Open Journal of Soil Science, **2013, 3, 213-217**
http://dx.doi.org/10.4236/ojss.2013.35025 Published Online September 2013 (http://www.scirp.org/journal/ojss)

Characteristics of Soil Organic Carbon, Total Nitrogen, and C/N Ratio in Chinese Apple Orchards

Shunfeng Ge, Haigang Xu, Mengmeng Ji, Yuanmao Jiang*

State Key Laboratory of Crop Biology, College of Horticulture Science and Engineering, Shandong Agricultural University, Taian, China.
Email: *ymjiang@sdau.edu.cn

Received July 1st, 2013; revised August 1st, 2013; accepted August 8th, 2013

ABSTRACT

Soil organic carbon and nitrogen are used as indexes of soil quality assessment and sustainable land use management. At the same time, soil C/N ratio is a sensitive indicator of soil quality and for assessing the carbon and nitrogen nutrition balance of soils. We studied the characteristics of soil organic carbon and total nitrogen by investigating a large number of apple orchards in major apple production areas in China. High apple orchard soil organic carbon content was observed in the provinces of Heilongjiang, Xinjiang, and Yunnan, whereas low content was found in the provinces of Shandong, Henan, Hebei, and Shaanxi, with the values ranging between 6.44 and 7.76 $g \cdot kg^{-1}$. Similar to soil organic carbon, soil total nitrogen content also exhibited obvious differences in the 12 major apple producing provinces. Shandong apple orchard soil had the highest total nitrogen content (1.26 $g \cdot kg^{-1}$), followed by Beijing (1.23 $g \cdot kg^{-1}$). No significant difference was noted between these two regions, but their total nitrogen content was significantly higher than the other nine provinces, excluding Yunnan. The soil total nitrogen content for Xinjiang, Heilongjiang, Hebei, Henan, and Gansu was between 0.87 and 1.03 $g \cdot kg^{-1}$, which was significantly lower than that in Shandong and Beijing, but significantly higher than that in Liaoning, Shanxi, and Shaanxi. Six provinces exhibited apple orchard soil C/N ratio higher than 10, including Heilongjiang (15.42), Xinjiang (13.38), Ningxia (14.45), Liaoning (12.24), Yunnan (11.03), and Gansu (10.63). The soil C/N ratio was below 10 in the remaining six provinces, in which the highest was found in Shaanxi (9.47), followed by Beijing (8.98), Henan (7.99), and Shanxi (7.62), and the lowest was found in Hebei (6.80) and Shandong (6.05). Therefore, the improvement of soil organic carbon should be given more attention to increase the steady growth of soil C/N ratio.

Keywords: Chinese Apple Orchard; Soil Organic Carbon; Total Nitrogen; C/N Ratio

1. Introduction

China currently has the largest apple cultivation area and production in the world, with 1.99×10^6 ha and 35×10^6 t in the 2011/2012 season [1]. Fruit production has gradually become an important pillar industry to increase the income of farmers. In addition, an increasing amount of nitrogen (N) fertilizers are used to improve yield with the corresponding intensive production of fruits. At present, N utilization has already reached 400 $kg \cdot hm^{-2}$ to 600 $kg \cdot hm^{-2}$ in Chinese apple orchards, which is four to five times more than that in other countries, and is showing an annual increasing trend [2,3]. Excessive use of N fertilizers not only cuts down utilization rate and decreases agricultural production benefits, but also leads to negative consequences, such as aggravated physiological fruit disease and environmental pollution [4-6].

Soil organic carbon and nitrogen are the main nutrition used for vegetation growth, and are also used as indexes of soil quality assessment and sustainable land use management [7-9]. Soil organic carbon and nitrogen not only can reflect the soil fertility level, but can also explain the regional ecological system evolution. The relationship between them can be represented as soil C/N ratio, a sensitive indicator of soil quality and for assessing carbon and nitrogen nutrition cycling of soils [10]. Many researches have shown that soil organic carbon and nitrogen content are not only affected by climate, altitude, terrain, but also land use management. At present, the superior apple production areas are concentrated in Bohai coast area (Shandong, Hebei, Liaoning, Beijing, Tianjin),

*Corresponding author.

Northwest Loess altiplano (Shaanxi, Gansu, Shanxi, Ningxia, Qinghai), Yellow River original (Henan, Jiangsu, Anhui), and Southwest Cool Highlands area [11]. The geographic latitude and longitude, soil type, management level, and fertilization conditions varied between the four superior apple production areas; thus, apple orchard soil carbon and nitrogen characteristics are different among these regions. This study aims to conduct a survey of Chinese apple orchard soils to establish the soil carbon and nitrogen status.

2. Materials and Methods

2.1. Sampling Sites

Soils from the superior apple production areas in China were sampled, including the Bohai coastal area, Northwest Loess altiplano, Yellow River original, and Southwest Cool Highlands area (**Figure 1**). Sampling sites covered 8583 apple orchards in 36 counties of 12 provinces, including Shandong province (Qixia, Penglai, Longkou, Zhaoyuan, Muping, Laishan, Fushan, Jiaonan, Rushan, Yiyuan), Shanxi province (Yuncheng and Taigu), Shaanxi province (Baishui, Luochuan, Qian), Gansu province (Tianshui, Pingliang, Qingyang), Heilongjiang province (Mudanjiang), Liaoning province (Suizhong, Xingcheng), Beijing (Changping), Hebei province (Shijiazhuang, Baoding, Changli), Henan province (Sanmenxia, Shangqiu), Ningxia Autonomous Region (Yongning, Zhongning, Qingtongxia), Yunnan province (Xishan, Zhaoyang, Malong), and Xinjiang Uygur Autonomous Region (Tekesi, Gongliu, Qiaolaketiereke), respectively.

2.2. Soil Sampling and Determination

Composite soil samples were taken from 0 cm to 30 cm depth (more than 20 random points) in each apple orchard in mid-august 2012. The moist soils were sieved (2 mm) after removing the visible plant debris, including roots. Soil organic carbon was determined by wet digestion according to the Turin method, and soil total nitrogen was determined by the Kjeldahl method.

2.3. Data Analyses

All data were analyzed by ANOVA using SPSS (Standard released version 11.5; SPSS Inc., IL, USA).

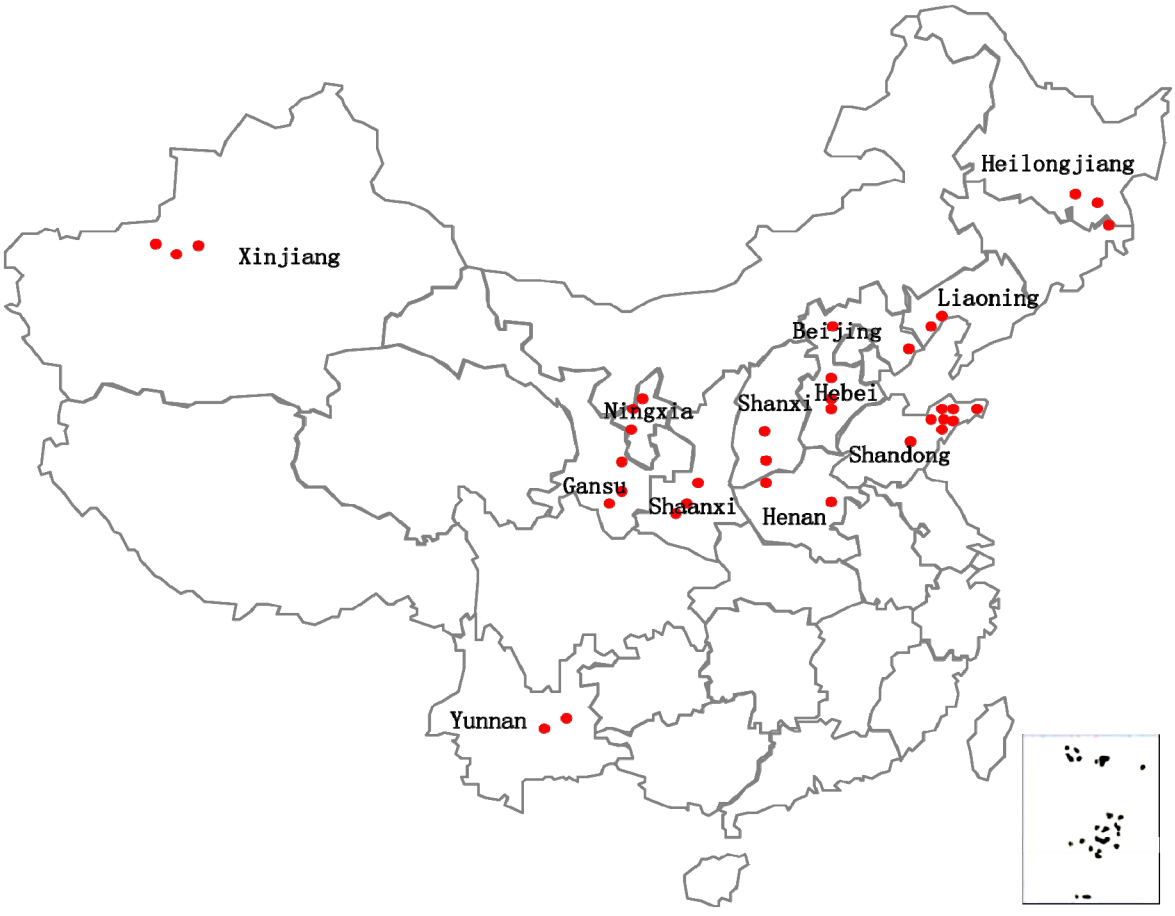

Figure 1. Geographical location of the sampling apple orchards.

3. Results and Discussion

3.1. Soil Organic Carbon Content

Soil organic carbon not only affects the soil fertility, but also has influence on releasing or holding CO_2 from the atmosphere through various channels, thereby possibly affecting the atmosphere—soil carbon balance [8,12,13]. **Table 1** shows obvious difference in soil organic carbon content between the 12 major apple production areas. The highest soil organic carbon content (15.57 g·kg^{-1}) was found in Heilongjiang province, followed by Xinjiang (14.88 g·kg^{-1}). No significant difference was found between these two areas, but their soil organic carbon content was significantly higher than that in the other nine areas (except Yunnan province). Soil organic carbon content in Yunnan and Beijing apple orchards was higher, with the values of 12.79 and 11.04 g·kg^{-1}, respectively. Soil organic carbon content in Liaoning (9.55 g·kg^{-1}) and Gansu provinces (9.25 g·kg^{-1}) were lower than that of Yunnan and Beijing, but no significant difference (P = 0.05) was found between these four areas. Soil organic carbon content in Ningxia, Shandong, Henan, Hebei, and Shaanxi province ranged from 6.44 g·kg^{-1} to 7.76 g·kg^{-1}, which were significantly lower than that in Heilongjiang, Xinjiang, Yunnan, and Beijing. The lowest apple orchard soil organic carbon content was found in Shanxi province (5.41 g·kg^{-1}, which only accounts for 34.75% that of Heilongjiang province). Some management measures, such as fertilization and irrigation in the apple production system, can significantly affect soil organic carbon content. Higher soil organic carbon content was found in Heilongjiang, Xinjiang, and Yunnan apple orchards, which may be attributed to the following two reasons: First, the soil type and climate in these areas are different with other areas. Second, much more organic fertilizer was used in the apple production. However, soil organic carbon content is relatively low in Shandong, Henan, Hebei, and Shaanxi apple orchards, which is ascribed to a change in fertilizer use strategy with greater use of inorganic fertilizers and less organic fertilizers in these areas. Many studies have shown that, organic combined with inorganic fertilizer is more beneficial to the improvement of the soil organic carbon content compared with the single application of inorganic chemical fertilizer [14,15]. In short, Chinese apple orchard soil organic carbon content is very low, with an average of 9.52 g·kg^{-1}.

Table 1. Soil organic carbon contents of apple orchards in different areas in China.

Area	Maximum (g·kg^{-1})	Minimum (g·kg^{-1})	Mean (g·kg^{-1})	SD
Heilongjiang	21.53	11.42	15.57 a	4.35
Liaoning	14.65	6.67	9.55 bc	2.17
Beijing	15.43	8.38	11.04 b	2.25
Shanxi	10.22	3.87	5.41 d	3.67
Hebei	9.45	4.81	6.53 c	1.83
Shannxi	9.29	4.38	6.44 c	2.17
Shandong	12.53	6.03	7.62 c	2.73
Henan	10.45	5.87	7.43 c	3.11
Gansu	13.22	6.83	9.25 bc	2.93
Ningxia	10.73	5.32	7.76 c	1.86
Xinjiang	22.63	9.74	14.88 a	4.36
Yunnan	16.74	9.89	12.79 ab	2.71

Note: Data in the same column with different letter indicate significant difference (P < 0.05), the same as follows.

3.2. Soil Total Nitrogen Content

Soil total nitrogen is used as an important index for soil fertility evaluation, and reflects the soil nitrogen status [9]. Similar to soil organic carbon, soil total nitrogen content also exhibited obvious differences in the 12 major apple production areas (**Table 2**). The highest soil total nitrogen content (1.26 g·kg^{-1}) was found in Shandong province, followed by Beijing (1.23 g·kg^{-1}). No significant difference was found between these two areas, but their soil total nitrogen content was significantly higher than the other nine areas, which is ascribed to the high nitrogen fertilizer application rate in these two areas. Soil total nitrogen content in Yunnan apple orchards is higher, with a value of 1.16 g·kg^{-1}. Soil total nitrogen content in Xinjiang, Heilongjiang, Hebei, Henan, and Gansu province ranged from 0.87 g·kg^{-1} to 1.03 g·kg^{-1}, which were significantly lower than that in Shandong and Beijing, but significantly higher than that in Liaoning, Shanxi, and Shaanxi. Although nitrogen fertilizer inputs is also at a higher level in Shaanxi province, the total nitrogen content is low because of the poor nitrogen retention ability of the sandy soil [16,17].

Table 2. Soil total nitrogen contents of apple orchards in different areas in China.

Area	Maximum (g·kg^{-1})	Minimum (g·kg^{-1})	Mean (g·kg^{-1})	SD
Heilongjiang	1.23	0.92	1.01 b	0.05
Liaoning	0.92	0.57	0.78 c	0.04
Beijing	1.43	1.08	1.23 a	0.02
Shanxi	1.02	0.57	0.71 c	0.04
Hebei	1.25	0.73	0.96 b	0.06
Shannxi	0.89	0.59	0.68 c	0.03
Shandong	1.56	0.83	1.26 a	0.06
Henan	1.35	0.74	0.93 b	0.04
Gansu	1.20	0.71	0.87 b	0.03
Ningxia	0.85	0.39	0.58 d	0.06
Xinjiang	1.33	0.74	1.03 b	0.06
Yunnan	1.41	0.76	1.16 ab	0.05

3.3. Soil Carbon and Nitrogen Ratio (C/N Ratio)

Soil C/N ratio is a sensitive indicator of soil quality. Soil C/N ratio is often considered as a sign of soil nitrogen mineralization capacity. High soil C/N ratio can slow down the decomposition rate of organic matter and organic nitrogen by limiting the soil microbial activity ability, whereas low soil C/N ratio could accelerate the process of microbial decomposition of organic matter and nitrogen, which is not conducive for carbon sequestration [13]. **Figure 2** shows that significant differences of soil C/N ratio exist among the 12 major apple production areas. Six provinces exhibited apple orchard soil C/N ratio of above 10. The highest soil C/N ratio was found in Heilongjiang (15.42), followed by Xinjiang (14.45), Ningxia (13.38), Liaoning (12.24), Yunnan (11.03), and Gansu (10.63) provinces. Soil C/N ratio was below 10 in the other six provinces, in which the highest was found in Shaanxi (9.47), Beijing (8.98), Henan (7.99), and Shanxi (7.62), and the lowest was found in Hebei (6.80) and Shandong (6.05). At present, China is facing the pressure of CO_2 emission reduction, which may be an effectively approach to make the atmosphere–CO_2 into the apple orchard soil through maintaining higher soil C/N ratio [18,19].

4. Conclusion

Average soil organic carbon, total nitrogen content, and C/N ratio was 9.52 g·kg^{-1}, 0.93 g·kg^{-1}, and 10.33, respectively. Therefore, more efforts should be given to increase soil C/N ratio by increasing the application of organic manure or straw to improve the level of soil organic carbon.

5. Acknowledgements

The study was conducted with the support of the Special Fund for Agro-scientific Research in the Public Interest (201103003), the Earmarked Fund for the China Agriculture Research System (CARS-28), and the Agricultural Application and Innovation Project of Shandong Province (201009).

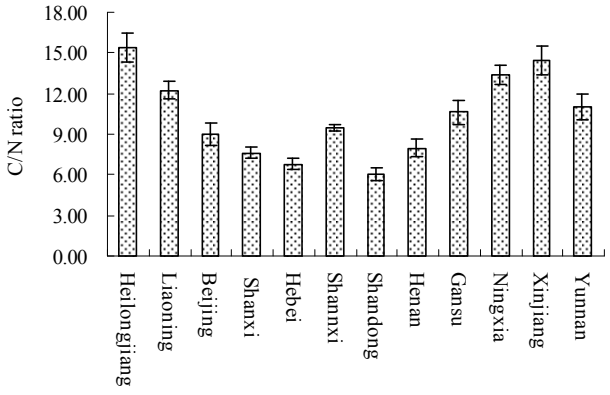

Figure 2. Soil C/N ratio of apple orchards in different areas in China.

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