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Effects of land use changes on soil organic carbon and soil microbial biomass carbon in low hills of North Yanshan Mountains

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Abstract

To reveal the effects of land use changes on soil organic carbon pool, four types of land use (M-G; natural grassland) (artificial forests changed from natural grassland including 36-years-old *Populus simonii*) M-36; 22-years-old *P. simonii* M-22, and sloping cropland M-A) were selected in the low hills of north Yanshan Mountains to investigate the changes of soil organic carbon (SOC) and soil microbial biomass carbon (SMBC). The results show that SOCs and SMBCs were significantly affected by land use changes, and the effects were significantly different among the four types of land use ($p<0.05$): M-36>M-22>M-G>M-A. Land use changes did not affect the vertical distribution of SOCs or SMBCs, which decreased with increase in soil depth. The four types of land use affected soil microbial biomass quotient (SMBC/SOC) in different ways. Analysis shows that the contents of SOC and SMBC increased after the transformation of M-G into man-made forests, but slightly decreased after the transformation into M-A, indicating that man-made forests were more capable than M-G in maintaining healthy and high-quality soils, but M-A was unfavourable for the development into higher soil quality.

Keywords: Land use changes, Low hills in north Yanshan Mountains, Soil microbial biomass carbon, Soil organic carbon

Abbreviations: SMBC: Soil microbial biomass carbon; **SOC:** Soil organic carbon

Introduction

Soil organic carbon (SOC) dynamics is a hotspot in the research on climate changes (Watson *et al*., 2000), while land use changes are key influencing factor on SOC dynamics (Bangroo *et al*., 2013). Land use change is the second human activity (after fossil combustion) that cause rapid increase of atmospheric CO$_2$ content; land use change not only directly affects the contents and distribution of SOC, but also indirectly affects SOC *via* impacting the factors related to its formation and transformation. It is estimated that (136±55)×10^{12} kg carbon (about 33% of the CO$_2$ content newly accumulated in the atmosphere) is emitted from terrestrial ecosystems into the atmosphere through land use changes between 1850 and 1998 (Wu *et al*., 2004). Microbial biomass is one of the essential living components of all terrestrial ecosystems because it regulates various critical processes such as the decomposition of organic material, its transformation, the nutrient cycles [carbon (C), nitrogen (N), etc.] (Cañizales-Paredes *et al*., 2012). Though soil microbial biomass carbon (SMBC) is generally low, its large turnover rate and shorter turnover time make it more sensitive to soil condition changes than SOC. Therefore, SMBC changes more quickly than SOC and monitors soil organic matter variation before soil total carbon can be detected. Basically, under the same climate and soil conditions, land use patterns are key influencing factor on SMBC (Fang *et al*., 2011). In recent decades, many unreasonable land use patterns and the rapid population growth have radically changed the ecosystem composition in the low hills of north Yanshan Mountains, but there are few reports on the effects of land use patterns on SOC and SMBC in this region. Therefore, in this study, 4 types of land use in a typical catchments in this region were selected to investigate the changes of SOCs and SMBCs and their correlations with soil nutrients. The objective is to provide a foundation for further study and evaluation on the effects of land uses on SOC pool dynamics and the mechanism.

Materials and Methods

The studied area and sample collection

The studied area, Huanghuadian catchments (42°172-

42°332 N, 119°362-119°532 E), is located in a typical catchment in the low hills of northern Yanshan Mountains. It enjoys a semi-arid continental monsoon climate in the middle latitude temperate zone, with an annual average temperature of 7.5 ^{o}C extremely highest and lowest temperatures of 39.7 and -30.7 ^{o}C respectively, and an annual rainfall of 435 mm. The major vegetation types include natural grassland, shrub forest, tree-shrub mixed forest, coniferous forest, coniferous-broadleaf mixed forest, and broadleaf forest. The major artificial vegetation species is *Populus simonii*.

Huanghuadian catchment is located in northern Yanshan Mountains and in eastern Nuluerhu Mountain. It has an area of 32 km^{2} and altitude of 440-906 m. The soils with alkalinity are most chestnut soil accompanied by a little sand soil. In 1980s, numerous cutting and artificial vegetation renewal activities were carried out there and finally several land use types appeared, including natural grassland, artificial forests, and cropland changed from natural grassland. In this study, four types of land use were selected, including natural grassland (M-G), 36-years-old *P. simonii* (M-36), 22-years-old *P. simonii* (M-22), and sloping cropland (M-A). The artificial forests were artificially renewed from M-G, and M-A was changed from M-G in late 1690s and now mainly planted with corn, broomcorn and millet without external fertilization for years.

To reduce the between-plot topographical and climate differences, sample plots were established in sections with basically the same terrain factors (angle and direction of slope). Three 20m×20m squares were set in each fixed sample plot in M-36 and M-22; in each square, sampling points were set along the diagonals and the center. Therefore, each type of forest had 15 duplicates. In M-A and M-G, three 20m×20m fixed squares were set, and in each square, sampling points were set along the diagonals and the center. Therefore, each type had 15 duplicates.

Soils were collected in August 2012. At each point, soils were collected from depths of 0-10, 10-20, 20-40, 40-60 and 60-100 cm. After roots, litter, and impurity like stones were cleared away, the soils were mixed fully and divided into 2 parts. One part for determination of SMBC was screened (2 mm), put into an aseptic bag and stored in a refrigerator at 0-4 !. The other part, after detection of natural water content, was naturally dried and put in aseptic bags until used, as per the requirements for detection of SOC, total nitrogen (TN), available phosphorus (AP), and available potassium (AK). The soil samples were analyzed separately, and the arithmetic mean of several points was used as the final result for each type of land use. The basic information of the sample plots is listed in Table 1.

Detection of SOC and soil physicochemical properties: Soil bulk density was measured by a ring sampler. Natural moisture content was measured by a drying method (105 ^{o}C). The measuring methods were: SOC by potassium dichromate - concentrated sulfuric acid with external heating; TN by Kjeldahlôs method; AP by Olsenôs method; AK by ammonium acetate extraction-flame photometry; pH by potentiometry (Bao, 2000); MBC by chloroform fumigation (Kushwaha *et al*., 2000) .

Data analysis: Statistical analysis was performed on Excel 2003 and SPSS 13.0 (Statistical Product and Service Solutions, SPSS).

Results and Discussion

Soil physicochemical properties under different land use patterns

In the studied region, the soil bulk density was in the range of 1.35-1.58 g/cm^{-3}, but differs largely among land use patterns; soil bulk density is generally lower in artificial forests (under relatively little human disturbance) than in M-G and M-A (Table 2). Because of differences in vegetation types, root depth and root density among land use patterns, the differences in soil evaporation and vegetation transpiration resulted in different soil water contents among land use patterns: woodland > grassland > sloping cropland. Soil pH ranged within 8.02-8.69 and changes in the order as M-A>M-G>M-22>M-36. Nutrient contents were generally higher in woodland than in grassland and croplands.

Effects of land use patterns on SOC and SMBC: The contents of SOC and SMBC ranked as: forests > M-G > M-A (Table 3). Specifically, in the 0-100 cm layer, the mean contents changed as follows: M-36>M-22>M-G>M-A. SOC in M-A was 62.25%, 56.26%, and 39.96% lower respectively and SMBC in M-A was 58.38%, 52.91% and 34.45% lower respectively than in M-36, M-22 and M-G. SOC in M-G is 37.12% and 27.15% lower respectively and SMBC in M-G is 36.50% and 28.16% lower respectively than in M-36 and M-22.

Land use changes also affected the sectional distributions of SOC and SMBC (Table 3). SOCs and SMBCs of the 4 types of land use all decreased with soil depth, indicating certain surface accumulation. For instance, in M-36, M-22, M-G and M-A, the SOCs at the 0-20 cm layer are 148.48%, 191.15%, 145.66% and 230.37% of corresponding contents at the 20-100 layer; SMBCs were 232.72%, 207.04%, 251.41% and 245.81% of corresponding contents at the 20-100 layer. SOCs decreased rapidly in the upper layers but decreased slowly in the lower layers (except in M-A, probably because of frequent ploughing, which mixes surface soil nutrients equally).

Effects of land use patterns on soil microbial quotient (SMBC/SOC): Soil microbial quotient is the ratio of SMBC to SOC (Cañizales-Paredes *et al*., 2012). It avoids some problems when using an absolute value or comparing soils with different organic matter contents; therefore, SMBC/SOC accurately reflects the effects of land use and management measures on soil. The change of SMBC/SOC reflects the efficiency of conversion from the input soil organic matter to SMBC, the soil carbon loss, and the fixation of organic matter by soil minerals (Zhang and Song, 2003).

Table 1. Basic information about the sample plots

Land uses	Site symbol	Longitude and latitude	Orientation of slope and slop	Altitude (m)	Mean height (m)	DBH (cm)	Density of living (trees·m^{-2})	Canopy cover (%)	Coverage (%)
Natural grassland	M-G	119°43ô043 E, 42° 26ô123 N	NW, 7°	672					30.3
36-year-old *Populus simonii*	M-36	119°40ô423 E, 42°26ô253 N	W, 8°	659	15.81	32	0.16	71.4	
22-year-old *Populus simonii*	M-22	119°42ô423 E, 42°24ô223 N	E, 5°	662	12.43	26	0.20	67.9	
Sloping cropland	M-A	119°42ô473 E, 42°25ô403 N	NE, 4°	652					

DBH is the diameter of the trunk from the ground surface at 1.3m.

Table 2. Soil physicochemical properties under different land use patterns

Site symbol	Soil depth (cm)	Bulk density (g·cm^{-3})	Moisture (%)	pH	TN (g·kg^{-1})	AP (mg·kg^{-1})	AK (mg·kg^{-1})
M-G	0-10	1.40±0.06	31.77±2.06	8.55±0.08	0.66±0.03	0.90±0.02	98.68±8.45
	10-20	1.38±0.07	20.44±3.03	8.58±0.12	0.43±0.05	0.87±0.04	85.42±7.03
	20-40	1.43±0.16	22.38±1.07	8.61±0.04	0.38±0.16	0.56±0.13	81.24±9.26
	40-60	1.52±0.08	10.85±0.18	8.62±0.03	0.33±0.17	0.41±0.11	80.61±6.07
	60-100	1.54±0.12	10.11±0.36	8.61±0.07	0.17±0.28	0.33±0.04	80.14±4.92
M-36	0-10	1.35±0.11	40.42±4.12	8.02±0.23	0.96±0.23	3.91±0.27	120.41±10.56
	10-20	1.37±0.19	20.51±2.04	8.09±0.21	0.58±0.19	3.60±0.35	99.98±7.88
	20-40	1.43±0.05	14.94±3.07	8.32±0.04	0.54±0.09	3.42±0.09	89.33±8.58
	40-60	1.45±0.15	14.38±4.06	8.36±0.07	0.38±0.24	3.37±0.07	86.58±6.72
	60-100	1.48±0.14	10.41±4.23	8.54±0.09	0.17±0.14	3.13±0.21	85.47±10.01
M-22	0-10	1.37±0.18	35.15±2.76	8.21±1.01	0.76±0.34	3.35±0.47	91.65±9.78
	10-20	1.40±0.13	24.64±1.30	8.57±0.07	0.67±0.15	3.41±0.42	84.37±6.91
	20-40	1.41±0.07	19.42±3.01	8.59±0.18	0.51±0.07	2.92±0.37	80.19±7.33
	40-60	1.46±0.02	13.18±3.11	8.61±0.11	0.42±0.14	2.42±0.17	79.76±8.98
	60-100	1.51±0.02	12.57±1.49	8.64±0.05	0.23±0.26	0.87±0.25	77.43±7.69
M-A	0-10	1.39±0.16	24.50±3.64	8.50±0.25	0.63±0.98	1.72±0.03	85.32±5.04
	10-20	1.41±0.09	23.78±3.01	8.55±0.43	0.44±0.04	1.21±0.05	84.01±3.09
	20-40	1.38±0.04	20.15±2.08	8.57±0.07	0.32±0.16	0.67±0.07	80.18±8.85
	40-60	1.42±0.07	18.64±2.15	8.60±0.16	0.24±0.32	0.32±0.04	80.13±4.35
	60-100	1.58±0.08	12.51±1.13	8.69±0.37	0.21±0.81	0.21±0.02	78.64±8.07

Data are expressed as mean ± standard error

Table 3. Effects of land use patterns on SOC and SMBC

Site symbol	Soil depth/(cm)	SOC (g·kg^{-1})	SMBC (mg·kg^{-1})	SMBC/SOC) %
M-G	0-10	10.72±4.45	524.36±14.35	4.89±0.35
	10-20	6.56±2.01	321.84±22.05	4.90±0.56
	20-40	5.92±1.07	306.31±32.88	5.17±1.16
	40-60	4.81±1.04	215.06±9.09	4.47±1.43
	60-100	2.82±1.12	91.22±10.17	3.23±0.73
Mean		6.17a	291.76a	4.53a
M-36	0-10	14.38±5.07	775.02±36.04	5.40±1.51
	10-20	10.01±6.02	526.30±11.02	5.48±0.29
	20-40	8.83±3.09	453.25±27.68	5.13±0.47
	40-60	8.28±4.01	214.51±16.96	2.59±0.14
	60-100	7.53±0.09	171.02±7.08	2.27±0.08
Mean		9.81b	459.44b	4.17ab
M-22	0-10	12.01±3.24	642.2±22.01	5.35±1.03
	10-20	8.84±2.08	423.81±10.11	4.79±0.95
	20-40	8.65±3.10	298.54±14.81	3.45±0.67
	40-60	7.45±2.56	206.63±12.69	2.77±0.18
	60-100	5.37±1.93	127.86±22.08	2.38±0.50
Mean		8.46c	406.12b	3.75b
M-A	0-10	5.98±3.70	307.39±18.75	5.14±0.16
	10-20	5.23±2.16	286.58±7.64	5.48±0.46
	20-40	3.29±2.02	185.46±8.59	5.64±0.54
	40-60	2.06±1.11	94.33±11.27	4.58±0.58
	60-100	1.95±1.03	82.45±9.73	4.23±0.17
Mean		3.70d	191.24c	5.01ac

The data within the same column with different small letters shows significant difference ($P<0.05$)

Table 4. Correlations of SOC and SMBC with soil nutrients

	SOC	TN	AP	AK	pH	Bulk density	Moisture
SMBC	0.835**	0.752**	-0.392	0.530*	-0.640**	-0.484*	0.352

Sample size n=300, (*) $P < 0.050$, (**) $P < 0.010$

SMBC/SOC was 2.27%-5.48% (mean 4.17%) in M-36, 2.38%- 5.35% (3.82%) in M-22, 3.23%-5.17% (4.53%) in M-G, and 4.23%-5.65% (5.01%) in M-A (Table 3). The four types of land use affected SMBC/SOC in different ways. The SMBC/SOC ratios at different layers differed among land use patterns, and were generally larger at surface layers than at bottom layers.

Correlations between SMBC and soil nutrients: Table 4 shows that SMBC has extremely or very significant positive correlation with SOC, TN, and AK; SMBC has extremely or very significant negative correlation with pH and bulk density; and weak positive correlation with water content.

Land use changes are in close relationships with soil carbon pool changes. Besides changes in the amount and nature of plant residual body entering soil, land use changes also lead to changes in soil moisture management and cultivation measures, thereby affecting and changing SOCs and SMBCs (Sharma *et al*., 2004). Research showed that SOC and SMBC fluctuations are mainly affected by the input of organic matter; temperature and humidity affected the fresh organic matter and SOC decomposition rate, thereby affecting SMBC. After natural vegetations are changed to other land use patterns, their SOC and SMBC will be changed; after conversion to artificial forests, grasslands will accumulate SOC and SMBC; M-G after cultivation will lose SOC and SMBC. This is because on one hand, after natural grassland is converted to artificial forests, soil vegetation coverage increases, and the vegetation litter is fully returned to soil every year; soil surface litter and humus contents increase; forest litter, root cast and root secretion continuously supplement soil carbon pools, resulting in higher SOC. On the other hand, the higher SOC and microbial content in woodlands are due to little surface disturbance and suitable soil structure, which provide a favourable habitat for SOC accumulation and microbial growth. After M-G is converted to M-A, the soil was mainly affected by human disturbance, and a majority of organic matter produced by crops was shifted. Without the input of fertilizers for years, the reduced input of organic matter will not timely supplement organic carbon; soil structure is changed by cultivation, and high soil temperature will accelerate the decomposition of organic carbon (Zeinab and Ataollah, 2013). M-G is slightly affected by humans, with relatively less nutrient loss than in M-A, so its SOC is obviously higher than in M-A. The results are basically consistent with existing reports. For instance, after natural secondary forest was converted to cropland or grassland, the reduced stability and quality of soil organic matter resulted in different degrees of decline of SOC and active carbon content (Blair and Crockcr, 2000). SOC declined rapidly after grassland and woodland were converted to cultivated cropland (Dameni *et al*., 2010). Organic carbon in forests lost by 46% and 70% respectively after 10 years and 80 years of logging and cultivation(Lugo *et al*., 1986). However, it was also found that land use changes did not significantly affect SOC or active organic carbon, such as in the natural forests, grassland and artificial ash forests in west Australia (Mendham *et al*., 2002). The cause of such difference is not clearly known, but it indicates that the effects of land use changes on SOC and SMBC may be complex and change among land use patterns or among regions.

Our results show that though SOCs and SMBCs are obviously affected by land use changes, but their vertical distributions were not affected. The SOCs and SMBCs under all the four land use patterns decreased with soil depth. This may relate to the plant root distribution, the amount and quality of litter, and SOC. Mean while, SOCs and SMBCs at most surface layers changed in a wide range, but gradually decreased with the increasing soil depth. Besides the amount and quality of litter, this may also relate to the fact that surface soil is more susceptible to temperature and humidity changes, while deep soils change in the reverse way, and thus carbon contents are not largely different between deep soil layers as between shallow layers. At certain depth, SOC and SMBC generally change in the order as M-36> M-22>M-G>M-A. This may be because roots of woods are distributed deeper than those of crops and grasses, and are affected by soil surface residual or root secretion, and thus at the same layer, SOC and SMBC in woods are higher than in crops and grasses. Moreover, the quality of litter directly relates to the formation of organic carbon, and the litter formed from woods contains more lignin than that from crops and grassland, so at the same layer, the soil surface in forest contains more litter residual, which will affect deep-layer SOC and SMBC. Vertical sections of SMBC and SOC change in identical laws, because most soil microorganism depends on organic nutrition, and more importantly, with the increase of soil depth, root secretion and cast gradually decrease, and soil temperature declines due to the decreasing solar radiation (Guo *et al*., 2012). The gradual decrease of soil organic and inorganic matter provides less nutrition for soil microorganism, which reduces the microbial anabolism, thereby resulting in gradually lower SMBC; another explanation is the significant positive correlativity between SOC and SMBC (Guo *et al*., 2012).

SMBC/SOC at different layers changed among land use patterns, and was generally larger at surface layers than at bottom layers. The differentiation laws are generally not obvious. It is believed that SMBC/SOC can be used to represent soil course or soil quality changes, and is more effective than SMBC or SOC. In SOC and SMBC dynamics in croplands, SMBC/SOC changes more quickly than SMBC (Saggar *et al*., 2001). In this study, SMBC/SOC was more stable than SOC and SMBC, and showed a more stable trend, but further studies are needed to validate whether SMBC/SOC can be used to measure SOC changes. It should be pointed out that SMBC/SOC is 2.27%-5.64% in this study, which is close to 3.6%-4.9% (Cañizales-Paredes *et al*., 2012), 1%-5% (Zeller *et al*., 2007) and 0.1% -6.0% (Wang *et al*., 2006).

In this study, SMBC had extremely significant positive correlation with SOC and TN, which is consistent with previous studies (Zhang *et al*., 2007). The increased soil P content will promote root growth, but increased AP had decreased SMBC; therefore further analysis is needed to reveal whether excessive AP will inhibit microbial activity. Soil pH is usually considered as the main factor that regulates the structure and activity of soil microbial community. Studies (Xu *et al*., 2006) showed that within a certain range, soil microbial biomass is in significantly positive correlation with pH, but we find significant negative correlation, probably because their soil samples vary within pH 4.5-5.4, showing acidity, while in this study, soil pH was generally above 8.02. Though the difference in background pH among soil samples may cause slightly different results, pH and SMBC are in significant correlation. Too high pH will negatively affect soil microorganisms by decreasing their total contents and thereby the SMBC contents. The analyses also showed that pH and SMBC were in significantly negative correlation.

Soils with higher moisture content provide an excellent habitat for soil microbial activity, which is advantageous for soil microbial growth (Zeller *et al*., 2007). Reportedly, soil water is closely related to the microbial biomass, and within a certain range, soil microbial biomass increases with the elevated water content. But another study indicates that water will take effect significantly only when severe drought becomes a barrier that limits microbial activity (Bottner, 1985). The influence of soil moisture content above 10.87% is not obvious (Srivastava, 1992). In this study, SMBC and soil water content are in weak correlation, probably because soil moisture content is not the limiting factor on soil microbial growth. Obviously, soil moisture below a certain level will become the limiting factor of soil microbial growth.

Conclusion

The effects of four land use patterns on SOC and SMBC in a typical watershed in the low hills of north Yanshan Mountains were investigated. The results showed that SOCs and SMBCs were significantly affected by land use changes. The SOCs and SMBCs were higher in forests than in M-G, and increased along with the prolonging of planting duration. The SOCs and SMBCs decreased after the transformation from M-G into M-A. Specifically, the SOCs and SMBCs changed significantly ($p<0.05$) as M-36> M-22>M-G>M-A. SOCs and SMBCs under different land use patterns all declined with soil depth. The four types of land use affected soil microbial biomass quotient (SMBC/SOC) in different ways. SMBC had extremely or very significant positive correlation with SOC, TN and AK and in extremely or very significant negative correlation with pH and bulk density.

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