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Original research article

Global patterns of the effects of land-use changes on soil carbon stocks

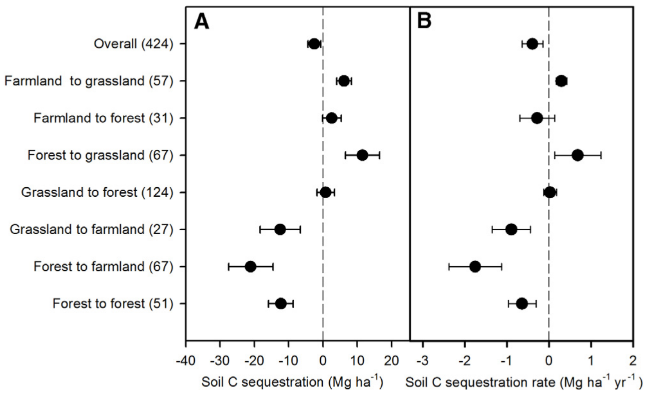
Lei Deng, Guang-yu Zhu, Zhuang-sheng Tang, Zhou-ping Shangguan *

State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Northwest A&F University, Yangling, Shaanxi 712100, China

HIGHLIGHTS

- Soil C sequestrations varied in different land use change types.
- Soil C sequestration dynamics were not determined by age at the global level.
- Globally, land use conversions have significantly reduced soil C stock.

GRAPHICAL ABSTRACT



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ABSTRACT

Despite hundreds of field studies and at least a dozen literature reviews, there is still considerable disagreement about the direction and magnitude of changes in soil C stocks with land use change. This paper reviews the literature on the effects of land use conversions on soil C stocks, based on a synthesis of 103 recent publications, including 160 sites in 29 countries, with the aims of determining the factors responsible for soil C sequestration and quantifying changes in soil C stocks from seven land use conversions. The results show that as an overall average across all land use change examined, land use conversions have significantly reduced soil C stocks (0.39 Mg ha^{-1} yr^{-1}). Soil C stocks significantly increased after conversions from farmland to grassland (0.30 Mg ha^{-1} yr^{-1}) and forest to grassland (0.68 Mg ha^{-1} yr^{-1}), but significantly declined after conversion from grassland to farmland (0.89 Mg ha^{-1} yr^{-1}), forest to farmland (1.74 Mg ha^{-1} yr^{-1}), and forest to forest (0.63 Mg ha^{-1} yr^{-1}). And after conversion from farmland to forest and grassland to forest, soil C stocks did not change significantly. Globally, soil C sequestration showed a significant negative correlation with initial soil C stocks ($P<0.05$), and the

* Corresponding author. Tel.: +86 29 87019107; fax: +86 29 87012210.
E-mail address: shangguan@ms.iswc.ac.cn (Z.-p. Shangguan).

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effects of climatic factors (mean annual temperature and mean annual precipitation) on soil C sequestration varied between the land use conversion types. Also, the relationships between soil C sequestration and age since land use conversion varied in different land use change types. Generally, where the land use changes decreased soil C, the reverse process usually increased soil C stocks and vice versa. Soil C sequestration dynamics were not determined by age since land use conversion at the global level when all land use change types were combined.

1. Introduction

The terrestrial biosphere can act either as a source or as a sink for atmospheric CO_2, both the vegetation and the soil may play a part in the residual terrestrial uptake (IPCC, 2000; Guo and Gifford, 2002). Organic carbon stored in the world's soils is the largest terrestrial pool of carbon, and is at least three times larger than the pool of atmospheric carbon dioxide (Jobbágy and Jackson, 2000; Amundson, 2001). It has long been recognized that land-cover change and management can alter the amount of organic carbon stored in the soil (Laganière et al., 2010; Deng et al., 2014a), and this in turn affects both soil fertility and atmospheric carbon dioxide (CO_2) concentrations (Powers et al., 2011). Although the contributions of land-cover change to anthropogenic CO_2 atmospheric emissions have recently been revised downward, the estimated current annual contribution of 1.2 Pg, or about 12%–15% of total anthropogenic fluxes, is still significant (Van der Werf et al., 2009). Therefore, a new challenge in the context of climate change mitigation is the management of terrestrial ecosystem to conserve existing carbon stocks and to remove carbon from the atmosphere by adding to stocks.

Land use change can cause a change in land cover and an associated change in carbon stocks (Bolin and Sukumar, 2000; Deng et al., 2014a,b). The change from one ecosystem to another could occur naturally or be the result of human activity. Each soil has a carbon carrying capacity, and an equilibrium carbon content depending on the nature of vegetation, precipitation and temperature (Jobbágy and Jackson, 2000). The equilibrium between carbon inflows and outflows in soil is disturbed by land use change until a new equilibrium is eventually reached in the new ecosystem (Guo and Gifford, 2002). During this process, soil C stocks would have been changed, either as a carbon source or as a carbon sink. Despite hundreds of field studies and dozens of literature reviews, there is still considerable disagreement on the direction and magnitude of changes in soil C stocks with land-use change (Van der Werf et al., 2009). Indeed, the current knowledge remains inconclusive on both the magnitude and direction of C stock changes in mineral soils associated with land use type, management and other disturbances, and cannot support broad generalizations (IPCC, 2006).

Recently, some studies have reviewed the effects of certain land use changes on soil C stocks, for example, Post and Kwon (2000) found an average rate of soil C accumulation after afforestation of former farmlands with the value of 0.338 Mg ha^{-1} yr^{-1} although values vary greatly among studies, however, Vesterdal et al. (2002) observed that afforestation of former farmlands did not lead to increase of SOC in three decades. In addition, for a tropical regions study, the conversion of forests to farmland reduced soil C stocks by an average of 15.4% or 18.5%, respectively. Interestingly, both the conversions of forests to grassland and grassland to secondary forests increased soil C stocks, and the establishment of perennial tree plantations on lands that were previously grazed or cropped increased soil C stocks, but the conversion of unmanaged forests, or grasslands to plantations had no effect (Powers et al., 2011). Globally, although Guo and Gifford (2002) concluded that soil C stocks significantly increased after the conversion from farmland to grassland (19%), tree plantation (18%) and secondary forest (53%), they uses a relative percentage change. In order to understand how C stocks change after land use conversions, the changes need to be recalculated as absolute values to meet the challenge of managing soil C stocks world-wide and to help understand the contribution of carbon emissions due to land use change to the global climate change.

In addition, understanding the factors that govern the size of the current land carbon stock and the balance between plant carbon inputs and soil carbon losses is crucial to predicting the effects of future land use change on the net greenhouse gas balance, and to the development of policy for 'carbon conscious' management of the land surface. Although several authors (Post and Kwon, 2000; Paul et al., 2002; Laganière et al., 2010) have analyzed the factors determining soil C stocks during the establishment of perennial vegetation, a consensus on the relative significance of these factors has yet to be achieved. While Paul et al. (2002) found that climate is one of the most important factors influencing soil C change after cropland conversion, Laganière et al. (2010) concluded that climate had a smaller effect on soil C accumulation during afforestation when compared to previous land use, tree species planted, soil clay content and preplanting disturbance. However, at a global scale, we had difficulties in getting access to many factors that may influence the soil C stock after land use change from the existing field studies, except for climatic factors, so this paper mainly analyzed the effects of mean annual precipitation and temperature on soil C sequestration after land use conversions, as was done by other national or global studies (Guo and Gifford, 2002; Paul et al., 2002; Yang et al., 2011).

The objectives of this study were: (1) explore the effect of various land use changes on soil C sequestration; (2) establish the temporal pattern of soil C sequestration for different land use changes; and (3) study those factors driving the changes in soil C. To achieve these objectives we synthesized the findings of 103 recent publications from the literature in which