Science of the Total Environment 648 (2019) 315–324

Contents lists available at ScienceDirect

Science of the Total Environment

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

Biophysical effect of conversion from croplands to grasslands in water-limited temperate regions of China

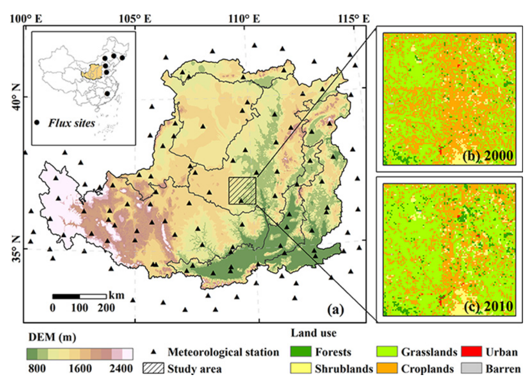
Zhengjia Liu [a,b,*], Yansui Liu [a,b,*], Muhammad Hasan Ali Baig [c]

[a] Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[b] University of Chinese Academy of Sciences, Beijing 100049, China
[c] Institute of Geo-Information and Earth Observation (IGEO), PMAS Arid Agriculture University, Rawalpindi, Pakistan

HIGHLIGHTS

- Biophysical effect of Conversion from Croplands to Grasslands (C2G) was analyzed.
- C2G resulted in the decrease in net radiation and latent heat.
- C2G led to a cooling effect at the annual scale.
- A warming effect was however found in summer due to more reduction in latent heat.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 24 May 2018
Received in revised form 8 August 2018
Accepted 9 August 2018
Available online 11 August 2018

Editor: Elena Paoletti

Keywords:
Land use change
Temperature regulation
Net radiation
Latent heat
Water-limited temperate regions

ABSTRACT

The biophysical effect of land use and land cover change (LUCC) on regional climatic regulation is currently of growing interest. However, in water-limited temperate regions, the net biophysical effect of conversion from croplands to grasslands on regional climatic regulation remains poorly understood to date. To answer this concern, a modified land surface model (mEASS) and two different land use scenarios in a typical study area of the Loess Plateau of China were used in this study. We first validated the performances of mEASS model by using observations from six flux tower sites with different land cover and three metrics of the coefficient of determination (R^2), the root mean square error (RMSE) and the difference between the simulated and observed data (bias). Subsequently, the biophysical effect of conversion from croplands to grasslands was investigated. Results indicated that mEASS model could well capture the seasonal dynamics of net radiation and latent heat with high R^2 and lower RMSE and bias at grassland, forest and cropland sites. In the context of semi-arid and semi-humid climatic conditions, conversion from croplands to grasslands caused the cooling effect (-0.3 W/m^2) at the annual scale. Similar cooling effects were found in spring (-0.4 W/m^2), autumn (-0.8 ± 0.1 W/m^2) and winter (-0.9 ± 0.1 W/m^2). The decreased latent heat (inducing warming effects) were completely offset by decreased net radiation (inducing cooling effects), which were responsible for the net cooling effects. However, a warming effect with 1.0 ± 0.1 W/m^2 was observed in summer. This is because that magnitude of decreased latent heat is greater than that of decreased net radiation in summer. These findings will enrich our understanding for the biophysical effect of conversion from croplands to grasslands in water-limited temperate regions.

* Corresponding authors at: Center for Regional Agriculture and Rural Development, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China.
E-mail addresses: liuzj@igsnrr.ac.cn (Z. Liu), liuys@igsnrr.ac.cn (Y. Liu).

https://doi.org/10.1016/j.scitotenv.2018.08.128
0048-9697/

1. Introduction

Anthropogenic land use largely alters the structures and functions of temperate ecosystems, further changes ecosystem services (Anderson-Teixeira et al., 2012; Q. Fu et al., 2017; Ouyang et al., 2016). As an important part of ecosystem services, the biophysical effect of land use and land cover change (LUCC) on regional climatic regulation is currently of growing interest (B. Fu et al., 2017; Q. Fu et al., 2017; Jiang et al., 2016; Reinmann et al., 2016; Schultz et al., 2017). LUCC, by altering the land surface biophysical properties, directly regulates regional climate change. Earlier some studies paid more attention to the biogeochemical effect of LUCC (e.g. carbon dynamics), but neglected the biophysical effect (water and energy regulation) of LUCC (Anderson-Teixeira et al., 2012; Simmons and Matthews, 2016). Recent studies suggest that the biophysical effect of LUCC should be fully considered in the studies of terrestrial ecosystems regulating climate (Ulrich et al., 2016; Zhao et al., 2017; Zhu et al., 2017). Besides, there are some studies reporting that if we neglect the biophysical effect of LUCC, the amplitude of climate change may be largely underestimated in tropical evergreen forests of Amazon and croplands of USA and Brazil, however, overestimated in deciduous forests and evergreen forests of North America (Anderson-Teixeira et al., 2012; Beltrán-Przekurat et al., 2012; Betts et al., 2007; Steyaert and Knox, 2008). Therefore, clarifying the biophysical effect of LUCC is very important for enriching our understanding in the impact of LUCC on regional climate change comprehensively.

In view of the importance of forests for climatic regulation, many of previous studies have paid more attention to the biophysical effects of deforestation and afforestation (Beltrán-Przekurat et al., 2012; Bonan, 2008; Li et al., 2016). For example, Bonan (2008) has reviewed that afforestation and reforestation in tropical regions mitigate climatic warming through evaporative cooling effect, however in boreal regions they enhance climatic warming by lowering albedo and increasing net radiation. Subsequently, some studies further support these findings (Lee et al., 2011; Liao et al., 2018). However, the biophysical effect of LUCC is disputed in temperate ecosystems. A main reason is that water conditions limit the evaporative cooling effect in temperate regions (Betts et al., 2007; Bonan, 2008). Many studies focus on clarifying the biological effect of temperate forests in different climatic regions (Li et al., 2016; Peng et al., 2014; Reinmann et al., 2016). These studies improve our understanding of temperate reforestation and afforestation. It is worth noting that in temperate regions, besides forests, croplands and grasslands are also two crucial ecosystems for human survival and development (J. Liu et al., 2014; Liu et al., 2018a). In order to achieve more crop yield, people early reclaimed swathes of grasslands and forests. In recent decades, some regions have been suffered from serious ecological issues due to unreasonable land use, especially in some temperate regions facing water scarcity (Feng et al., 2016; J. Liu et al., 2014). To recover the function of ecosystems, some ecological engineering were practiced in these fragile ecological zones (Liu et al., 2018a; Ouyang et al., 2016). For example, in the Loess Plateau, the 'Grain for Green' project has been carried out since 1999. By changing regional land use types, this project effectively reduced area of slope cropland and the amount of soil erosion in the Loess Plateau (Feng et al., 2016; Liu et al., 2018a; Wang et al., 2015). Some studies suggest that instead of obtaining huge ecological benefits, large reforestation could potentially aggravate water availability crisis in arid and semi-arid regions, and could further result in more serious ecological damage (Feng et al., 2016; Gao et al., 2014). Another study reports that vegetation expansion in water-limited regions creates potentially conflicting demands for water between ecosystems and humans, and indicates that if regional net primary productivity is far >400 $\pm$ 5 gC/m^2/a, humans will suffer from water shortages (Feng et al., 2016). Among ecological engineering, conversion from croplands to grasslands is thus thought of as the best measure for revegetation in water-limited Loess Plateau. However, based on the above mentioned studies in water-limited temperate regions, the net effect of conversion from croplands to grasslands on regional climatic regulation, resulting from the combined positive and negative effects on net radiation and latent heat, remains poorly understood to date.

In recent years, remote sensing techniques and process simulation models are regarded as two main tools for investigating the biophysical effect of LUCC (Beltrán-Przekurat et al., 2012; Bonan, 2008; Li et al., 2016; Peng et al., 2014; Thompson and Paull, 2017; Zhu et al., 2017). The former usually assesses the changes of climatic variables response to LUCC through the space-for-time substitution method (Chen et al., 2017; Peng et al., 2014). These satellite-based methods assume that spatial and temporal variations are equivalent (Pickett, 1989). In contrast, the latter is a main tool for investigating the complex heat interactions between land and atmosphere by setting different LUCC scenarios (Betts, 2000; Bonan et al., 1992; Reinmann et al., 2016). More importantly, the strength of process simulation models is that it can more clearly explain the variation mechanisms of complex processes (Betts et al., 2007; Bonan, 2008; Feddema et al., 2005). In this study, we thus employed a process-based land surface model to investigate the biophysical effect of conversion from croplands to grasslands.

The objectives of this study are: (1) to compute net radiation and latent heat based on different LUCC scenarios; (2) to analyze the biophysical effect of conversion from croplands to grasslands in water-limited mid-latitude regions; and (3) to further clarify potential mechanisms of the biophysical effect. The analyses are based on the assumption that land use change can alter land cover properties (e.g. land surface albedo, leaf area index, and clumping index), and further primarily affect the dynamics of net radiation and latent heat.

2. Data and methods

2.1. Study area

To improve the simulation effectively and clarify the concern of this study clearly, we select the study area with 100 km × 100 km (Fig. 1), given that this region experienced from large-area conversion from croplands to grasslands in the past decade. During the period from 2000 to 2010, land use data indicate that the area of croplands decreased by 16.5% of the study area (J. Liu et al., 2014). Most decreased croplands are replaced by grasslands. Specifically, increased grasslands account for 12.6% of the study area.

The study area is located in the central Loess Plateau, China (36°27′–37°23′N, 108°59′–110°11′E), covering some regions of Ansai, Baota, Yanchang, Qingjian, Yanchuan, Zizhou and Zichang counties. This region has a typical arid, semi-arid and semi-humid continental monsoon climate. Croplands (covering rain-fed spring wheat or spring maize) and grasslands, as two main land use types, both accounted for 87.5% of study area in 2010.

2.2. Meteorological and observed flux data

Daily station-based meteorological data, covering precipitation, air temperature (maximum and minimum), sunshine hour, relative humidity, and wind speed for the period from 1980 to 2012, were collected from the China Meteorological Data Sharing Service (CMA). There is a total of 118 meteorological stations, including 74 meteorological stations in the Loess Plateau and 44 meteorological stations around the Loess Plateau within a range of 10 km. Based on the thin-plate smoothing spline method (ANUSPLIN) and 1 km SRTM digital elevation model (DEM) from SRTM, these above station-based meteorological data were first used for deriving 1 km spatial resolution meteorological datasets (Hutchinson et al., 2009; Liu et al., 2018b). The downward shortwave radiation is a function of latitude, date and sunshine hour (Allen et al., 1998). Then, according to the input requirement of the land surface model used in this study (see Section 2.4), daily interpolated meteorological data were converted to hourly data using the recommended