Science of the Total Environment 599–600 (2017) 891–898

Contents lists available at ScienceDirect

Science of the Total Environment

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

# Comparison of surface energy budgets and feedbacks to microclimate among different land use types in an agro-pastoral ecotone of northern China

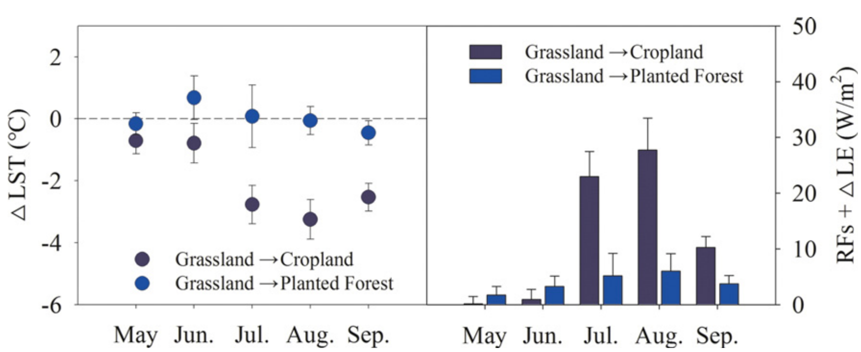
Wei Zhao [a,b], Zhongmin Hu [c,a,b,*], Shenggong Li [a,b,**], Qun Guo [a], Zhengjia Liu [a], Leiming Zhang [a,b]

[a] Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China
[b] College of Resources and Environment (CRE), University of Chinese Academy of Sciences, Beijing, China
[c] School of Geography, South China Normal University, Guangzhou, China

## HIGHLIGHTS

- Grassland-cropland difference in albedo is similar to that of grassland-forest.
- Grassland-cropland difference in ET is larger than that of grassland-forest.
- Conversion from grassland to cropland may cool land surface temperature.
- ET is key to determine ecosystem energy budget and surface temperature.

## GRAPHICAL ABSTRACT




## ARTICLE INFO

*Article history:*
Received 16 December 2016
Received in revised form 26 April 2017
Accepted 26 April 2017
Available online 10 May 2017

Editor name: Elena Paoletti

*Keywords:*
Albedo
Evapotranspiration
Land surface temperature
Temperate semi-arid region

## ABSTRACT

The biophysical effect of land use conversion plays a significant role in regulating climate change. Owing to albedo and evapotranspiration (ET) change, the effect of energy budget difference on land surface temperature (LST) is important but unclear among contrasting land use types, especially in temperate semi-arid regions. Based on moderate-resolution imaging spectroradiometer (MODIS) data, we compared the differences in albedo, ET, and LST between cropland and grassland (CR-GR), and between planted forest and grassland (PF-GR) in the Horqin Sandy Land of Inner Mongolia, an agro-pastoral ecotone of northern China. Our main objective was to explore the magnitude and direction of albedo and ET change during the growing season and, subsequently, to estimate the biophysical effects on LST as a result of land use and land cover change. Our results indicate no significant difference in mean monthly albedo for CR-GR and PF-GR. Cropland lost more water through ET and significantly decreased daytime LST compared with grassland from July to September, but no significant differences in ET and LST were observed for PF-GR in any month. The biophysical climate effects were more pronounced for CR-GR compared with PF-GR. The response of LST to the changes in energy budget confirmed that ET was the critical driving factor relative to albedo. Compared with grassland, cropland and planted forest tended to cool the land surface by 5.15 °C and 1.51 °C during the growing season, respectively, because of the biophysical effects. Our findings suggest the significance of local-scale biophysical effect on climate variation after land use conversion in semi-arid regions.


* Corresponding author at: School of Geography, South China Normal University, Shipai Campus, Tianhe District, Guangzhou 510631, China.
** Corresponding author at: Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Datun Road A 11, Chaoyang District, Beijing 100101, China.
*E-mail addresses:* huzm@igsnrr.ac.cn (Z. Hu), lisg@igsnrr.ac.cn (S. Li).

http://dx.doi.org/10.1016/j.scitotenv.2017.04.200
0048-9697/

## 1. Introduction

The terrestrial ecosystem of Earth and the climate system interact with one another (Betts et al., 1996), and the climatic effects due to land use change have been widely reported (Avila et al., 2012; Mahmood et al., 2014; Pongratz et al., 2010; Shen et al., 2017). In particular, the biophysical effects of land use conversion are receiving attention in recent years (Bathiany et al., 2010; Bright et al., 2015; Zhao and Jackson, 2014). This is because that such effect is probably similar or even larger in magnitude than the greenhouse effect. Moreover, they could probably even offset the biochemical climate benefits (Avila et al., 2012; Betts, 2000; Bonan, 2008). For instance, simulations by Gibbard et al. (2005) indicated that the magnitude of warming attributable to global forestation is of the same order in magnitude as the cooling effects attributable to carbon storage. Therefore, the biophysical effects of land use change are of significance for land use management relevant to climate change mitigation and the estimation of regional and global climate effects.

Albedo and evapotranspiration (ET) are two important biophysical properties that regulate land–surface energy budgets by altering short-wave radiation loading and energy partitioning in the land surface (Chen and Dirmeyer, 2016; Li et al., 2015; Liu et al., 2017). As regards global climate change owing to biophysical effects, ET generally produces a counteractive energy effect relative to albedo. Employing the temperature change model relevant to land use change only, Chen and Dirmeyer (2016) found an increase in surface albedo from the 1850s to the 2000s. This increase led to the global average temperature dropping by approximately 0.03 K, whereas the latent heat flux decreased and warming of approximately 0.04 K occurred. Davin and de Noblet-Ducoudré (2010) showed that the surface albedo increase had a cooling effect of 1.36 K, and because of the decreasing ET, a surface warming effect of 0.24 K, owing to the global replacement of forests by grassland. In addition, the contribution of albedo and ET feedbacks to surface temperature is reliant on the ecological climate region (Pitman et al., 2011). In the high-latitude boreal forest zone, deforestation generally cools the land surface because of the high albedo resulting from the snow cover, inducing strong negative radiative forcing (Bala et al., 2007; Bathiany et al., 2010; Claussen et al., 2001). On the other hand, deforestation produces warming effects attributable to the strong ET decline in tropical forest zones (Davin and de Noblet-Ducoudré, 2010; Findell and Thomas, 2006). However, relative contribution from altered albedo and ET to differences in energy budget and subsequently to surface temperature in contrasting land use types is unclear in temperate climate zones, because of the complex relationship of water and energy fluxes. For instance, forest usually absorbs more short wave radiation than does grassland because of the lower albedo, and dissipates significantly more latent energy through ET. However, water shortage can weaken the forest ET and could cause the forest die (Wilske et al., 2009). Therefore, albedo could increase and ET could decrease, which would lead to the warming of the land surface.

The agro-pastoral ecotone of northern China e.g. the Horqin Sandy Land of Inner Mongolia, is sensitive to climate change. Moreover, this region has been subjected to the effects of intensive human-induced land use changes, or is expected to undergo such intensive changes in the future (Cao et al., 2015). Grassland, planted forest, and cropland coexist here because of extensive cultivation and implementation of ecological projects (e.g. afforestation) in recent decades, providing a “place” to assess the biophysical effects on surface temperature following the change of land use types. Remotely sensed land surface temperature (LST) is the radiometric temperature of the ground or the canopy surface, and is sensitive to land-surface properties, such as land cover, albedo, and soil moisture (Jin and Dickinson, 2010; Mostovoy et al., 2006). LST is therefore an effective parameter relevant to the physics of land-surface processes at a local scale. Based on the moderate-resolution imaging spectroradiometer (MODIS) data, the main goals of this study are: (1) to examine the differences in albedo, ET, and LST among grassland, planted forest, and cropland in the Horqin Sandy Land; and (2) to explore the magnitude and direction of surface energy change resulted from the variation of albedo and ET, and their potential biophysical effects on LST during the growing season between cropland and grassland (CR-GR), and between planted forest and grassland (PF-GR).

## 2. Materials and methods

### 2.1. Study area

Our study region is located at the Horqin Sandy Land in Inner Mongolia, a typical agro-pastoral ecotone of northern China (Fig. 1). It has a temperate continental semi-arid monsoon climate, with mean annual solar radiation of 5200 MJ $m^{-2}$, mean annual precipitation of 362 mm, mean annual pan-evaporation of 1935 mm, mean annual temperature of 6.4 °C, and mean annual wind speed, ranging from 3.4 to 4.1 m $s^{-1}$ (Li et al., 2000). The zonal soils are classified as Kastanozems, with some sandy soils present. The original vegetation is sparse forest grassland, stemming from the Eurasian steppe (Zhao et al., 2002).

Three land use types were identified including 10 grasslands, 10 croplands, and 10 planted forests (Fig. 1). We conducted a continuous field experiment from 2009 to 2013 to ensure consistency in the land use type. The main grass species include *Agropyron cristatum*, *Pennisetum flaeccidum*, *Artemisia scoparia*, and *Cleistogenes squarrosa*. The crop is *Zea mays*, which is the most widely planted vegetation in our study area, and is irrigated especially during the peak growth period. We chose three main species of planted forests, namely, *Populus simonii* (six sites), *Pinus sylvestris* var *mongolica* (three sites), and *Pinus tabulaeformis* (one site). The number of each species was determined according to the area percentage and the average stand age of planted forests of each species. All the sample sites share a similar background climate, e.g., short-wave radiation, air temperature, and precipitation (Fig. 2).

### 2.2. Data source

The MODIS albedo product (MCD43A3) was used in this study, with a spatial resolution of 500 m, and the bias was mostly <5% (Liu et al., 2009). We used white-sky albedo over the short-wave broadband (0.3–5.0 μm). White-sky albedo, also called diffuse albedo, can actually reflect the surface characteristics independently from the conditions in the sky (Schaaf et al., 2002; Zhao and Jackson, 2014). The temporal patterns of the MODIS albedo data in China have been proven to be of good quality (Wang et al., 2004). The MODIS LST data (MOD11A2) are retrieved in clear-sky conditions at a resolution of 1 km, and, with the overpass time at 10:30 am, with the absolute bias being generally <1 K (Wan, 2008). The albedo and LST data were downloaded from the NASA website (https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table) (accessed December 15, 2016).

We used the ET product MOD16A2 (MODIS-ET) at a resolution of 1 km, which is independent from the MODIS LST. Mu et al. (2011) employed the observations from the eddy flux towers for MODIS ET verification, with the mean absolute bias being approximately 0.3 mm/day. The ET data are freely available from the NASA Earth Observing System website (http://www.ntsg.umt.edu/project/mod16) (accessed December 15, 2016). In addition, we used another ET dataset, derived from Breathing Earth System Simulator (BESS-ET), to confirm our results. BESS-ET 8-day composite 1-km resolution products, with a bias of 0.78 mm/day (Jiang and Ryu, 2016) are freely available to the public at http://environment.snu.ac.kr/(accessed February 5, 2017).

The downward short-wave radiation at a resolution of 1 km was calculated cross China using the Angstrom formula, which relates solar radiation to extraterrestrial radiation and the duration of relative sunshine, the recommended algorithm of the Food and Agriculture Organization (FAO) (http://www.fao.org/docrep/x0490e/x0490e07.htm#radiation) (accessed December 15, 2016). The mean air