Earth-Science Reviews 194 (2019) 452–454

Contents lists available at ScienceDirect

Earth-Science Reviews

journal homepage: www.elsevier.com/locate/earscirev

Discussion

Reply to the comment on "Effects of grazing exclusion on carbon sequestration in China's grassland"

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1. Introduction

Vegetation biomass and soil are two major C pools in the grassland ecosystem (Hu et al., 2016). Globally, although the importance of grazing exclusion (GE) in grassland C sequestration and the dynamics of C pools as a result of grazing exclusion have been well reported (Mcsherry and Ritchie, 2013), there is little knowledge about how much C is sequestration or loss after grassland with grazing exclusion (Hu et al., 2016). In our results, the rate of carbon stock change was significantly declined along with the years of grazing exclusion increase, which showed an exponential decay trend since grazing exclusion (Deng et al., 2017). However, this conclusion cannot be accepted by some researchers, such as Yuan et al., who are supposed that the exponential decay trend varies with the years of grazing exclusion was incorrect. In their Comment, Yuan et al. (2018) claim that the discordance of the best model exploring the change rate in C pool with the years of grazing exclusion.

Specifically, they insist that the carbon stock change rate after GE as a function of GE duration is a quotient calculated from the carbon stock change after GE, and GE duration rather than carbon stock changes drives the close relationship of inverse proportional function. They also added that overestimation in degraded grasslands in china make our results unreliable (Harris, 2010). In addition, they propose that moderate grazing intensity will increase or stable vegetation carbon stock based on the compensatory growth theory (Doescher et al., 1997; Leriche et al., 2001), and GE management may further decrease the possibility to restore grassland (Yuan et al., 2018).

According to the comments by Yuan et al. (2018), we first check the reliability and accuracy of all the data, in the process of which there is no mistakes and computation error. Similarly, we modeled the varying carbon stock change rates with grazing exclusion durations based on our data from meta-analysis by Deng et al. (2017). Importantly, the development of vegetation is often restricted by eternal resource, and eventually become stable and balanced (Jannedy et al., 2003), indicating the importance of natural raw and stability of ecological progress. For that reason, we conducted a comparative approach to address the following question: (1) which models are better for predicting the change rate in C pools with the years of grazing exclusion (2) Whether the exponential decay trend of the carbon stock change rate was mainly cause by the year of grazing exclusion rather than the change rate in C pools after grazing exclusion. (3) whether overestimation of GE management on grassland carbon stock change.

2. Methods

The relationships between C pools (biomass C pools and soil C pool) and the years of grazing exclusion were estimated by a nonlinear model using the nonlinear (weighted) least-squares estimates of the parameters (Bates and Watts, 1988). The least-squares estimates of the parameters were determined using the *nls* function in R.

The *nls* function uses a relative-offset convergence criterion that compares the numerical imprecision at the current parameter estimates to the residual sum-of-squares. This performs well on data of the form.

$y = f(x, \theta) + eps.$

(with var.(eps) $>$ 0). It fails to indicate convergence on data of the form.

$y = f(x, \theta).$

because the criterion amounts to comparing two components of the round-off error.

3. Results

3.1. Model the carbon stock change rate after grazing exclusion

The rates of changes in biomass C pools and soil C stocks showed an decreasing trend with the years of gazing exclusion (All: $R^2 \geq 0.80$; $P < .001$). Meanwhile, the exponential decrease function, depicting

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https://doi.org/10.1016/j.earscirev.2019.04.010
Received 23 October 2018; Received in revised form 20 November 2018; Accepted 6 April 2019
Available online 09 April 2019

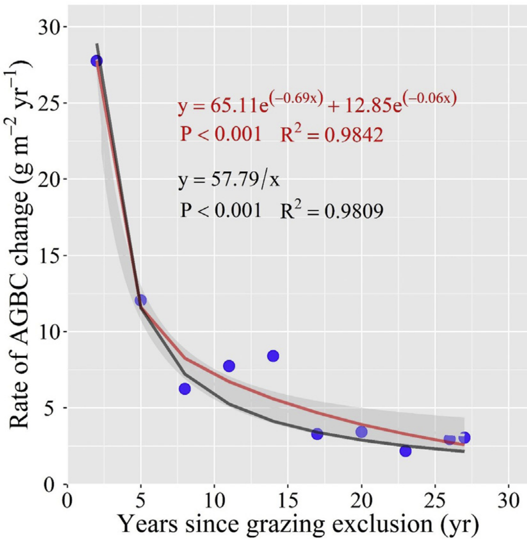

Fig. 1. The exponential function model and inverse proportional function model of the change rate between aboveground biomass carbon stock (AGBC) and years of grazing exclusion. The black line and the red line indicate the exponential function and inverse proportional function, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

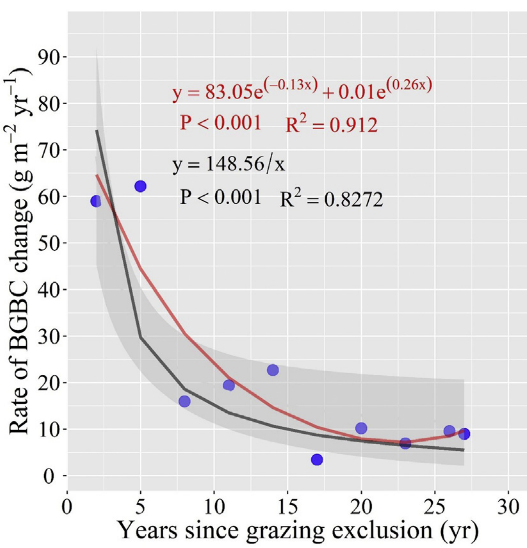

Fig. 2. The exponential function model and inverse proportional function model of the change rate between belowground biomass carbon stock (BGBC) and age of grazing exclusion. The black line and the red line indicate the exponential function and inverse proportional function, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the dynamics of C stocks change, have the more higher explanatory power than the inverse proportional function (R^2 = 0.9842, R^2 = 0.9809, Fig. 1; R^2 = 0.9120, R^2 = 0.8272, Fig. 2; R^2 = 0.9615, R^2 = 0.9555, Fig. 3). This finding potentially suggested that exponential decay model of C stocks change is more appropriate for depicting its decreasing trend with years of grazing exclusion. Contrary to the results of Yuan et al. (2018), the exponential decay function also has more explanatory power than the inverse proportional function.

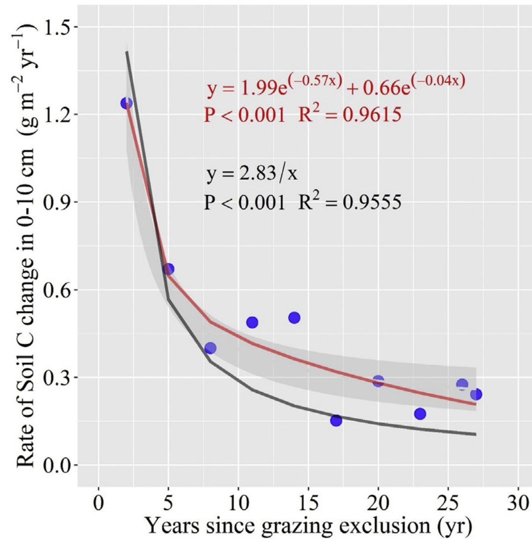

Fig. 3. The exponential function model and inverse proportional function model of the change rate between soil carbon stock (Soil C) and age of grazing exclusion. The black line and the red line indicate the exponential function and inverse proportional function, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.2. The exponential decay model of carbon stock change rate with the years of grazing exclusion

Regressing the rates of changes in C pools with the years of grazing exclusion, showed a general exponential decreasing trend, depicting the dynamics of the changing rate in biomass C pools and soil C stocks after grazing exclusion. In comparison, the change rate of soil C stocks reached a steady state (when the rate at the equilibrium point), followed by AGBC and BGBC, indicating that the increase of soil C stock lags behind the accumulation of biomass C stock after grazing exclusion (Figs. 1, 2 and 3). Importantly, the steady state, rather than a decline trend, was a common trend with the year of grazing exclusion.

4. Discussion

With the years of grazing exclusion, the change rates in C pools showed a common decline trends both in biomass and soil, indicating C pool increases with the year of grazing exclusion in grassland ecosystem. The increasing trends in C pools with grazing exclusion is consistent with most studies on grassland of the world (Yayneshet et al., 2009; Bagchi and Ritchie, 2010; Steffens et al., 2008; Golluscio et al., 2009; Deng et al., 2017). Grazing exclusion increases biomass and plant cover (Wang et al., 2014), and then reduces of output of C from ecosystem to livestock due to the removal of grazing pressure accelerates organic matter (Deng et al., 2014).

4.1. The exponential decay function can better model the relationship between GE duration and the change rates in C pools

Importantly, the changing rates in C pools first decrease rapidly and then slowly decrease with the increasing GE duration, which has been modeled by the exponential decay function or inverse proportional function (Deng et al., 2017). Yuan et al. (2018) indicated that inverse proportional function can more accurately model the carbon stock change rate as a function of GE duration, in which process the precise statistical methods and essence of ecological process are shortage (Saunders et al., 2010). Similarly, comparing the results of two models, we found the exponential decay function have more higher explanatory ability both in grassland C pools and soil C stocks than inverse proportional function (Figs. 1, 2, 3). Therefore, our finding is more accurate than the results of Yuan et al., (2018), and it is more accordant with ecological progress (Saunders et al., 2010; Jannedy et al., 2003). And, the inverse proportional function model was incorrect, and was not accordant with eventually stable theory. It is well known that the pursuit of the statistical power is a precise behavior; Moreover, what we are explore is the tendency and essence of natural low rather than the more significant statistics. Importantly, the development of biome is often restricted by eternal resource, and eventually become stable and balanced (Jannedy et al., 2003). The exponential decay function is more accordant with the eventually stable theory, while the inverse function does not conform with the common theory, indicating blind pursuit of significant statistic neglects the natural process of ecology ecosystems. The exponential decay function was also fully demonstrated in previous study (Hu et al., 2016; Xiong et al., 2016).

4.2. GE duration mainly drive the close exponential decay function relationship between GE duration and the change rates in C pools

In addition, Yuan et al., 2018 also concluded that the exponential decay trend of the carbon stock change rate was mainly caused by GE duration, not by the changes in AGBC, BGBC and soil carbon stock after grazing exclusion (Deng et al., 2017). In our study, we found that AGBC changes reached a steady state (when the rate at the equilibrium point) first, followed by BGBC, and then soil C (Appendix Fig. S1; Deng et al., 2017), suggesting that the increase of BGBC lags behind the accumulation of AGBC, and the increase of soil C stock lags behind the accumulation of biomass C stock after GE. These results are consistent with the expectation that changes in soil C stock lag behind changes in vegetation biomass C, as plant biomass is the major source of soil C inputs (Hu et al., 2016). However, we did not illustrate the accurate estimates of how long grazing exclusion duration must be for grassland restoration. Combined with the part results of GE duration driven the relationship, we can make our results improved. According to the two theory: exponential decay function and carbon stock change rate mainly caused by GE duration, the best estimates GE duration for stable accumulation of C pool can be modeled and deduced after grassland restoration.

4.3. GE duration initially increase and then continuously stable vegetation carbon stock

Yuan et al., (2017) also claim that the overestimation in degraded grasslands, and propose that moderate grazing intensity will increase or stable vegetation carbon stock. The proof mainly concentrated on that the most grazed sites in our results was under medium or severe grazing and experienced degradation (Hu et al., 2016; Pei et al., 2008; Wu et al., 2010). However, many researches do not have a consensus on degradation grassland, even though gazing management has come into being for a long time (Golluscio et al., 2009; Deng et al., 2017), which can mislead that moderate grazing intensity will increase or stable vegetation carbon stock. Moreover, our result only discussed the relationship rather than grazing management on grassland C pools (Deng et al., 2017), although GE management may further decrease the possibility to restore grassland (Yuan et al., 2018). Thus, GE duration initially increase the vegetation carbon stock, and then continuously stable vegetation carbon stock.

5. Conclusion

We simultaneously modeled the relationship between the change rates of C pools and GE duration in grassland ecosystem. With the years of grazing exclusion, a common decreasing rates of C pools both in biomass and soil was found by two models, including exponential decay function and inverse proportional function. Inconsistent with the results of Yuan et al. (2018), we found that the exponential decay function has higher explanatory ability to depict the change rates in C pool with the years of grazing exclusion, which is accordant with ecological progress. Thus, we insist on that exponential decay function can be more accurate than inverse proportional function. In addition, we estimated and concluded the best GE duration for grassland restoration when considering grazing exclusion duration as the primary reason for the changing rate in the carbon stock change rate. In this aspect, we are in accord with the result of Yuan et al., (2018), which duration rather than vegetation carbon stock change drives the relationship between GE duration and vegetation carbon stock change. Moreover, GE duration initially increase the vegetation carbon stock, and then continuously stable vegetation carbon stock, which deny the light grazing management will increase or stable vegetation carbon stock in Yuan et al., (2018). The new comprehensive findings will provide more useful ecological management for grassland restoration and C storage.

Acknowledgments

This work was supported by the National Natural Science Foundationof China (41390463, 41501094, 41722107, 41525003), the Youth Talent Plan Foundation of Northwest A&F University (2452018025).

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