Science of the Total Environment 609 (2017) 556–562

Contents lists available at ScienceDirect

Science of the Total Environment

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

Land use change effects on ecosystem carbon budget in the Sichuan Basin of Southwest China: Conversion of cropland to forest ecosystem

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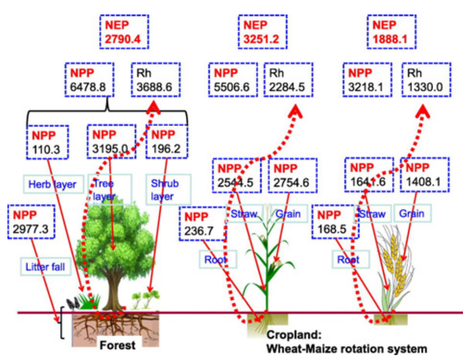
HIGHLIGHTS

- Effects of conversion of cropland to forest ecosystem on soil respiration and carbon budget were measured over three years.
- Forest released more CO_2 via soil heterotrophic respiration than cropland.
- The average NEP for forest ecosystem were over three times greater than cropland.
- Conversion of cropland to forest significantly enhanced carbon sequestration in Southwestern China.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 17 April 2017
Received in revised form 25 June 2017
Accepted 19 July 2017
Available online 27 July 2017

Editor: D. Barcelo

Keywords:
Land use change
Soil organic carbon
Net primary productivity
Carbon balance

ABSTRACT

In the humid subtropics, conversion of cropland to forest has been recognized to influence carbon cycling (e.g., soil CO_2 emissions) and the associated ecosystem carbon balance. A three-year field study was conducted in situ to quantitatively evaluate effects of land use change on carbon budget in a cropland (under winter wheat-summer maize rotation) comparison with the adjacent forest ecosystem. During the three-year experimental period, on average, soil heterotrophic respirations were 35.19 mg $C\cdot m^{-2}\cdot h^{-1}$ for the cropland and 40.02 mg $C\cdot m^{-2}\cdot h^{-1}$ for the adjacent forest ecosystem. The quantified net primary production (NPP) were 8724.78 kg $C\cdot ha^{-1}\cdot year^{-1}$ for the cropland (3218.14 kg $C\cdot ha^{-1}$ for winter wheat season and 5506.64 kg $C\cdot ha^{-1}$ for summer maize season) and 6478.99 kg $C\cdot ha^{-1}\cdot year^{-1}$ for the adjacent forest ecosystem. Thus, the average positive net ecosystem production (NEP) of 5139.33 kg $C\cdot ha^{-1}\cdot year^{-1}$ and 2790.43 kg $C\cdot ha^{-1}\cdot year^{-1}$ were gained in the cropland and the adjacent forest ecosystem, respectively. Nonetheless, if take into consideration of crop grain harvest (i.e., removal), the mean NEP was only 976.69 kg $C\cdot ha^{-1}\cdot year^{-1}$ for cropland which were over three-fold lower than for the adjacent forest ecosystem. The practice of conversion of cropland (maize-wheat rotation system) to forest consequently resulted in an average annual net carbon sequestration of 1813.74 kg $C\cdot ha^{-1}\cdot year^{-1}$ in the study. Therefore, our findings highlight that practices of conversion of subtropical cropland to forest commonly conducted in the last decades act as sinks of atmospheric CO_2 in southwest China.

1. Introduction

The exchange of CO_2 between soil and atmosphere is the most important component of the carbon cycles in terrestrial ecosystem (IPCC,

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http://dx.doi.org/10.1016/j.scitotenv.2017.07.167

2001; Janzen, 2004). Land use changes and vegetation types not only affect soil CO_2 emissions but also soil carbon accumulation and turnover rates, carbon loss through soil erosion and carbon storage in vegetation biomass in various ecosystems (Post and Kwon, 2000; Houghton, 2003; Schulp et al., 2008; Leifeld, 2013). For instance, globally, conversion of forests to croplands decreased soil organic carbon (SOC) stocks by 31–52% (Wei et al., 2014). In contrast, conversion of croplands to forests increased SOC stocks with a global average of 0.3 Mg C ha^{-1} yr^{-1} likely through presenting soil erosion, increasing organic matter inputs and decreasing carbon decomposition (Post and Kwon, 2000). Reforestation and afforestation have been well known as the important land-use change types that drive the increases in carbon sequestration of terrestrial ecosystems globally (Schulp et al., 2008; Xiong et al., 2014). Therefore, in the context of ratification of the Kyoto protocol, afforestation and/or reforestation on cropland have been proposed as an effective climate change mitigation practice through enhancing soil carbon sequestrations (IPCC, 2000; Saurette et al., 2008).

Afforestation and reforestation practices on cropland consistently increased in a number of countries across the world over the past two decades (Paul et al., 2002; Vesterdal et al., 2002; Smal and Olszewska, 2008; Saurette et al., 2008; Kula, 2010; Maia et al., 2010; Lei et al., 2014). The recent estimate indicated that afforestation, reforestation, and restoration of cultivated and abandoned croplands could increase carbon sinks of 52–104 Pg C by year of 2040 globally with relatively large uncertainty (Yao et al., 2014). Previous studies have observed large variations in afforestation and reforestation effects on ecosystem and/or soil carbon dynamic due to specific site conditions of climate and soil type, and vegetation type (Schulp et al., 2008; Don et al., 2009; Sheng et al., 2010; Wiesmeier et al., 2015). These variations in carbon dynamics on the other hand cause uncertainty in regional and global estimates of afforestation and reforestation effects on SOC stocks (e.g., Thompson et al., 2016). Therefore, it is critical to understanding effects of the conversion of cropland to forest on C dynamics and the net C benefits (Guo and Gifford, 2002; Miehle et al., 2006; Zhang et al., 2007). However, it still remains uncertain how practices of conversion of cropland to forest affect ecosystem carbon cycles and net carbon budgets across different climates and sites (Paul et al., 2002; Van Vliet et al., 2003; Hargreaves et al., 2003). Therefore, site-specific evaluation is needed to improve understanding of the impact of converting cropland to forest on ecosystem C dynamics and budget under different management regimes and climate zones. In China, the Sloping Land Conversion Program (also known as “Grain for Green” or the Upland Conversion Program) that converts cropland to forest is one of China's most ambitious environmental initiatives and also the largest land conservation programs and also the largest land conservation program in the world to date. For this program, 14.7 million ha of cropland and 17.3 million ha of degraded land are to be converted to forest (Chen et al., 2009). Thus, a considerable amount of new forest areas have been established by the large-scale afforestation under the GGP to enhance carbon sequestration capacity in the terrestrial ecosystems of China (Wei et al., 2012). Although carbon sequestration was not the only objective of the GGP, the great potential for using forests as a short-term method for enhancing terrestrial C sequestration is well recognized (Wang et al., 2007). However, there were few available evaluations on the carbon sequestration potential of the large-scale afforestation program.

The limited available studies have focused on carbon sequestration in the Loess Plateau Region (Wei et al., 2012; Hu et al., 2017), while in particular few studies have investigated the potential of carbon sequestration with full consideration of C budgets by conversion of cropland to forest in the upper Yangtze River watershed of southwest China. In the present study, the net primary production (NPP), soil heterotrophic respiration, net ecosystem productivity (NEP) and net ecosystem C sequestration were quantified from cropland under a wheat-maize rotation system and an adjacent 40-year old subtropical conifer forest in southwestern China. The primary objective of this study was to evaluate the effects of land use change (i.e. conversion of cropland to forest) on the ecosystem carbon budgets.

2. Materials and methods

2.1. Site description

The experimental site is located at the Yanting Agro-ecological Station of Purple Soil, which is managed by the Chinese Academy of Science as part of the Chinese Ecosystem Research Network. The site is situated in the middle of the Sichuan Basin at 31°16′N, 105°28′E, at an altitude of 400 to 600 m. This area experiences a subtropical monsoon climate, and between 1981 and 2012, the site had an annual mean temperature of 17.3 °C and mean precipitation of about 826.0 mm. The soil in the study area is referred to as purple soil and classified as Pup-Orthic Entisols in the Chinese soil taxonomy and Eutric Regosol in the Food and Agriculture Organization's Soil Classification. This regosols are widely distributed in the Sichuan Basin, with an area of 160,000 km^2 (Zhu et al., 2009). The soil is particularly vulnerable to erosion, however, owing to intensive cultivation and the wet climate of the area. Soil physical and chemical characteristics are shown in Table 1.

The measurements were conducted in cropland with wheat-maize rotation system and the adjacent afforested plots. The forest plantation is an artificial forest of cypress (*Cupressus funebris*), which is the representative forest type throughout the central Sichuan Basin, Southwest China. Most of the forest in this area was planted between 1970 and 1980, but prior to 1970, the soil had been intensively used for agriculture. The trees have an average diameter at breast height (DBH > 3 cm) of 11.4 cm, an average height of 12.3 m, and a density of 1595 stems ha^{-1}. Shrubs and herbage include *Vitex negundo*, *Coriaria sinica*, *Gramineae*, and *Cyperaceae*.

The experimental cropland site was conventionally cultivated with maize from May to September and followed wheat from October to May of the following year. This double cropping rotation has been cultivated for >50 years at this region. Usually, wheat and maize seeds were directly drilled into the soil. Plowing of the top soil (0–20 cm) occurred twice a year after the harvest of the wheat crop in May and maize crop in October.

2.2. Forest biomass estimation

In May 2013, three 20 m × 20 m plots were established at the forest site. Two trees from each plot were harvested for aboveground (separated into wood, bark, and foliage components) and belowground measurements of biomass. Allometric biomass regression equations (power functions) relating to tree DBH and biomass were then derived from the above- and belowground biomass measurements, and the annual growth rate was determined as the annual ring increment from cores obtained using a corer. More detailed descriptions of this approach can be found in our previous study (Yang et al., 2007).

Table 1
Soil physical and chemical properties at 0–20 cm and 20–40 cm of adjacent cropland and forestland.

Soil properties	Forestland soil		Cropland soil	
	0–20 cm	20–40 cm	0–20 cm	20–40 cm
Soil organic C content g kg^{-1} (±SE)	21.03 ± 2.45	9.68 ± 1.42	12.31 ± 1.69	8.19 ± 0.96
Total N g kg^{-1} (±SE)	1.62 ± 0.24	0.43 ± 0.12	0.86 ± 0.09	0.67 ± 0.07
Total P g kg^{-1} (±SE)	0.51 ± 0.06	0.37 ± 0.04	0.26 ± 0.03	0.14 ± 0.02
Bulk density (g cm^{-3})	1.42	1.45	1.34	1.40
Soil pH	8.4	8.1	8.1	7.9
Clay (%)	17.6	13.3	19.6	15.4
Silt (%)	42.2	49.4	50.3	53.9

SE, standard error (n = 3).