Soil fertility affected by long-term application of chemical fertilizers in orchards of Chinese hickory (*Carya Cathayensis*) grown in limestone soils

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Abstract
The Distribution of Chinese hickory (*Carya cathayensis*), a popular nut food tree species, is confined tp mountain regions in Zhejiang and Anhui provinces of China. A 2-year field survey was carried out to examine soil fertility status and nut yield of Chinese hickory grown in limestone soils. Soil samples were collected in March prior to the first application of fertilizers. Results showed that nut yield variation between years could be as high as about 50%, and it differed much more between orchards (from low yield of less than 3 kg/tree to high yield of 9-10 kg/tree). Soil analysis showed that soil organic matter content (SOM) (9.0-54.1 g/kg), pH (4.6-8.2), and soil available nitrogen (N) (50.8-236.2 mg/kg), phosphorus (P) (0.5-27.4 mg/kg) and potassium (K) (24.8-298.2 mg/kg) varied greatly between different orchards. More than 60% of the soils were lower than 20 g/kg of SOM and 70% of the soils with pH <6.0. And 47% , 88% and 47% of the orchards with soil available N, P and K were below 100 mg/kg, 10 mg/kg and 80 mg/kg, respectively. There is an urgent need to optimize soil management of the Chinese hickory orchards to improve soil conditions.

Key Words
Carya cathayensis, limestone soil, soil fertility, soil acidification, nut yield

Introduction
Chinese hickory (*Carya cathayensis*) is a deciduous tree species. Its distribution is confined in mountain regions in Zhejiang and Anhui provinces of China, in 29 - 30^o N, 118-120^o E (Li and Qian 1992). More than 90% of the trees are grown in limestone soils with shallow stony soil profiles due to the steep slope landscape. It is one of the two popular nut food tree species belonging to *Carya* genus, another is American pecan (*Carya illionoinensis*) (Li and Qian 1992). The kernel of the Chinese hickory nuts is a reputed healthy food in China, and the quality of kernel is considered best in nuts from tree grown in limestone soil, which is pH in neutral to calcareous and rich in soil organic matter content (SOM), in addition to rich in some nutritional trace elements to human such as selenium, copper and zinc (Lü 2005). The trees that produce the majority of the nuts at present are about 60 - 70 years old. The Chinese hickory trees were almost carelessly managed before 1980, and the practice of chemical fertilizer application became a common measure with the development of economic conditions and market demand of the nut product since then. The nut yield was increased remarkably and its variation between on-year and off-year was reduced greatly with fertilization (Hong *et al.* 1997; Li and Qian 1992). Yet, studies of soil fertility and fertilization affecting tree growth and nut yield and quality are very few. Only a few field surveys were conducted more than 10 years ago (Hong *et al.* 1997; Li and Qian 1992), and results from fertilizer research experiments undertaken in field or controlled conditions have not been reported. A better understanding to manage the orchards of Chinese hickory is therefore not available. Due to its highly economic profit of nut production, intensive management to the orchards is common, such as high rate of fertilizer application, but without any research results to provide feedback. Only chemical fertilizers, mostly the complex fertilizer (15-15-15) at present, are applied. Poor growth of the trees such as dieback of the shoot tips appeared recently in some areas. The shoot-tip dieback was caused by root disease. This was considered to be due to soil degradation, a consequence of long-term application of chemical fertilizers. Therefore, a soil survey to understand the status of soil fertility is necessary to maintain sustainable production of the Chinese hickory orchards. In the present study, a 2-year field survey from 2007 to 2008 was carried out to examine soil fertility and the response of nut yield to fertilizer application.

Materials and methods

Location of field survey and data collection

The Chinese hickory orchards were located in a mountain area, in DaoShi town of Lin'an city, Zhejiang province, China, where orchard occupies 50% and produce 50% of total nut yield over in China (Wu *et al.* 2003). The orchards cover 6000 ha over a total land of 7000 ha in this town. This survey was based on our previous field experiment (Tong *et al.* 2009) and an investigation of the farmers in year 2006. Twenty orchards were included in the field survey. All the Chinese hickory trees were grown in the limestone soils and shoot-tip dieback in the trees was absent. The trees, mostly 12 – 15 metres at height, were at similar age of about 60 -70 years old but managed by different farmers. Soil samples were collected in early spring (March) in years of 2007 and 2008 prior to the first application of fertilizers. The corresponding nut yield was recorded after fruit harvest (early September). The fertilizer application rate and tree number in each orchard were also recorded. Complex fertilizer (15-15-15) was applied by these farmers. The amount of applied fertilizers per tree was calculated. The soil samples were air dried and passed 2 mm mesh for soil pH and available nutrient analysis, and 1 mm for SOM analysis.

Chemical analysis

Soil organic matter content was measured with wet digestion method (dichromate oxidation method, Mebius *et al.* 1960). Soil pH was determined by a pH metre with a soil-to-water ratio of 1 : 5. Soil available N, expressed as alkali-hydrolysable N, was determined by the method of Lu (2000). Olsen P method was used to test the soil available P, and soil available K was extracted by ammonium acetate and determined by flame photometry. All detailed procedures are in Lu (2000).

Data analysis

The data were subjected to one-way ANOVA analysis using the SPSS 10.0 software.

Results and discussion

The weather in March is still cool in the mountain area and the tree leaves of Chinese hickory are not open until late April (Li and Qian 1992). The farmers usually start to the first fertilizer application in late March. So the soils collected in March before the fertilizer application might be meaningful to represent basic information of the soil properties in long-term for Chinese hickory production. Soil analysis results showed that the chemical properties of SOM and pH between years were significantly changed, whilst soil available N, P and K were not (Table 1). Soil pH from 4 of the 20 orchards decreased by 1 unit from year 2007 to 2008 although the soil samples were collected at the same time of each year. This needs to be further investigated. In fact, not only the soil available nutrients but also soil pH, changed greatly with growth seasons (Tong *et al.* 2009). In the field experiment (Tong *et al.* 2009), we found that soil pH was 5.4 in May and decreased to 4.6 in August, but SOM did not change during the growth period from May to September (prior to fruit harvest). Moreover, the soil properties differed much greater between different orchards (Table 1). The minimum and maximum values of SOM and soil available N, P and K differed several times by more than 10 times. These differences apparently result from long-term management by different farmers. In general, the soil properties were so profoundly influenced by farmers management so that the soil fertilities differed remarkably. According to a local soil survey report, the limestone soils in the study area had SOM 22 - 50 g/kg and pH > 6.0 in the early 1980's (from an unpublished document in "Lin'an Soil", Lin'an Agricultural Bureau, 1984).

Table 1. Variations of different soil properties between year 2007 and year 2008 (ANNOVA analysis).

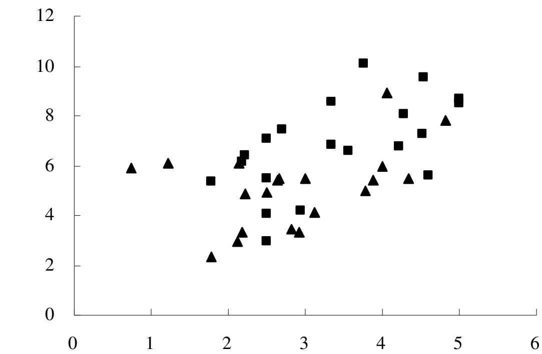
Soil properties	Year	Mean	Std. Deviation	Minimum	Maximum	F test	Sig.
SOM (g/kg)	2007	16.73	4.52	10.05	26.03	5.231	0.000
	2008	28.16	14.11	9.04	54.08		
pH	2007	6.19	0.84	5.00	8.15	9.932	0.004
	2008	5.43	0.49	4.61	6.82		
Available N (mg/kg)	2007	126.47	34.61	86.63	195.13	0.164	0.688
	2008	119.70	57.18	50.75	236.25		
Available P (mg/kg)	2007	3.02	3.40	0.50	13.35	2.147	0.152
	2008	5.90	7.00	1.50	27.40		
Available K (mg/kg)	2007	91.60	32.02	59.25	190.00	0.005	0.942
	2008	92.96	68.37	24.75	298.25		

However, in the present survey, 60% of the soils had less than 20 g/kg of SOM and 71% of the soils had pH <6.0, and some of the soils had extremely severe conditions (SOM <10 g/g, pH <5.0) (Table 2). The occurrence of tree shoot-tip dieback, which was caused by root rot disease, was considered to be due to a consequence of soil degradation. One of the features was said to be that the microbial population of root rot disease developed in soil environment with long-term application of chemical fertilizers, because the shoot-tip dieback symptom had not been noticed in the Chinese hickory orchards before the popular use of chemical fertilizers. The strongly acidified soils induced by long-term fertilizer application might be favourable for root rot disease development. The young trees would die in a few years if they were transplanted in the same soil as the shoot-tip dieback tree are grown on. The incidence of shoot-tip dieback increased quickly in Chinese hickory orchards recently. The lowered soil pH may be one of the key factors which impair the soil conditions for the growth of Chinese hickory trees, for the natural distribution of this species is on the slightly acid to calcareous soils (Li and Qian 1992).

Table 2. Distributions of different soil properties over 20 Chinese hickory orchards investigated in 2007-2008 (expressed as percentage, %).

Soil properties	Grade 1	Grade 2	Grade 3	Grade 4
OM (g/kg)	<10	10-20	20-30	>30
%	10.0	50.0	22.5	17.5
pH	<5.0	5.0-6.0	6.0-7.0	>7.0
%	9.7	61.3	25.8	3.2
Available N (mg/kg)	<80.0	80.0-100.0	100.0-200.0	>200.0
%	22.9	14.3	57.1	5.7
Available P (mg/kg)	<5.0	5.0-10.0	10.0-20.0	>20.0
%	74.3	14.3	5.7	5.7
Available K (mg/kg)	<50.0	50.0-80.0	80.0-120.0	>120.0
%	11.1	36.1	41.7	11.1

Many of the orchards were also low in soil nutrients: 47%, 88% and 47% of the orchards had soil available N, P and K less than 100 mg/kg, 10 mg/kg and 80 mg/kg, respectively (Table 2). In addition to the different rates of fertilizer applied by farmers (Figure 1), this could also be largely attributed to the nutrient runoff especially after the fruit harvest in early September and to soil P fixation. Prior to the fruit harvest, the grasses under the trees in the orchards were all removed either by hands or herbicides, and the fruits in the tree were knocked down with a pole by hand at harvest. As a result, the soils were strongly disturbed and were of great risk of soil erosion in the sloping land especially after leaf drop in autumn and weather conditions.



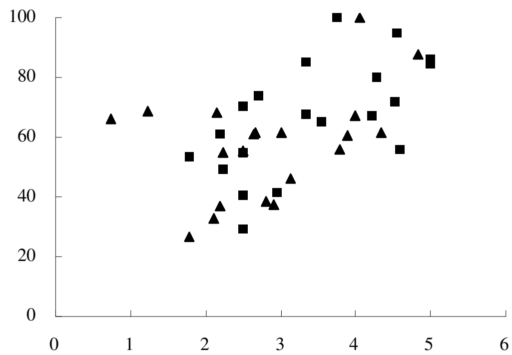


Figure 1. Response of nut yield (Left: kg/tree; Right: relative yield expressed as percentage) to fertilizer application (kg/tree). ▲ -- year 2007; ■ – year 2008.

The rates of applied fertilizer varied widely; some farmers used less than 2 kg/tree and many used more than 4 kg/tree. Nut yield increased strongly with the increase of fertilizer application rate although there existed a great variation between years (Figure 1, Table 3). In year 2008, a simple linear regression analysis showed that the nut yield was significantly correlated with application fertilizer rate (y = 1.055x + 3.194, R^2 = 0.344. $R^2_{0.01}$=0.315). However, even with the same amount of the fertilizers applied the nut yield differed greatly between different orchards regardless of the yearly variations (as shown with relative yield, Figure 1). For example, at fertilizer application rate of ≥4 kg/tree, the nut yield varied from nearly 60% to 100%. This implies an important contribution of soil fertility to yield. The prevalence of low available P and soil acidification in orchards could be very important limiting soil factors. In a 7-year long-term field experiment with American pecan (*Carya illionoinensis*), tree growth and nut yield were increased by N but not by P application (Smith *et al.* 1995). Available information on the nutrient requirement of Chinese hickory is limited. The key limiting soil factor for Chinese hickory orchards is uncertain.

Table 3. Variation of nut yield (kg/tree) of Chinese hickory (*Carya cathayensis*) between years and between orchards (Values followed with different letters mean significant at *p*0.01).

Year	Mean	Minimum	Maximum
2007	5.12 A	2.36	8.92
2008	6.78 B	2.94	10.06

Conclusion
The 2 – year field survey showed that degradation of the soils in the Chinese hickory orchards, such as soil acidification, was serious under long-term intensive management. It is difficult to make a clear conclusion on which soil factors are most important in affecting the production of Chinese hickory orchards at this stage. There were greatly different in fertilizer application between farmers and there exists a serious worsening of soil properties such as acute soil acidification induced by the long-term use of chemical fertilizers. Optimization of fertilization is urgently needed. Great efforts should be made to improve soil conditions for the sustained production of Chinese hickory orchards.

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