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Carbon exchange fluxes over peatlands in Western Siberia: Possible feedback between land-use change and climate change

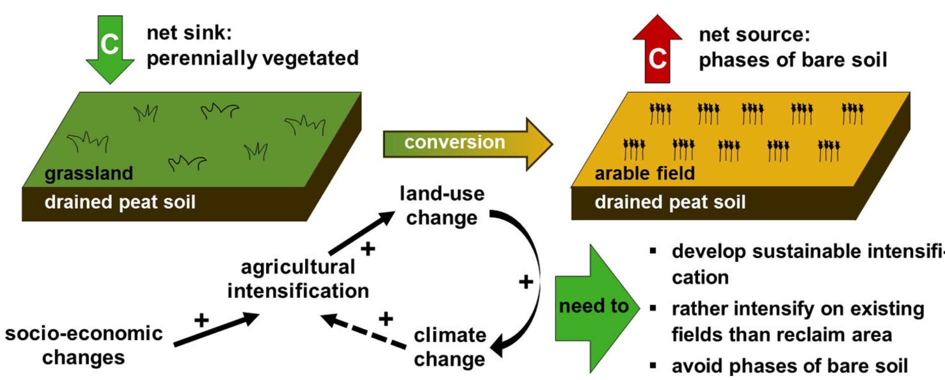
Elisa Fleischer [a,*], Ilhom Khashimov [b], Norbert Hölzel [c], Otto Klemm [a]

[a] Institute of Landscape Ecology, Climatology Research Group, University of Münster, Münster, Germany
[b] Institute of Earth Science, Physical Geography and Geoecology Department, Tyumen State University, Tyumen, Russia
[c] Institute of Landscape Ecology, Biodiversity and Ecosystem Research Group, University of Münster, Münster, Germany

HIGHLIGHTS

- Grasslands on drained peat soil can act as carbon sinks.
- Arable fields on drained peat act as carbon sources due to long phases of bare soil.
- CH_4 emissions from drained peatlands seem to play a smaller role than CO_2 fluxes.
- Conversion from grassland to arable field has a positive feedback on climate change.
- Positive feedback between projected land-use change and climate change is suggested.

GRAPHICAL ABSTRACT



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ABSTRACT

The growing demand for agricultural products has been leading to an expansion and intensification of agriculture around the world. More and more unused land is currently reclaimed in the regions of the former Soviet Union. Driven by climate change, the Western Siberian grain belt might, in a long-term, even expand into the drained peatland areas to the North. It is crucial to study the consequences of this land-use change with respect to the carbon cycling as this is still a major knowledge gap.

We present for the first time data on the atmosphere-ecosystem exchange of carbon dioxide and methane of an arable field and a neighboring unused grassland on peat soil in Western Siberia. Eddy covariance measurements were performed over one vegetation period. No directed methane fluxes were found due to an effective drainage of the study sites. The carbon dioxide fluxes appeared to be of high relevance for the global carbon and greenhouse gas cycles. They showed very site-specific patterns resulting from the development of vegetation: the persistent plants of the grassland were able to start photosynthesizing soon after snow melt, while the absence of vegetation on the managed field lead to a phase of emissions until the oat plants started to grow in June. The uptake peak of the oat field is much later than that of the grassland, but larger due to a rapid plant growth. Budgeting the whole measurement period, the grassland served as a carbon sink, whereas the oat field was identified to be a carbon source. The conversion from non-used grasslands on peat soil to cultivated fields in Western Siberia is therefore considered to have a positive feedback on climate change.

* Corresponding author.
E-mail addresses: elisa.fleischer@uni-muenster.de (E. Fleischer), nixonlp@mail.ru (I. Khashimov), nhoelzel@uni-muenster.de (N. Hölzel), otto.klemm@uni-muenster.de (O. Klemm).

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1. Introduction

The growing demand for agricultural products has been leading to an expansion and intensification of agriculture around the world (Foley et al., 2011; McKenzie and Williams, 2015). The agricultural potential is virtually exhausted in many developed countries, meaning that the costs of further intensification or expansion would outweigh the potential benefits. However, large, unused capacities still exist in developing and transitional countries (Godfray et al., 2010; Schierhorn et al., 2014a). The regions of the former Soviet Union play a key role in this context, where in Russia alone 45 million ha were abandoned after the collapse of collective farming in the early 1990s (Bokusheva, 2005; Kurganova et al., 2014; Schierhorn et al., 2013). Abandoned cropland in Russia was found to significantly mitigate the atmospheric carbon dioxide (CO_2) increase by accumulating carbon in the soils (Dolman et al., 2012; Kurganova et al., 2015; Schierhorn et al., 2013). However, the available estimates vary largely, and are mostly located in European Russia (Alcantara et al., 2013; Vuichard et al., 2008). Since 2000, agriculture is strongly developing again and unused ex-arable land is currently reclaimed in vast regions of the former Soviet Union (Griffiths et al., 2013; Kamp et al., 2011; Rosstat, 2015). In South Western Siberia, for example, the efficiency of land use has been enhanced by mechanization, shallower crop rotations, and an increased input of pesticides and fertilizer during the last few years (Kühling et al., 2016). In parallel, the transition zone between the temperate and boreal climates (Kottek et al., 2006), i.e. between the forest steppe and pre-taiga in the South of Western Siberia, is strongly affected by climate change (Balzter et al., 2010; Frey and Smith, 2003; Tchebakova et al., 2009). Shulgina et al. (2011) and Degefie et al. (2014) revealed a significant increase of growing season length and number of growing degree days in the past four decades in South Western Siberia. Degefie et al. (2014) further state that the South of South Western Siberia is expected to become drier and warmer, while the North shows the tendency to get wetter and warmer. In conjunction with a worldwide growing demand for arable land, these changes could not only foster a recultivation of ex-arable land in South Western Siberia, but, in a long-term, may also lead to an expansion of the Western Siberian grain belt into drained peatland areas to the North (Kicklighter et al., 2014; Perelet et al., 2007; Robarts et al., 2013). Simulations of Kicklighter et al. (2014) estimate an increase of the agriculturally used land of 16–22% over the 21st century in Northern Eurasia due to climate-induced vegetation-shifts. Such a development might lead to a degradation of carbon stocks in the soils, turning the South of Western Siberia from a sink to a source of greenhouse-gas (GHG) emissions. So it is crucial to study the consequences of this land transition with respect to the carbon cycling (Kamp, 2014; Schiermeier, 2013). It is known that land use can exert significant impact on the carbon turnover. For example, crop rotations, fertilization, tillage, drainage or irrigation can determine whether, and in which intensity, fields act as carbon sinks or carbon sources (Hauggaard-Nielsen et al., 2016; Negassa et al., 2015; Oberholzer et al., 2014). Climate models and regional projections should be adapted to account for these processes, but data on this topic are scarce (Haddaway et al., 2014). Most of the relevant research on that topic was carried out in Finland, Canada, The Netherlands, and Germany, commonly based on flux chamber or soil properties measurements, and focusing on the comparison of dry versus wet, of fertilized versus less fertilized, of restored versus unrestored, and of drained versus undrained conditions. However, there is a general lack of carbon exchange data east of the Ural Mountains (Gilmanov et al., 2010; ORNL DAAC, 2013). There are only few studies on forests (Kotani et al., 2014; Röser et al., 2002), bogs and fens (Arneth et al., 2002; Kurbatova et al., 2002) and tundra and steppe grasslands (e.g., Marchesini et al., 2007; Mbufong et al., 2014). Studies about land-use effects in agricultural systems on GHG emissions are practically non-existing (Guo and Gifford, 2002; Haddaway et al., 2014). Findings from western studies concerning the effect of cultivation would not be comparable to the conditions in Western Siberia, not only because of the highly continental climate, but also because of the very different cropping system with major differences in the dominance of summer cultures, the timing of tillage, sowing and harvesting, and the amount and type of fertilizers applied. The climate-induced start time of tillage and sowing is probably the most important parameter leading to bare soil conditions until the middle of June (Bondeau et al., 2007; Rosstat, 2015). Up to now, no study has been carried out on the comparison between cropped and unused or bare soil in boreo-temperate ecosystems, and the effect of the respective agricultural practices on the cycling of carbon and greenhouse gases.

Our study addresses this knowledge gap. The goal is to determine the impact of a conversion from non-used peat grasslands to cultivated fields on the GHG fluxes and thus climate change in Western Siberia, where future land-use change has to be anticipated. We analyze the atmosphere-ecosystem exchange of carbon dioxide and methane of an arable field and a corresponding unused grassland on peat soil with the eddy covariance technique over a full vegetation period in the pre-taiga of the Tyumen Oblast in Western Siberia. This twin-station experiment shall (i) exhibit differences of GHG fluxes between these two sites, (ii) unveil differences in timing (phenology) of CO_2 fluxes between the two systems, and (iii) assess differences in the carbon budgets of the two fields. The results of this comparison are used as a proxy for land-use change, for which the potential feedback with climate change will be discussed.

2. Materials and methods

2.1. Description of the study area and study sites

The study sites are located in the southern part of the Western Siberian Lowland, approximately 20 km northeast of the city of Tyumen in Russia and in the transition between the temperate zone (forest steppe) to the south and the boreal zone to the north (Schmithüsen, 1976) (Fig. 1). The area exhibits a humid, continental climate with mean annual temperatures between −2.3 and +2.7 °C. The average temperature in July is 17–21 °C, and −25 to −12 °C in January (Tyumen weather station, 1971–2011; 37 km away from the study sites at 51.10105° N 65.42098° E). The precipitation amounts to about 480 mm per year, of which the major part is summer rainfall. The average duration of the growing is about 170 days (Tyumen weather station, 1969–2011) (Afonin et al., 2008; Degefie et al., 2014; Tutiempo Network, 2015).

The landscape consists of natural habitats such as wetlands and coniferous and deciduous forests as well as grasslands and croplands that are used for agriculture on different scales and intensities (IIASA and RAS, 2002). Chernozems, Phaeozems and drained Histosols are the most prevalent soil types relevant for agricultural use (Eremin, 2012). Due to their vast extension and richness in organic matter, Histosols are of major importance for the regional carbon cycle (FAO, 2014; Sheng et al., 2004). At the same time, drained eutrophic to mesotrophic fen Histosols are among the fertile soil types of the Tyumen Oblast. They are used as meadows, pastures or croplands (Karetin, 1990). About 89,000 ha of Histosols around the sampling sites have been drained so far due to former and present land-use interests and further drainage ditches are being built for peat mining (coroma.ru, 2015; Rosreestr, 2013).

The surface–atmosphere GHG exchange of an agriculturally used peatland was examined in comparison to the GHG exchange of a non-used peat grassland. Two adjacent study locations were chosen to minimize site effects and to ensure similar environmental conditions, e.g. soil type and weather conditions. The grassland (57.25280° N 65.99321° E) had an area of 200 ha. It was drained in Soviet times and was sporadically used for hay making. After 1990, it was abandoned, and only patchily mown in 2010. It was not mown during the study period. The grassland was vegetated throughout and characterized by a