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TWO METHODS IN EVALUATING SOIL FERTILITY IN SEMI-NATURAL LARCH-SPRUCE-FIR (*LARIX OLGENSIS-PICEA JEZOENSIS-ABIES NEPHROLEPIS*) PLANTATIONS IN NORTHEAST CHINA

YUE WANG[1,3], HAI-YAN WANG[2]*, GUO-DONG DING[1] AND XU LI[3]

[1]*College of Soil and Water Conservation, Beijing Forestry University, Beijing 100083, P. R. China*
[2]*College of Forestry, Beijing Forestry University, Beijing 100083, P.R. China*
[3]*Key Laboratory of State Forestry Administration on Soil and Water Conservation (Beijing Forestry University), Beijing 100083, China*
**Corresponding author's email: haiyanwang72@aliyun.com*

Abstract

The objective of this study is to compare two methods in evaluating soil quality, and to find the change regulation of soil quality with varied stand density. The result will provide a theoretical basis for local forest management. Study area was Jingouling forest farm, Jilin Province, northeast China. A total of 10 temporary circular sample plots with different stand density ranging from 488 trees/hm^2 to 930 trees/hm^2 were set up in semi-natural larch-spruce-fir plantations. Principal component analysis and particle size distribution were used to evaluate soil quality under different stand densities. Although the result did not show a change pattern following stand densities, soil quality showed the same tendency using these two methods. Soil particle structure is more sensitive to soil moisture and it is much easier using particle size distribution (PSD). Therefore, we could use PSD to evaluate soil quality in similar stands in the future research.

Key words: Soil quality, Principal component analysis, Particle size distribution, Stand density.

Introduction

Forest soil is a matrix for tree growth and its importance in forest ecosystems has attracted more attention worldwide. Soil physicochemical characteristics are not only basic soil properties, but also direct response of the capacity which sustains and coordinates on plant growth. Studies have shown that there were significant differences about soil physical and chemical conditions in different stands (Rhoades *et al*., 2004, Fu *et al*., 2000).

Fertility can directly reflect soil capacity which consorts vegetation growth. Evaluation of soil quality based on soil fertility has been the focus of research in soil science (Pilbeam *et al*., 2005, Jeremy *et al*., 2009). There are many soil factors with coefficient of variation, so we need to make the evaluation system simplify during forest soil quality evaluation. Principal component analysis (PCA) can make multiple soil factors as one comprehensive score by reducing dimensions, and thus make the result more objective and accurate. As the PCA will lose a part of the experimental information, we have to increase the number of edaphic factors to improve the accuracy. Therefore, a large number of soil variables should be determined before using PCA. Recently more attention has been paid to choose an easier method. Particle size distribution (PSD), based on the appearance and development of the fractal geometry science, is a way to evaluate soil quality (Kigami, 2001, Falconer, 2003, Watkins, 2008). The PSD makes the complex soil structure quantitatively analyzed and it becomes the new direction of soil quality evaluation (Liu, 2009, Perfect, 2009).

Larix olgensis Henry is one of the main timber species in northeast China. Since its planting in a large area at the beginning of the 1950s, most stands have become larch-spruce-fir mixed coniferous after years of evolution, with some characteristics of natural forests, and are thus called semi-natural larch-spruce-fir (*Larix olgensis-Picea jezoensis-Abies nephrolepis*) plantations. Although such stands are evolved from plantations, they are similar to natural forests, with soil quality different from both natural forests and plantations. In this study, principal component analysis and particle size distribution were used to evaluate soil quality under different stand densities in order to compare these two methods and find the change regulation of soil quality with varied stand density, and therefore provide a theoretical basis for local forest management.

Materials and Methods

Study area: The study area was located in Jingouling forest farm, Jilin Province (130°05'～130°20'E, 43°17'～43°25'N). It belongs to the snowy ridge line, Changbai Mountains, with an area of 16 286 hm^2, and the landscape is hilly area. Altitude of this area is between 550 m and 1100 m. The dominant species in the stand are Changbai larch (*Larix olgensis*), spruce (*Picea asperata*) and fir (*Abies nephrolepis*), and there are some kinds of broad-leaved species such as manchurian ash (*Fraxinus mandshurica*), white birch (*Betula platyphylla*), basswood (*Tilia amurensis*), ribbed birch (*Betula costata*) and elm (*Ulmus propinqua*). Soil types are mainly humic cambisols (Dark brown forest soils, in Chinese soil taxonomy).

Soil sampling and analysis: In September 2012, a total of 10 temporary circular sample plots with different stand density from 488 trees/ha to 930 trees/ha were set up in the study area and divided into five groups. The acreage was between 0.0775-0.25 hm^2. Within each plot, a soil profile was dug to describe profile characteristics and samples from the "bottom up" were taken with a ring sampler for the measurement of soil bulk density and soil water content. The surface litter was removed prior to composite soil sampling. Soil samples at depths of 0–10, 10–20, 20–40 and 40-60 cm were collected with 9 soil cores each well mixed into a composite soil sample, which was further divided into two sets of sub-samples. One set of the sub-samples were air dried and passed through a 2 mm sieve for analysis of soil texture (particle size distribution), pH, available phosphorus (AP) and readily available potassium (AK); the remaining sub-sample was air-dried, homogenized and passed through a 0.25 mm sieve for analyses of soil organic matter (SOM), total nitrogen (TN), total potassium (TK), total phosphorus (TP) and cation exchange capacity (CEC) (Bao, 2000).

Particle size distribution: Particle size distribution is one of soil basic physical properties, which is described by the fractal dimension of the particle. The self-similar structure of the porous medium was constituted by particles which were larger than d_i ($di > d_{i+1}$, i = 1, 2, ...), and the volume could be represented using equations (1)-(7) (Li HL. *et al*., 2012).

$$V(\delta > di) = A\,[1 - (di/k)^{3-D}] \quad (1)$$

where, δ is size, A and k are constants describing the shape and yardstick, and D is the fractal dimension. The result of particle size analysis was indicated by their weight, the same as the volume distribution if we default the soil particle was a ball. The d_i was the average particle size of d_i and d_{i+1}, and the difference of proportion was ignored. Just accepted that $\rho_i=\rho$ (i=1, 2,…), and

$$W(\delta > d_i) = V(\delta > d_i)\ \rho = \rho A[1 - (d_i/k)^{3-D}] \quad (2)$$

where, $W(\delta > d_i)$ is the sum of weight. It is larger than d_i and W_0 is the weight of all soil particles. Because of the lim d_i=0, we could find that

$$W_0 = \lim W(\delta > d_i) = \rho A \quad (3)$$

$$W(\delta > d_i)/W_0 = 1 - (d_i/k)^{3-D} \quad (4)$$

$$W(\delta > d_i)/W_0 = 1 - (d_i/d\max)^{3-D} \quad (5)$$

$$\text{or } (d_i/d\max)^{3-D} = W_i(\delta < d_i)/W_0 \quad (6)$$

then the final equation was

$$D = 3 - \lg[W(\delta < d_i)/W_0]/\lg(d_i/d\max) \quad (7)$$

Principal component analysis: The principal component analysis can reduce the number of soil factors so as to simplify evaluation system. The most importantly, principal component analysis is the standardization of the data. Different units of the same variables may produce different principal components, and the calculation would pay more attention to the larger variance variable, while ignoring small variance variables. So we should make the data standardized before analysis, calculate covariance matrix of standardized data and all eigenvalues of the covariance matrix, and determine the number of principal components based on the cumulative contribution rate of eigenvalues, loading values and expression of principal components (He *et al*., 2009).

Results

Soil fertility evaluation in different densities using principal component analysis: The results in Table 1 were weighted calculation depending on soil depth. In the same density, all soil samples were acid with slightly lower pH in surface soil. There was a significant difference (p<0.05) for TP and TK between soil depths except the surface, and the AP, AK, SOM and TN significantly decreased with soil depth (p<0.05).

Certain correlations were found between soil properties (Table 2). There was a very significant correlation between TN and soil physical properties, and a significant correlation between TN and SOC. The cumulative contribution rate of the first three main components reached 83.63%, so it could reflect basic fertility quality of the plot (Table 3).

According to coefficient matrix of the principal component score (Table 4), the first principal component contained soil water content, SOM, AP and TN; the second principal component contained soil bulk density, TP and TK; and the third principal component contained pH, AK and CEC.

Soil fertility quality composite score in different stand densities could be obtained based on equations (8), (9) and (10). The result showed that there was significant difference between groups and the scores didn’t show a change pattern with stand densities (Table 5). In the same density, there was a significant difference of the (PCA) score, which proved that density was not the only stand factor indicative of soil fertility.

Particle size distribution under different stand densities: We selected a plot in each group with a large density gradient to calculate soil particle size distribution. In each density, PSD decreased with soil depth, but the clay content increased with increasing stand density (Table 6).

$$F_1=(-0.216X_1)+0.239X_2+0.061X_3+0.216X_4+0.078X_5+0.131X_6+0.243X_7+0.119X_8+0.047X_9+(-0.131X_{10}) \quad (8)$$

$$F_2=0.128X_1+0.107X_2+0.232X_3+(-0.195X_4)+(-0.243X_5)+0.096X_6+(-0.124X_7)+0.288X_8+0.201X_9+(-0.176X_{10}) \quad (9)$$

$$F_3=(-0.179X_1)+0.020X_2+0.382X_3+(-0.037X_4)+(-0.195X_5)+0.230X_6+(-0.029X_7)+(-0.039X_8)+(-0.383X_9)+0.341X_{10} \quad (10)$$

X_1: Soil bulk density, X_2: Soil moisture, X_3: pH, X_4: SOM, X_5: AP, X_6: AK, X_7: TN, X_8: TP, X_9: TK, X_{10}: CEC

Table 1. Soil physical and chemical properties under different stand densities (n=40).

Stand density (N/ha)	Soil bulk density (g/cm³)	Soil water content (%)	pH	SOM (g/kg)	TN (g/kg)	TP (g/kg)	TK (g/kg)	AP (mg/kg)	AK (mg/kg)	CEC (cmol/kg)
488	1.47	21.32	5.17	25.68	0.28	0.80	23.84	39.03	43.01	14.17
490	1.24	22.30	5.42	44.88	0.38	0.52	13.24	52.01	58.33	19.65
510	1.19	24.77	5.37	64.77	0.60	0.55	18.98	32.82	44.69	17.85
550	1.11	33.65	5.87	73.58	0.97	1.42	21.71	38.13	65.08	14.17
687	1.02	28.74	4.94	150.75	1.33	0.53	20.09	68.65	47.86	14.90
700	1.28	21.33	5.27	52.06	0.58	0.53	18.03	48.45	30.36	21.72
760	1.19	24.40	5.35	50.62	0.65	0.68	20.43	35.21	20.08	18.14
773	1.23	20.92	5.11	37.03	0.60	0.89	21.83	56.74	43.47	16.78
929	1.34	27.53	5.15	44.55	0.48	0.88	22.45	51.56	32.16	12.98
930	1.18	24.76	5.51	48.95	0.58	0.76	22.16	38.25	59.48	16.28

SOM: Soil organic matter, TN: Total nitrogen, TP: Total phosphorus, TK: Total potassium, AP: Available phosphorus, AK: Readily available potassium, CEC: Cation exchange capacity

Table 2. Correlation analysis between soil factors (n=40).

	Soil bulk density	Soil water content	pH	SOM	TN	TP	TK	AP	AK
Soil bulk density	1								
Soil water content	-0.581	1							
pH	-0.194	0.445	1						
SOM	-0.791**	0.566	-0.220	1					
TN	-0.868**	0.681*	-0.039	0.929**	1				
TP	-0.035	0.606	0.583	-0.150	0.140	1			
TK	0.219	0.226	-0.095	-0.099	0.068	0.544	1		
AP	-0.265	-0.003	-0.649*	0.526	0.434	-0.248	-0.190	1	
AK	-0.334	0.379	0.513	0.184	0.202	0.370	-0.120	0.026	1
CEC	-0.046	-0.568	0.055	-0.167	-0.222	-0.592	-0.733*	-0.073	-0.230

Note: * Significant correlation at probability level of 0.05. ** Significant correlation at probability level of 0.01

Table 3. Interpretation of total variance.

Composition	Initial eigenvalues			Extracting square		
	Total	Variance %	Accumulation %	Total	Variance %	Accumulation %
1	3.704	37.039	37.039	3.704	37.04	37.04
2	2.794	27.941	64.980	2.794	27.94	64.98
3	1.865	18.654	83.634	1.865	18.65	83.63
4	0.830	8.304	91.938			
5	0.375	3.753	95.691			
6	0.302	3.024	98.715			
7	0.093	0.926	99.641			
8	0.030	0.301	99.942			
9	0.006	0.058	100.000			
10	9.972E-17	9.972E-16	100.000			

Table 5. Comprehensive scores of soil fertility quality in different stand densities.

Group	Stand density (N/ha)	F1	F2	F3	Score
I	488.	-2.024	1.588	-1.629	-0.610
	490.	-1.248	-1.191	2.163	-0.391
II	510.	-0.375	-0.164	0.959	-0.006
	550.	3.393	2.771	1.191	2.253
III	687.	3.434	-3.079	-1.231	0.182
	700.	-1.750	-1.456	0.718	-0.921
IV	760.	-0.800	-0.119	0.100	-0.311
	773.	-0.638	-0.239	-0.965	-0.483
V	929.	-0.244	0.835	-1.935	-0.218
	930	0.048	0.176	0.086	0.310

Table 4. Coefficient matrix of composition scores.

Parameters	Composition		
	1	2	3
Soil bulk density	-0.216	0.128	-0.179
Soil moisture	0.239	0.107	0.020
pH	0.061	0.232	0.382
SOM	0.216	-0.195	-0.037
AP	0.078	-0.243	-0.195
AK	0.131	0.096	0.230
TN	0.243	-0.124	-0.029
TP	0.119	0.288	-0.039
TK	0.047	0.201	-0.383
CEC	-0.131	-0.176	0.341

Discussion

Change of soil properties under different stand densities: The soil bulk density and soil water content changed with soil depth significantly ($p<0.05$). There were many plants under the stand condition, and the thick litter played an important role in water and soil conservation, and increased soil root system for water absorption. At the same time, surface soil nutrients concentration was higher because of stronger litter decomposition, which is in agreement with the conclusion made by Wang *et al*., (2009) and Geng *et al*., (1999), and the changing trend was similar to most of the researches (Zhai *et al*., 2006).

It can be seen that the differences of soil pH were not significant between varied stand densities. It is characterized as typical acidic soil, and pH values at soil depth of 40-60 cm under different densities were very close because the litter and eluviation had less influence on this soil layer. In theory, soil pH in a region or an area may not have a significant difference.

Soil quality evaluation of different stand densities: Soil quality was improving with increasing stand density in general, no matter we used particle size distribution or principal component analysis. Liu *et al*., (2012) found that when the stand density was 800-880 hm^{-2}, the score was significantly higher than that at other densities. We got similar result in stands with the same dominant tree species (the score was the highest in the 930 hm^{-2}). Nutrients from litter decomposition are the main source of tree growth, and some studies have shown that coefficient of decomposition changed over the stand densities during growing period (Aerts, 1997). Under similar conditions, litter decomposed most at moderate density. Ren *et al*., (2012) found that when the stand density changed between 740 hm^{-2} and 1480 hm^{-2}, soil organic carbon content, organic carbon density and soil total N had an increasing trend in the larch plantation in north China. Most of the studies on the larch plantation had also found that when the density was below 2000 hm^{-2}, soil nutrients concentration had an increasing trend with the increase of stand density (Ren *et al.*, 2012, Chang *et al.*, 2008). Due to the competition of undergrowth (shrubs, herbs) or trees in semi-natural larch-spruce-fir forest (Chang *et al.*, 2008), the stand density should be less than 1000 hm^{-2} after taking a consideration of soil nutrient concentration, the relationship between soil carrying capacity and stand volume and the need for thinning.

Table 6. Variation in soil particle size distribution under different stand densities.

Stand density (N/ha)	Soil depth	1-0.25 mm %	0.25-0.05 mm %	0.05-0.01 mm %	0.01-0.001 mm %	<0.001 mm %	Fractal dimension	Average fractal dimension
488	0-10	7.14	16.13	35.73	23.08	17.91	2.5762	2.5697
	10-20	10.07	30.57	24.63	23.75	10.99	2.5720	
	20-40	6.05	47.70	14.14	15.85	16.26	2.5676	
	40-60	6.63	50.76	13.92	14.86	13.84	2.5630	
510	0-10	11.53	17.08	37.50	29.66	4.23	2.5703	2.5746
	10-20	16.36	12.67	31.42	20.16	19.39	2.5812	
	20-40	12.03	30.02	18.78	32.47	6.70	2.5794	
	40-60	12.51	12.91	42.69	17.51	14.39	2.5676	
687	0-10	7.47	5.13	38.77	34.35	14.28	2.5838	2.5795
	10-20	6.35	2.27	43.41	33.25	14.72	2.5821	
	20-40	8.72	5.05	48.60	22.92	14.72	2.5721	
	40-60	9.26	3.71	42.97	23.03	21.04	2.5801	
773	0-10	19.00	6.91	37.00	22.97	14.12	2.5797	2.5750
	10-20	15.23	14.38	29.66	26.62	14.12	2.5820	
	20-40	23.55	35.38	14.69	12.37	14.01	2.5710	
	40-60	22.88	14.84	35.79	14.86	11.65	2.5674	
930	0-10	15.63	2.45	39.87	24.85	17.19	2.5826	2.5839
	10-20	20.32	3.65	32.47	30.43	13.13	2.5883	
	20-40	15.63	7.98	34.35	24.85	17.19	2.5832	
	40-60	21.86	22.21	20.43	21.37	14.12	2.5816	

The comparison of principal component analysis and particle size distribution: We could judge soil quality by the composite scores using principal component analysis. There is no overlap of every two variables because of non-relationship between the soil factors, and it could make the final score become more objective and comprehensive. The disadvantages of this method are the large number of soil variables, significant difference in different region and the unstable coefficient of variations. We have to do a lot of experiments to make sure the result is more accurate. There is also no uniform standard on the selection of soil factors, so the researches would have more randomness. Particle size distribution is a method based on soil particle composition, which evaluates soil quality via soil structure and is much easier than principal component analysis. The comparison between two evaluation methods could be more scientific.

It has always been an important part of soil science research that how to use a single parameter instead of complex soil quality evaluation methods (Su *et al.*, 2004). Some studies found the correlations between particle size distribution and soil physical properties (Su *et al.*, 2004), and moreover, some researches used PSD to evaluate soil quality (Falconer, 2003, Liu *et al.*, 2009). They found the advantage of this method was the better sensitivity of PSD than soil nutrients. In addition, this medium could unite different size of soil particles to avoid wasting data (Gao *et al.*, 2014).

Conclusion

The change of soil physical and chemical properties with stand density is not regular. The main reason is that stand density could not be able to accurately express the vegetation laws for nutrient uptake because of the large number of shrubs and herbs in the semi-natural larch-spruce-fir forest. They would also lead to the superiority of competition to soil nutrients. Therefore, the understory vegetation in semi-natural larch-spruce-fir forest may be the reason why the changing trend of soil factors with stand density was not significant.

This paper used two different methods to assess soil quality under different stand density of semi-natural larch-spruce-fir forest. Soil quality showed the same tendency with the change of stand density. Compared with principal component analysis, the PSD was much easier, and at the same time, the effectiveness of many nutrients was affected by soil water content, and soil particle structure is more sensitive to soil moisture, so we could use particle size distribution to evaluate soil quality in similar stands in the future researches.

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