Effects of intercropping systems of trees with soybean on soil physicochemical properties in juvenile plantations

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Abstract: The intercropping system of tree with soybean in juvenile plantations, as a short-term practice, was applied at Lao Shan Experimental Station in Mao'er Shan Forest of Northeast Forestry University, Harbin, China. The larch (*Larix gmelinii*)/soybean (*Glycine max.*) and ash (*Fraxinus mandshurica*) intercropping systems were studied in the field to assess the effects of the intercropping on soil physicochemical properties. The results showed that soil physical properties were improved after soybean intercropping with larch and ash in one growing season. The soil bulk density in larch/soybean and ash/soybean systems was 1.112 $g \cdot cm^{-3}$ and 1.058 $g \cdot cm^{-3}$, respectively, which was lower than that in the pure larch or ash plantation without intercropping. The total soil porosity also increased after intercropping. The organic matter amount in larch/soybean system was 1.77 times higher than that in the pure larch plantation, and it was 1.09 times higher in ash/soybean system than that in the pure ash plantation. Contents of total nitrogen and hydrolyzable nitrogen in larch/soybean system were 4.2% and 53.0% higher than those in the pure larch stand. Total nitrogen and hydrolyzable nitrogen contents in ash/soybean system were 75.5% and 3.3% higher than those in the pure ash plantation. Total phosphorus content decreased after intercropping, while change of available phosphorus showed an increasing trend. Total potassium and available potassium contents in the larch/soybean system were 0.6% and 17.5% higher than those in the pure larch stand. Total potassium and available potassium contents in the ash/soybean system were 56.4% and 21.8% higher than those in the pure ash plantation.

Keywords: Intercropping systems; Soil nutrient content; Soil physicochemical properties; larch/soybean intercropping system; ash/soybean intercropping system

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Introduction

Two or more crops planted together with trees were known as intercropping system in order to maximize beneficial interactions. Intercropping is a sustainable soil management means in many developed and developing countries (Massimo *et al*. 2003). It can be applied in field, vegetables, trees, and even crops. Intercropping systems have been practised in China for more than 2000 years (Li *et al.* 2005).

Comparing with high-input mono-cropping of upland vegetables or maize, especially on steep slopes, intercropping system may generate more long-term returns, improve fertilizer-use efficiency, and reduce erosion on steep lands (Nissen *et al.* 2001). The purpose of planting periodical crops in intercropping system is to control shrub encroachment and favor the grass layer. Different land use patterns determined the differences in soil fertility and tree nutritional status that could affect the productivity and profitability of the trees.

Soil is the material foundation that plantation depends on. Maintaining and improving the soil fertility is the key factor to keep the stability of forest ecosystem and the sustainability of the forestry. Soil physicochemical properties directly affect the soil fertility. Forests with better soil have higher productivity.

Intercropping, to some extent, could be considered as one kind of mixed communities. It can accelerate the nutrients circulation rate, improve the soil physicochemical properties, and sustain the soil productivity (Butterfield 1993; Yu 1989).

The intercropping system of two-year-old larch and ash with soybean, as a soil management practice, was applied at Lao Shan Experimental Station in Mao'er Shan Forest of Northeast Forestry University, Harbin, China. The two species were artificially regenerated after clear cutting of secondary forest. Planting crop was soybean. It is well known that leguminous plants can give benefits to the soil, such as improving nutrient availability, improving the structure of soil, reducing pest and disease incidence and hormonal effects through rhyzodeposition (Wani *et al.* 1995). The major benefit of leguminous plants comes from biologically fixed N_2 of symbiosis, involving leguminous plants and bacterial diazotrophs (Vance 1998).

The purpose of this study was to assess the impacts of the intercropping systems on physical and chemical properties in the planted fields. The concrete objectives included, (1) to assess the effects of woody species/soybean intercropping systems on soil bulk density and capillary porosity, (2) to assess the changing of contents of soil organic matter (SOM), total nitrogen (TN), total phosphorus (TP), total potassium (TK), hydrolyzable nitrogen (HN), available phosphorus (AP) and available potassium (AK).

Materials and methods

Study sites

The field study was conducted at Lao Shan Experimental Station in Mao'er Shan Forest of Northeast Forestry University,

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Harbin, China, which is located in the northwest part of Mt. Zhangguangcai in the range of Changbai Mountain (45º20'N, 127º34'E, about 340 m.a.s.l.). Lao Shan Experiment Station has a continental monsoon climate, with a long, cold, dry winter and a short, warm, humid summer. Mean annual air temperature is 2.8 °C and the frostfree period varies from 120 to 140 days. Rain falls mainly in July and August. Mean annual precipitation and mean potential annual evaporation are 724 mm and 1 094 mm, respectively. Zonal soil type is dark brown soil. The broad-leaved/Korean pine mixed forest is the zonal vegetation. Secondary forests are dominated by *Quercus mongolicus Fisch.*, *Betula platyphylla* and hard broad-leaved trees (*Phellodendron amurense, Juglans mandshurica* Maxim.). Plantations are mainly composed by *Larix gmelinii*; *Pinus sylvestris* var. *mongolica*, *Pinus koraiensis* and *Betula platyphylla*.

In order to examine the effect of intercropped woody species with soybean (*Glycine max*.) on soil properties, we selected four plots as follows: pure larch (*Larix gmelinii*) stand, pure ash (*Fraxinus mandshurica*) stand, larch/soybean (*Glycine max*.) and ash/soybean intercropping system plot. The area of each plot was 0.01 hm^2.

Table 1. The general situations of the experimental plots

Plantation type	Component species	Line Spacing	Notes
Pure larch	larch	2m×2m	Planted in 1997
Larch- soybean intercropping	Larch-soybean	1m×1m	Larch planted in 1997, intercropped with soybean in 1998
Pure ash	ash	2m×2m	Planted in 1997
Ash- soybean intercropping	Ash -soybean	1m×1m	Ash planted in 1997, intercropped with soybean in 1998

Soil sample collection and analysis

Mineral soils were sampled from two different layers at 0−20 cm, 20–40 cm (Zhang *et al*. 1986) with a sampling corer (area of 10 cm^2) in each plot at the end of September, 1998. Three sample positions were randomly selected in each plot. Each sample consisted of 5 evenly–distributed sub-samples mixed together (Fig. 1). The soil was air dried and freed from small stones, visible roots, macro-fauna, and other dead debris, and then, was sieved for determination of soil physical and chemical properties. There were three replicates for each measurement. The results were based on the average.

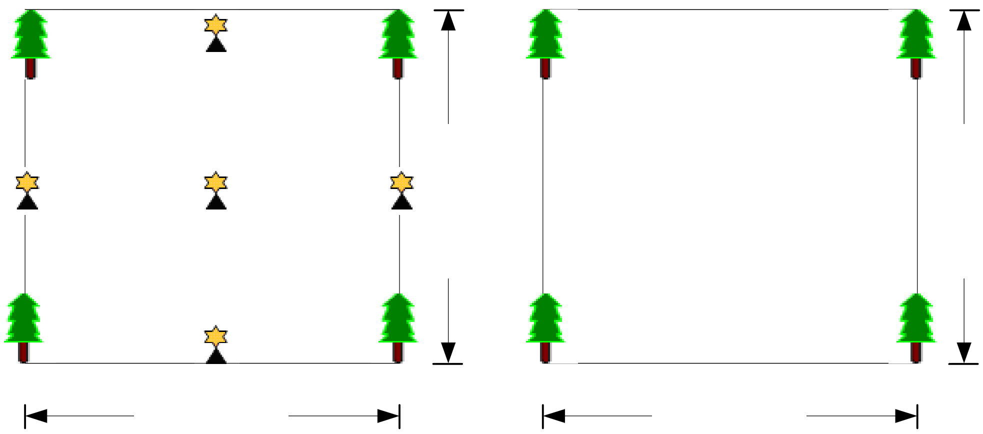

Fig. 1 Sketch for the collection of soil samples

Mineral soil bulk density was measured for each plot by using dry weights of known-volume composite cores from the upper layer (0–20 cm) and lower layer (20–40 cm). The percent of inclusion volume was calculated as the percentage of the soil volume occupied by roots and stones which were greater than 4 mm in diameter (Pamela 1981).

The soil bulk density was determined according to the method of Blakemore *et al.* (1987). The capillary porosity was determined according to the method of Guan (1988).

The chemical characteristics of soils were analyzed with the traditional methods. Total nitrogen was determined with a Technicon autoanalyzer by using KJEL (VS-KT-P, Japan) by digestion with oil of vitrio, $CuSO_4$ -K_2SO_4 mixture as catalyst (Blakemore *et al* 1987). Total phosphorous was determined colorimetrically after wet digestion with H_2SO_4-$HClO_4$ (GB7852-87). Total potassium was determined by NaOH melt flamer method (Bao 1981). Hydrolyzable nitrogen was determined by diffusion-absorption method (GB7849-87) and available phosphorous was determined by Olsen method (Bao 1981). Available potassium was determined by atomic absorption spectroscopy. Soil organic carbon was determined according to the classical K-dichromate method (Liu 1996). Organic matter content was obtained by multiplying carbon values by a factor of 1.72 (Allen *et al*. 1974).

Results

Soil bulk density and porosity

The soil bulk density at soil top layer was lower than that at soil lower layer for all of the four plots (Table 2). Soil bulk densities of larch/soybean and ash/soybean intercropping systems were lower than those of the corresponding pure plantations for larch and ash. Soil bulk density of larch/soybean intercropping system at soil top layer and soil lower layer were 11.1% and 14.4% lower than those of the pure larch plantation, respectively. Soil bulk density of ash/soybean intercropping system in soil top layer and soil lower layer were 5.0% and 6.2% lower than those of the pure ash plantation, respectively.

The capillary porosity, non-capillary porosity and total porosity of soil top layer were higher than those of soil lower layer for all of the four plots. Total porosity in soil top layer and soil lower layer of intercropping systems was higher than that of the corresponding pure plantation. Total porosity of larch/soybean intercropping system in soil top layer and soil lower layer was 7.2% and 0.3% higher than that of the pure larch plantation, respectively. Total porosity in soil top layer and soil lower layer of ash/soybean intercropping system was 15.7% and 21.5% higher than that of the pure ash plantation, respectively.

Table 2. Soil bulk density and porosity of each plot

Plantation type	Sampling depth (cm)	Bulk density ($g \cdot cm^{-3}$)	Capillary porosity (%)	Non-capillary porosity (%)	Total porosity (%)	Non-capillary porosity to total porosity (%)
Pure larch plantation	0-20	1.125	54.40	3.40	57.80	5.9
	20-40	1.346	45.42	2.00	47.42	4.0
	average	1.235	49.91	2.70	52.61	5.0
Larch/soybean intercropping	0-20	1.047	55.17	6.77	61.94	11.0
	20-40	1.176	40.84	6.73	47.57	12.0
	average	1.112	48.01	6.75	54.76	11.5
Ash/soybean intercropping	0-20	0.997	44.74	9.07	62.28	16.9
	20-40	1.120	43.23	6.70	60.67	12.0
	average	1.058	43.99	7.89	61.48	14.5
Pure ash plantation	0-20	1.034	57.14	5.13	53.81	8.2
	20-40	1.189	56.81	3.80	49.93	6.3
	average	1.112	57.01	4.47	51.88	7.3

Soil nutrient content

Soil organic matter

Soil organic matter at soil top layer was more than that at soil lower layer for all of the four plots (Table 3). Soil organic matter in larch-soybean and ash-soybean intercropping systems was also more than that of the corresponding pure plantations for larch and ash. In the depth of 0−20 cm, content of soil organic matter in larch/soybean intercropping system was 1.77 times higher than that in pure larch plantation, and content of the soil organic matter in ash/soybean intercropping system was 0.41 times higher than that in pure ash plantation. In the depth of 20−40 cm, soil organic matter amount in larch/soybean intercropping system was 0.14 times higher than that in the pure larch plantation, and in ash/soybean intercropping system soil organic matter amount was 1.09 times higher than that in pure ash plantation.

Nitrogen content

The total nitrogen and hydrolyzable nitrogen contents at soil top layer were higher than those at soil lower layer for all of the four plots (Table 2). In the depth of 0–20cm, total nitrogen contents in larch/soybean intercropping system account for 0.460%, 4.2% higher than that of in the pure larch plantation. Total nitrogen content in ash/soybean intercropping system and in the pure ash stand was 0.402% and 0.286%, respectively. In the depth of 0-20cm, hydrolyzable nitrogen content in larch-soybean and ash/soybean intercropping system was 53.0% and 3.3% higher than those in the corresponding pure larch and ash plantation, respectively.

Table 3. Soil nutrient contents of the study sites

Type	Sampling depth (cm)	Soil organic matter (%)	Total nitrogen (%)	Total phosphorous (%)	Total potassium (%)	Hydrolyzable nitrogen ($mg \cdot kg^{-1}$)	Available phosphorous ($mg \cdot kg^{-1}$)	Available potassium ($mg \cdot kg^{-1}$)
Pure larch plantation	0-20	5.31	0.374	0.197	1.654	89.33	330.87	142.37
	20-40	4.15	0.267	0.171	1.811	41.33	284.93	57.83
Larch/soybean intercropping	0-20	14.69	0.460	0.188	1.664	136.67	367.63	167.33
	20-40	4.74	0.208	0.132	1.665	64.67	318.60	84.20
Ash/soybean intercropping	0-20	9.51	0.402	0.190	1.564	105.67	370.80	144.80
	20-40	7.36	0.232	0.143	1.773	49.00	343.27	105.37
Pure ash plantation	0-20	6.74	0.286	0.204	1.000	102.33	340.07	118.93
	20-40	3.51	0.141	0.143	1.832	45.67	300.20	71.417

Phosphorous content

There was significant difference in total phosphorous content at different soil depths for all the four plots. Total phosphorous content in the depth of 0–20 cm was higher than that in the depth of 20–40 cm. Total phosphorous content in larch/soybean and ash/soybean intercropping system was lower than that in the corresponding pure ash plantation. In the depth of 0–20cm, total phosphorous content in larch/soybean and ash/soybean intercropping system was 4.8% and 7.4% lower than those in the pure larch and pure ash plantation, respectively.

Available phosphorous content showed an opposite tendency compared with the changes of total phosphorous content, i.e. available phosphorous contents in larch/soybean and ash/soybean intercropping systems were higher than those in the corresponding pure larch and ash plantation. In the depth of 0–20 cm, available phosphorous content in larch/soybean intercropping system was 367.63 $mg\cdot kg^{-1}$, which was 11.1% higher than that in pure larch plantation. In ash/soybean intercropping system, available phosphorous content was 370.80 $mg\cdot kg^{-1}$, which was 9.0% higher than that in pure ash plantation.

Potassium content

Total potassium content at soil top layer was higher than that at soil lower layer for all the four plots. The change of available potassium content showed the reverse results. In the depth of 0–20cm, content of total potassium and available potassium in larch/soybean intercropping system were 0.6% and 17.5% higher than those in the pure larch plantation, respectively. Content of total potassium and available potassium in ash/soybean intercropping system were 56.4% and 21.8% higher than those in the pure ash plantation, respectively.

Discussion and conclusions

A given soil function is supported by a number of soil attributes, while any given soil property or process may be relevant to several soil attributes and/or soil functions simultaneously (Harris *et al*. 1996; Burger *et al*. 1999).

Forest soil physical properties are affected by its gaseous, liquid and solid phases. When these three parts are in a proper ratio, the soil characters will be sustainable for the growth of trees. To some extent, woody species/soybean intercropping systems could be considered as one kind of mixed forest (Butterfield 1993). There was more aggregate structure and more loose arrangement of the soil particle, especially in the soil top layer at the woody tree species/soybean intercropping systems than those of the pure plantations (Wang *et al.* 1994; Nissen 2001). Therefore, the soil bulk density was less than that of pure plantation (Wang *et al.* 1994). The soil bulk density of the pure larch was less than that of the pure ash, which was similar to the previous research results by Hu *et al*. (1987), Chen *et al.* (1991) and Wang *et al.* (1994).

Total soil porosity is the parameter of the gas and water movement in the soil. The soil saturation capacity was improved in the intercropping systems of trees and crops. Soybean root system was concentrated in the soil top layer of 0−20cm (Wu 1995), while the two-year larch and ash root systems mostly concentrated in the depth of 0−40cm (Wang *et al.*1994). After intercropping, root biomass of the unit area increased, which resulted in the soil pore's increment.

Though the physical properties of soil are important, nutrient contents in soil are more important for the soil fertility. Better physical properties, including moisture capacity and aeration, are important for the activities of soil microorganism and the transformation of the nutrients (Perry 1989). Soil organic matter plays an important role in almost every soil function (Henderson 1995; Harris *et al*. 1996; Nambiar 1997; Powers *et al*. 1998).

Available nutrients primarily come from the decomposable material of the soil organic matter (Barber 1984; Wang *et al.* 1994; Yu 1996). Soil organic matter is decomposed by microbes. The changes of the kinds and quantities of the microbes that take part in the degradation of the soil organic matter can indirectly affect the content of organic matter in soil (Cheng 1994).

The results in this paper showed soil organic matter amount in larch/soybean and ash-soybean intercropping was more than that in the corresponding pure larch and ash plantation. It may be attributed to the microbial kinds and quantities that have been changed after intercropping. Soybeans fix nitrogen from the air via a symbiotic relationship with Rhizobium bacteria. The process will increase the mineral soil nitrogen content, in the other hand, it also benefit for neighboring plants (Kuepper *et al*. 2001; Cheng 1994; Wani *et al*. 1995; Vance 1998). The results in this paper showed that the change of total nitrogen content of mineral soil in ash/soybean intercropping system was more significant than that in larch/soybean intercropping system. The change of hydrolyzable nitrogen content at all plots was consistent with that of total nitrogen, which indicated that the hydrolyzable nitrogen content was mainly affected by total nitrogen content.

The total phosphorous content in the depth 0−20cm of larch/soybean and ash/soybean intercropping systems was 4.8% and 7.4% lower than that of the corresponding pure plantation for larch and ash, respectively. Soybean consumed a large quantity of phosphorous during the growing season, which directly resulted in the decrease of total phosphorous content in mineral soil (Haggar 1991; Wu 1995).Mineral soil available nutrient content was the key indicator for the soil validity (Perry 1989). Available phosphorous content in larch/soybean and ash/soybean intercropping systems was higher than that in the corresponding pure plantation for larch and ash. That showed woody species/soybean intercropping systems increased available phosphorous content. It also showed that the decrease of total phosphorous content in mineral soil did not mean the decrease of available phosphorous content in mineral soil.

The changes of total potassium and available potassium content may attribute to the availability of mineral soil potassium, which was affected by the growth of the trees. The catabolites of the litter layer and root secretion played a main role in activation of mineral soil potassium during the process of the tree growth (Yu 1996), which improved indirectly the availability of potassium.

From the results above, the soil physicochemical characters were improved after intercropping trees with soybean. As for the long-term effects of intercropping with soybean on woody tree species, it needs further study. As a short-term soil management method, woody species/soybean intercropping can be practiced in mountain land, especially after newly clear-cutting.

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References

Alene, S.E., Grimshaw, H.M., Parkinson, J.A., *et al.* 1974. Chemical analysis of ecological materials [M]. New York: John Wiley and Sons., p52.

Bao Shidan. 2000. Methods of soil agricultural analysis [M].Beijing: China

Agricultural Publishing House, p101–103. (in Chinese)

Barber, S.A. Soil nutrient bioavailability: A mechanistic approach [M]. New York: John Willey and Sons., p243.

Blakemore, L.C., Searle, P.L. & Daly, B.K. 1987. Methods for the chemical analysis of soils [R] New Zealand Soil Bureau Scientific Report 80, New Zealand, Lower Hutt: New Zealand Society of Soil Science, p103.

Burger, J.A., Kelting, D.L. 1999. Using soil quality indicators to assess forest stand management [J]. For. Ecol. Manage., **122**: 155–156.

Butterfield, J. 1993. Effect of mixed-species trees planting on the distribution of soil invertebrates [C]. In: Cannell MGR, Malcolm DC and Robertson PA (eds) The Ecology of Mixed-species Stands of Trees, Oxford: Blackwell, p255–265.

Chen Xiquan, Guo Qiuhui, Wang Zhengquan. 1991. Physical and chemical properties of soils in larch and larch-juglans mandshurica mixture stands [J]. Journal of Northeast Forestry University, **19**(3): 258–274. (in Chinese)

Cheng Dongsheng. 1994. Resource microbiology [M]. Harbin: Northeast Forestry University Press, p32. (in Chinese)

Guan Jiyi. 1988. Experiment course of forestry soil [M]. Harbin: Northeast Foretry University Press, p57. (in Chinese)

Haggar, J.P. 1991. The effect on land P dynamics of introducing legume trees to tropical annual cropping system [D]. Ph.D.thesis, United Kingdom: University of Cambridge, p205.

Harris, R.F., Karlen, D.L., Mulla, D.J. 1996. A conceptual framework for assessment and management of soil quality and health [C]. In: Doran, J.W., Jones, A.J. (Eds.), Methods for Assessing Soil Quality. USA: Soil Society of America, Special Publication, **49**: 61–82.

Henderson, G.S. 1995. Soil organic matter: a link between forest management and productivity [C]. In: McFee, W.W., Kelly, J.M. (Eds.), Proceedings of the 8th North American Forest Soils Conference on Carbon Forms and Functions in Forest Soils. Soil Sci. Soc. Am., Madison, WI, pp.419–435.

Hu Yihui., Chen Lingzhi., Chen Qinglang. *et al*. 1987. Studies on litter decomposition between plantations [J]. Acta Phytoecologica Sinica, **11**(2):124–132. (in Chinese)

Kuepper, G. & Dodson, M. 2001. Companion Planting: Basic Concepts and Resources. Berkeley, California: ATTRA (Appropriate Technology Transfer for Rural Areas) Publication. #IP125–71.

Li Wenxue, Li Long, Sun Jianhao, *et al.* 2005. Effects of intercropping and nitrogen application on nitrate present in the profile of an Orthic Anthrosol in Northwest China [J]. Agriculture, Ecosystems and Environment, **105**: 483–491.

Liu Guangsong, Jiang Nenghui, Zhang Liandi, *et al.* 1996. Analysis of soil physical and chemical properties and description of soil profiles [M]. Beijing: China Standard Press, p85. (in Chinese)

Luo Ruying. 1983. Forest soil: Questions and Methods [M]. Beijing: Science Press (in Chinese), p23.

Massimo, M. & Marco, M. 2003. Essential oil yield in peppermint/soybean strip intercropping [J]. Field Crops Research, **84**: 229–240.

Nambiar, E.K.S. 1997. Sustained productivity of forests as a continuing challenge to soil science [J]. Soil Sci. Soc. Am. J. **60**: 1629–1642.

Nissen, T.M., Midmore, D.J. Keeler, A.G. 2001. Biophysical and economic tradeoffs of intercropping timber with food crops in Philippine uplands [J]. Agricultural Systems, **67**: 49–69.

Powers, R.F., Tiarks, A.E., Boyle J.R. 1998. Assessing soil quality: practicable standards for sustainable forest productivity in the United States [C]. In: Adams, M.B., Ramakrishma K., Davidson, E.A. (Eds.), The Contribution of Soil Science to the Development and Implimentation of Criterial and Indicators of Sustainable Forest Management. Madison: Soil Sci. Soc. Am. Special Publication, No. **53**: 53–80.

Wance, C.P. 1998. Legume symbiotic nitrogen fixation: agronomic aspects [C]. In: Spaink, H.P., *et al*. (Eds.), The Rhizobiaceae. Dordrecht: Kluwer Academic Publishers, p509–530.

Wang Qingcheng, Wang Chunli, Zhang Guozhen. 1994. Physical and chemical properties of soils within larch and larch-ash mixture stands [J]. Journal of Northeast Forestry University, **22**(6): 24–29. (in Chinese)

Wani, S.P., Rupela, O.P., Lee, K.K. 1995.Sustainable agriculture in the semi-arid tropics through biological nitrogen fixation in grain legumes [J]. Plant Soil, **174**: 29–49.

Wu Zuying, Jia Jinliang. 1995. Study on young fir forest-soybean intercropping and its integrative effects [J]. Journal. Zhejiang Forestry. Science. & Technologr. **15**(3): 54−59. (in Chinese)

Yu Xingjun. 1996. Growth and interspecific nutrients relation within larch-ash mixture stand [M]. Master thesis. Harbin: Northeast Forestry University Press, p31.

Zhang Wanru, Xu Bentong 1986. Oreitation methology for forest soils [M].Beijing: China Forestry Publishing House, p22. (in Chinese)