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Research Article

Changes of Soil Organic Carbon and Nitrogen Storage with Vegetation Degradation in the Qinghai Lake Basin

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1. Abstract

At present, grassland degradation is a serious threat to the ecological environment of the Qinghai Lake Basin. Under the background of climate/environmental change, it is an important factor affecting carbon/nitrogen balance. Qinghai Lake Basin is a typical ecologically fragile area in China's alpine region, which is highly sensitive to grassland degradation. However, its sensitivity will be disturbed by other factors. For example, soil layer and calculation methods (such as fixed depth method, FD and equivalent mass method, ESM). A data set of 149 sets of Soil Organic Carbon (SOC) and 197 sets of Total Nitrogen (TN) data was established in this study. Responses of SOC and TN storage to grassland degradation and methodological deviations were discussed. Firstly, we evaluated the calculation method. Grassland degradation resulted in a significant increase in soil Bulk Density (BD). The FD method, which ignored the change of BD, underestimated the loss of SOC and TN storage. Then the response of SOC and TN storage to specific degradation types was analyzed, especially when grassland degenerated into desert, which resulted in serious loss of SOC and TN storage. Finally, we found that with the increase of soil depth, the negative effects of SOC and TN storage on grassland degradation gradually weakened. In summary, we identified a series of control factors (such as sampling depth, specific degradation patterns and calculation methods) to evaluate the impact of grassland degradation on SOC and TN storage.

2. Keywords:

Qinghai Lake Basin; Land use and cover change; Grassland degradation; Meta-analysis; Soil organic carbon; Total nitrogen

3. Introduction

Grassland accounts for 40% of the total land ecosystem area and plays an important role in the global carbon and nitrogen cycle [44]. The role of grassland ecosystem in terrestrial carbon/nitrogen cycle depends not only on specific plant types, but also on degradation process, which can change the carbon source/sink function of grassland ecosystem, resulting in serious losses of Soil Organic Carbon (SOC) and Total Nitrogen (TN) [2]. Previous studies have clearly shown that land use change (especially grassland degradation and forest destruction) will directly change soil carbon pools, leading to environmental degradation and global climate change [12]. Generally speaking, SOC and TN are the key factors to maintain soil quality. Grassland degradation will directly change the quality and quantity of soil litter and root exudates in microbial environment [31], water and heat conditions [18], thus changing the dynamic changes of SOC and TN storage, accelerating SOC and TN. The release intensifies the pressure of climate change. If combined with the impact of human activities [5], this will bring unprecedented challenges to the future ecological environment. Therefore, improving grassland management (such as converting farmland to forestry and grassland and land reclamation) is considered as one of the main strategies to mitigate climate change [42].

Grassland degradation has an important impact on SOC and TN storage, but it still receives interference from other specific factors. Previous studies have shown that there is a significant deviation in characterizing the impact of land use change on SOC and TN storage [49] if only sampling in selected soil layers, which does not represent the overall response in the soil [29]. Therefore, it is necessary to evaluate the behavior of SOC and TN storage in different soil layers. In addition, more attention should be paid to the deviation caused by the choice of calculation methods. Fixed Depth Method (FD) is one of the most commonly used methods for calculating SOC/TN storage. It is expressed as the product of soil Bulk Density

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(BD), soil depth and concentration [27]. However, FD may introduce numerical errors [7] in its calculations, which directly results in the incorrect estimation of SOC/TN storage [37]. Compared with FD, ESM can quantify SOC and TN storage more accurately by calibrating soil mass per unit area between different treatments [8, 10]. Because both grassland degradation and sampling depth can lead to changes in BD, more accurate methods (ESM) are needed in practice.

The Qinghai Lake Basin (QHLB) is located in the northeastern part of the Qinghai-Tibet Plateau (QTP). This area belongs to the ecologically fragile area, which has a certain degree of ecological fragility. Because of its sensitivity to climate change and the long-term development of animal husbandry, grassland degradation, soil erosion and biodiversity degradation have resulted in significant dynamic changes in SOC and TN storage. In recent years, grassland degradation has become a serious environmental crisis plaguing regional development and sustainable development. Up to now, the research on grassland degradation in QHLB is limited to specific sampling points and lacks systematic and integrated analysis. Therefore, this study intends to integrate independent studies and further analysis to study the overall response of SOC and TN to grassland degradation in QHLB. Based on the literature, a database of SOC and TN was established and meta-analyzed to quantify the response of SOC and TN to grassland degradation. The research objectives include: (1) evaluation and calculation methods (FD and ESM) and (2) quantitative analysis of the effects of specific degradation patterns and soil depth on SOC and TN in QHLB.

4. Materials and methods

4.1. Data Resource

Literature searches were performed using online internet databases in the Google Scholar, CNKI, Elsevier and Web of science with search topics related to SOC/TN change occurring in natural grasslands degradation, we compiled a series of peer-reviewed literature with the subject of the impact of the natural grasslands degradation on SOC and TN storage in the QLB from 2000 to 2019 (Table 1). We excluded studies before Year 2000 because natural grassland degradation has not caused enough attention before the new millennium. Based on extensive search, we also carried out screening carefully:

(1) Select appropriate experimental categories for each study: experimental and control. In other words, the study included at least one form of land use after natural grassland degradation.

(2) Make sure all studies in this database are independent of each other.

(3) Samples from natural grasslands and control sites should be taken using the same stratified soil sampling method and samples must be taken from mineral soil at least 10 cm deeper than 0-10 cm. Therefore, we obtained data of different soil layers from a single experiment (the minimum soil stratification in this study).

(4) In a few studies, there is no doubt that we used natural grasslands or special experiments with low disturbance intensity as the control group.

(5) The publication should explicitly present results on SOC or TN concentrations. If only Soil Organic Matter (SOM) concentrations were recorded in the study, a conversion factor of 0.58 was used to convert the data to SOC concentration [46]. In addition, if the reported data was expressed graphically, all the data were extracted using the Get Data Graph Digitizer (Version 2.22, Russian Federation).

After the above strict screening process, the 15 scientific journal articles with the most consistent topics were retained (Table 1), with 149 sets of SOC data and 197 sets of TN data extracted/downloaded for further analysis. All the sampling sites/points summarized from the database are marked in (Figure 1). According to the detailed description in the article, the land cover in the QHL was categorized into Natural grassland (Undisturbed or least disturbed in the corresponding study, NG), Degraded grassland (Grassland disturbed by grazing, artificial grassland and farmland converted to grass, DG), and Farmland (Mainly Arable land, FL), desert (Desert land resulting from overgrazing) and other land (Mainly refers to a few shrubs).

In order to explain the impact of grassland degradation on SOC/TN storage, the associated field measurements were partitioned into three subcategories corresponding to:

(1) response of SOC and TN storage to grassland degradation within multiple soil layers (0-10, 10-20, 20-30, 30-40 cm)

(2) Difference of SOC/TN storage level among different land use patterns formed by natural grassland degradation; More specifically,

(3) the performance of SOC and TN storage in different soil layers under different degradation modes.

4.2. Main Calculations

The Fixed-Depth (FD) is a commonly used method to estimate SOC/TN storage in past studies. However, in recent years, it has been suggested that improper calculation methods (such as FD method) may introduce deviations in comparing SOC/TN stocks in soils, which are often ignored [27, 38]. We use ESM method to recalculate the data based on FD, in order to compare the advantages of ESM with FD. The principles of the ESM method were given by [8, 27]: given non-uniform distribution of SOC and TN within soil profile, the treatment with the lightest soil mass was designated as the equivalent soil mass.

$$FDstock = Con * Soil_{BD} * h * 10^{-1} \quad (1)$$

$$ESMstock = FDstock - M_{ex} * \frac{C_{en}}{1000} \quad (2)$$

$$M_{ex} = \sum_1^n Soil_{BD} * 100 - M_{ref} \quad (3)$$

where $FDstock$ and $ESMstock$ represent the SOC or TN storage estimated based on the FD and ESM methods, respectively; Con indicates the concentration of SOC or TN; $Soil_{BD}$ and h represent soil bulk density and soil thickness, respectively; M_{ref} is the lightest soil mass as the reference mass, and M_{ex} is the excess soil mass.

Not all data are ideal, such as $Soil_{BD}$ data missing, and the classifications of soil layers are inconsistent among studies. we need the following methods to transform [45, 46, 56]:

$$Soil_{BD} = 1.3770 * \mathrm{Exp}(-0.0048 * Con_{SOC}) \quad (4)(4)$$

$$Y = 1 - \beta^{h} \quad (5)$$

$$C_{20} = \frac{1-\beta^{20}}{1-\beta^{\hbar}} * C_h \quad (6)$$

where Y is the cumulative ratio of SOC or TN stocks from the soil surface to the depth h (cm); β is the relative reduction rate of SOC or TN within the soil layer (SOC for 0.9928, TN for 0.983) [21, 22]; C_{20} is the expected SOC or TN storage adjusted to 0-20 cm soil layer at a specific depth; $\hbar$ is the original soil depth (cm) available in each study; C_h is measured at a specific sample depth h (cm) for SOC or TN storage.

4.3. Meta-Analysis

The SOC/TN Storage in the soil under grassland degradation were analyzed in the meta-analysis. The natural logarithm of the response ratio (R) was employed to determine the effect size as [13]:

$$\ln R = \ln(R_d / R_c) = \ln R_d - \ln R_c \quad (7)$$

Among them, R_d is the average SOC/TN storage after the degradation, and R_c is the average SOC/TN storage of control land. In general, meta-analysis requires mean, standard deviation (or standard error) and repetition times to be more accurate [13, 30], But some studies have reported missing these indicators. Similar to other meta-analyses [34], unweighted meta-analysis was used to cover as many studies as possible. The average effect size (lnR) was calculated by bootstrapping program (4999 iterations) on meta-win software, and 95% Confidence Interval (CI) was generated [43].

Sigma Plot (Version 12.5, Systat Software Inc.) was used for normality test and non-parametric analysis. Kruskal-Wallis one-way ANOVA were performed using IBM SPSS 20.0 (SPSS Inc., Chicago, USA). Fisher's protected Least Significant Difference (LSD) test was used for multiple comparisons. Except as otherwise indicated, the differences in all discussions were significant at the probability level of $P < 0.05$. Shapiro-Wilk test (Shapiro and Wilk, 1965) was used to test the normality of data before meta-analysis. Generally speaking, the LnR of SOC, TN storage and BD matches well with the normal distribution in both FD and ESM methods. Unsurprisingly, some data sets fail to satisfy the hypothesis of parametric statistical tests (e.g., the data distribution of various grassland degradation patterns in different soil layers), a non-parametric program is used for further analysis. In this study, whether LnR deviates from zero is the criterion to judge whether SOC/TN storage have changed significantly.

5. Results and Discussion

5.1. General Dataset Information

Fifteen scientific articles and 346 databases (149 sets of SOC data and 197 sets of TN data) with the most consistent topics were obtained through a series of screening procedures. In addition to verifying the methodological variations in estimating SOC/TN storage, this study discussed the different depths of SOC/TN storage after grassland degradation, the different depths of SOC/TN storage between different degradation modes and the different depths of degradation modes. Specific data distribution is shown in (Table 1, Figure 1) and the charts of the chapters to make it clear at a glance.

5.2. Responses of SOC, TN Storage and Soil Bulk Density (BD) to Grassland Degradation

Obviously, grassland degradation has a profound impact on SOC/TN storage and soil bulk density (Figure 2). FD and ESM methods were used to estimate 149 groups of SOC data and 197 groups of TN data after grassland degradation. The results clearly show that both SOC and TN show significant losses, whether FD or ESM. Specifically, the effect values of SOC storage are -0.72, -0.84 by FD and ESM methods, respectively. In other words, 51.1% and 56.8%

of SOC losses were due to grassland degradation. Based on FD and ESM, the effect values of TN storage are -0.73 and -0.85, respectively. This means that the loss of TN storage is 51.9% and 57.1%. It is not difficult to explain the loss of SOC and TN storage caused by grassland degradation. Even at this time scale, any change in land use patterns that breaks the original balance will result in changes in SOC/TN storage [1, 17]. Especially in the degradation of grassland or forest, the army will cause significant losses of SOC and TN [6, 32, 52]. Our results are supported by relevant studies in arid and semi-arid areas of Northwest China, karst areas of Southwest China and other regions of the world [12, 15, 16, 35, 49, 51]. The

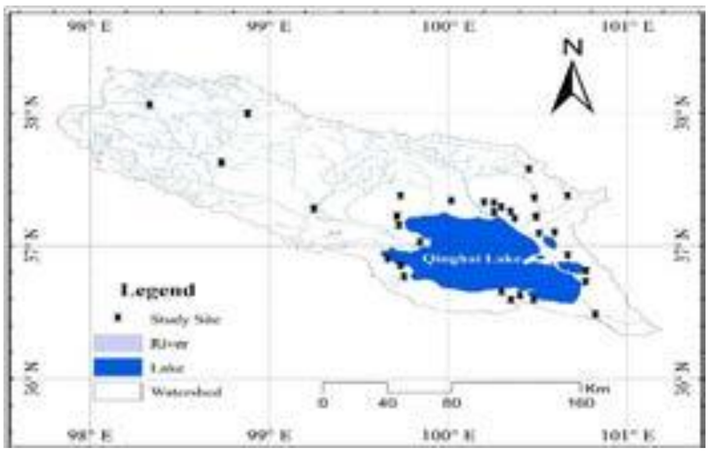


Figure 1: Study site and the locations of the experimental sites in the Qinghai Lake Basin.

Table 1: Sources and conditions of the dataset used in this study.

Number	Author	Year	Data points		Journal
			SOC	TN	
1	Yuan J, E C Y, Cao G C, et al.,	2017	4	4	Arid Zone Research
2	Zhang Z, Duo H R, Yang M, et al.,	2018	6	-	Wetland Science
3	Shi H L, Wang Q j, Jing Z C, et al.,	2011	4	4	Chinese Agricultural Science Bulletin
4	Li C L, Li Q, Zhao L, et al.,	2016	3	-	Chinese Journal of Plant Ecology
5	Zhang Y F, Yao Z, Ma Q, et al.,	2018	6	3	ADVANCES IN EARTH SCIENCE
6	Qiao Y M, Wang Z Q, Duan Z H	2009	15	15	ACTA PRATACULTURAE SINICA
7	Cao S K, Cao G C, Chen K L, et al.,	2013	44	2	Soils
8	Hu W G, Cao J J, Han Y M, et al.,	2011	1	48	Journal of Arid Land Resources and Environment
9	Li Z C, Hu X, Liu Y et al.,	2017	17	10	Soils
10	Wang Z Q, Qiao Y M, Duan Z H	2008	12	70	Journal of Qinghai University
11	Tian Y M, Wu F, Zhang L, et al.,	2013	8	6	Safety and Environmental Engineering
12	Wang Z Q	2009	4	4	Qinghai University (Master Thesis)
13	Yang Y G, Yang Y, Geng Y Q, et al.,	2018	12	10	Wetlands
14	Li C L, Li Q, Zhao L, et al.,	2016	10	16	Catena
15	Zhao H Y	2016	3	5	Beijing Forestry University (Master Thesis)

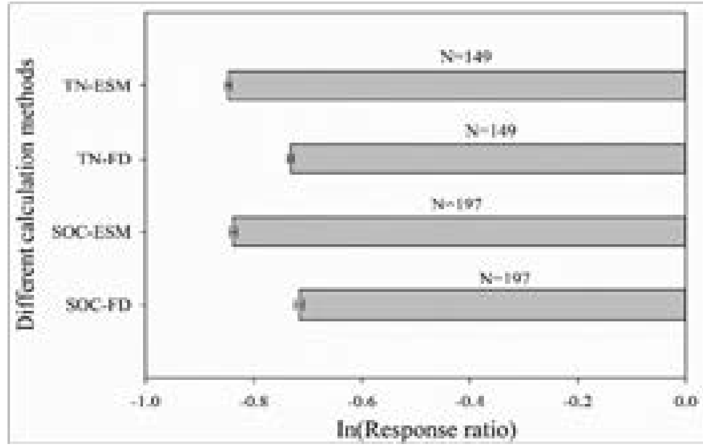


Figure 2: Overall response of SOC and TN storage to grassland degradation

loss of SOC and TN storage is considered to be caused by land degradation caused by land use change. Especially for the ecologically fragile Qinghai Lake Basin, the loss of SOC and TN storage caused by grassland degradation will be an ecological challenge that we have to face in the future.

In addition, we also find that FD and ESM methods have significant variations in estimating SOC and TN storage. Therefore, the soil bulk density corresponding to the data set was also analyzed by large sample statistics. Not surprisingly, soil bulk density also changed significantly after grassland degradation. The main reason for the difference of SOC and TN storage in Estimating Grassland degradation due to the change of soil bulk density, which is also supported by other studies [7, 27, 40]. The key to accurately grasp the impacts of grassland degradation on SOC/TN storage is to correctly evaluate the variation between the two methods and select appropriate calculation methods.

5.3. SOC and TN Storage Calculated using the FD and ESM Methods

The response of SOC and TN storage to grassland degradation was significantly different between FD and ESM. Therefore, the FD and ESM methods are preliminarily evaluated and discussed in this section. Based on FD and ESM, SOC storage lost 51.1% and 56.8%, TN storage lost 51.9% and 57.1% respectively. There was significant variation in the data, and FD significantly underestimated the impacts of grassland degradation on SOC and TN storage. This cannot be ignored when considering the fragile ecological environment of Qinghai Lake Basin. In this study, ESM method is proposed to recalculate the data of SOC and TN based on FD, which can standardize the fixed depth to the specific soil quality in a specific soil layer. When estimating SOC/TN storage, ESM takes into account the change of soil bulk density after grassland degra-

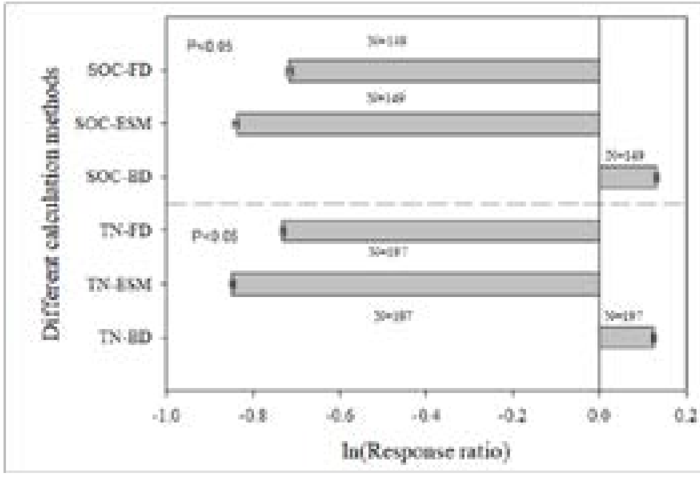


Figure 3: SOC and TN storage calculated using the FD and ESM methods, with changes in soil BD. N indicates the number of samples. The squared dots in the figure represent the mean response ration (lnR+), the solid lines on both sides of the dots represent 95%CI, and the dashed line is the standard line (lnR= 0). If 95%CI intersects the dashed line, the change is not significant. Vice versa, if there is no intersection, the change is significant.

dation, and its accuracy is higher than FD (usually described as the product of SOC/TN concentration, soil bulk density and soil thickness) [27]. As early as a decade ago, it was suggested that the difference between FD and ESM might be due to the change of soil bulk density [39]. This view is supported by other studies [6, 27, 49]. In order to explore the variation between FD and ESM, the data of soil bulk density in the literature were collected as comprehensively as possible, and the results were summarized as shown in (Figure 3). The statistical results showed that the soil bulk density of SOC and TN datasets increased by 14.2% and 13.4% respectively. The significant increase of soil bulk density will inevitably lead to FD overestimating SOC/TN storage after grassland degradation, or FD underestimating the loss of SOC/TN storage caused by grassland degradation, and this was supported by other studies [6, 51]. Our results clearly show that ESM has higher accuracy in estimating SOC/TN storage than FD. Therefore, the following data show only the results of ESM method.

5.4. Responses of SOC and TN Storages to Different Degradation Patterns

Based on the method variation, ESM was selected to further study the effects of different degradation modes on SOC/TN storage. The results of meta-analysis are shown in (Figure 4). There are significant variations among different degradation modes of grassland ($P < 0.01$). On the one hand, SOC storage in different degradation modes of grassland has significant differences. Specifically, the maximum effect of Natural Grassland (NG) degradation to cultivated land (FL) is -0.22, which means that the storage loss of SOC after NG degradation to FL is at least 42.3%. The minimum effect value of NG degradation to Desert Land (DL) is -2.78, which means that the maximum SOC loss of NG degradation to DL is 93.8%. The effects of NGs on Degraded Grassland (DG) and other degradation patterns (Others) were - 0.55 and - 0.47 respectively, which meant that SOC storage decreased by 42.3% and 37.5% respectively.TN storage has the same trend as SOC in different degradation modes: the greatest loss of NG is 95.8% after degradation to DL, NG is DG, FL and Others also suffer different degrees of loss, 42.3%, 29.5% and 17.3% respectively.

On the whole, the SOC and TN storage of QHLB is obviously lost after grassland degradation, regardless of the degradation mode. SOC and TN are the key factors of soil fertility and the basis of maintaining ecosystem services, environmental protection and sustainable land use development [23, 25]. The loss of SOC and TN storage poses a great challenge to the sustainable development of QHLB, which has become the key to improving and protecting the fragile ecological environment of QHLB. At the same time, the same results have been shown in other areas of China [15, 20, 58]. In our meta-analysis, vegetation determines the quality and quantity of soil litter and root exudation, as well as the activity of humus formation and decomposition, thus determining the content of SOC and nitrogen, resulting in loss of SOC and TN storage

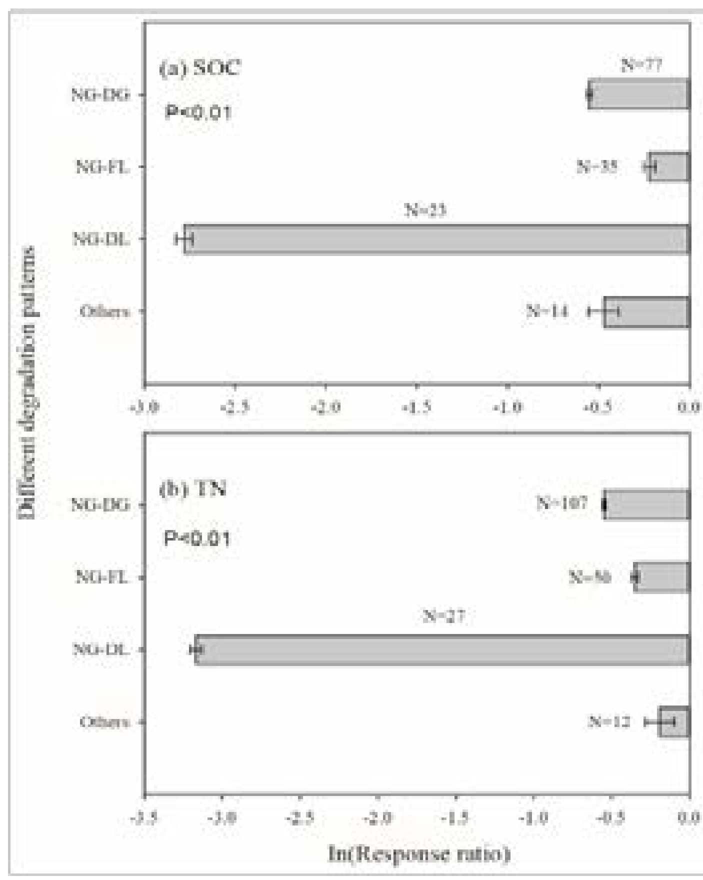


Figure 4: Effects of different Degradation patterns on SOC (a) and TN (b) storage (Natural grassland: NG; Degraded grassland: DG; Farmland: FL; Desert: DL and others).

after grassland degradation [31, 54]. In other words, the decrease of net productivity of vegetation after NG degradation leads to the decrease of organic matter input. On the other hand, grassland degradation may affect soil moisture and temperature conditions, which accelerates carbon and nitrogen decomposition and reduces SOC and TN storage [9, 31]. QHLB is located in the alpine region with large temperature difference and abundant precipitation. Soil moisture and temperature conditions limit the storage of SOC and TN. Last but not least, the significant freeze-thaw process of QHLB may cause a lot of SOC losses [11, 57]. Strengthening grassland management and controlling the disturbance of human activities are of great significance to the maintenance and improvement of ecological environment in the QHLB.

5.5. Effect of Sampling Depth on the SOC and TN Storage

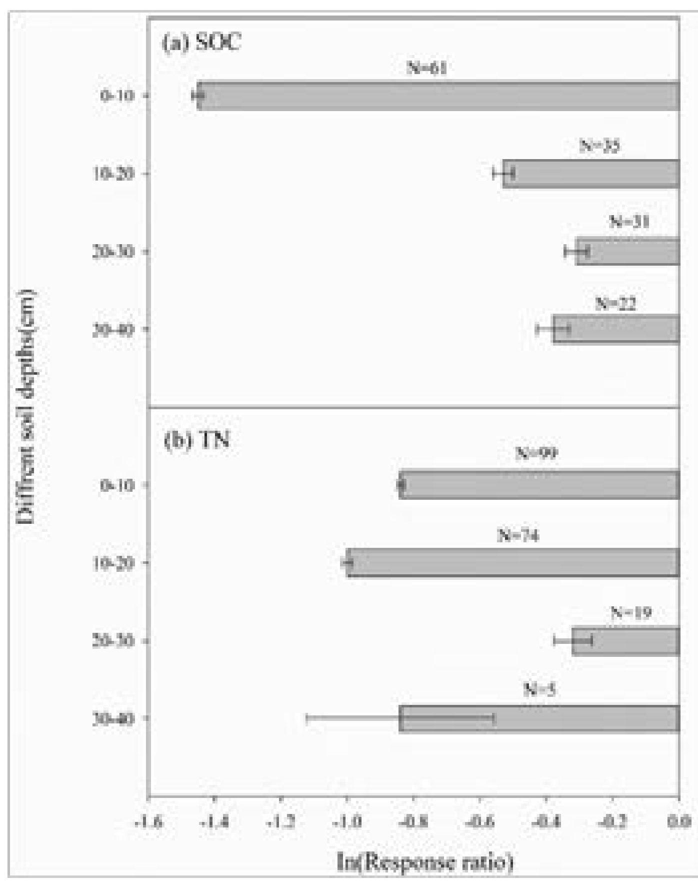
In addition to the variation of calculation methods and different degradation patterns, it is noteworthy that SOC and TN storage also show certain regularity in response to grassland degradation at different soil depths. Hu et al. (2016) claimed that SOC and TN storage at different depths responded significantly to land use change. Therefore, we also discussed the response of SOC and TN to grassland degradation at different depths (0-10, 10-20, 20-30 and 30-40 cm). As shown in (Figure 5 and Figure 6), the overall performance of SOC and TN is that the storage loss decreases with the increase of soil depth. Specifically, the effects of SOC storage are - 1.45, - 0.53, - 0.31 and - 0.38 respectively, while the effects of TN storage are - 0.84, - 1, - 0.32 and - 0.84 (uncertainty caused by too small sample size, sample size = 5). What is more interesting is that we can focus on the performance of SOC and TN storage in different soil layers under specific degradation modes, as shown in (Figure 6). It is not difficult to find that the loss effect of SOC and TN storage also decreases gradually with the increase of soil depth under the condition of sufficient sample size.

In conclusion, our meta-analysis results show that grassland degradation leads to SOC and TN storage loss in all soil layers, and SOC and TN storage have significant variations in grassland degradation among different soil layers. Obviously, shallow sampling soil is more sensitive to grassland degradation. For example, grazing (especially overgrazing) increases heterotrophic respiration in the aboveground parts of plants, resulting in an increase in their share of ecosystem respiration, thereby reducing the storage of shallow organic carbon, while the response of deep SOC/TN storage is weak [14, 19]. Therefore, the differences in soil selection may lead to deviations in the assessment of SOC and TN storage [36]. In addition, we can find that the sampling depth is generally concentrated in 0-40 cm shallow soil, which is still widely used in other areas [3, 28,48]. This will inevitably lead to uncertainty and error, and even to biased conclusions. In order to evaluate the response of SOC and TN storage to grassland degradation more accurately, appropriate sampling depth was selected. [24] believes that plant roots contribute to the transport of carbon and nitrogen in soil. The sampling depth for accurately evaluating SOC and TN storage changes should be at least 1m, preferably 2m. Therefore, we suggest that more attention should be paid to the uncertainty of sampling depth in future research. Otherwise, the response of SOC and TN to grassland degradation would be overestimated/underestimated if soil samples were collected only at a specific depth.

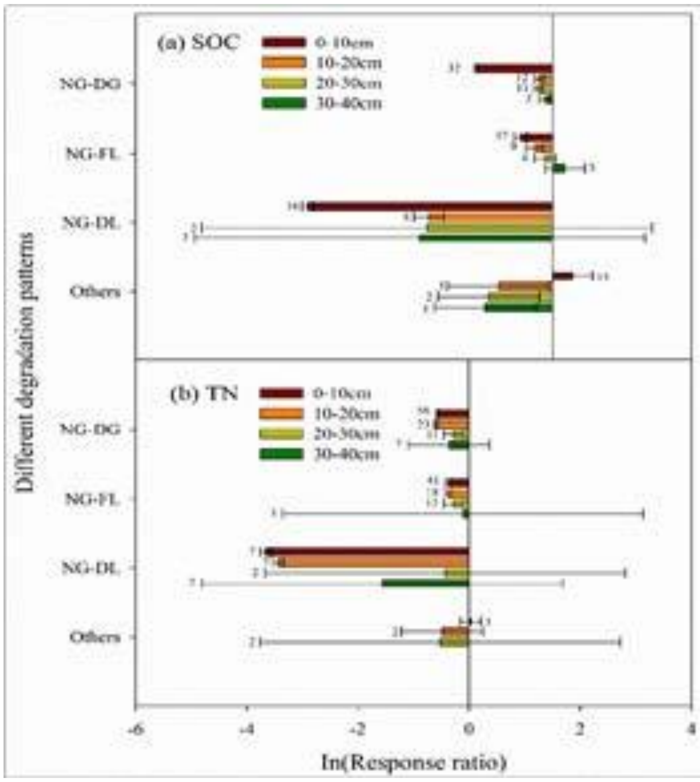
6. Conclusion

In this study, the response of SOC and TN storage to grassland degradation in Qinghai Lake Basin was studied by meta-analysis. The conclusions are as follows:

(1) SOC and TN storage showed significant negative response (loss) to grassland degradation, which depended on specific degradation patterns, soil depth and calculation methods (fixed depth, FD and equivalent mass, ESM).



Figures 5: The overall response of SOC (a) and TN (b) storage in different soil layers.



Figures 6: Response of SOC and TN storage in different depths to specific Degradation patterns.

(2) At watershed scale, grassland degradation leads to an increase in soil bulk density, and FD underestimates the loss of SOC and TN storage. In order to evaluate the response of SOC and TN to grassland degradation more accurately, more attention should be paid to the variation between different soil layers.

(3) The response of SOC and TN storage to specific degradation modes varies greatly. Therefore, in future research, we should focus on specific degradation patterns, sampling depth and calculation methods. In addition, we need to pay more attention to the basic processes and related mechanisms of SOC and TN storage loss.

(4) In addition to the differences in specific degradation modes, sampling depth and calculation methods, we are also paying attention to the differential effects of initial environment on SOC and TN storage. This will also be our next priority.

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