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Seasonal Changes in Soil Microbial Biomass Carbon and Nitrogen of Different Vegetation Types in the Mu Us Sandland, Northwestern China

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ABSTRACT

The aim of the study is to determine the seasonal changes in sand soil microbial biomass carbon (C) and nitrogen (N) and to identify the pattern of sand soil microbial biomass of four vegetation types in the Mu Us Sandland in northwestern China. Four types of psammophyte plots were established in a desert botanical garden. Soil samples were collected at the depths of 0-10, 10-20 and 20-40 cm, before the 10th of each month, from April to October 2015. The microbial biomass C (MBC) and microbial biomass N (MBN) concentrations were determined using chloroform fumigation extraction. The concentration of MBC did not show consistent patterns as the soil depth increased from 0-10 cm to 20-40 cm, although it was higher in the top layer than in the other layers in some stands (p<0.05). There was also a consistent pattern in different soil layers. All of the top layers showed similar changes from August to October. The MBN concentration in the middle layer was maximal in April, which experiences different types of vegetation, and was significantly higher in the *Pinus sylvestris* L. var. *mongholica* Litv and *Salix cheilophila* stands (p<0.05). Seasonal changes in desert soil MBC and MBN concentrations were obvious in the top soil layer. The peak MBC and MBN concentrations occurred during different seasons, with MBN higher during the colder months.

INTRODUCTION

Soil is a fundamental component of most ecosystems. It supports plant growth by modulating the flow of water, energy and nutrients. Energy flow and nutrient cycling are affected by microbial biomass, which is an essential component of the soil. Microbial biomass not only influences the transformation of organic matter in soil, but it is also an important source of soil nutrients (Zhou et al. 2001).

Soil microbial biomass is defined as the total biomass with a volume less than 5×10^3 m^{-3}, which does not include living plants (Jenkinsons & Ladd 1981). It is the active portion of soil organic matter and the most dynamic factor in soil. Soil microbial biomass generally include microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), microbial biomass phosphorus, and microbial biomass sulfur. Among these microbial biomass sources, the concentrations of MBC and MBN tend to be relatively more stable and account for 1-5% and 2-6% of the total soil C and N contents, respectively. Globally, total soil MBC accounts for approximately 1.4% of the world's soil organic C content, but it contributes significantly to the global C cycle (Wardle 1992).

Understanding the patterns of change in MBC and MBN contents is important; yet, according to numerous previous studies, it is difficult to determine how changes in soil microbial biomass are regulated (Devi & Yadava 2006, Edwards et al. 2006). In general, the patterns of regulation differ according to climate. Changes in soil biomass are relatively low in the summer and high in the winter in tropical and subtropical regions. This pattern is very different in transition areas (Zhou et al. 2006). These differences have been evaluated in terms of whether moisture and temperature directly affect the soil microbial biomass. Additional patterns were identified in other studies that focused on seasonal changes in soil microbial biomass (Lipson et al. 1999, Basu et al. 1991, Yang & Insam 1991, Luizo et al. 1998, Singh et al. 1989, Raghubanshi et al. 1990, Barbhuiya et al. 2004, Vinisa et al. 2005). The majority of these studies were conducted in areas of abundant rainfall, but only a few were conducted in sandy soil in arid and semi-arid regions with extreme water deficits.

In addition to climate, Richards et al. (2010) and Malchair et al. (2009) found that changes in tree species and composition potentially affect soil organic matter quantity and dynamics, along with microsite conditions.

Furthermore, dehydrogenase activity and metabolic quotients do not show the same patterns among different vegetation types (Pereira et al. 2011). The vegetation type might influence the soil microbial biomass composition.

The objectives of this study were to determine the seasonal changes in the sand soil MBC and MBN and to identify the patterns of sand soil microbial biomass in four vegetation types in Mu Us Sandland, NW China. The nutrient concentrations at different soil depths were also investigated.

MATERIALS AND METHODS

Experimental site and soil sampling: This study was conducted in southeastern Mu Us Sandland, Yulin, Shaanxi Province (109°12'E, 38°26'N). This area has a temperate semi-arid continental monsoon climate, with an average temperature of 7.8-8.6°C. Annual rainfall is 250-440 mm, with highest levels from July to September. Rain and heat occur during the same period in this area. Drought in the spring and winter is often combined with intense sandstorms.

Four types of psammophyte plant plots were established in a desert botanical garden (*Pinus sylvestris* L. var. *mongholica* Litv, *Pinus tabulaeformis* Carr., *Salix cheilophila* and *Caragana microphylla* Lam). Each plot was 20 × 20 m, with three replicates. Mean canopy coverage was 55-83%. Mean stand densities in the arbor were 670 N ha^{-1} and 1220 N ha^{-1}. Soil samples were simultaneously collected at depths of 0-10, 10-20, and 20-40 cm, before the 10^{th} of each month from April to October. There was no rain for 5 d. There were 12 plots and 252 soil samples in total.

Each sample was divided into two parts. One part was air dried and passed through a 2 mm sieve for analysis of available phosphorus (AP), available potassium (AK), and available nitrogen (AN), and the remaining sub-sample was passed through a 0.25 mm sieve for analysis of soil total nitrogen (TN), total potassium (TK) and total phosphorus(TP). The other part was stored at 4°C in the dark to measure the contents of MBC and MBN. The MBC concentration was determined using chloroform fumigation extraction (Vance et al. 1987). Fresh soil was adjusted to 55% of the water-holding capacity, pre-cultured at 25°C for 7 d, and then fumigated for 1 d with alcohol-free chloroform ($CHCl_3$) vapors. Soluble C in the 0.5 M K_2SO_4 extracts was then measured using a liquid TOC analyzer. The MBCandMBN contents were calculated using the formulas MBC=E_C/K_{EC} and MBN=E_N/K_{EN}, where E_C(E_N) is the difference between C(N) extracted from the fumigated and non-fumigated samples, K_{EC} =0.45, and K_{EN}=0.54.

Statistical analysis: The effects of vegetation type and soil horizon on soil properties, MBC, MBN, MBC/MBN and MBC/soil organic carbon (C_{org}) were tested by one-way analysis of variance and Turkey's multiple range test, using SPSS 18.0. Differences were regarded as significant at $p<0.05$.

RESULTS

Soil nutrients: Soil nutrient properties are stable over long periods, except in cases of fertilization and prescribed burning (Muqaddas et al. 2015), which could influence the contents of MBC and MBN. As a result, it is necessary to characterize the study area in terms of nutrient composition.

Soil nutrient concentrations in different layers, under four kinds of vegetation, are shown in Fig. 1. Nutrient content was higher in the organic layer and lower in the deeper layers, indicating that the major nutrient pool for the four vegetation types was in the top soil layer. This is similar to the results of other studies conducted on different types of forest. Accumulation of the macronutrients was evident in the surface layer, which had significantly higher levels compared with macronutrients at other depths, with the exception of AP under *P. sylvestris* stands ($p<0.05$). The levels of all available nutrients were almost two-fold higher at 0-10 cm than at 20-40 cm. In addition, N concentrations were higher in the top layer of *C. microphylla* stands than for other vegetation types, with 0.04 ± 0.01% TN and 48.55 ± 6.95 mg/kg AN. In the *P. tabulaeformis* stands, nutrient concentrations were stable among the three soil layers, and TN, TP and TK concentrations were more stable compared with those in other vegetation types. The nutrient concentrations at the 20-40 cm layer were close or slightly higher under shrub vegetation, than under arbor vegetation. The differences among macronutrients were not significant among the vegetation types at 10-20 cm, expect for AP in *S. cheilophila* stands.

Soil microbial biomass carbon and N: Soil microbial biomass C and N in different layers, under four kinds of vegetation, are shown in Figs. 2 and 3. Microbial biomass C represents the living component of organic matter in soils, indicative of the size and diversity of the soil microbial community. The concentration of MBC was not consistent among the depths, as it decreased from 0-10 cm to 20-40 cm. The MBC concentration in the top layer was greater than that in other layers in some stands ($p<0.05$). The MBC concentration in the top layer under shrub stands showed a bimodal change during the growing season. The highest concentrations in this layer under the *C. microphylla* and *S. cheilophila* stands were 310.40 ± 21.20 and 372.08 ± 37.49 mg/kg, with the first peaks appearing in June and May, respectively. The MBC content in arbor stands showed similar patterns, which were a parabola shape in the 0-10 and

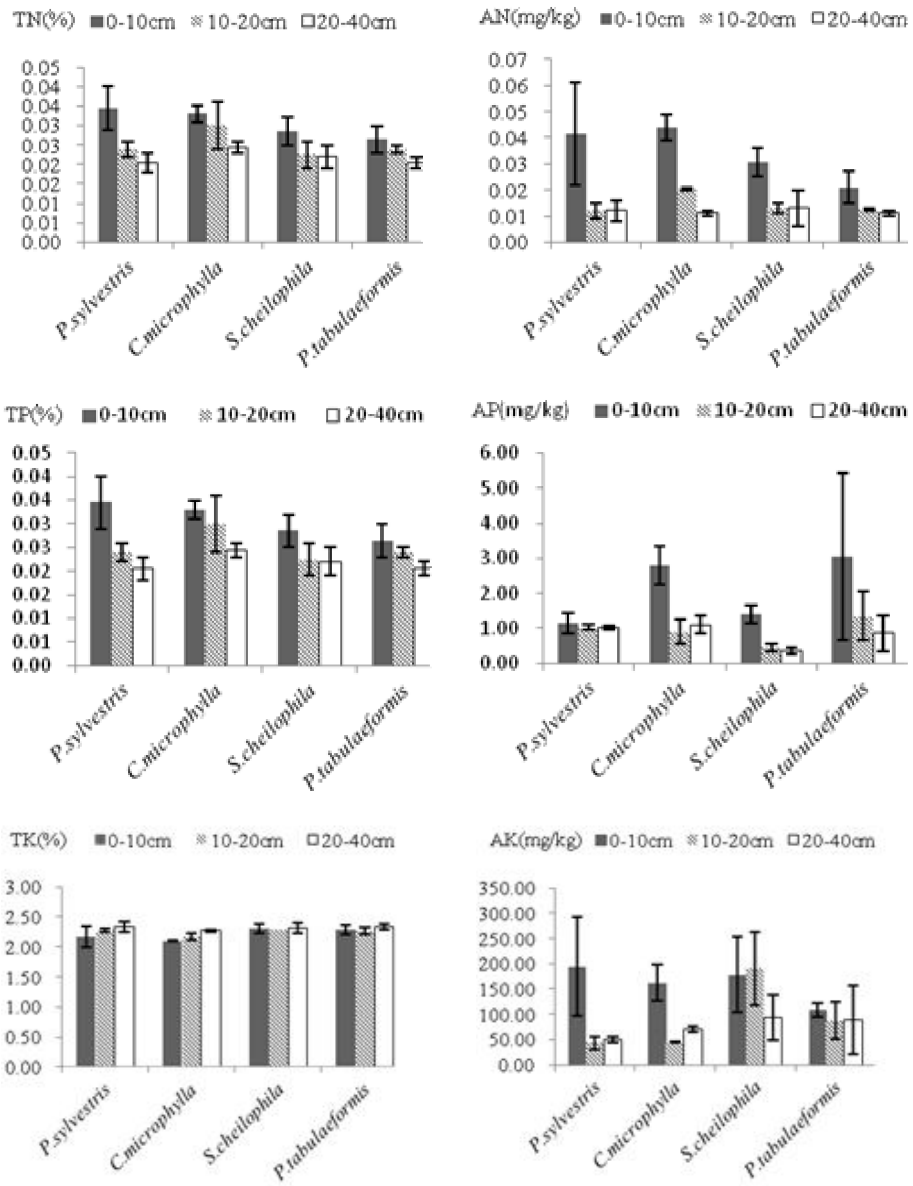

Fig.1: Soil nutrient concentrations in different layers.

10-20 cm layers. The extreme value occurred in July in the *P. sylvestris* stands, and in August in the *S. cheilophila* stands.

The MBC content in the top layer under shrub stands was higher than that under arbor stands during the colder months, but this difference disappeared with increasing soil depth. There were no consistent patterns among the stands, although the MBC concentration of *P. tabulaeformis* plots was more stable than that of other vegetation plots. The variation in MBC content in the top layer was more obvious than that in other layers.

The concentration patterns of MBN differed from those of MBC. All top layers showed similar changes from August to October. The MBN concentration of the middle layer reached its maximum in April under all vegetation types, and it was significantly higher in *P. sylvestris* and *S. cheilophila* plots ($p<0.05$). The MBN content did not show a consistent pattern according to month in the deep layers among the stands. However, from August to October, there were no significant differences among the plots. Prior to that period, the change in MBN content was not related to vegetation type or soil depth, although the coefficient of

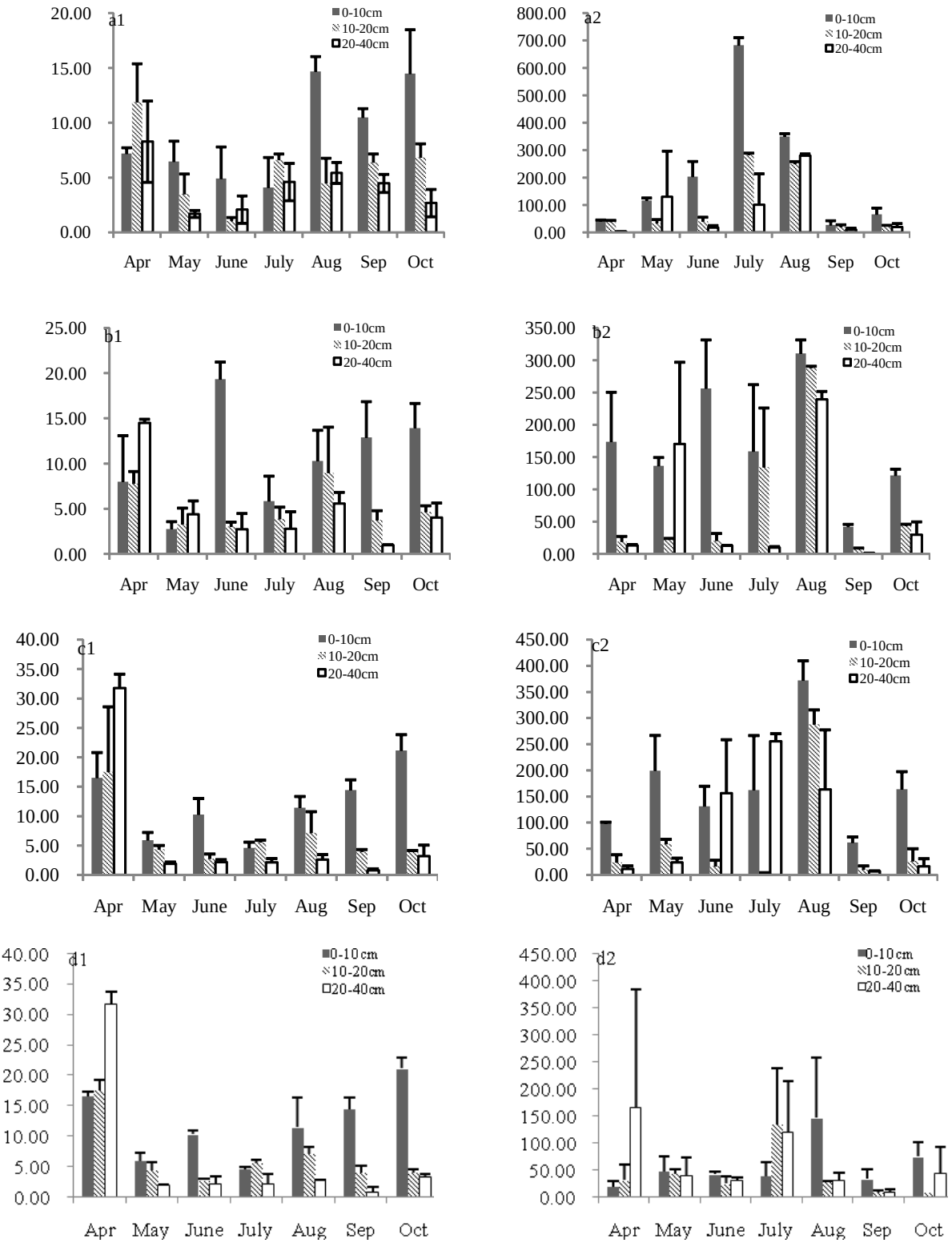

Fig. 2: Soil microbial biomass carbon and nitrogen under different vegetation types. a: *P. sylvestris*, b: *P. tabulaeformis*, c: *C. microphylla*, d: *S. cheilophila*. 1: microbial biomass nitrogen (mg/kg); 2: microbial biomass carbon (mg/kg).

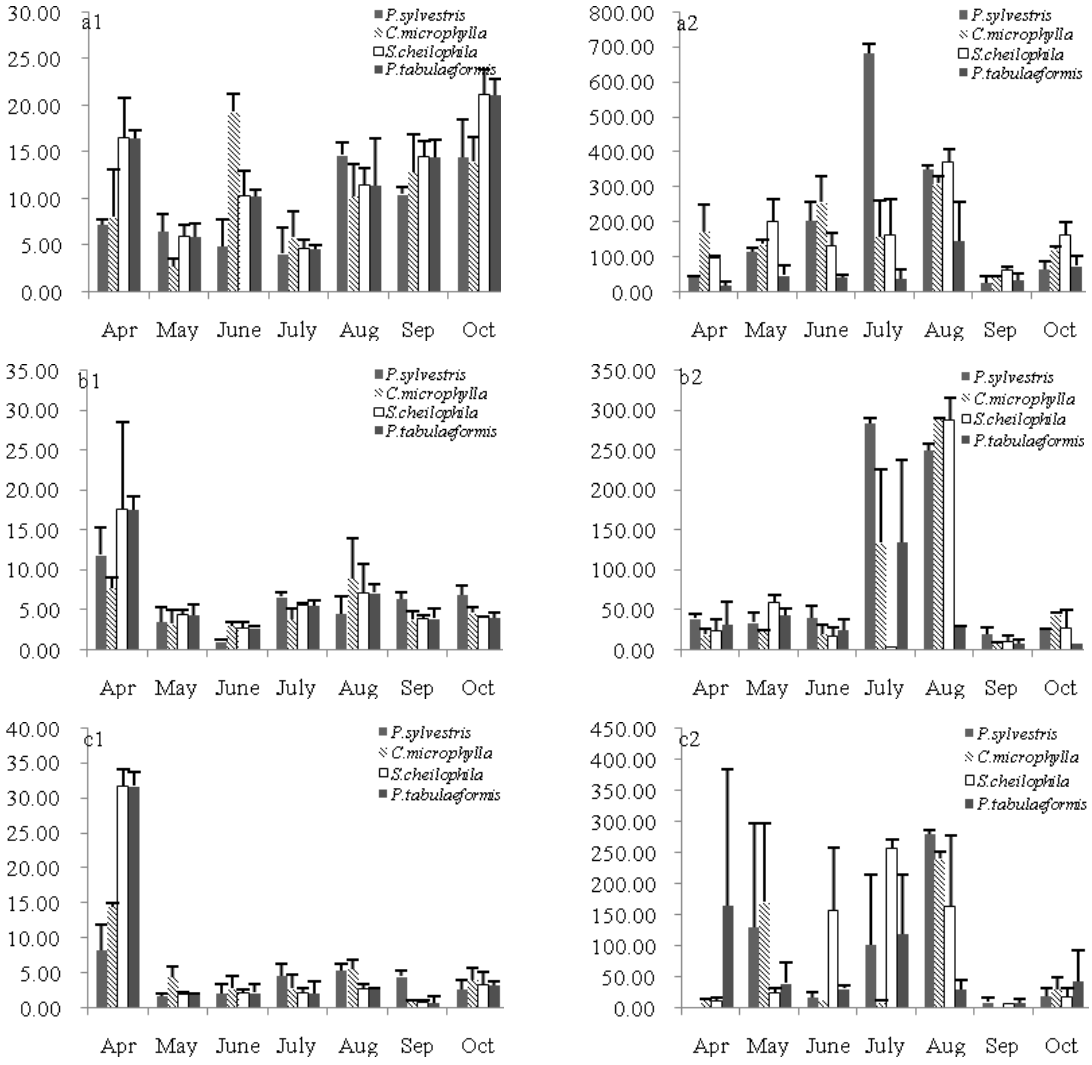

Fig. 3: Soil microbial biomass carbon and nitrogen at different depths. a: 0-10 cm, b: 10-20 cm, 20-40 cm. 1: microbial biomass nitrogen (mg/kg); 2: microbial biomass carbon (mg/kg)

variation was much higher than that in autumn and decreased slowly with soil depth.

Cmic/Corg order of the four stands soil was totally different, there is no consistent result between the depth of the soil and the time series. MBC/MBN showed no obvious difference or change pattern between stands or between soil depths. This is mainly due to the inconsistent trend of MBC and MBN during the growing season and the small proportion of fungi in the soil, which is hard to be reflected by the MBC/MBN even with seasonal changes (Fig 4).

DISCUSSION

MBC and MBN concentrations: The highest MBC concentration in the present study was 682.83 ± 28.02 mg/kg, which was much less than that reported by Vance et al. (1987) and Henrot & Robertson (1994) in various temperate and tropical forest soils. In addition, the MBC concentration was not comparable to the minimum MBC concentration reported by Arunachalam (2000) in subtropical forests (978-2088 mg/kg). Soil MBN concentrations ranged from 0.80 ± 0.25 to 31.75 ± 2.03 mg/kg, which were significantly lower than the concentrations reported in Taiwan (48-275 mg/kg) and Germany (317-2116 mg/kg), but comparable to those in evergreen (42-242 mg/kg) and broad-leaved deciduous forest soils (132-240 mg/kg) (Diaz-Ravina et al. 1988, Joergensen et al. 1995). The disparity is attributed to the poor nutrient status of sandy soils, even though some shrubs have the *Azorhizobium*

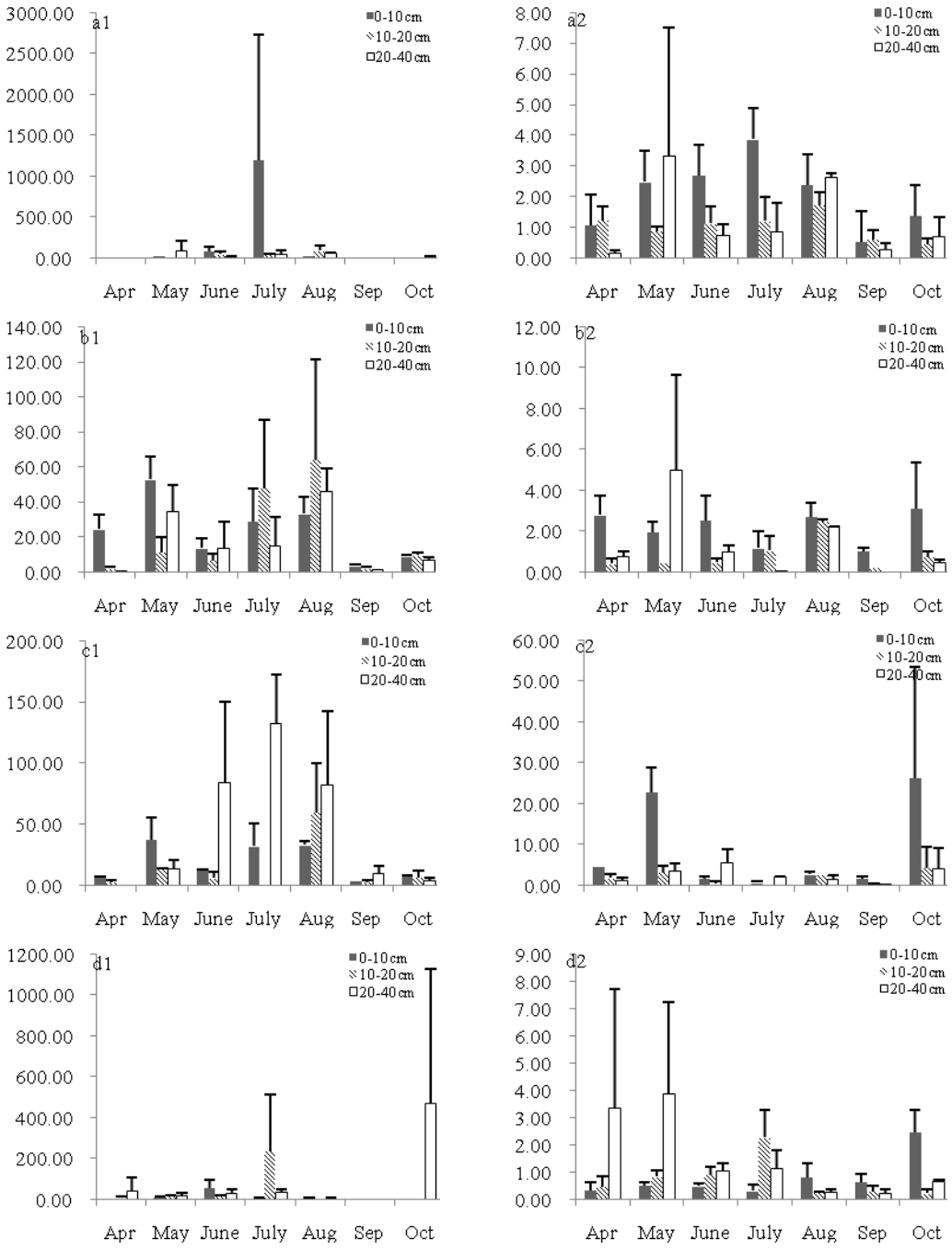

Fig. 4: The changes in microbial biomass carbon (MBC)/microbial biomass nitrogen (MBN) and MBC/soil organic carbon (C_{org}) per month. a: *Pinus sylvestris* L. var. *mongholica* Litv., b: *Pinus tabulaeformis* Carr., c: *Caragana microphylla* Lam., d: *Salix cheilophila*. 1: MBC/MBN, 2: MBC/C_{org}

Dreyfus bacteria. The other responsible factor is erosion, which effectively decreases the depth of the soil layer (Ravindran & Yang 2014). The higher MBC and MBN contents in the top layer, compared with the other two soil layers, were likely the result of an increased supply of resources, such as soil organic matter, more diverse organic matter input, and associated processes (Xu 2013).

Numerous studies have shown that the MBC and MBN contents are generally related to the soil organic matter content in forest soils (Yang et al. 2006, Kujur et al. 2012). The

higher MBC and MBN contents in the surface layers than in the deeper layers is due to their positive correlations with organic matter content and oxygen availability (Idol et al. 2002). It can be concluded that differences in substrate quantities among vegetation types contribute to the differences in MBC and MBN concentrations. Organic matter content influences the concentrations of MBC and MBN, as do the soil moisture and temperature, which are related to nutrient availability.

Seasonal changes in MBC and MBN: The MBC and MBN contents of the four evaluated vegetation types exhibited different patterns of variation according to season. MBC was significantly higher in late summer and early autumn. Saratchandra et al. (1984) and Singh et al. (1989) reported a similar phenomenon in tropical dry deciduous forests. An increase in MBN content can last from July to October. The reason for the low values in the spring may be due to low microorganism activity and slow rates of litter decomposition, characteristic of dry, cool periods (Devi & Yadava 2006). It is uncertain if N application can significantly reduce MBC and MBN contents and decrease the MBC/MBN ratio.

The effect of N application might explain the results of this study. Treseder (2008) and Rudrappa et al. (2006) came to an opposite conclusion, in that vegetation types became more pronounced as the rainfall amount decreased. Those results were not consistent with this study, suggesting the need for further studies.

In the present study, the MBC/MBN ratio did not show monthly variations, but it was higher in shrubs than in arbors. Although the MBC/MBN ratio is unstable, it is often used to describe the structure and state of the microbial community. A high MBC/MBN ratio indicates a high proportion of fungi in the microbial biomass, while a low value suggesting a high proportion of bacteria in the microbial populations (Joergensen et al. 1995). Bacteria were predominant, despite high variable coefficients of variation in this study compared with those from other studies (Paul & Clark 1996 and Ravindran & Yang 2006).

Soil microbial entropy could reflect the proportion of occupied active soil organic C and reveal differences in soil fertility. Specific climate conditions prevented making definitive conclusions in this study. The intense rainfall and dramatic differences in temperature in sandy soil obscured the influence of vegetation on microbial entropy. Additional studies should be performed, but over smaller time scales to control climate factors better.

CONCLUSIONS

Seasonal changes in desert soil MBC and MBN contents were obvious in the top soil layer. The peaks in MBN and MBC contents occurred during different seasons, with MBN content being high in colder months. There were no significant differences among vegetation types. Thus, the results from the present study support further studies on soil microbial biomass changes, focusing on soil moisture and temperature in sandy soils.

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