African Journal of Biotechnology Vol. 10(78), pp. 17997-18004, 7 December, 2011
Available online at http://www.academicjournals.org/AJB
DOI: 10.5897/AJB11.2825
ISSN 1684–5315 © 2011 Academic Journals

Full Length Research Paper

The relationship between ancient trees health and soil properties

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Accepted 11 November, 2011

This study focuses on the representative ancient trees including *Pinus bungeana* Zucc.ex Endl., *Platycladus orientalis* (Linn.) Franco, *Pinus tabulaeformis* Carr., *Sophora japonica* Linn. in the Beijing City as these trees have increasingly high cultural and aesthetic values. We employed tree visual assessment to evaluate the level of health of ancient trees. This study also analyzed soil physical and chemical properties, and the relationship between the ancient trees health level and their soil physical and chemical properties. These results show that among the 110 ancient trees evaluated, 3.64, 29.09, 60.00, 5.45 and 1.82% were found for healthiest, healthier, healthy, unhealthy and dying trees, respectively. The average soil water content was recorded as 10.62%, while the mean bulk density was recorded as 1.20 g/cm^3, and the average compactness was recorded as 3.94 kg/m^2. The average total porosity, mean capillary porosity and medial non-capillary porosity of soil samples were found as 20.72, 11.77 and 8.96%, respectively. The mean soil pH, organic matter, total N, total P, total K, available N, available K and available P were 7.79, 3.41%, 1.41 g/kg, 0.99 g/kg , 16.48 g/kg, 88.90 mg/kg, 335.97 mg/kg and 15.36 mg/kg, respectively. All soil physical properties had medium variant characteristic. The soil pH and total K had low variations and the soil organic matter, total N and available N had medium variations. Other chemical indicators such as total P, available P and available K varied strongly. Our results indicate that with an increasing health level of the ancient trees, the soil bulk density decreased, and the soil compactness, total K, available K, total P and available P increased, however, soil pH and organic matter remained unchanged. This research provides the scientific basis for the rejuvenation and management of the ancient and popular trees in cities like Beijing.

Key words: Ancient trees health, soil properties, Beijing.

INTRODUCTION

The general age of the tree is more than a hundred years and is called ancient trees. Those rare species or historical value, with memorable names can be called famous trees (BMBLF, 2007). When the age is more than 300 years, the ancient tree belongs to the first ancient tree, but when the age is from 100 to 300 years, it is named the second ancient tree with (BMBLF, 2007).

Ancient and famous trees are not merely only a witness of long history but also a symbol of social civilization (Hu et al., 2004). Soil acts as a matrix of root growth and development; efficiently providing water and nutrients for plant growth and development, and harmonizing a relationship among these materials, and exerting the supply of soil nutrients for biomass production (Wang et al., 2000).

The soil chemical properties function as water retention and dissolution of mineral elements, as well as help plant rooting and moisture absorption of plant roots system, and consequently affecting soil fertility condition and plant growth. Soil chemical properties play an invaluable role for the healthy growth of ancient trees (Liu et.al, 2003).

There have been increasing interests in the research on soil chemical properties because of its significance in

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keeping ancient trees healthy. The changes in soil chemical properties, including the dynamics of soil nutrients have been a concern amongst forest scientists since the mid-nineteenth century (Luo, 1983).

These studies have been carried out on health assessment of ancient trees, including the application of numerical methods such correlations which discuss in detail the technical supports that help in achieving the best possible health assessment of the ancient tree communities. Mattheck and Breloer (1994) presented the tree visual assessment method for evaluating the degree of health and risk of trees, and diagnosed tree structure and mechanical strength. An ultrasonic speed of the standing tree's diameter was evaluated using ultrasonic techniques, where the ultrasound was applied to detect a decay or void in the tree so that the relevant information could be obtained by comparing the normal velocity value (normal speed of standard wood) with the measured velocity value of the perfect trees (Mattheck and Breloer, 1994; Sandoz, 1994). The ultrasound instrument integrated with the sectional image techniques can detect a rotten beech cross-section (Martinis, 2004). In 1985, Rinn used a technique to evaluate the decay of wooden poles by using a borer to drill into the pith (Rinn, 1994). In 1992, the resistograph technique was developed as a decay detection method (Rinn et al, 1996). Later, Hokkanen et al. (1995) analyzed the relationship between soil and trees by detecting properties of top soil in a boreal Scots pine stand. At the same time, Holford (1997) analyzed the absorption of plants soil for phosphorus and indicated that phosphorus is the most important nutrient element (after nitrogen) limiting agricultural production in most regions of the world.

This research shows that pH, organic carbon, total phosphorus, total nitrogen, thickness, texture, and clay content are used directly in environmental process modeling including global climate change models. These models are then used to extend predictions continentally by applying the rules derived to the exhaustively available environmental predictors (Henderson et al., 2005). Stoeckel and Miller-Goodman (2001) suggested that the micro-topography and depth has a dynamic effect on the seasonal nutrient of soil in forest beach area. Similarly, She and Shao (2009) analyzed the soil organic carbon and total nitrogen using spatial variation approach China Loess Plateau Watershed. However, it has been shown that intensified land management practices seriously affect the SOC status of the soil. Tran (2005) employed a quantitative analysis to assess the influence of the application of saw dust on corn yield and the soil chemical properties. Figueiredo and Matosinho., (1975) analyzed the connection between yield of three rows of planted corn and soybean, and nutrient uptake as well as root distribution relationships with soil physical and chemical properties (Figueiredo, 1975).

Beijing City contains some of the most ancient and famous trees of China (Rinn et al., 1996). A survey showed that more than 10000 ancient trees of as old as 300 years are protected under the first-class plant cover protection in Beijing, while more than 40,000 trees of more than 200 years old are protected under the state's second-class plant cover protection, which include *Platycladns orientalis* (Linn) Franco, *Pinus tabulaeformis* Carr., *Sophora japonica* Linn. and *Zizyphus jujuba* (Huang, 2000). This study aimed to analyze the soil chemical properties in four species; *Pinus bungeana* Zucc.ex Endl., *Platycladus orientalis* (Linn.) Franco, *Pinus tabulaeformis* Carr. and *Sophora japonica* Linn. in the Beijing region, and explore the relationship between the health of ancient tree and their soil chemical properties followed by providing a comprehensive synthesis on rejuvenation of ancient trees and soil improvement.

MATERIALS AND METHODS

Study sites description

This study site, Beijing (115°25' -117°30'E, 39° 28 '-41°05'N) is located on the west coast of Pacific, and at the northern tip of North China Plain. It covers an area of 16807.8 km^2, including 39% flat land and 61% mountainous area. Beijing has the semi-humid climate of warm temperate zone with four distinct seasons, featuring short in spring and autumn and long in summer and winter. Its annual temperate averages 12℃ (53°F) and the annual average precipitation is 507.7 mm (Luo, 1983).

The oldest trees are distributed in the temple of the suburb in Beijing, or in historic site of parks of the city. According to the distribution of types and location of ancient trees in Beijing, four sampling sites were established in the Qingwangfeng, Yongling, Xishan and urban region of the inner second-ring road. Among which Qingwangfeng and Yongling belong to forest area. Xishan belongs to the city park and urban region belongs to city street trees. The ancient trees are uniformly distributed in Qingwangfeng and Yongling, but are randomly distributed in Xishan forest farm and urban region.

Field survey and samples collection

Based on field investigation of the growth environment, site conditions and the morphological characteristics of ancient trees in study sites, soil samples were collected in the following format: "sampling area - sample line - sample plot". For each collected sample of the ancient tree, it was extracted from the range of 120℃ under the shadowing area of tree crown.

The 110 soil samples in this study were extracted from *Pinus bungeana* Zucc.ex Endl., *Platycladus orientalis* (Linn.) Franco, *Pinus tabulaeformis* Carr. and *Sophora japonica* Linn. Soil sampling were dug in each tree, the thickness of soil layer was 0 to 30, 30 to 60 cm, respectively. Two layers samples of each tree were mixed with roots and stones removed by hand. The soil samples were air-dried and sieved (2 mm). Soil water content was determined by drying method, soil bulk density was determined by cutting ring, and capillary porosity was done for the cutting ring and soaking method. Total soil porosity was calculated based on the proportion of soil and soil bulk density, non-capillary porosity from the total porosity and capillary porosity was calculated. Total N was measured using sulfate-perchlorate acid heating digestionazotometer distillation titration method, available N was measured using the alkaline

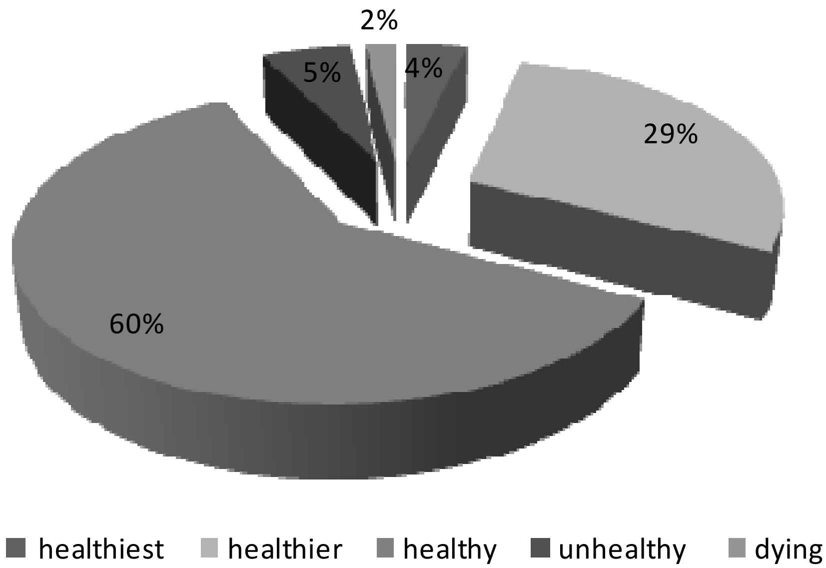

Figure 1. Statistics of heath assessment of Beijing important ancient trees.

Table1. Summary statistics for soil physical properties.

Soil Properties	Minimum	Maximum	Mean	SD[a]	CV[b]
Soil water content (%)	4.38	45.02	10.62	3.64	34.27
Bulk density (g/cm^3)	0.54	1.69	1.20	0.28	23.33
Compactness (kg/m^2)	0.20	5.80	3.94	2.12	53.81
Total porosity (%)	10.28	52.26	20.72	9.62	46.43
Capillary porosity (%)	5.19	46.06	11.77	4.62	25.55
Non-capillary porosity (%)	1.70	21.80	8.96	5.19	57.92

[a]Standard deviation and [b]coefficient of variation

hydrolysis diffusion method, total P was measured by sulfate-perchlorate acid heating digestion-MoSb coloimetry and total K was measured by Flare Photometer (Lu, 1999)

Calculation and data analysis

On the ground of investigation and statistics on soil samples for ancient trees, the analysis on correlation of various indicators and the influence on type and level of various species to soil chemical properties of ancient trees were conducted by using the software including SPSS17.0 and Sigmaplot11.0.

RESULTS

Evaluation on health of ancient trees

In the appearance assessment, one of the tree visual assessments proposed by Ming-Hsun Chans, was employed to evaluate the health level of the ancient trees (Zhan et al., 2007). The health level of ancient trees was assessed by tree vigor, tree form, extension length of branch, tree top mortality, foliage density and bark condition. The ancient trees' health level was evaluated by the ratio of total metrics points and number of metrics, and was classified into five levels: healthiest, healthier, healthy, unhealthy and dying, respectively. The analysis of 110 trees showed that the percentage of healthy, healthier, unhealthy and dying trees were 3.64, 29.09, 60, 5.45 and 1.82%, respectively (Figure 1).

Soil physical and chemical properties of ancient trees analysis

The soil physical properties were used including the soil water content, bulk density, compactness, total porosity, capillary porosity and non-capillary porosity. In Table 1, the mean indicators were shown as follows: About 10.62% of water content, 1.20 g/cm^3 of bulk density, while the effective range of soil water content were 4.38 to 45.02%, and bulk density were 0.54 to 1.69 g/cm^3. The coefficient of variation (CV) of the water content and bulk density were recorded as 34.27 and 22.50%, respectively (Table 1). Within the soil depth of 30 cm, the mean and

Table 2. Summary statistics for soil chemical properties.

Chemical property	Minimum	Maximum	Mean	SD[a]	CV[b]
PH	6.20	8.51	7.79	.56	7.15
Organic matter (%)	0.66	11.65	3.41	2.8	83.93
Total N (g/kg)	0.28	4.29	1.41	1.03	73.12
Total K (g/kg)	11.21	19.77	16.48	1.58	9.57
Total P (g/kg)	0.16	9.00	0.99	1.31	131.86
Available N (mg/kg)	21.40	268.00	88.90	64.20	72.21
Available P (mg/kg)	1.00	143.00	15.36	25.55	166.32
Available K (mg/kg)	93.10	1792.70	335.97	417.01	124.12

[a]Standard deviation and [b]coefficient of variation

Table 3. Correlation of different soil physical properties.

Physical properties	Soil water content	Bulk density	Compactness	Total porosity	Capillary porosity	Non-capillary porosity
Soil water content	1	-	-	-	-	-
Bulk density	-.572**	1	-	-	-	-
Compactness	.947**	-.487**	1	-	-	-
Total porosity	.865**	-.431**	.829**	1	-	-
Capillary porosity	.877**	-0.164	.862**	.876**	1	-
Non-capillary porosity	.385**	-.618**	.344*	.660**	0.216	1

**Represent the degree of correlation by 0.01（two-sided test); * represent the degree of correlation by 0.05（two-sided test）.

CV of the compactness were 3.94 kg/m^2 and 53.81%, and the range was 0.20 to 5.80 kg/m^2 (Table 1). The mean of soil porosity, non-capillary porosity and capillary porosity were 20.72, 11.77 and 8.96%, respectively.

Table 2 shows the mean soil pH of all ancient trees comprising 7.79 within 6.20 to 8.51. The soil pH reaction levels of soil samples were found as relatively weak, acidic and alkaline in nature, and the average soil pH was alkaline in nature. According to the criteria proposed by Ma et al. (2005), the mean of the organic matter was 3.41% ranging from 0.66 to 11.65% (Table 2). The mean of the total N was 1.41 g/kg ranging from 0.28 to 4.29 g/kg. Similarly, the mean of total P was 0.99 g/kg ranging from 0.16 to 9.00 g/kg. Soil of the total K ranged from 11.21 to 19.77 g/kg with the mean 16.48 g/kg. The mean of the available N was 88.90 mg/kg ranging from 21.41 to 267.98 mg/kg, representing from the poorest to the richest and average at the middle (Table 2). The mean of the available P was 15.36 mg/kg, ranging from 1.35 to 143.20 mg/kg. The soil available P was manifested from the poorest to the richest, and was above average level. The mean of the available K was 335.97 mg/kg ranging from 93.11 to 1792.71 mg/kg; the level appeared between poorest and the richest. The values for coefficient of variation for soil pH, organic matter, total N, total P, total K, available N, available P, available K are represented as 7.15, 83.93, 73.12, 131.86, 9.57, 72.21, 166.32 and 124.12%, respectively (Table 2). The CV was regarded low, medium, medium, high, low, medium, high and high, respectively.

Correlations of soil physical and chemical properties

Table 3 shows that compactness, soil water content and bulk density have a significant correlation with several physical indicators. Compactness was positively correlated with total porosity, capillary porosity and soil water content, respectively ($r > 0.8$, $P > 0.01$) and was negatively correlated with bulk density($r < -0.4$, $P > 0.01$). Similarly, the soil water content positively correlated with compactment total porosity, capillary porosity and non-capillary porosity ($r > 0.3$, $P > 0.01$), and negatively correlated with bulk density ($r < -0.4$, $P > 0.01$). However, bulk density was significantly and negatively correlated with total porosity, non-capillary porosity, soil water content and compactness, respectively ($r < -0.4$, $P > 0.01$). These results indicate that compactness, water content and bulk density can be initially selected as soil physical indicators to evaluate the health level of ancient trees.

Table 4 shows that soil pH, organic matter and total K

Table 4. Correlation of different soil chemical properties.

Chemical indictor	pH	Organic matter	Total N	Total P	Total K	Available N	Available P	Available K
pH	1	-	-	-	-	-	-	-
Organic matter	-.461**	1	-	-	-	-	-	-
Total N	-.730**	.814**	1	-	-	-	-	-
Total P	0.172	0.234	0.097	1	-	-	-	-
Total K	0.1	-.314*	-.294*	-.300*	1	-	-	-
Available N	-.765**	.755**	.968**	0.04	-0.263	1	-	-
Available P	0.267	0.04	-0.134	0.272	-0.055	-0.122	1	-
Available K	.403**	0.163	-0.056	.603**	-.296*	-0.149	.612**	1

** Represent the degree of correlation by 0.01（two-sided test, * Represent the degree of correlation by 0.05（two-sided test）.

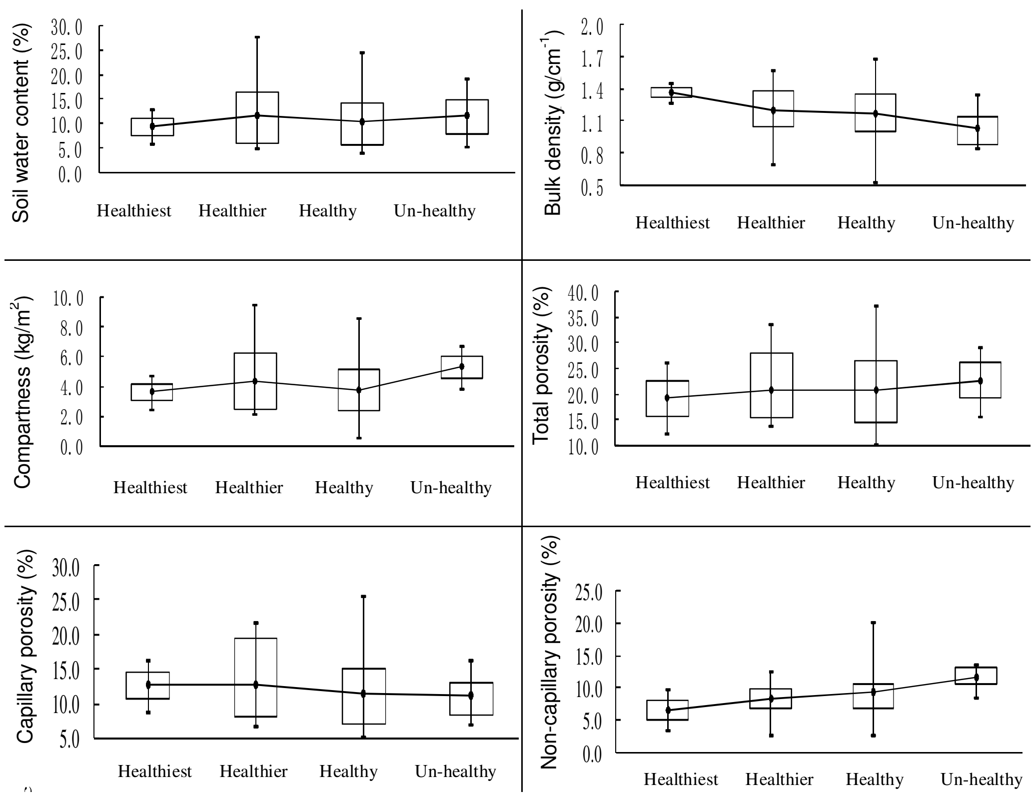

Figure 2. The relationship between soil physical properties and the ancient trees health levels.

were significantly correlated with chemical indicators. For example, total K was negatively related with organic matter, total P, total N, available K (r = -0.314, r = -0.300, r = -0.294, r = -0.296) (p <0.05 and > 0.01), while pH was significantly negatively correlated with organic matter, total N, available N (r = -0.461, r = -0.730, r = -0.765) respectively, but positively correlated with available K (r = 0.403). Organic matter was positively correlated with total N and available N (r = 0.814, r = 0.755). Although it was negatively correlated with total K (r = 0.968). The factors such as pH, organic matter and soil K are selected as diagnostic indicators for health of ancient trees.

Relationships between health level for ancient trees and physical and chemical indicators

This study found the important relationships between ancient trees health level and soil physical properties (Figure 2). The results show ancient trees health level was negatively correlated with the soil physical properties such as total porosity, non-capillary porosity

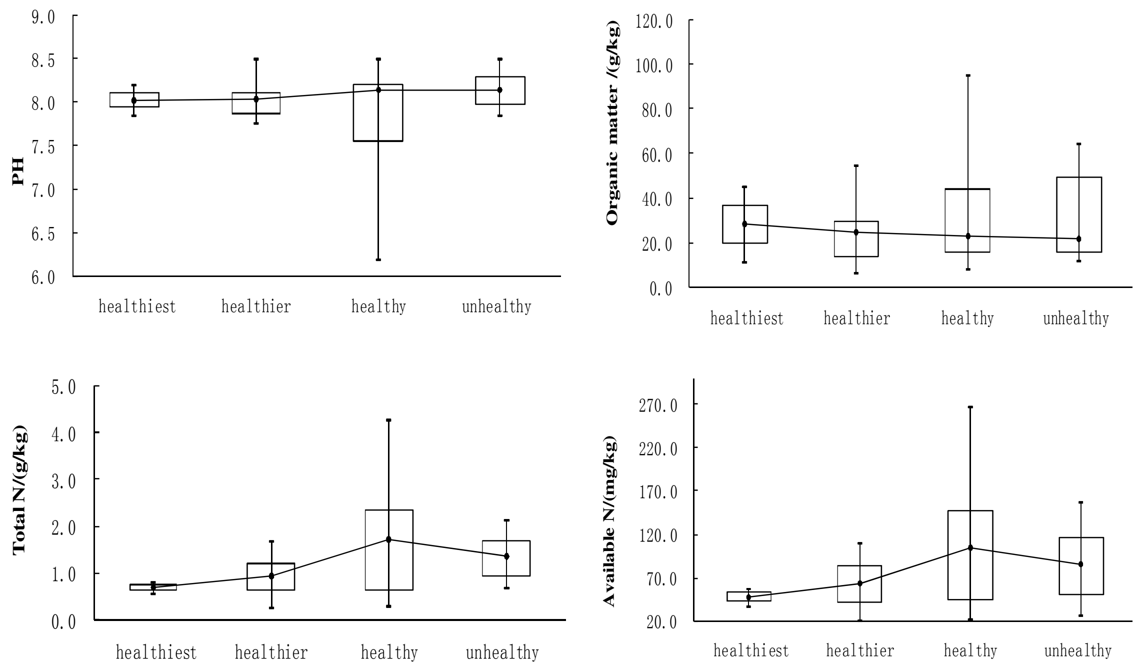

Figure 3. The relationship between soil chemical properties and the ancient trees health levels.

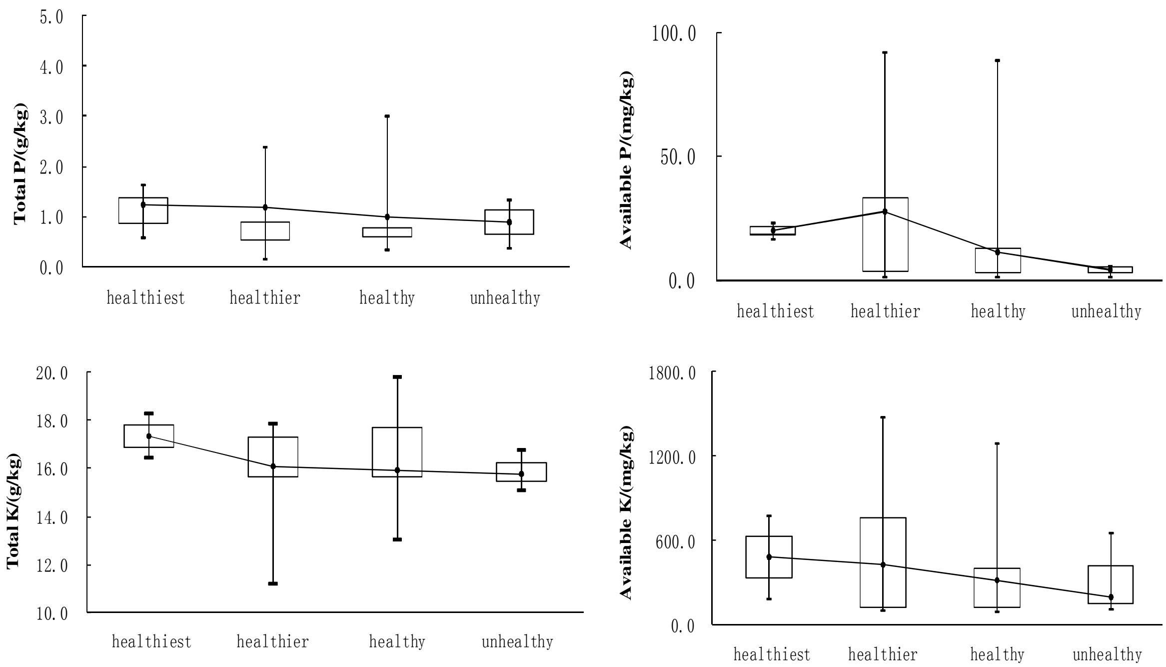

Figure 3. Contd.

and compactness. When the ancient trees health level is increasing with total soil porosity, soil non-capillary porosity and compactness gradually decreased, but the health level inversely associated with capillary porosity and bulk density (Figure 2). Also, it was found that ancient trees health level had no significant correlation with water content.

The relationship between the ancient trees health level and their soil chemical properties are illustrated in Figure 3. No significant correlation between soil pH, organic matter of chemical indicators and the ancient trees health level was recorded. These results show that the ancient trees health level was negatively correlated with the available N and total N, while positively associated with the proportion of the total P, available P, total K and available K. The ancient trees health level was gradually decreased along with the total N and available N increased (Figure 3)

DISCUSSION

The soil porosity exerts direct influence on the distribution of water, heat, gas and fertilizer, closely associated with soil texture, organic matter content, and structure and bulk density, reflecting various soil factors (Zhang et al., 1991). Beside natural factors, artificial disturbance in forest production can also change the condition of the soil porosity (Zheng et al., 2010). On the whole, the indicators condition was demonstrated that small porosity was predominant in soil and soil compactness was relatively high. The main reason for a significant decrease in ancient trees health level from the healthy to unhealthy condition is a low bulk density which is an important indicator of soil physical properties to reflect the state of soil porosity, compactness and soil fertility (Gong et al., 1998). The bulk density can have a direct effect on soil porosity and aeration, influencing the number of ancient tree health attributes including for the plant root growth and biomass accumulation, soil permeability and water retention capacity. The reason behind a poor ancient health as a result of increased soil compactness could be the degree of compactness. As compactness becomes greater, soil hardness becomes harder leading to a rise in mechanical stress in plant roots interpenetrated in soil. Drought and other natural factors can also change soil compactness influencing ground water temperature and soil fertilizer thereby reducing the tree health (Liu et al., 2001; Jiao et al., 2009).

The relationships among soil pH, organic matter, total K and other indicators are common. The change between soil pH and organic matter remained stable (Figure 2) with the change in the ancient trees' health level from healthy to unhealthy, which is possibly due to the reflection that the soil pH is synthesized by soil chemical properties widely affected by soil microbial activities, composition and decomposition of organic matter, morphology transformation and release of N, P and other nutrients (Fu and Wang, 2007). The soil pH measurement is an important diagnostic indicator of plant production. For example, the soil pH in a wetland becomes acidic when the arid soil is alkaline. The ancient trees health level can be improved by regular monitoring of soil pH. Soil organic matter contains not only plenty of carbon providing energies for the vital activity of soil microbes, but also all kinds of essential nutrients for the plant growth. Furthermore, it can constantly supply essential nutrients for ancient trees in the long-term, by affecting a loose soil formation, improving fertility and preserving capability and buffering consequently the growth of the trees. The role of soil media content has been a focal point for the study of tree health in recent time (Hao, 2006). For example, when the total K declines gradually, the ancient trees' health level changes from healthy to unhealthy conditions indicating that the total K concentration in soil is a critical component of organic matter for crop production (Jia and Xing, 2010). In our result, the soil chemical properties and the ancient trees health level were not as obvious as we expected. Firstly, this may be due to biases occurred in sampling. Secondly, the optimum range of the basic nutrient contents of soil was different in growth of various ancient trees. Finally, the soil chemical properties was influenced by climatic variables temporal and spatial scales

ACKNOWLEDGMENTS

This research was supported by the Forestry Public's Welfare Project of the State Forestry Administration of China (200904019),the Natural Science Foundation of China (41001024), The National's 12th five-year Science and Technology Plan Foundation Project (2011BAD38B05), Doctoral Fund of the Ministry of Education (20100014120011) . We would like to warmly thank all the reviewers that have contributed to this paper by their constructive comments.

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