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Effects of Prescribed Fire on Meadow Soil Chemical Properties in Nanwenghe Nature Reserve

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Abstract: The Nanwenghe Nature Reserve is located in the Daxing'anling forest region, which is abundant meadow resource which is prone to fire in fire season every year. In this paper, the change in the soil chemical properties of burned stands was emphasized. The results showed that: (1) Soil organic matter (SOM) concentration in burned stands showed an extremely significant difference from that in the control stands ($p < 0.01$). Alkali-hydrolysable N, available K and total N in the burned stands were significantly lower than those in the control stands ($p < 0.05$). (2) Total P, total K, pH and available P in the burned stands were not significantly different from the concentrations in the control stands ($p > 0.05$). (3) Available K, total N, total P and total K concentration showed no significant difference from June to September. The pH values increased with a variance of 8%, and pH values in July, August and September were significantly different from those in June. SOM concentrations obtained in July, August and September increased significantly, compared to the concentrations in June ($p < 0.05$). Alkali-hydrolysable N showed a decreasing trend for all conditions.

Keywords: meadow; meteorological factors; prescribed burning; soil chemical properties; forest fire management

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1. Introduction

As a main disturbance factor affecting the function of the forest structure and ecosystem, fire can change the carbon balance and soil nutrient dynamics [1–3]. A large number of studies have shown that forest fire frequency and severity are increasing due to the climate becoming warmer [4,5]. The organic matter is transformed into an inorganic form during the burning process which is then reacted in the soil once again [6], thereby affecting soil pH and soil fertility. Forest fire plays an important role in nutrient cycling of coniferous forest ecosystem [7], which can cause effect on the physical, chemical and biological properties in the soil [8–12]. The changes in soil systems after wildfires are mainly caused by high temperatures, duration and the severity of the wildfire. Soil quality and fertility are important for maintaining plant growth in the ecosystem, among which soil chemical properties are key criteria for measuring soil quality [13]. Monitoring post-fire vegetation recovery is critical to quantifying the effects of wildfire on ecosystems and conducting forest resource management. After the fire, soil chemical properties change, and some are short-term effects (<5 years), while others are long-term effects or even permanent. The degree of influence is closely related to the fire intensity, frequency and fire types [14]. Based on these factors, domestic and foreign researchers have carried out a number of studies. It has been found that soil chemical properties change differently, and are affected by fuels, soil, site condition, vegetation and local meteorological factors, etc. In this paper, Heilongjiang Nanwenghe National Nature Reserve was selected as the research site. The reserve is the only inland and wetland ecosystem in China, belonging to cold temperature zone, which is rich in resources such as virgin forests, swamps and meadows. Due to the presence of hay, which is easy to ignite, prescribed burning or controlled burning is usually used in the protected area [15–19], by regularly removing surface organisms, litter and so on to prevent big fires and restore biodiversity, which is involves identifying the area to be burned and establishing control lines in order to prevent the fire from burning unintended areas. In this paper, our objectives are to compare the change in soil chemical properties in the burned stands with the control stands to reveal the influence of fire on soil.

2. Materials and Methods

2.1. Study Area

The Nanwenghe Nature Reserve is located at 125°07′55″~125°50′05″ E, 51°05′07″~51°39′24″ N in the southeastern part of the Daxinganling Mountains, Heilongjiang Province of China (Figure 1). The study area has a continental monsoon climate, with an annual average temperature of −3 °C and an annual precipitation of about 500 mm, 80% of which occurs from July to August. The area is 229,523 ha, and the elevation ranges from 370 to 1000 m. There is mainly brown coniferous forest soil, dark brown soil, river beach forest soil, marsh soil and meadow soil in the study area, and dominant vegetation species include trees such as *Larix gmelinii*, *Picea asperata*, *Betula platyphylla*, *Salix babylonica* and *Populus simonii*, shrubs such as *Rhododendron dauricum* L., *Rosa multiflora*, *Lonicera japonica* and *Rosa davurica* and grass such as Pyrola calliantha H. Andr., *Cyperus difformis.*

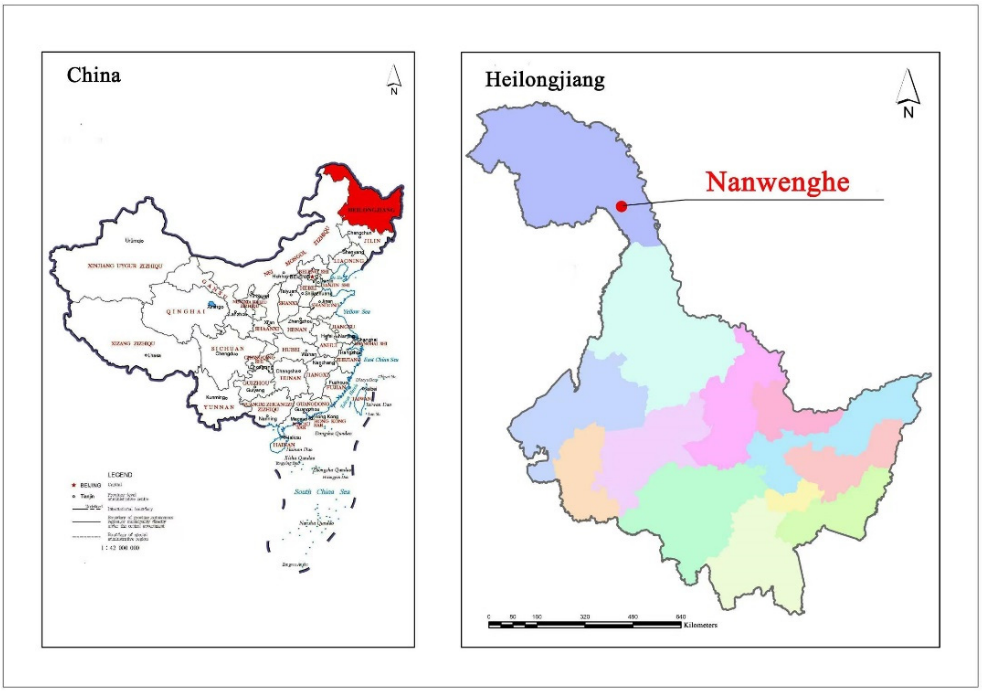

Figure 1. Location of the study area.

Prescribed burning was carried out on the meadow soil in Nanwenghe Nature Reserve in the spring of 2014. Based on similar vegetation type, elevation and slope, we selected three burned stands, respectively, with a distance of 2 km between each stand. In each stand, we randomly selected three sites with area of 30 m × 30 m and chose five small plots with an area of 50 cm × 50 cm from each site at the shape of "X". At the same time, we chose a neighboring meadow land which was not affected by fire, which acted as a control (Table 1).

Table 1. The status of experimental field.

Pattern	Unburning	Plot 1	Plot 2	Plot 3
Area/hm^2	15	15	20	15
Altitude/m	560	486	650	625
Slope/(°)	10	10	13	12
Main vegetation	Pyrola calliantha H. Andr., Cyperus difformis, Orobanche coerulescens Steph	Pyrola calliantha H. Andr., Cyperus difformis, Vaccinium Vitis-Idaea	Pyrola calliantha H. Andr., Cyperus difformis, Orobanche coerulescens Steph	Pyrola calliantha H. Andr., Cyperus difformis, Pteridium aquilinum var.latiusculum
Type of soil	Meadow soil	Meadow soil	Meadow soil	Meadow soil
Fire intensity	Low	Low	Low	Low

2.2. Soil Sample Collection and Analysis

Soil is an excellent thermal insulator and therefore the effects of fires on it are confined to the most superficial part, often to a depth of a few centimeters. Some soil samples at the depth of 0–20 cm in each plot were collected, and then brought back to the laboratory and roots and stones were picked out.

In the laboratory, soil samples were air dried, ground and passed through a sieve (2 mm) before analysis for the following parameters: soil pH (electrode method); organic matter (Walkley–Black wet digestion); and alkali-hydrolysable N was determined by alkaline hydrolysis diffusion method, K by flame photometry, P by molybdenum antimony colorimetric assay and total N by micro-Kjeldahl method [20–23].

2.3. Meteorological Data Resources and Analysis

The meteorological data used in this paper are obtained from the China Meteorological Data Network (data.cma.cn). The time ranges from June to September. The data are monthly mean values, including mean wind speed, sunshine hours, mean temperature, mean relative humidity and mean precipitation (Table 2).

Table 2. Meteorological data of monthly mean values in the study area.

Month	Mean Wind Speed/(m/s)	Sunshine Duration/h	Mean Temperature/°C	Mean Relative Humidity/%	20-20 h Precipitation/mm
June	1.91	9.31	18.27	70.47	114
July	2.16	6.80	18.78	80.43	452.4
August	1.46	6.85	17.47	83.81	203.3
September	2.02	7.08	9.75	74.46	162.4

3. Results

3.1. Soil Chemical Properties Change after Prescribed Fire

The fire caused a significant ($p < 0.01$) decrease in SOM, and the content fell by approximately 32.01%. Additionally, alkali-hydrolysable N, available K and total N decreased significantly ($p < 0.05$), which dropped by about 25.05%, 27.27% and 29.56%, respectively. (Table 3). The comparisons indicated non-significant differences among soil pH, available P, total P and total K (Table 3).

Table 3. Change in soil chemical properties after prescribed fire.

Parameter	Reference Plots	Burned Plots	Change Rate/%	Significant Difference t Value
pH	5.05	4.97	−1.58	1.75
SOM (g kg^{-1})	222.9	156.3	−32.01	3.38 **
Alkali-hydrolysable N (mg kg^{-1})	867.3	650.0	−25.05	2.33 *
Available P (mg kg^{-1})	29.5	22.1	−25.08	1.57
Available K (mg kg^{-1})	22.0	16.0	−27.27	2.99 *
Total N (g kg^{-1})	11.5	8.1	−29.56	2.64 *
Total P (g kg^{-1})	1.8	2.0	11.11	1.51
Total K (g kg^{-1})	9.0	10.4	15.56	1.08

* Significant at $p < 0.05$; ** Significant at $p < 0.01$; SOM: soil organic matter.

3.2. The Effects of Summer Condition on Soil Chemical Properties in Burned Plots and Reference Plots

From June to September, the soil of the burned plots was acidic. The climate condition effects showed a tendency to increase soil pH with a variance of 8%. The pH values of July, August and September were significantly ($p < 0.05$) higher than that of June, respectively (Table 4, Figure 2).

Table 4. Change in soil chemical properties in the burned plots from June to September.

Parameter	Month			
	June	July	August	September
pH	5.11 b (0.07)	5.43 a (0.14)	5.30 b (0.11)	5.52 a (0.08)
SOM (g kg^{-1})	206.8 b (45.53)	814.3 a (55.43)	770.2 a (70.89)	749.4 a (41.01)
Alkali-hydrolysable N (mg kg^{-1})	664.8 a (197.77)	521.5 a (79.70)	669.4 a (220.37)	356.2 b (47.66)
Available P (mg kg^{-1})	28.3 c (8.28)	77.4 b (31.92)	111.6 a (13.25)	128.5 a (2.28)
Available K (mg kg^{-1})	24.1 a (10.09)	15.1 a (2.98)	22.8 a (11.54)	13.7 a (3.01)
Total N (g kg^{-1})	10.4 a (2.41)	7.9 a (3.10)	8.2 a (2.38)	10.0 a (1.22)
Total P (g kg^{-1})	1.7 a (0.22)	1.6 a (0.69)	1.8 a (0.57)	1.9 a (0.64)
Total K (g kg^{-1})	9.0 a (0.37)	8.4 a (1.29)	10.2 a (2.66)	8.6 a (3.14)

Different letters indicate significant differences between months ($p < 0.05$); SOM: soil organic matter; the standard deviation is given in parentheses.

SOM content was highest in July, which increased by 607.5 g kg^{-1}, 44.1 g kg^{-1} and 64.9 g kg^{-1}, compared with the other three months. SOM content did not change significantly ($p > 0.05$) in July, August and September, while SOM concentration of these three months increased significantly ($p < 0.05$) compared with June (Table 4). Alkali-hydrolysable N concentration changed in volatility, which showed a decreasing trend. Then, the content of alkali-hydrolysable N showed a non-significant difference ($p > 0.05$) among June, July and August, while the concentration of these three months increased by 86.7%, 46.4% and 87.6%, respectively, compared with September ($p < 0.05$) (Table 4). The concentration of available P was increasing gradually. The soil available P in September was 4.5 times higher than that in June and 1.66 times higher than that in July ($p < 0.05$). On the other hand, there was no significant difference ($p > 0.05$) between August and September (Table 4, Figure 2).

The change trend of available K is similar to alkali-hydrolysable N, which decreased by 43.1% from June to September. However, unlike alkali-hydrolysable N, the concentration of available K over the 4 months showed no significant difference ($p > 0.05$).

Total N, total P and total K content in the soil from June to September did not have a significant difference ($p > 0.05$) and all change variations were small. Total N content obtained in September increased compared to July and August, but showed an overall downturn with a variance of 3.8%. The concentration of total P increased with a variance of 11.8%. Total K content obtained in the burned plot in September was lower than that in

June, with a variance of 4.4%, while it increased from June to September (Table 4, Figure 2). These three indicators changed uniformly, but decreased in July and increased in August, and the variance was also different (Figure 2).

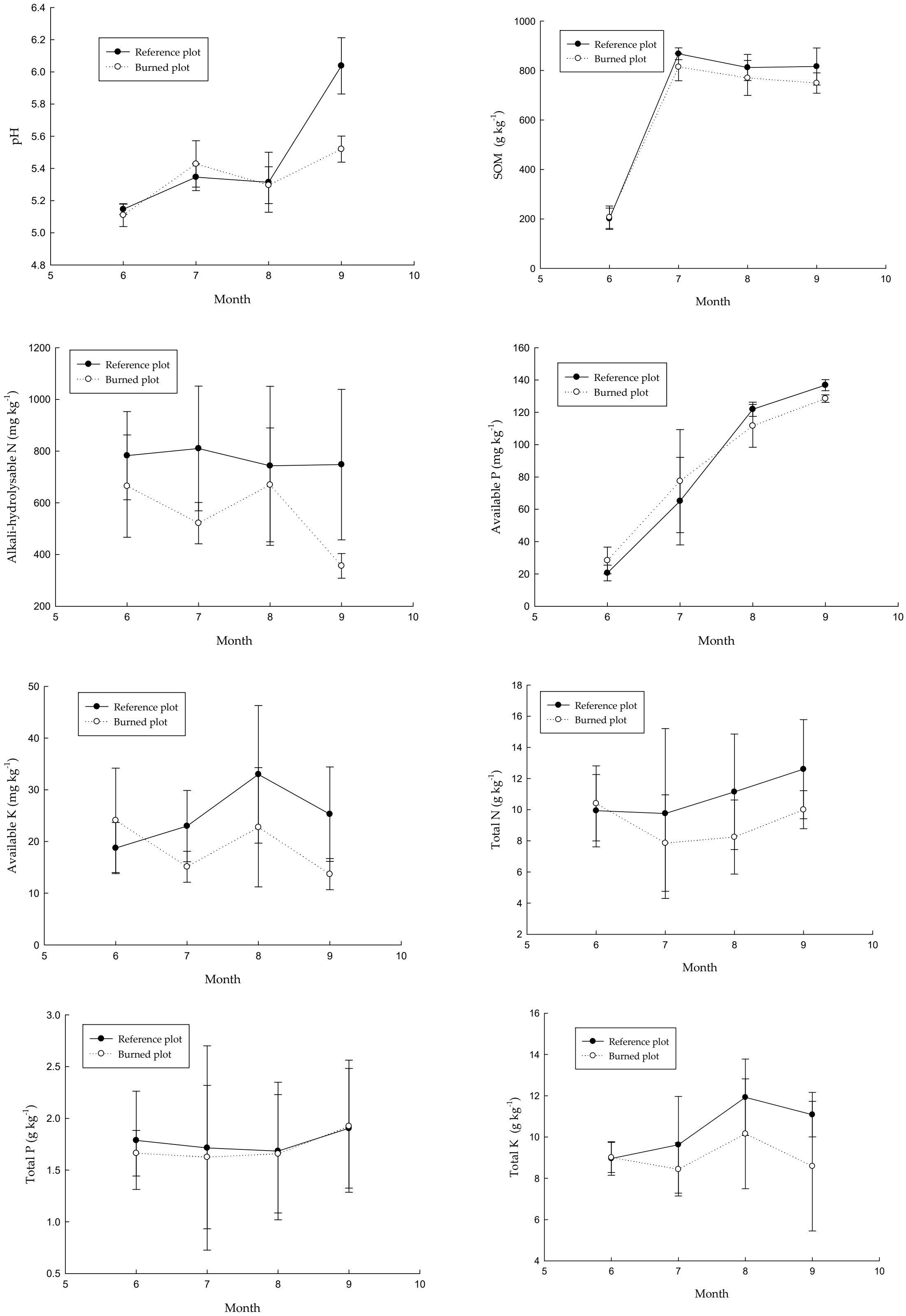

Figure 2. Chemical property change in the soil of burned plots and reference plots after fire from June to September (Mean ± SD).

As shown in Figure 2, it showed significant dynamic changes in burned plots and reference plots from June to September. Available P, total P content of the burned plots were not significantly different from those of the reference plots. The PH value of the burned plots showed an increasing trend with the month, which changed the most from August to September. The SOM in the reference plots and the burned plots did not change significantly, which is little correlation with the month in reference plots, compared with the burned plots. Alkali-hydrolysable N decreased in the burned plots, and did not change significantly in reference plots area. Available K, Total K changes in burned plots were the same in reference plots and burned plots, which increased from June to August, and decreased from August to September in reference plots, while fluctuated with month in burned plots.

4. Discussion

For soil pH, several researchers in China have concluded that the soil pH increased after the fire, due to the combustion of above-ground organic matter, which produced large quantities of ash containing bases cations, and to the loss of hydroxyl groups (-OH) and organic acids during the oxidation process of burning [24–27], but there are also different conclusions that soil pH value decreased after fire [14,20]. Our experiment were consistent with those of the latter, showed a slight decrease in soil pH. The fire did not cause significant difference to pH values. This was probably resulted from low-intensity prescribed fire. It has been found the impact of fire on soil pH was related to fire intensity, and low-intensity prescribed fire would have small influence on soil pH value [28], which may promote the meadow renewal in the future. During the following summer, the groundcover recovered, and improved the soil pH, which increased by 8% from June to September. The soil pH was high related to mean temperature, while the correlation coefficient was not significant.

SOM content is a judge of soil fertility and recovery. It has been shown that SOM content decreased with fire intensity increasing [16,17,19]. In this paper, fire caused a significant ($p < 0.01$) decrease of SOM, caused by loss of massive grass by fire, which reduced litter, resulting the lack of SOM resources, or reallocation of SOM. We only measured the SOM content of 0–20 cm without further measuring that over 20 cm depth. SOM content changed slightly among July, August and September, while they increased significantly ($p < 0.05$) compared with June. The decomposition of ash and humus of the ground surface were accelerated during high temperature and rainy summer, so this may improve soil matrix and increase the SOM content.

N content was prone to volatilize at a high temperature and heat. Alkali-hydrolysable N and total N concentration significantly ($p < 0.05$) decreased. There were no uniform research results, some studies pointed out the total N content increased after fire [29–33], while some thought the total N of all soil layers decreased after human-caused fire [34]. It may be dependent on fire intensity, fire type (grown fire, surface fire and ground fire), site condition, combustibles and climate conditions [35].

Available P content decreased by 25%, while total P content increased slightly, with a variance of 11% after fire. Both changes were not significant. Li pointed out the increase in total P content in soil was closely related to inorganic P release when burning, fire intensity and fire duration [6]. Alcañiz found that the available P content in soil decreased at the beginning of a fire, and then showed an upward trend [36]. The results in this study were consistent with that study, and it was found that the available P in soil increased gradually with a significant ($p < 0.05$) difference.

Fire caused a significant ($p < 0.05$) decrease in available K, with a variance of 27%, while total K increased by 15%, this was probably caused by the release of mineral potassium during the fire, but the change difference was not significant. Song found that fire did not affect total K and available K significantly [20], while Wang found that fire caused an increase in the total K content and decrease in available K [16], which was consistent with our result. This may be due to fire intensity and climatic conditions. Both total K and available K content did not have a significant difference over the four months.

5. Conclusions

The soil chemical properties of Nanwenghe Nature Reserve were significantly different after burning, in which, the content of SOM decreased significantly ($p < 0.01$), falling by approximately 32.01%. Alkali-hydrolysable N, available K and total N decreased significantly ($p < 0.05$), which dropped by about 25.05%, 27.27% and 29.56%, respectively. The content of total P and total K increased, while the changes were not significant. The pH value of the soil decreased and the content of available P also decreased. At the same time, the difference was not significant. There were no significant differences in available K, total N, total P and total K for the different summer months, while soil pH, alkali-hydrolyzed N and available P content varied greatly in summer. After a short period of recovery over the summer, soil nutrient status improved.

Prescribed fire is a common economical and effective forestry practice, which can help reduce hazardous fuels, recycle nutrients back to the soil and promote the growth of local plants; therefore, it is important for the managers in Nanwenghe Nature Reserve to understand the effects of fire on soil properties for better soil management. Meanwhile, the effect of meteorological factors on soil chemical properties should be considered for the assessment and management of soil environmental change.

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