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Research article

Soil–air greenhouse gas fluxes influenced by farming practices in reservoir drawdown area: A case at the Three Gorges Reservoir in China

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ABSTRACT

The Three Gorges Reservoir (TGR) in China has large water level variations, creating about 393 km^2 of drawdown area seasonally. Farming practices in drawdown area during the low water level period is common in the TGR. Field experiments on soil-air greenhouse gas (GHG) emissions in fallow grassland, peanut field and corn field in reservoir drawdown area at Lijiaba Bay of the Pengxi River, a tributary of the Yangtze River in the TGR were carried out from March through September 2011. Experimental fields in drawdown area had the same land use history. They were adjacent to each other horizontally at a narrow range of elevation i.e. 167–169 m, which assured that they had the same duration of reservoir inundation. Unflooded grassland with the same land-use history was selected as control for study. Results showed that mean value of soil CO_2 emissions in drawdown area was 10.38 ± 0.97 mmol m^{-2} h^{-1}. The corresponding CH_4 fluxes and N_2O fluxes were −8.61 ± 2.15 μmol m^{-2} h^{-1} and 3.42 ± 0.80 μmol m^{-2} h^{-1}. Significant differences and monthly variations among land uses in treatments of drawdown area and unflooded grassland were evident. These were impacted by the change in soil physiochemical properties which were alerted by reservoir operation and farming. Particularly, *N*-fertilization in corn field stimulated N_2O emissions from March to May. In terms of global warming potentials (GWP), corn field in drawdown area had the maximum GWP mainly due to N-fertilization. Gross GWP in peanut field in drawdown area was about 7% lower than that in fallow grassland. Compared to unflooded grassland, reservoir operation created positive net effect on GHG emissions and GWPs in drawdown area. However, selection of crop species, e.g. peanut, and best practices in farming, e.g. prohibiting N-fertilization, could potentially mitigate GWPs in drawdown area. In the net GHG emissions evaluation in the TGR, farming practices in the drawdown area shall be taken into consideration.

1. Introduction

Excess emissions of greenhouse gases (GHGs) from anthropogenic activities, e.g., CO_2, CH_4, N_2O and others, are regarded as the main drivers of global climate change (Ciais et al., 2013). Quantifying carbon footprints from all human activities and assessing their global warming potentials (GWPs) have been widely done in recent decades (Ciais et al., 2010). Dam construction and reservoir creation are also human products with carbon footprints that potentially contribute to global warming (Hertwich, 2013; Oud, 1993; Rudd et al., 1993). Reservoir carbon footprints are not solely based on the initial carbon stock before impoundment (Teodoru

Abbreviations: GHG, Greenhouse gas; GHGI, Greenhouse gas intensity; $GHGI_b$, GWP_r of each treatment type is divided by full biomass with dry weight, which measures the intensity of GHG emissions per unit biomass; $GHGI_g$, GWP_r is divided by the total grain harvest of corn and peanut field, which gave the GHGI of corn and peanut production; GWP, Global warming potentials; GWP_f, GWP from farming practices in drawdown area; GWP_r, Net GWP from reservoir construction and operation; TGR, Three gorges reservoir; VWC, Volumetric water content.

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et al., 2012). Carbon inputted from upstream and terrestrial ecosystems, as well as increased in reservoir primary production, also significantly contribute to the net effect of reservoir construction and impoundment (Hertwich, 2013). Designed for multiple purposes, some reservoirs, e.g. the Three Gorges Reservoir (TGR) in China, are commonly operated with substantial water level variations (Li et al., 2014). Artificial operation of reservoirs not only perturbs carbon budgets in aquatic ecosystems, but may also create a large nearshore drawdown area with complicated carbon biogeochemical processes (Backeus, 1993). Without quantification on GHG emissions, research on human carbon footprints from reservoir operation remains limited.

Created by the Yangtze Three Gorges Dam project, the TGR is the largest reservoir in China. Field surveys on water surface GHG emissions in the TGR indicated that gross emission of CH_4 in the reservoir is comparable to those from other temperate reservoirs but significantly less than those from tropical reservoirs (Chen et al., 2011; Yang et al., 2013; Zhao et al., 2013). However, the TGR performs ~30 m vertical and seasonal water level variations for both hydropower generation and flood control, creating about 393 km^2 of nearshore area in the form of seasonal drawdown and submersion. Chen et al. (2009) showed that newly created reservoir drawdown area resulted in remarkable CH_4 emissions. Yang et al. (2012) estimated that CH_4 emissions from reservoir drawdown area accounted for about 42–54% of the total CH_4 emissions from the water surface of the TGR, which indicated that GHG emissions from drawdown area had significant contribution in gross GHG emissions of the reservoir.

Besides, drawdown area in the TGR during summer has become popular for cultivation by local farmers in recent years. Impoundment of the TGR directly lose about 278 km^2 nearshore arable farmland along the Yangtze River and its tributaries, which is approximately about 43.9% of total inundated area (632 km^2) in the reservoir (Tullos, 2009; Xu et al., 2013). Resettlement of local people to higher land in this mountainous region significantly reduces the accessibility of fertile arable lands for farming. Exposure time in certain upper parts of reservoir drawdown area (elevation 165 m or higher) is approximately 180 days. This duration is feasible for cultivating crops for at least one growing season (Fig. 1). Living near the shore in the TGR, local farmers wish to use parts of the reservoir drawdown area as arable farmland for cultivation.

A conservative estimation from incomplete survey in 2010 indicated that over 70 km^2 of drawdown area in the TGR was restored to agriculture (He et al., 2011). About 43% of them (~30 km^2) were used for corn (*Zea mays* L.) cultivation, and 34% of them (~23.8 km^2) of them were applied for growing peanut (*Arachis hypogaea* L.) (He et al., 2011). Other corps in farming practices in drawdown area in the TGR were rice (*Oryza sativa*) and green-leaf vegetables such as Chinese cabbage (*Brassica rapa*) and Chinese lettuce (*Lactuca sativa var. asparagina*). Even some drawdown area that were not historically farmlands, e.g., woodland and urban area before impoundment, were also reclaimed for cultivation.

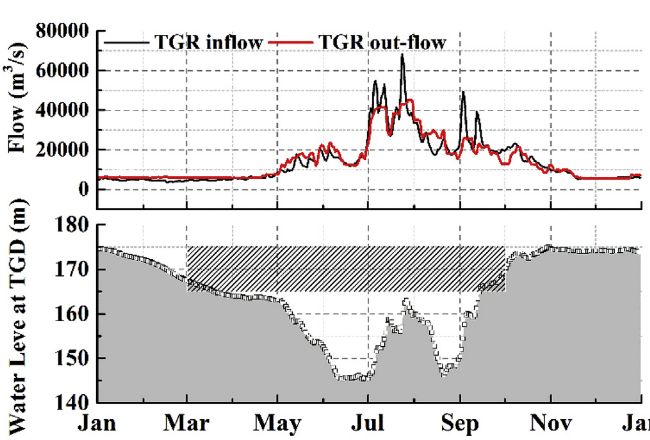

Fig. 1. Water level, inflow and outflow of the Three Gorges Reservoir (indicated as "TGR" in the figure) in 2012. Area of hatching indicates the period from March to September and elevation range for crop cultivation in drawdown area. The normal water level of the TGR is 175 m. For flood control, water level in the TGR gradually decreases from February to May and prepares about 22.0 km^3 capacity for incoming floods.

Farming and management practices can change soil–air GHG emissions. Crop species, crop planting, field tillage, fertilization, application of herbicide and pesticide are the major factors. In recent years, global concern regarding climate change has fostered rapid growth of research on carbon footprints of agriculture (Robertson et al., 2000; Sainju et al., 2012, 2014b). Through changes in soil moisture, structure, porosity and other physico-chemical parameters, agricultural activities (in particular management of fields) are regarded as drivers of soil–air GHG emissions. Reduction of N_2O and CH_4 emissions and increasing in C sequestration in the form of soil organic carbon could be achieved through effective practice, such as no tillage, low level of fertilization, and diversified crop rotation (Liebig et al., 2010; Robertson et al., 2000).

Recently, Yang et al. (2012) reported that land uses, i.e. farming practices, played an important role in CH_4 emissions during various water levels in the TGR. The study partially supported the hypothesis that land use change due to farming in drawdown area significantly impact GHG emissions of the TGR. However, lack of information on GHG emissions before impoundment, i.e. pre-impoundment GHG emissions, and land use history, as well as the status GHG emissions among different farming practices still impeded the evaluation of net GHG emissions of the TGR. The objectives of the present study were to: (1) compare flux differences of CO_2, CH_4 and N_2O between farming practices and fallow grassland during reservoir drawdowns; (2) evaluate GWP and GHGI among different types of crops in drawdown area; (3) address the implications of farming practices in drawdown area for net GHG emissions evaluation in the TGR.

2. Methods and materials

2.1. General description of farming practices and experimental design

Because the drawdown area available to farming is relatively small and in patches (see photos of S1 in supplementary materials), in most cases, crop harvests in drawdown area are mainly supplied parts of daily food requirements. The remainder goes to feeding livestock, with little for sale in local farmers' markets. No machinery are invested for planting, irrigation or fertilization. General procedures of corn and peanut cultivation in drawdown area has the following characteristics. 1) After reservoir drawdown in March (Fig. 1), fields of corn and peanuts are planted. 2) *N* fertilizer with urea is manually applied immediately after corn planting with amounts 40–50 g m^{-2}, and no fertilizers were applied to peanut fields. 3) A second round of *N*-fertilization is carried out in corn fields at the end of April, with the same amounts as that in March. 4) No-till, no-pesticide applications, with a few herbicides, are served manually as needed. 5) Corn harvests are normally in July and peanut harvests normally in August. 6) After harvest, most corn straw are cut, collected outside fields and burned for cooking, and plant bodies of peanuts are mainly used for feeding livestock. Underground parts of both crops and other residues are left in drawdown area and submerged by the subsequent impoundment in October.