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Effects of straw and plastic film mulching on greenhouse gas emissions in Loess Plateau, China: A field study of 2 consecutive wheat-maize rotation cycles

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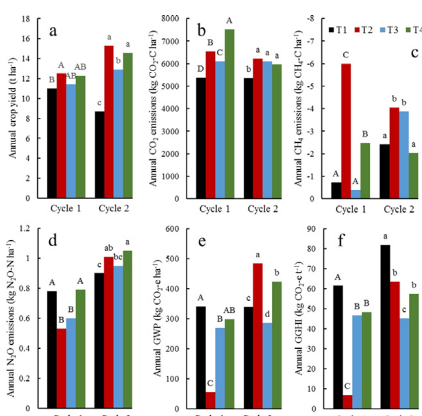
HIGHLIGHTS

- Crop yields were significantly increased by straw mulching over both cycles, and by plastic film mulching in cycle 2.
- Both straw and film mulching significantly increased soil CO_2 emission over both cycles.
- Patterns of soil N_2O emissions under straw or film mulching are not consistent.
- Both straw and film mulching significantly decreased annual GHGI.
- Straw mulching is recommended in Loess Plateau, China.

GRAPHICAL ABSTRACT



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ABSTRACT

Mulching practices have long been used to modify the soil temperature and moisture conditions and thus potentially improve crop production in dryland agriculture, but few studies have focused on mulching effects on soil gaseous emissions. We monitored annual greenhouse gas (GHG) emissions under the regime of straw and plastic film mulching using a closed chamber method on a typical winter-wheat (*Triticum aestivum* L. cv Xiaoyan 22) and summer-maize (*Zea mays* L. cv Qinlong 11) rotation field over two-year period in the Loess Plateau, northwestern China. The following four field treatments were included: T1 (control, no mulching), T2 (4000 kg ha^{-1} wheat straw mulching, covering 100% of soil surface), T3 (half plastic film mulching, covering 50% of soil surface), and T4 (complete plastic film mulching, covering 100% of soil surface). Compared with the control, straw mulching decreased soil temperature and increased soil moisture, whereas plastic film mulching increased both soil temperature and moisture. Accordingly, straw mulching increased annual crop yields over both cycles, while plastic film mulching significantly enhanced annual crop yield over cycle 2. Compared to the no-mulching

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treatment, all mulching treatments increased soil CO_2 emission over both cycles, and straw mulching increased soil CH_4 absorption over both cycles, but patterns of soil N_2O emissions under straw or film mulching are not consistent. Overall, compared to T1, annual GHG intensity was significantly decreased by 106%, 24% and 26% under T2, T3 and T4 over cycle 1, respectively; and by 20%, 51% and 29% under T2, T3 and T4 over cycle 2, respectively. Considering the additional cost and environmental issues associated with plastic film mulching, the application of straw mulching might achieve a balance between food security and GHG emissions in the Chinese Loess Plateau. However, further research is required to investigate the perennial influence of different mulching applications.

1. Introduction

Atmospheric carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are known as long-lived greenhouse gases (GHGs) driving global warming (IPCC, 2013). According to IPCC (2007), global agriculture contributed 10–12% to the anthropogenic greenhouse effect in 2005, releasing 5.1–6.1 Pg CO_2-equivalents (CO_2-e) of GHGs to the atmosphere. It is a significant challenge to mitigate GHG emissions from cultivated soils, since anthropogenic uses on farmland to acquire higher crop yield are supposed to increase, and by no means to decrease, to sustain the population growth. Under this circumstance, alteration on agricultural practices such as mulching is supposed as viable method to deliver beneficial effects to change agricultural practices to increase soil organic matter content thereby decrease CO_2 and N_2O emissions (Mosier et al., 2006; Smith et al., 2008).

Mulching soil with natural or artificial materials is used worldwide, especially in arid, semiarid and sub-humid areas. In Europe, both complete and half plastic film mulching by far has been the largest proportion of covered agricultural surface (4270 km^2) in field, which is four times larger than that used in greenhouses (Steinmetz et al., 2016). In China, plastic mulch use has increased from 319 to 1245 megatons between 1991 and 2011 (National Bureau of Statistics of China, 2012). Complete soil surface plastic film mulching can reduce evaporation to a great extent by physically blocking the movement of water vapor from the soil surface to the air (Anikwe et al., 2007; Liu et al., 2010c), which on the other hand prevents water infiltration from rain fall (assuming plastic films remain in-tact during the whole crop growing season). As a result, half soil surface plastic film mulching with less material investments and disposal fees is usually considered as a compromise between evaporation and rainfall infiltration (Zhang et al., 2011a). Crop straw mulching is one of the alternatives to plastic film mulching, with merits of biodegradable and environmentally friendly. In China, straw mulching has been introduced, tested and extended since the 1970s (Xie et al., 2007). Straw mulching can protect the soil surface from the direct strike of raindrops, and even reduce soil erosion caused by rainstorms and wind. Thus, it will keep soil loose, reduce runoff, improve soil permeability and hydraulic conductivity, and increase water storage in the soil profile (Chen et al., 2007; Zhang et al., 2007). Given these positive effects, the applications of plastic film and straw mulching have well been developed in recent years (Sharma et al., 2011; Lenka and Lal, 2013; Ram et al., 2013; Ruidisch et al., 2013; Stagnari et al., 2014), including in the Loess Plateau (Zhang et al., 2007, 2009; Zhou et al., 2009, 2011; Liu et al., 2010b, 2010c, 2016; Bu et al., 2013; Cai et al., 2015; Wang et al., 2016a, 2016b), which has a typical semi-arid monsoon climate with limited precipitation and high evaporation in the northeast China (Liu et al., 2009). Although the positive results on water and/or soil preservation by mulching, few studies have compared the effects of these mulching managements on the environmental effect, such as GHG emissions.

Changes in soil temperature and moisture, by mulching, can have a strong impact on GHG emissions between the soil and atmosphere (Mosier et al., 2006; Smith et al., 2008; Berger et al., 2013; Liu et al., 2014). Studies investigating GHG emissions under straw mulching in agricultural fields have reported inconsistent results (Liu et al., 2011, 2016; Yagioka et al., 2015). Decomposition of straw provided readily available C and N, increased CO_2 emissions (Oorts et al., 2007; Bavin et al., 2009; Lenka and Lal, 2013), and tended to intensify (Almaraz et al., 2009; Gomes et al., 2009; Ma et al., 2009; Liu et al., 2011; Lenka and Lal, 2013) or to reduce (Ma et al., 2008; Ahmad et al., 2009; Jarecki et al., 2009; Yagioka et al., 2015) CH_4 and N_2O emissions. Similarly, it has been reported that plastic film mulching decreased CO_2 emissions (Okuda et al., 2007; Li et al., 2011, 2012), CH_4 absorption (Okuda et al., 2007; Li et al., 2014; Cuello et al., 2015), and decrease N_2O emissions (Berger et al., 2013; Li et al., 2014; Liu et al., 2014), or increase N_2O emissions (Okuda et al., 2007; Arriaga et al., 2011; Nishimura et al., 2012; Cuello et al., 2015). The contradiction could be a result of the inconsistent investigations of agronomical measures, as well as the corresponding geological, mineralogical and meteorological characteristics. To improve our knowledge of straw and plastic film mulching effects on CO_2, CH_4 and N_2O emissions and to optimize agricultural practices, additional field measurements made simultaneously under different mulching practices are required in various farming systems and regions. In this study, we performed a field experiment for two years to measure the annual CO_2, CH_4 and N_2O emissions from a winter-wheat and summer-maize rotation field under different mulching practices (wheat straw and plastic film mulching) in the Chinese Loess Plateau. The objectives of this study were to (1) assess the effects of soil surface mulching on CO_2, CH_4 and N_2O emissions, and to (2) identify an optimum mulching method to achieve high grain yield and low GHG intensity, in the Chinese Loess Plateau.

2. Materials and methods

2.1. Site description

The field experiment was conducted at the Experimental Station of Water Saving Irrigation (34°20′ N, 108°24′ E, 521 m a.s.l.), at Northwest A&F University, Yangling, China during the period of 2013–2015. The site is located in a semi-arid to sub-humid climate zone, with a mean annual precipitation of 620 mm and a mean temperature of 13.0 °C (Chen et al., 2015). Soil texture (0–10 cm) is silty clay loam, consisting of 8% sand, 75% silt, and 17% clay. The soil properties in the top 20 cm (sampled on October 2, 2013) are as follows: bulk density 1.37 g cm^{-3}, pH (H_2O, 1:1) 8.20, field capacity 27.92% (v/v), soil organic carbon (SOC) 8.14 g kg^{-1}, total soil nitrogen 0.95 g kg^{-1}, soil NO_3^--N 5.41 mg kg^{-1}, soil NH_4^+-N 1.35 mg kg^{-1}, available soil phosphorus 20.91 mg kg^{-1}, and available soil potassium 134 mg kg^{-1}. The air temperature and daily precipitation were collected from an automatic weather station located in our experimental field (Fig. 1). Mean annual maximum and minimum temperatures were 19.6 °C and 9.2 °C over the 2013–2014 rotation cycle (cycle 1), and 19.7 °C and 9.2 °C over the 2014–2015 rotation cycle (cycle 2). Annual precipitation was 682.6 mm over cycle 1 (302.3 mm and 380.3 mm for wheat and maize season, respectively), and 523.3 mm over cycle 2 (239.4 mm and 283.9 mm for wheat and maize season, respectively).