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Perennial forb invasions alter greenhouse gas balance between ecosystem and atmosphere in an annual grassland in China

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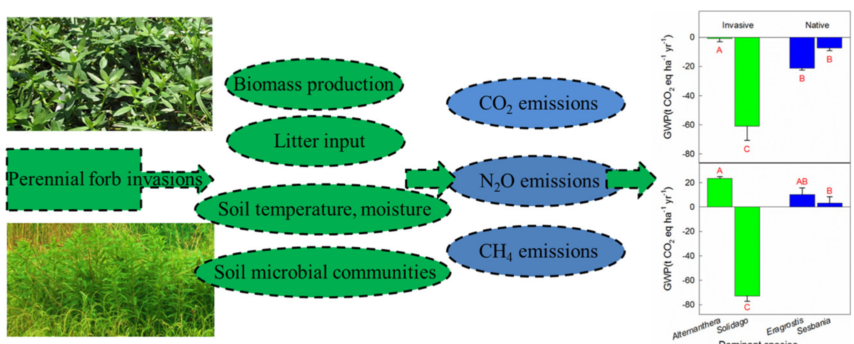
HIGHLIGHTS

- Perennial forb invasions into annual grasslands impact soil GHG emissions.
- Invasion increased soil CO_2 and N_2O (but not CH_4) emissions.
- Total biomass C of invaded sites was higher than that of native dominated sites.
- GWP increased by *Alternanthera* invasions and decreased by *Solidago* invasions.
- Perennial forb invasions change GHG balance but effects vary among species.

GRAPHICAL ABSTRACT



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ABSTRACT

Grassland ecosystems are sensitive to invasions by plants from other functional groups which can alter soil greenhouse gas (GHG) fluxes. However, the effects of plant invasion on net GHG exchanges between soils and the atmosphere, plant production, and global warming potential (GWP) of annual grasslands is poorly understood. To evaluate the impacts of perennial forb invasions on GHG budgets of an annual grassland in China, we measured soil carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) fluxes over two years in replicated invaded (dominated by *Alternanthera philoxeroides* or *Solidago canadensis*) and non-invaded (dominated by the annual grass *Eragrostis pilosa* or the annual forb *Sesbania cannabina*) field sites. On average, soil CO_2 and N_2O emissions from invaded sites were 30% and 76% higher, respectively, relative to sites dominated by native species. Emissions of N_2O and CO_2 were especially high in *Solidago* and *Alternanthera* dominated sites, respectively. Soil CH_4 emissions did not vary with plant species. On average, total biomass C of invaded sites was higher than that of the native dominated sites but this reflected the high C in *Solidago* dominated sites. Global warming potential (GWP) was increased by *Alternanthera* invasions and decreased by *Solidago* invasions. Plant invasions affected GWP of these annual grasslands through higher emissions of some GHGs but also sometimes higher biomass C. Together, this suggests that perennial forb invasions could change the net source or sink role of annual grasslands for GHG budgets, but the effects on GWP vary among species depending on GHG responses and C storage.

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1. Introduction

Atmospheric methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O) are three important greenhouse gases (GHGs) associated with global climate change (IPCC, 2014a). N_2O has a global warming potential 265 times that of CO_2 and can persist as long as 121 years in the atmosphere (IPCC, 2014b). Many efforts have been made to understand contributions of agriculture, forestry and land use management to terrestrial GHG emissions (IPCC, 2014a). Grassland ecosystems play an important role in global GHG emissions and hence also in climate change due to their large soil carbon (C) and nitrogen (N) pools and wide distribution around the world (Saggar et al., 2013). Slight changes in C and N fluxes between grassland ecosystems and the atmosphere could lead to large changes in atmospheric GHG concentrations. Associated changes in C and N fluxes might be caused by overgrazing, desertification and wildfires (Deng et al., 2016; Hu et al., 2010). In addition, substantial ecosystem functional composition or land cover change as a result of exotic plant invasions could also influence GHG emissions via altered biotic and abiotic factors (Wolkovich et al., 2010; Yuan et al., 2014).

Conversions of native plant communities to non-native plant dominated communities, or even complete displacement of native communities by exotic plant invasions, have been observed globally (Ehrenfeld, 2003; Liao et al., 2008). However, the potential effects on climate change via changes in GHG emissions from plant invasions have not been thoroughly studied (Chen et al., 2015; Yuan et al., 2014). Therefore, community transformation effects on C and N cycling following plant invasions require rigorous assessment in global GHG budgets.

Invasive plants may increase soil nutrient mineralization during the invasion process, increasing soil nutrient availabilities in invaded sites, potentially accelerating C and N cycling processes associated with soil GHG production and emission (Ehrenfeld, 2003; Liao et al., 2008; Litton et al., 2008; Strickland et al., 2010). In addition, invasive plants are often characterized by higher photosynthetic capacity associated with higher atmospheric C assimilation (Feng et al., 2007). Higher soil nutrient use efficiency and larger photosynthetic capacity might act in combination to produce larger net primary production (NPP) with higher nutrient pools fixed by plant biomass (Ehrenfeld, 2003; Liao et al., 2008). Larger NPP is generally followed by enhancement of soil C input, more complete plant coverage at the soil surface, and regulation of soil microclimate conditions which would further impact both soil C and N storage and soil GHG emissions.

Native ecosystems are often invaded by functionally different plant species (Drenovsky et al., 2012; Scharfy et al., 2011). The differences in functional traits (e.g., life span and morphological traits) between the native and invasive plants typically alter soil microbial community composition and biomass allocation (Adair and Burke, 2010; Lazzaro et al., 2018; Reinhart and Callaway, 2006) and hence soil C and N processes (Zhang et al., 2010; Zou et al., 2006). Therefore, invasive plants that are functionally different from native plant species would also have large effects on soil GHG emissions in the invaded grasslands.

Given the global extent of plant invasions and the potential effects on ecosystem C and N processes, there is growing interest in addressing plant invasion effects on GHG emissions (Chen et al., 2015; Liao et al., 2008; Yuan et al., 2014). Studies conducted using laboratory incubations, mesocosms, or in situ field measurement experiments have all independently shown enhanced CH_4, CO_2 or NO_X emissions from some invaded soils (Cheng et al., 2007; Hall and Asner, 2007; Hickman et al., 2010; Yuan et al., 2014) though some other studies have shown the opposite results (Hickman and Lerdau, 2013; Stefanowicz et al., 2017). However, rigorous overall accounting of GHG emissions following plant invasions into grasslands has been scarce due to a lack of simultaneous in situ GHG measurements. Net accounting of GHG emission quantifications from invaded sites is important on account of the potential effects linked to global climate change.

To investigate the effects of plant invasions on GHG emissions, we conducted in situ measurements of soil CH_4, CO_2 and N_2O emissions over two years in an annual grassland being invaded by exotic perennial forbs in China. We calculated the global warming potentials (GWP) of replicate field sites dominated by different native or exotic species based on measurements of GHG fluxes and NPP. We predicted that exotic plant invasions would increase NPP and overall soil GHG emissions due to the combined effects of stronger competitive ability and greater growth of invasive plants. Our objectives were: (1) to determine the effects of plant invasions on the dynamics and magnitude of soil GHG fluxes and (2) to obtain an overall accounting of GWP in an annual grassland undergoing exotic plant invasions.

2. Materials and methods

2.1. Site description

We used annual grassland areas located at the Nanjing Agricultural University experimental station (6 m elevation, 32°02′N, 118°38′E), Jiangsu province, China, for measurements of GHG fluxes. The experimental region is characterized by a monsoon climate with annual mean temperature of 17.6 °C and precipitation of 980 mm. The monthly mean temperatures ranged from 3 °C in January to 29 °C in July across the experimental years. The soils are fertile with high clay content due to seasonal Yangtze River flooding until the early 20th century. Soils are classified as Gleysol or hydromorphic soils. Soil organic C and total N contents were 17.6 g kg^{-1} and 1.5 g kg^{-1}, respectively. Exotic plant species, including the focal ones used here, were first detected at the research station 6 years before this study. Presently, several invasive species are still aggressively expanding their distributions into sites dominated by native plants. Common native plant species include *Abutilon theophrasti* Medic, *Acalypha australis* L., *Amaranthus mangostanus* L., *Bidens pilosa* L., *Conyza sumatrensis* (Retz.) Walker, *Digitaria sanguinalis* (L.) Scop, *Eleusine indica* (L.) Gaertn, *Eragrostis pilosa* (L.) Beauv., *Phragmites australis* (Cav.) Trin. ex Steud., *Polygonum perfoliatum* L., *Sesbania cannabina* (Retz.) Poir., and *Xanthium sibiricum* Patrin ex Widder.

2.2. Focal species

The perennial forb species *Alternanthera philoxeroides* (Mart) Griseb. (alligator weed, Amaranthaceae, hereafter "*Alternanthera*") and *Solidago canadensis* L. (Canada goldenrod, Asteraceae, hereafter "*Solidago*") were introduced from South America (via Japan) in the 1930s and from North America in the 1910s, respectively, and are invasive in China (Weber et al., 2008). *Alternanthera* and *Solidago* have been reported to be invaders in North America (*Alternanthera* only), Australia and Europe as well. At the experimental station, both species form monospecific patches among native species. The native annual plants *Eragrostis pilosa* (Indian love grass, Poaceae, hereafter "*Eragrostis*") and *Sesbania cannabina* (Canicha, Leguminosae, hereafter "*Sesbania*") are two dominant local plants in the grassland. However, as *Alternanthera* and *Solidago* invasions proceed, the local abundances of native plants are decreasing.

2.3. Field experiment set-up

For each of the four species (*Alternanthera*, *Solidago*, *Eragrostis* or *Sesbania*), we established a plot (2 × 2 m) in three replicate sites dominated (>90% cover) by the species. In three randomly selected corners of each plot we conducted in situ measurements of soil GHG fluxes over two years, measured year 1 litterfall and biomass, or measured year 2 litterfall and biomass.

2.4. GHG fluxes measurement

We measured GHG fluxes with static chamber methods at fixed circle collars. In February 2010, we installed three aluminum flux collars