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Impact of plastic film mulching on increasing greenhouse gas emissions in temperate upland soil during maize cultivation

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ABSTRACT

Plastic film mulching (PFM) is an agricultural management practice that is commonly used to suppress weed growth. However, its effect on greenhouse gas (GHG) emissions has not been well evaluated. To investigate the effect of PFM on GHG emissions and crop productivities, black PFM and no-mulching plots were installed as the main treatment, and three sub-treatments, chemical fertilizer (NPK) and two green manures, were arranged within each main treatment. Two cover crops (hairy vetch and barley) with different carbon/nitrogen (C/N) ratios were cultivated in the two green manure treatments during the fallow season. The aboveground biomasses of vetch (23–25 Mg fresh weight ha^{-1}) and barley (10–11 Mg ha^{-1}) were incorporated before maize seedling transplanting. Maize was cultivated without chemical fertilization in the two green manure treatments, whereas the recommended chemical fertilizers were applied in the NPK treatment. During two annual cropping seasons, the emission rates of methane (CH_4) and nitrous oxide (N_2O) gases were simultaneously monitored once a week using the closed-chamber method. Total global warming potential (GWP) was calculated as CO_2 equivalents by multiplying the seasonal CH_4 and N_2O fluxes by 25 and 298, respectively. Irrespective of soil amendments, PFM significantly increased soil temperature and moisture content by a mean of 2 °C and 0.04 $m^3\,m^{-3}$ over no-mulching, respectively. Plastic film mulching increased grain productivity by 8–33% over no-mulching. However, PFM significantly decreased soil organic matter content and largely increased the two major GHG emissions. As a result, PFM increased the total GWP by 12–82% over no-mulching, irrespective of the soil amendments. In conclusion, more sustainable mulching systems should be developed that can sustain soil quality and minimize environmental impacts, including GHG emissions.

1. Introduction

In modern intensive farming, plastic film mulching (PFM) has been widely applied throughout the world. Over 30 million acres of agricultural lands worldwide were covered with plastic mulch as of 1999 (Miles et al., 2006), and an estimated 1 million tons of mulch films were used annually in the agricultural sector (Halley et al., 2001). Many advantages of PFM have been reported, including inhibiting weeds, increasing soil temperature, reducing water evaporation, controlling leaching of plant nutrients, triggering plant growth, and increasing yield (Unger, 1975; Hopen and Oebker, 1976; Zhao and Xiao, 1982; Shen et al., 1997; Wakamatsu, 1997; Peng et al., 1999; Wu et al., 1999; Yang et al., 2000). Because of the many benefits of PFM in the fields, its application is expected to continue to grow.

The improved soil moisture and temperature conditions by PFM can increase crop productivities over a short duration but also disturb the original balance between abiotic and biotic factors in the farming ecosystem (Li et al., 2007). In general the improvements to the soil temperature and moisture regime are favorable conditions for microbial activity (Li and Sarah, 2003), which in turn enhances the mineralization rate of soil organic matter (SOM) that provides readily available nutrients to plant growth. The mineralization of SOM favors the release of readily available nutrients, thereby increasing crop production (Moreno-Cornejo et al., 2014). However, the faster microbial mineralization under PFM can lead to conditions that promote the emission of greenhouse gases (GHG) such as CH_4, CO_2, and N_2O.

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An increase in the atmospheric concentrations of these three major GHGs has been of worldwide concern due to their impacts on global warming. Agriculture plays an important role in the global fluxes of these gases. In particular, CH_4 and N_2O are the primary contributors to global warming, and the agricultural sector produces approximately 50 and 70%, respectively, of the total anthropogenic emissions of those gases (IPCC, 2007). The increase in the application of PFM under different soil amendment conditions may increase the contribution of the agricultural sector to global GHG emissions, but this effect has not been extensively verified.

In this study, to evaluate the effect of PFM on GHG emissions in a typical temperate upland soil, PFM and no-mulching plots were installed as the main treatments, and three sub-treatments, chemical fertilizer (NPK) and two green manures (hairy vetch and barley), were arranged in each main treatment. The emission patterns of two major GHGs (CH_4 and N_2O) were characterized during the cropping seasons, and the GWPs for the different treatments were compared.

2. Materials and methods

2.1. Experimental plot preparation

Experimental plots were prepared in a typical temperate upland soil at the Gyeongsang National University Experimental Farm (35°146′N and 128°096′E), Jinju, South Korea. The annual mean temperature and precipitation for the last 30 years were 13.1 °C and 1513 mm, respectively, and more than 60% of the annual precipitation was concentrated from May to September. The selected soil was classified as fine silty, mixed, mesic Typic Endoaquepts. The primary chemical properties of soil were neutral (pH 7.3) and low fertility (organic matter 17.5 g kg^{-1}, total N 2.4 g kg^{-1}, available P_2O_5 159 mg kg^{-1}).

To investigate the effect of PFM on the maize productivities and GHG emission characteristics during cropping season, a total of six treatments were arranged using a split-plot design and replicated three times. The black PFM and no-mulching plots were designed as the main treatment, and three sub-treatments, chemical fertilization (NPK) and two green manure application (barley and hairy vetch), were installed in each main treatment. During two fallow seasons from November to the following May hairy vetch (*Viciavillosa* R.) and barley (*Hordeumvulgare* R.) were cultivated in two green manure treatments without fertilization and mulching. The recommended seeding rates of hairy vetch (90 kg ha^{-1}) and barley seeds (180 kg ha^{-1}) were broadcast onto the 10 m × 20 m plots in early November 2011 and 2012. In early June of the following years, the aboveground biomass of the cover crops was harvested manually at the mid-maturing stage of barley.

The total fresh aboveground biomass productivity of hairy vetch was much greater (23–25 Mg ha^{-1}) than that of barley (10–11 Mg ha^{-1}), but the biomass productivities of the two cover crops were similar in both cultivation years. The barley biomass contained 41–43% moisture content, 42.6–43.0% total organic C, 0.81–0.84% total N and a 51–53 C/N ratio (wt wt^{-1} on a dry weight base). In comparison, the hairy vetch biomass had 74% moisture content, 41.0–41.4% total organic C, 2.31–2.36% total N, and a 17–18 C/N ratio. The harvested biomasses were manually chopped (size 5–10 cm) and then mixed mechanically into the surface soil one week before maize transplanting. The recommended chemical fertilizers ($N–P_2O_5–K_2O$ = 186–35–70 kg ha^{-1}) for maize cultivation were applied in the NPK treatment during maize cultivation (RDA, 1999).

To investigate the effect of PFM on GHG emissions and crop productivities, each plot was sectioned into two parts, for installing PFM and the no-mulching treatments. Black plastic film (40 micron thickness) was used to uniformly cover the PFM plots.

2.2. Maize cultivation

Fifteen day old maize seedlings were transplanted by hand with a spacing of 50 cm × 45 cm in mid-June of 2012 and 2013. On the following mid-September of the same years, the maize plants were harvested from 2 linear meters on different rows, avoiding plot edges. Husks were left on the plants. The ears were shelled by hand, and the grain and cobs were dried first in the sun and then in an oven at 60 °C for 72 h. The grain moisture after drying was determined using a hand-held moisture tester (John Deere, Moline IL, USA), and the grain yield is reported on a 15% moisture content basis.

2.3. Gas sampling and analysis

A closed-chamber method was used to estimate the CH_4 and N_2O emission rates and their total fluxes for the entire cropping period (Rolston, 1986). A permanent cylindrical acrylic base chamber with a hollow ring attached on its brim was buried in the ground, extending only 5 cm above the soil surface. The base chambers were installed in three replicates for each plot (Iqbal et al., 2008; Kusa et al., 2008; Kim et al., 2014). Gas samples were collected by covering the base chamber with an opaque cylindrical acrylic cover (diameter 24 cm; height 20 cm). The hollow ring on the brim was filled with water to seal the chamber while the gas was sampled. An air circulation fan and a thermometer were installed in the chamber. All of the chambers were kept open in the field throughout the maize cultivation period, except during the gas sampling time.

One day a week, gas was sampled three times (08:00–12:00–16:00 h) at 0, 15, and 30-min intervals to obtain the average GHGs emissions during the maize growing season (Kim et al., 2014). Three gas samples in each treatment were drawn from the chamber headspace using 50-mL plastic syringes equipped with three-way stopcocks. The collected gas samples were immediately transferred into 30-mL air-evacuated glass vials sealed with a butyl rubber septum for gas analysis.

The CH_4 concentrations were analysed using a gas chromatograph (Shimadzu, GC-2010) coupled with a stainless steel column packed with a Porapak NQ column (Q80-100 mesh) and a flame ionization detector (FID). The temperatures of the column, injector, and detector were adjusted to 80, 100, and 110 °C, respectively. The N_2O concentrations were measured using a gas chromatograph (Varian CP-3800) coupled with an electron capture detector (ECD) with a Poropak Q column (CP-3800, Varian, CA, USA). The temperatures of the column, injector and detector were adjusted to 55, 100, and 330 °C, respectively. Both of the gas chromatographs used helium as a carrier gas, and air and hydrogen were used as the burning gases.

The following closed-chamber equation was used to estimate the CH_4 and N_2O fluxes from each treatment (Rolston, 1986):

$$F = \rho \times \left(\frac{V}{A}\right) \times \left(\frac{\Delta c}{\Delta t}\right) \times \left(\frac{273}{T}\right),$$

where F is the CH_4 flux (mg $CH_4\,m^{-2}\,h^{-1}$) or N_2O flux (μg N_2O $m^{-2}\,h^{-1}$), ρ is the gas density of CH_4 or N_2O under a standardized state (mg cm^{-3}), V is the volume of the chamber (m^3), A is the chamber area (m^2), $\Delta c/\Delta t$ is the rate of CH_4 or N_2O gas accumulation in the chamber, and T is the absolute temperature (273+ mean temperature in the chamber, °C).

The seasonal CH_4 or N_2O fluxes for the entire cropping period were computed using the following equation from Singh et al. (1999):