The amount of soil microbial biomass carbon and nitrogen in global dryland regions

Yujue Wang[1], Shuchen Wang[1], Jing Wang[1], Lei Hou[2], Weiguo Sang[1], and Chunwang Xiao[1]

[1]Minzu University of China
[2]Beijing Pollution Source Releated Affair Management Center

April 16, 2024

Abstract

Abstract: Dryland regions cover 41% of the Earth's land surface and support the livelihood of half of the world's population. Soil microbes play an important role in carbon (C) and nitrogen (N) cycling, therefore affecting soil health. Soil microbial biomass C (SMBC) and N (SMBN) are indicators of soil microbial activities. A better understanding of patterns and drivers of SMBC and SMBN in global dryland regions can provide important insights to enhance ecosystem functioning services. Here, we compiled 109 observations of SMBC (0-30 cm) and 79 observations of SMBN (0-30 cm) from 100 sites across global dryland regions with aridity index less than 0.65. The results showed that the average amount of SMBC and SMBN in dryland regions were 358.47 ± 25.45 mg kg-1 and 51.86 ± 4.59 mg kg-1. The amount of SMBC and SMBN did significantly vary among different dryland types and ecosystem types. Meanwhile, the ratio of SMBC to SMBN in global dryland regions was 8.73. Soil sand fraction and pH had significant negative effect on the ratio of SMBC to SMBN. Our research has initially explored the pattern and control factors of soil microbial biomass in dryland, and provided basic research data for dryland management in the future.

The amount of soil microbial biomass carbon and nitrogen in global dryland regions

Yujue Wang[1,2], Shuchen Wang[1,2], Jing Wang[1,2], Lei Hou[3], Weiguo Sang[1,2,*], Chunwang Xiao[1,2,*]

1. Key Laboratory of Ecology and Environment in Minority Areas (Minzu University of China), National Ethnic Affairs Commission, Beijing, 100081, China

2. College of Life and Environmental Sciences, Minzu University of China, Beijing, 100081, China

3. Beijing Pollution Source Releated Affair Management Center, Beijing 100089, China

* Corresponding author. E-mail:

Weiguo Sang, swg@muc.edu.cn

Chunwang Xiao, cwxiao@muc.edu.cn

Abstract: Dryland regions cover 41% of the Earth's land surface and support the livelihood of half of the world's population. Soil microbes play an important role in carbon (C) and nitrogen (N) cycling, therefore affecting soil health. Soil microbial biomass C (SMBC) and N (SMBN) are indicators of soil microbial activities. A better understanding of patterns and drivers of SMBC and SMBN in global dryland regions can provide important insights to enhance ecosystem functioning services. Here, we compiled 109 observations of SMBC (0-30 cm) and 79 observations of SMBN (0-30 cm) from 100 sites across global dryland regions with aridity index less than 0.65. The results showed that the average amount of SMBC and SMBN in dryland regions were 358.47 ± 25.45 mg kg^{-1} and 51.86 ± 4.59 mg kg^{-1}. The amount of SMBC and SMBN

did significantly vary among different dryland types and ecosystem types. Meanwhile, the ratio of SMBC to SMBN in global dryland regions was 8.73. Soil sand fraction and pH had significant negative effect on the ratio of SMBC to SMBN. Our research has initially explored the pattern and control factors of soil microbial biomass in dryland, and provided basic research data for dryland management in the future.

Keywords:

soil microbial biomass, ratio of soil microbial biomass carbon to soil microbial biomass nitrogen, global dryland regions, aridity index, carbon and nitrogen cycling

Introduction

Drylands cover about 41% of the Earth's land surface and support more than 38% of the total global population, representing a globally important biome of great significance to human welfare (Millennium Ecosystem Assessment, 2005). In the next decades, dryland regions may face less frequent rainfall events and experience more intense drought events due to climate change. As a consequence, a worldwide expansion of drylands is expected for the near future (Gao and Giorgi, 2008; Dai et al., 2013; Feng and Fu, 2013; Berg et al., 2016; Huang et al., 2016). These changes may exacerbate water scarcity, land desertification, and soil degradation, threatening the populations depending on drylands for food production and the associated income. The United Nations Environment Programme (UNEP) defines drylands according to aridity index (AI), which is the ratio of mean annual precipitation to mean annual potential evaporation, and drylands are lands with an AI of less than 0.65 (UNEP, 1992; UN Environment Management Group, 2011). To a certain extent, AI can also indicate whether a certain area is rich in water with a higher value of AI (Wan et al. 2021). In general, soil water content is of particular importance as a driver of microbial community since many microbial metabolism processes such as heterotrophic respiration are affected by soil water (Moyano et al., 2012). Microbial activity and the amount of soil microbial biomass generally increase with soil water content to reach a maximum; but extremely high soil water content can induce oxygen limitation and decrease soil microbial activity (Moyano et al., 2012). Several studies indicated that soil water content may vary with space and time, and the reason is generally correlated closely with AI and air temperature (Delgado-Baquerizo et al., 2013; Wang et al., 2014). Therefore, we may expect negative correlations between the amount of soil microbial biomass and AI, especially in dryland regions where water is often the main limiting factor for soil living organisms (Xu et al., 2017).

A key composition of ecosystem is the soil microbes, which take part in energy flow, nutrient cycling and ultimately ecosystem productivity (Wardle et al., 1998). Soil microbial biomass carbon (SMBC) and nitrogen (SMBN) are indicators of soil microbial activities. In fact, soil microbial biomass (SMB) just accounts for a small fraction of soil weight, and it has been suggested that the amount of SMBC in forest soils is estimated to be less than 5% of the total soil organic carbon stock (Fierer et al., 2009). Nevertheless, SMB is undoubtedly the most active nutrient pool in soils. Likewise, the ratio of SMBC to SMBN also provides evidence and insights to understand soil nutrient cycle and other biochemical characteristics of soil (Bargali et al., 2018; Li et al., 2018). Moreover, the amount of SMBC and SMBN and the ratio of SMBC to SMBN can be used as indicators of soil quality (Schloter et al., 2003), as their high values was generally associated with energetic and nutritious soils. It is attributed to the fact that soil microbes are the drivers of these flows and cycles, because soil microbes have short turnover time and are sensitive to environmental disturbance. A recent study provides evidence that soil fungal communities showed significant differences with the different amount of SMBC, and the amount of SMBC was the prime factor in fungal community structure (Liu et al., 2019). Additionally, some studies also suggest that soil condition was correlated with the amount of SMBC (Zhou et al., 2015). Collectively, the amount of SMB and ratio of SMBC to SMBN are robust indexes to evaluate and understand the underground ecology.

Given different conditions between dryland regions and other terrestrial regions, including differences in above ground productivity, edaphic properties and nutrient cycling, general universal law in terrestrial regions do not represent necessarily a relevant benchmark for the fragile dryland regions. There have been some experiments and studies on the driving factors on the amount of SMB, but the results of these studies are often inconsistent or even completely opposite. The amount of SMBC and SMBN is not only affected by the amount of dead primary products and soil organic matter (Kaiser et al., 1992; Zak et al., 2003), but also regulated by soil environmental conditions, such as soil temperature, pH, oxygen, soil water content and nutrient availability (Gallardo and Schlesinger, 1992; Zhou et al., 2015). However, the relative contributions of these factors are inconsistent among the above studies. Therefore, we still know little about the controlling factors of SMB in dryland regions.

Since most drylands region are relatively infertile and fragile (Reynolds et al., 2007), a better understanding of patterns and drivers of SMBC and SMBN is essential for the sake of maintaining dryland regions ecosystem functioning and services. We hypothesized that in the dryland regions, (1) in global dryland regions, the higher the degree of drought (the lower the aridity index), the lower the amount of SMBC and SMBN, (2) the amount of SMBC and SMBN would be different among ecosystem types, (3) the pattern of SMB in dryland regions would be affected by climatic factors and soil factors.

1 Materials and methods

1.1 Data collection

Data in our study was collected from Web of Science and Science Direct. We compiled the dataset by searching the literature published from January 2000 to March 2021 with the following key words: "dryland" OR "arid" OR "semi-arid" AND "microbial biomass". This resulted in a total of 2755 published references, after a duplicated filtering literature retrieved from both database with EndNote references manager software (EndNote X9). We performed a filtering through the abstract and title of each reference, then through the full text to decide whether the article matched our selection criteria. Data was chosen based on the following criterion: (1) the article contained at least the amount of SMBC or SMBN; (2) the amount of SMBC or SMBN was measured by the fumigation extraction method, which is the most widely applied and standardized method for the estimation of SMBC and SMBN (Vance et al., 1987). We use only one method and ignore those based on dilution plate court, microware irradiation, microscopy, phospholipid fatty acid, quantitative PCR or substrate-induced respiration to avoid methodological discrepancies; meanwhile fumigation extraction method was most frequent method we found; (3) experiments were taken under natural conditions (laboratory or greenhouse experiments were excluded), when manipulation experiments were reported, only data from the "control" plots was used; (4) measurements were conducted in dryland ecosystems (AI < 0.65).

Altogether, we found 86 relevant published papers, including 109 observations of SMBC and 79 observations of SMBN from 100 study sites across global dryland regions (**Fig. 1**). A list of articles including climatic and soil information was presented in Appendix. All original data were extracted from the text, tables, figures and appendices of the publications. If data was present graphically, we used the Web Plot Digitizer 4.2 software to digitize the numerical data.

1.2 Data preparation

Given that the soil was collected from different depth in the original studies, we treated soil depth as a continuous variable when performing statistical analysis and processed according to the following rules. At the same location (same latitude and longitude), if the amount of SMB came from different depths (such as 0-10, 10-20, 20-30 cm), we averaged them and the result was used as represent 0-30cm soil layer data. In one location, data of soil samples from the same soil layer would be averaged. If the soil depth was less than 30cm, we assumed that the measurements represent the top 0-30 cm soil profile.

For each selected study site, we collected the geographic location, ecosystem type, parameters of soil (soil organic carbon(SOC), soil pH, and soil sand fraction), SMBC and/or SMBN, if reported. Other data, such as AI, were collected in open access databases based on their geographic location (http://www.csi.cgiar.org). To explore the pattern, we classified AI into different categories. According to FAO guidelines, sites with AI < 0.65 were considered as drylands and further divided into drought subtypes of hyper-arid class (AI $<$ 0.05), arid class (0.05 [?] AI < 0.2), semi-arid class (0.2 [?] AI < 0.5), and dry sub-humid class (0.5 [?] AI < 0.65) (UNEP, 1992). In our study, the values of AI ranged from 0.0868 to 0.6477. Ecosystem types are mainly divided into four categories: desert, grassland, forest, and cropland. The classification standard is to look for keywords in the method of the references. If those data were not given in the references, we used the Harmonized World Soil Database V1.2 to extract such information based on the coordinates.

1.3 Statistical analysis

The original data of SMBC and SMBN was ln-transformed to improve the normality of the dataset. Violin plot and column chart was used to report the mean and standard error graphically. One-way analysis of variance (ANOVA) followed by Duncan's post hoc tests were used to detect differences in the amount of SMBC, SMBN, the ratio of SMBC to SMBN among the three drought classes and four ecosystem types (a level of $p< 0.05$ was accepted as significant). Scatter plots and linear fitting are used to report the relationship and trend between two parameters. Pearson correlation coefficient was used to verify the correlation between two factors (significant level: * means 0.05, ** means 0.01). Besides, Pearson correlation coefficient test, univariate analysis of variance and one-way analysis of variance test were used IBM SPSS Statistics 23 software. Origin 9.0 was used to generate graphs and Arc GIS 10.7 was used to generate the map of sample sites.

2. Results

2.1 SMB among different drought classes

In our study, the average contents of SMBC and SMBN in global dryland regions were 358.47 +- 25.45 mg kg^{-1} and 51.86 +- 4.59 mg kg^{-1}, respectively. At drought level, the amount of SMBC and SMBN did vary among different drought classes, which both increased from arid to semi-arid to dry sub-humid drought classes (**Fig. 2**). The amount of SMB in arid drought class was significantly less than the other two classes, but there was not a significantly difference between semi-arid drought and dry sub-humid drought classes. The relationship between SMBC and SMBN is a crucial parameter to determine soil stoichiometry balance, which is closely related with the microbes' use efficiency. Our study showed that the relationship between the amount of SMBC and SMBN was significantly positive (**Fig.3**).

2.2 SMB among different ecosystem types

In order to conduct vegetation-level analysis, we aggregated the original data into four ecosystem types: desert, grassland, forest and cropland. On the whole, the drought degree of the desert ecosystem was significantly higher, because its aridity index was significantly lower than that of the other three ecosystems (**Fig. 4**). At ecosystem level, the amount of SMB and the ratio of SMBC to SMBN varied among different ecosystem types. The amount of SMBC in desert was significantly lower than those of other ecosystem types, and the remaining three ecosystem types were not significantly different from each other (**Fig. 5**). The amount of SMBN had same order as SMBC; desert was also the lowest one, but there was a significant difference between grassland and cropland (**Fig. 5**). The ratio of SMBC to SMBN showed a completely different pattern between cropland and the rest three types. Cropland ecosystem had the highest ratio of SMBC to SMBN (**Fig. 5**).

2.3 Factors affecting the SMB

Based on pearson correlation analysis, the amount and ratios of SMB were controlled by a variety of factors (**Table 1**). Mean annual temperature, soil bulk density and soil C/N had positive relationship with the amount of SMBC. Opposite relationships were observed for SMBN. There was no significant difference between environmental factors and the amount of SMB. The ratio of SMBC to SMBN had a strong and negative correlation with soil properties as pH ($p < 0.05$) and sand fraction ($p < 0.05$); whereas, soil bulk density and soil C/N did not differ. Soil bulk density and soil C/N increased with aridity index, while mean annual temperature, soil sand fraction and soil pH decreased with it.

3. Discussion

3.1 SMB under low vegetation cover level in dryland regions

Our study summarized that in the dryland regions, the amount of SMBC and SMBN were 358.47 +- 25.45 mg kg^{-1} and 51.86 +- 4.59 mg kg^{-1} in the 0-30 cm soil profile, which were almost half of the previous terrestrial ecosystems study (SMBC 680.4 mg $kg^{-1}$and SMBN 105 mg kg^{-1}, Xu et al. 2013). It has been speculated that the discrepancy might be due to the study regions. Dryland regions are part of land and just cover about 41% of Earth's land surface, which include four main ecosystem types: grassland, desert, cropland and forest. The total area of these four ecosystem types accounts for at least 65% of the dryland regions area; meanwhile, forests which with high vegetation cover only account for 18% of the dryland regions area. (Millennium Ecosystem Assessment, 2005). Desert and grassland have lower vegetation cover rate and plant diversity compared to tropical forest (Schuldt et al., 2019; Conti et al., 2013; Cook-Patton et al., 2011). Vegetation cover and plant diversity influence the plant quantity directly and the quality of plant litter and root exudates which in turn indirectly affect the soil condition (Drenovsky et al., 2010; Xiao et al., 2017); meanwhile, the microbial processes of carbon and nitrogen cycles were affected by soil condition due to the differences in quality and quantity of nutrient (Bargali et al., 1993; Kara et al., 2008).

Consistent with our hypothesis, the amount of SMBC and SMBN were significantly different among ecosystem types in dryland regions (**Fig. 5**). Different ecosystems develop unique patterns of adaptation, especially under extreme conditions such as drought. Desert which was the main ecosystem type in drylands region is with sparse vegetation cover, in turn the soil in desert was lacked of ample root networks and plant litter to provide enough nutrient to soil microbes (Yang et al., 2014; Luna et al., 2016; Gang et al., 2012). The reason for low amount of SMBC and SMBN in the desert was likely a deficiency available nutrient content by low degree of aboveground vegetation cover. To some extent, the greater amount of organic matter accumulates may indirectly affect soil microbial activity and abundance, then soil becomes more suitable for microbial growth (Shrestha et al., 2008).

According to the plant-soil-microbes theory supported by many studies, the response among the three parts is significant and sensitive. The roots-dominated soil usually shows a greater chance of nutrient supply and cycling, thus enhances the contents of SMBC and SMBN around the root zone especially in desert soil (Jia et al., 2017). Jia et al. (2017) found after plant restoration in an arid desert of northern China, the vegetation cover rate increased and the greater amount of plant litter enters the soil, which in turn governs the soil organic matter and nutrients, consequently the content of SMBC significantly increased. In the grassland ecosystem, grazing was one of the major and special factors to affect the ecosystem nutrient cycles. There was no doubt that microbes and animals, such as sheep, competed for ecosystem nutrient. When grazing was reduced, higher organic matter inputs to soil from root exudates and plant litter which are more conducive to microbial growth, and then the contents of SMBC and SMBN increased (Wu et al., 2014). On the contrary, some researchers found no evidence of a difference between SMB and land cover, soil quality was important instead (Moghimian et al., 2017).

3.2 stoichiometry of soil and soil microbial biomass

The stoichiometry of SMB from open-access papers and our study were together summarized in the table (**Table 2**). We indicated that the soil C/N and SMBC/SMBN in dryland regions was 10.69 and 8.73, which were different compared to other publications. Firstly, the data only included research from drylands region (aridity index < 0.65) in our study, concluding grasslands and deserts mainly (accounted for 75.4%); while the data in other studies like Xu et al. (2013) and Cleveland et al. (2007) were extracted from global region, including all ecosystem types. Differences in vegetation cover and plant diversity are the main reasons. Secondly, the sampling depth used in our study was different from that of the studies at global scale (i.e., 0-30 cm vs. 0-10 cm). There were a lot of studies that show the microbes were distributed differently in the vertical direction of soil, and the content in the top layer soil was higher than that of the deep soil (Jia et al. 2017; Xu et al., 2013).

The ratio of SMBC to SMBN was an indicator of soil stoichiometry balance and was close related with microbial C use efficiency (CUE) and N use efficiency (NUE), which was important in predicting efficiency of nutrient cycling (Mooshammer et al., 2014). The definition of CUE or NUE is a ration of nutrient allocated to growth over nutrient taken up by microbial community composition (Manzoni et al., 2012; Sinsabaugh et al., 2013). High ratio of soil C/N meant soil is rich in available C (N deficiency), microbes would have high NUE and low CUE, finally lead a low degree of SMBC/SMBN. In our study, the ratio of soil C/N was 10.69, which waslower than other previous results, indicated that in dryland regions, the soil was at a high substrate N sufficient condition. Thus, it was not surprising that microbes would be adjusted to high CUE, then lead to a high SMBC/SMBN. This inference was consistent with our research result, the ratio of SMBC/SMBN in our study was 8.73, which was higher than other results.

Providing additional evidence that the SMBC/SMBN was higher in dryland regions, we also found a previous study shown that soil with high water content usually had more available C than available N. Actually, it would result in lower SMBC/SMBN. The study reinforced our results. Dryland regions often were characterized by water deficiency, which is a plausible explanation for SMBC/SMBN in dryland regions was lower than global average. To the best of our knowledge, the mechanisms behind this relationship are not clear, and this might be also related to differences in microbial communities at different soil depths.

3.3 Factors affecting SMB

Accurately predicting SMBC and SMBN response to drought requires more comprehensive insights into the influence of edaphic properties and environmental conditions. In our study, we found the amount of SMBC and SMBN varied significantly among drought types (**Fig. 2**). Recent study suggested that increasing drought and global change have pronounced negative effects on the SMB in terrestrial ecosystems (Wan et al., 2021), which was in line with our results. Thakur et al. (2015) found that soil microbes were sensitive to soil water content, even in a short-term drought, microbial physiology and plant diversity would change a lot. Similarly, drought's legacy effect to shrubland lasting for two years after the drought ended has been observed by Hinojosa et al. (2019) in a post-fire experiment, drought mainly did have an important impact on soil processes. The amount of SMBC increased but SMBN decreased with drought, and in total the drought decreased the amount of SMB (Hinojosa et al., 2019).

In our study, pH insignificantly affected the amount of SMBC and SMBN but had a significantly negative correlation with the ratio of SMBC to SMBN (Table 1). The soil pH has been regarded as a crucial factor for the growth of soil microbial communities. A study found that bacteria grow better in slightly alkaline soil, while most fungi prefer acidic soil (Ma et al., 2016). The mainstream view is that compared to bacteria, fungi characterized by higher growth efficiency and slower degradation rate. Thus, the soil rich in fungi would accumulate higher contents of SMBC and SMBC than which rich in bacteria (Six et al., 2006). Several publications confirmed that soil pH was the main factor regulating the microbial community structure and biomass content (Liu et al., 2014; Cao et al., 2017). Moreover, Cao et al., 2017 showed pH was a significant driver to regulate the size and abundance of the microbial community and Mendes confirmed that pH had a strong relationship with the bacterial community structure in south-eastern region of the Amazon (Mendes et al., 2015).

Temperature played an important role in soil microbes carbon and nitrogen cycling. Moreover, opposite responses along temperature gradient were observed in our results, temperature had a positive correlation with the amount of SMBC but was negative with SMBN (Table.1). The results were not totally consistent with a prior study that SMBC and SMBN showed positive response (3.61% and 5.85% respectively) to warming (Xu et al., 2017). Water loss due to rising temperature might inhibit microbial growth, which eventually decrease the contents of SMBC and SMBN, especially in water-limited ecosystem (i.e., grassland). Therefore, the influence of temperature on microbes has both direct and indirect effects, and the final change of microbial biomass was the result of multiple processes. In general, it was difficult to summarize a universally suitable law about the microbes' adaptation to temperature. The main reasons for this finding were, firstly, the increase of temperature would enhance the activity of soil microbes, which would promote the development of more organisms, then increase the soil microbial biomass of the community. However, increasing temperature can contribute to greater decomposition of SOC, and cause the loss of soil carbon pool. SOC was the main nutrient source for soil microbes, and the loss of SOC directly leads to the decrease of nutrient source for microbes. Altogether, these finding emphasized the importance of environmental factors in regulating the microbes.

4. Conclusion

We used the dataset to determine the amount and pattern of SMBC and SMBN in global dryland regions. Here, we compiled 109 observations of SMBC (0-30 cm) and 79 observations of SMBN (0-30 cm) from 100 sites across global dryland regions with aridity index less than 0.65. The results showed that the average amount of SMBC and SMBN in global drylands were 358.47 +- 25.45 mg kg^{-1} and 51.86 +- 4.59 mg kg^{-1}, respectively. The amount of SMBC and SMBN did significantly vary among different drought types and ecosystem types. A significant positive correlation was showed between the amount of SMBC and SMBN regardless of the level of drought. Meanwhile, the ratio of SMBC to SMBN in global drylands region was 8.73, which is lower than the global value (7.6). Soil sand fraction and pH had significant negative effect on the ratio of SMBC to SMBN. To further improve our understanding on how dryland regions might respond to climate changes, long-term ecosystem-scale studies on soils are urgently required. Although there are a lot number of uncertainties, this study applies a new attempt to focus on the fragile dryland regions.

Acknowledgments

This study was financially supported by the National Natural Science Foundation of China (Number: 31770501). We are grateful to Dr. Yong Zhou, Dr. Lizhi Jia and Dr. Bertrand Guenet for their constructive comments of the manuscript.

Data Accessibility

literature sources, geographic information of sample sites, aridity index, soil properties, climate data, the amount of soil microbial biomass carbon and nitrogen, etc: Dryad

https://doi.org/10.5061/dryad.59zw3r292

References

Bargali K, Manral V, Padalia K, et al., 2018. Effect of vegetation type and season on microbial biomass carbon in Central Himalayan forest soils, India. Catena, 171: 125-135.

Bargali S S, Singh S P, Singh R P., 1993. Patterns of weight loss and nutrient release from decomposing leaf litter in an age series of eucalypt plantations. Soil. Biol. Biochem, 25(12): 1731-1738.

Cao C, Zhang Y, Qian W, et al., 2017. Land-use changes influence soil bacterial communities in a meadow grassland in Northeast China. Solid Earth, 8(5): 1119-1129.

Cleveland, C.C., Liptzin, D., 2007. C:N:P stoichiometry in soil, is there a " Redfield ratio " for the microbial biomass?. Biogeochemistry, 85:235–252.

Conti G, Diaz S, 2013. Plant functional diversity and carbon storage–an empirical test in semi-arid forest ecosystems. J. Ecol, 101(1): 18-28.

Cook-Patton S C, McArt S H, Parachnowitsch A L, et al., 2011. A direct comparison of the consequences of plant genotypic and species diversity on communities and ecosystem function. Ecology, 92(4): 915-923.

Dai, A.G., 2013. Increasing drought under global warming in observations and models. Nat. Clim. Change, 3(1):52-58.

Delgado-Baquerizo, M., Maestre, F.T., et al., 2013. Decoupling of soil nutrient cycles as a function of aridity in global drylands. Nature, 502:672-676.

Drenovsky R E, Steenwerth K L, Jackson L E, et al., 2010. Land use and climatic factors structure regional patterns in soil microbial communities. Global. Ecol. Biogeogr, 19(1): 27-39.

Feng S, Fu Q., 2013. Expansion of global drylands under a warming climate. Atmos. Chem. Phys, 13(10): 081-10.

Fierer, N., Strickland, M. S., et al. (2009). Global patterns in belowground communities. Ecol. Lett, 12:1238–1249.

Gallardo, A., Schlesinger, W.H., 1992. Carbon and Nitrogen Limitations of Soil Microbial Biomass in Desert Ecosystems. Biogeochemistry, 18:1-17.

Gang H, Xue-yong Z, Yu-qiang L, et al., 2012. Restoration of shrub communities elevates organic carbon in arid soils of northwestern China. Soil. Biol. Biochem, 47: 123-132.

Gao, X.J., Giorgi, F., 2008. Increased aridity in the Mediterranean region under greenhouse gas forcing estimated from high resolution simulations with a regional climate model. Global Planet. Change, 62:195-209.

Hinojosa, Maria Belen, Laudicina V A , Parra A , et al, 2019. Drought and its legacy modulate the post-fire recovery of soil functionality and microbial community structure in a Mediterranean shrubland. Global Change Biol, 25(4):1409-1427.

Huang J, Yu H, Guan X, et al., 2016. Accelerated dryland expansion under climate change. Nat. Clim. Change, 6(2): 166.

Jia X, Li Y, Wu B, et al., 2017. Effects of plant restoration on soil microbial biomass in an arid desert in northern China. J. Arid. Environ, 144: 192-200.

Kaiser E A, Mueller T, Joergensen R G, et al., 1992. Evaluation of methods to estimate the soil microbial biomass and the relationship with soil texture and organic matter. Soil Biol. Biochem, 24(7): 675-683.

Kara O, Bolat İ., 2008. The effect of different land uses on soil microbial biomass carbon and nitrogen in Bartın Province. Turk. J. Agric. for, 32(4): 281-288.

Li Y, Chang S X, Tian L, et al., 2018. Conservation agriculture practices increase soil microbial biomass carbon and nitrogen in agricultural soils: a global meta-analysis. Soil Biol. Biochem, 121: 50-58.

Liu D, Wang H, An S, et al., 2019. Geographic distance and soil microbial biomass carbon drive biogeographical distribution of fungal communities in Chinese Loess Plateau soils. Sci. Total. Environ., 660: 1058-1069.

Liu J, Hua Z S, Chen L X, et al., 2014. Correlating microbial diversity patterns with geochemistry in an extreme and heterogeneous environment of mine tailings. Appl. Environ. Microbiol. 80(12): 3677-3686.

Luna L, Pastorelli R, Bastida F, et al., 2016. The combination of quarry restoration strategies in semiarid climate induces different responses in biochemical and microbiological soil properties. Appl. Soil Ecol., 107: 33-47.

Manzoni, S., Taylor, P., Richter, A., Porporato, A., Agren, G.I., 2012. Environmental and stoichiometric controls on microbial carbon-use efficiency in soils. New Phytol. 196, 79-91.

Ma H K, Bai G Y, Sun Y, et al, 2016. Opposing effects of nitrogen and water addition on soil bacterial and fungal communities in the Inner Mongolia steppe: A field experiment. Appl. Soil Ecol., 108:128-135.

Mendes L W, de Lima Brossi M J, Kuramae E E, et al., 2015. Land-use system shapes soil bacterial communities in Southeastern Amazon region. Appl. Soil Ecol., 95: 151-160.

Millennium Ecosystem Assessment. 2005. Dryland systems. Chapter 2 in: Millennium ecosystem assessment. Washington, DC, World Resources Institute.

Moghimian N, Hosseini S M, Kooch Y, et al., 2017. Impacts of changes in land use/cover on soil microbial and enzyme activities. Catena, 157: 407-414.

Mooshammer, Wanek, Hammerle, et al., 2014 Adjustment of microbial nitrogen use efficiency to carbon:nitrogen imbalances regulates soil nitrogen cycling. Nat. commun., 5.

Moyano F E, Vasilyeva N A, Bouckaert L, et al., 2012. The moisture response of soil heterotrophic respiration: interaction with soil properties. Biogeosciences, 9(3): 1173-1182.

Schloter, M., Dilly, O., Munch, J.C., 2003. Indicators for evaluating soil quality. Agr. Ecosyst. Environ., 98:255-262.

Ran X, Shen Y, Marschner P. 2017.Soil water content during and after plant growth influence nutrient availability and microbial biomass. J. Soil Sci. Plant Nut., 17(3):702-715.

Reynolds, J.F., Stafford Smith, D.M., et al, 2007. Global desertification: Building a science for dryland development. Science. 316:847-851.

Schuldt A, Ebeling A, Kunz M, et al., 2019. Multiple plant diversity components drive consumer communities across ecosystems. Nat commun, 10(1): 1460.

Shrestha, G., Stahl, P.D., 2008. Carbon accumulation and storage in semi-arid sagebrush steppe: effects of long-term grazing exclusion. Agric. Ecosyst. Environ. 125:173–181.

Sinsabaugh, R.L., 2010. Phenol oxidase, peroxidase and organic matter dynamics of soil. Soil Biol. Biochem., 42:391-404

Six J, Frey S D, Thiet R K, et al., 2006. Bacterial and fungal contributions to carbon sequestration in agroecosystems. Soil Sci. Soc. Am. J., 70(2): 555-569.

Thakur M P, Milcu A, Manning P, et al., 2015. Plant diversity drives soil microbial biomass carbon in grasslands irrespective of global environmental change factors. Global Change Biol., 21(11): 4076-4085.

UN Environment Management Group. 2011. Global drylands: a UN system-wide response. United Nations.

UNEP. 1992. World atlas of desertification. London, UK, and Baltimore, USA, United Nations Environment Programme (UNEP).

Vance E D, Brookes P C, Jenkinson D S., 1987. An extraction method for measuring soil microbial biomass C. Soil Biol. Biochem., 19(6): 703-707.

Wang C, Wang X, Liu D, et al., 2014. Aridity threshold in controlling ecosystem nitrogen cycling in arid and semi-arid grasslands. Nat commun, 5: 4799.

Wan X, Chen X, Huang Z, et al., 2021. Global soil microbial biomass decreases with aridity and land-use intensification. Global Ecol. Biogeogr.,30(5):1056-1069.

Wardle D A., 1998. Controls of temporal variability of the soil microbial biomass: a global-scale synthesis. Soil Biol. Biochem., 30(13): 1627-1637.

Wu X, Li Z, Fu B, et al., 2014. Restoration of ecosystem carbon and nitrogen storage and microbial biomass after grazing exclusion in semi-arid grasslands of Inner Mongolia. Ecol. Eng., 73: 395-403.

Xiao C, Zhou Y, Su J, et al., 2017. Effects of plant functional group loss on soil microbial community and litter decomposition in a steppe vegetation. Front. Plant Sci., 8: 2040.

Xu W, Yuan W., 2017. Responses of microbial biomass carbon and nitrogen to experimental warming: A meta-analysis. Soil Biol. Biochem., 115: 265-274.

Xu X, Thornton P E, Post W M., 2013. A global analysis of soil microbial biomass carbon, nitrogen and phosphorus in terrestrial ecosystems. Global Ecol. Biogeogr., 22(6): 737-749.

Yang H, Li X, Wang Z, et al. 2014. Carbon sequestration capacity of shifting sand dune after establishing new vegetation in the Tengger Desert, northern China. Sci. Total. Environ., 478: 1-11.

Zak D R, Holmes W E, White D C, et al., 2003. Plant diversity, soil microbial communities, and ecosystem function: are there any links?. Ecology, 84(8): 2042-2050.

Zhou Y, Clark M, Su J, et al., 2015. Litter decomposition and soil microbial community composition in three Korean pine (Pinus koraiensis) forests along an altitudinal gradient. Plant. soil, 386(1-2): 171-183.

Hosted file

`figures and tables.docx` available at https://authorea.com/users/594221/articles/713216-the-amount-of-soil-microbial-biomass-carbon-and-nitrogen-in-global-dryland-regions