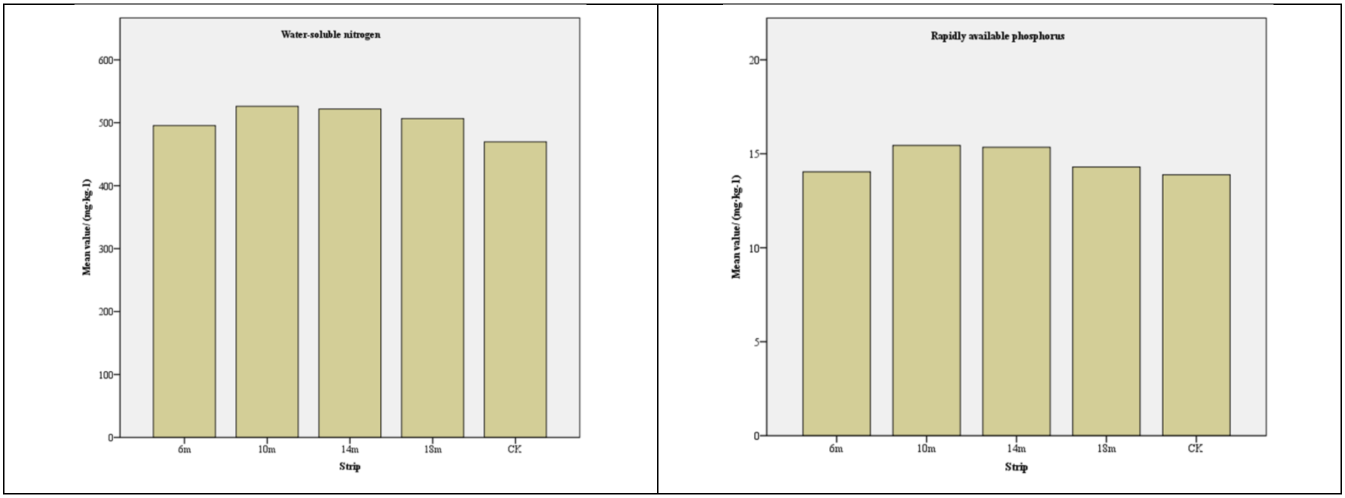


Figure 6. The mean value of chemical indicators which have significant difference in various strips

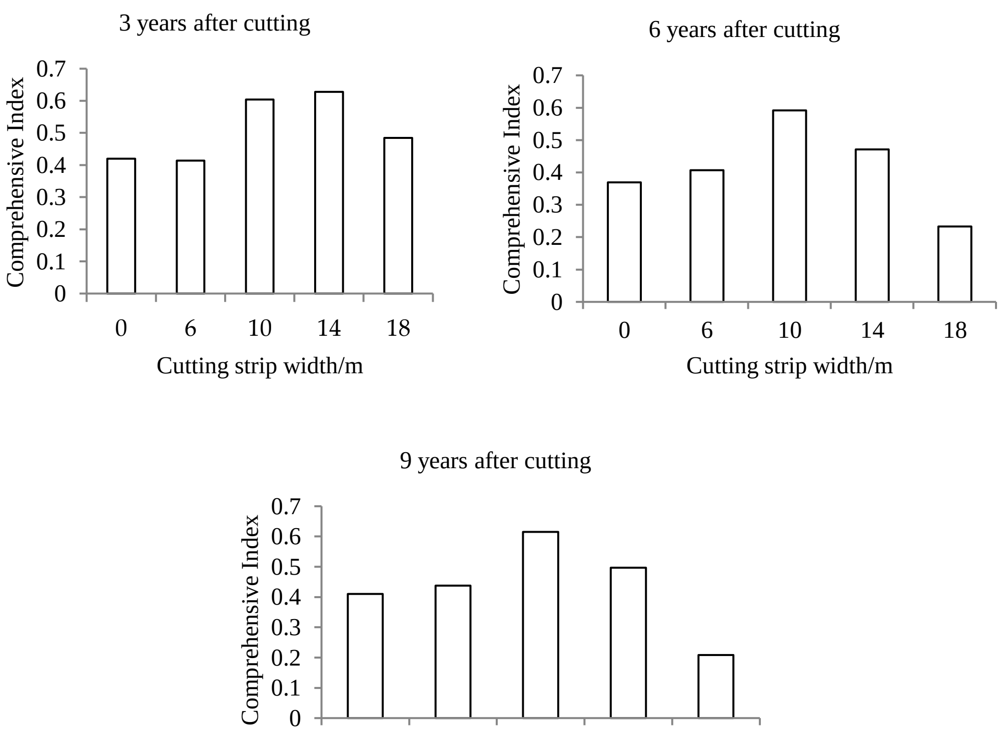


Figure 7: Comprehensive soil quality index under cutting strips 3, 6 and 9 years after cutting