# Postprint: Response of Soil Greenhouse Gas Emissions to Plastic Film Mulching in Cropping Systems in the Arid Region of Xinjiang

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## Abstract

Plastic mulching is an effective approach for improving crop yields in arid region farmlands and is widely applied in agricultural production. Investigating the response of soil greenhouse gas emissions to mulching under different cropping systems is of great significance for greenhouse gas mitigation in croplands. A plot experiment was conducted to perform in-situ observations of greenhouse gas emissions from mulched and non-mulched soils (MM, MN, CM, CN) in maize and cotton plots. The results showed that: (1) Mulching significantly increased soil temperature and moisture content ($P<0.05$). The mulched treatments (MM, CM) exhibited a greater number of soil $CH_4$ emission events than the non-mulched treatments (MN, CN), with the highest $CH_4$ emission fluxes in the two systems occurring in the MM and CM treatments, at 63.47 g·m-2·h-1 and 16.67 g·m-2·h-1, respectively. (2) The highest $N_2O$ emission fluxes were observed in the MM (616.70 g·m-2·h-1) and CN treatments (244.92 g·m-2·h-1). (3) The maximum soil $CO_2$ emission fluxes in maize and cotton plots appeared in July (505.93 g·m-2·h-1) and June (848.32 g·m-2·h-1), respectively, after which both exhibited a decreasing trend. (4) Soil moisture content exerted significant effects on $CH_4$, $N_2O$, and $CO_2$ emissions from the MM and CM treatments ($P<0.05$). (5) Soil temperature had a significant effect on $CH_4$ emissions from the MM treatment, $N_2O$ emissions from the MM and CM treatments were significantly positively correlated with soil temperature, and $CO_2$ emissions from all treatments showed significant correlations with soil temperature ($P<0.05$). Crop type and plastic mulching produced an interactive effect on $CO_2$ emissions. (6) The global warming potential (GWP) of soils in the MM and MN treatments was significantly higher than that in the CM and CN treatments, with an increase of 61.83%~74.63%. Greenhouse gas emissions from cropland soils are comprehensively influenced by mulching and crop type, and the response of greenhouse gas emissions under mulched soils to hydrothermal factors is stronger than that of non-mulched soils.

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# Full Text

## Effects of Soil Mulching on Greenhouse Gas Emissions from Cropland in Arid Regions of Xinjiang

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## Abstract

Film mulching is an effective approach to improve crop yield in arid farmland and is widely used in agricultural production. Investigating the response of soil greenhouse gas emissions to mulching under different crop systems is important for reducing farmland greenhouse gas emissions. Using a plot experiment, we conducted in situ observations of greenhouse gas emissions from mulched and non-mulched soils in maize and cotton plots. The results showed: (1) Mulching significantly increased soil temperature and water content ($P<0.05$). The frequency of $CH_4$ emissions from mulched soils was greater than from non-mulched soils. The highest emission fluxes of $CH_4$ in maize and cotton plots were 63.47 $g \cdot m^{-2} \cdot h^{-1}$ and 16.67 $g \cdot m^{-2} \cdot h^{-1}$, respectively. The highest $N_2O$ emission fluxes appeared in July, with maximum values of 616.70 $g \cdot m^{-2} \cdot h^{-1}$ and 244.92 $g \cdot m^{-2} \cdot h^{-1}$ for mulched maize and cotton soils, respectively, after which they showed a downward trend. The maximum $CO_2$ emission fluxes occurred in June, reaching 848.32 $g \cdot m^{-2} \cdot h^{-1}$ and 505.93 $g \cdot m^{-2} \cdot h^{-1}$ for maize and cotton plots, respectively. (2) Soil water content had significant effects on $CH_4$, $N_2O$, and $CO_2$ emissions from mulched soils ($P<0.05$). Soil temperature significantly affected $CH_4$ emissions from mulched maize soil. $N_2O$ emissions from mulched soils were significantly positively correlated with soil temperature. $CO_2$ emissions under all treatments were significantly correlated with soil temperature ($P<0.05$). Crop species and film mulching had interactive effects on $CO_2$ emissions. (3) The global warming potential (GWP) of mulched maize soil was significantly higher than that of mulched cotton soil, with an increase of 61.83%~74.63%. Farmland soil greenhouse gas emissions are affected by the combination of mulching and crop type, and greenhouse gas emissions from soils under film respond more strongly to hydrothermal factors than non-mulched soils.

**Keywords:** arid area farmland; maize; cotton; plastic film mulching; greenhouse gases

## Introduction

Global climate warming has become an indisputable fact, and emissions of greenhouse gases such as carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$) are among the primary causes of global warming. According to statistics, farmland greenhouse gas emissions account for approximately 13.5% of global anthropogenic greenhouse gas emissions, making farmland an important source of atmospheric greenhouse gases. Xinjiang represents a typical arid farmland region, with agricultural land area reaching 6.27 million hectares, of which cotton and maize planting areas account for about 40% of the total farmland area. Film mulching is an effective approach to improve crop yield in arid farmland and is widely used in agricultural production. Film mulching can reduce soil water evaporation and increase soil temperature, thereby altering the hydrothermal conditions beneath the film. Meanwhile, different crops' physiological characteristics and cultivation management practices also affect soil environmental conditions, which influences greenhouse gas emissions from mulched farmland and often leads to divergent research results.

Previous studies on mulched cotton fields in arid regions found that mulching significantly reduced cumulative $N_2O$ emissions from cotton fields, with emission fluxes 7.91% lower than non-mulched cotton fields. Studies on mulched maize farmland suggested that mulching had no significant effect on $CO_2$ and $N_2O$ emission fluxes from farmland soil. Additionally, research on mulched maize farmland found that in the same study area but during different experimental periods, mulching produced different effects on $CH_4$ uptake by maize farmland soil. Xinjiang is the province with the largest agricultural film mulching area in China, with film usage approaching 270,000 tons. Evidently, different study regions, crop types, climatic conditions, and experimental periods are important reasons for inconsistent research results on greenhouse gas emissions from mulched farmland.

Currently, numerous studies have reported on greenhouse gas emissions from mulched farmland for individual crops, but comparative studies on different mulched farmlands under the same climatic conditions and soil types are scarce. Meanwhile, few reports exist on differences in greenhouse gas emissions between mulched and non-mulched soils in mulched farmland. Therefore, investigating the response mechanisms of greenhouse gas emissions from cotton and maize farmland in Xinjiang' s arid region to mulching is an urgent problem to be solved in the current process of agricultural sustainable development.

## 1. Materials and Methods

### 1.1 Study Site

The experiment was conducted in 2020 at the Aksu Farmland Ecosystem National Field Scientific Observation and Research Station of the Chinese Academy of Sciences (40°37 N, 80°45 E). The station is located in the Tarim Basin at an altitude of 1030 m, with a multi-year average precipitation of 45.2 mm, mean annual temperature of 11.2°C, annual sunshine duration of 2940 h, and a frost-free period of 211 d. It belongs to an arid oasis farmland ecosystem and represents a typical example of farmland in arid regions. The soil type in the experimental area is salinized fluvo-aquic soil with a silty loam texture. The soil organic matter content is 15.95 $g \cdot kg^{-1}$, alkali-hydrolyzable nitrogen content is 4.81 $mg \cdot kg^{-1}$, available phosphorus content is 12.31 $mg \cdot kg^{-1}$, available potassium content is 0.87 $mg \cdot kg^{-1}$, total nitrogen content is 0.58 $g \cdot kg^{-1}$, total phosphorus content is 0.20 $g \cdot kg^{-1}$, and total potassium content is 20.56 $g \cdot kg^{-1}$. Changes in rainfall and daily mean temperature during the experimental period are shown in Fig. 1.

### 1.2 Experimental Design

This study focused on typical crops in Xinjiang' s arid region—maize and cotton—and conducted in situ monitoring of farmland greenhouse gases while simultaneously measuring environmental factors such as soil water content and temperature to calculate cumulative emissions and warming potential. The objective was to clarify the dynamic changes in soil greenhouse gas emissions from the two crop systems during the growing season, analyze the relationship between soil environmental factors and farmland greenhouse gas emissions under mulching conditions, and explore differences in soil greenhouse gas emissions among different crop systems in arid areas under mulching, aiming to provide scientific data and theoretical basis for farmland planting structure adjustment in Xinjiang.

A plot experiment was established using mulching cultivation practices, conducted from April to September 2020. Individual plots measured 8 m × 8 m. Two crop treatments were established, with three replicate plots for each crop treatment arranged in a randomized block design. Within each plot, two sampling treatments were established: for maize plots, mulched maize soil (MM) and non-mulched maize soil (MN); for cotton plots, mulched cotton soil (CM) and non-mulched cotton soil (CN). Mulching employed 0.005 mm thick transparent polyethylene film with a width of 1.2 m. Plant spacing used a wide-narrow row configuration, with four rows of cotton planted under one film, narrow row spacing of 15 cm, wide row spacing of 70 cm, and plant spacing of 10 cm; maize variety was Zhongnuo No. 1, with narrow row spacing of 15 cm, wide row spacing of 70 cm, and plant spacing of 50 cm. Cotton variety was Xinluzao No. 70.

Both cotton and maize fields used urea (N 46.4%) as nitrogen fertilizer, diammonium phosphate (N 18%, $P_2O_5$ 20%) as base fertilizer, and compound fertilizer (N 18%, $P_2O_5$ 20%, $K_2O$ 24%) as drip irrigation fertilizer. Field management adopted water-fertilizer management practices, with drip irrigation during the growth period. Drip irrigation tapes were laid in the center of wide rows, with regular irrigation events lasting 7-11 h each and intervals of 7–9 d between irrigations, totaling 8–10 irrigation events.

### 1.3 Sample Collection and Measurement Methods

Gas samples were collected using the static dark chamber method. The sampling chamber was an opaque rectangular box made of plexiglass material, measuring 50 cm in length, 50 cm in width, and 25 cm in height. A three-way valve at the top of the chamber was used for gas collection, and a small fan inside the chamber was used to mix the gas during sampling. The chamber base measured 50 cm × 50 cm and was inserted 10 cm into the soil. The chamber was placed on the base' s groove and sealed by filling the groove with water. Bases were placed in both mulched and non-mulched soils within each plot, and the chamber contained no crops or weeds during the observation period (Fig. 2). When inserting the base into the mulched portion of the farmland, care was taken to avoid damaging the film.

Sampling frequency was every 7-8 days. On each sampling day, between 9:00–10:00, after placing the chamber, the small fan was turned on. Gas samples were collected with a syringe at 0, 5, 10, 15, 20, and 30 minutes after sealing, with each sample volume being 30 mL. Gas samples were analyzed within 7 days using a gas chromatograph (Agilent 7890A). During each sampling period, temperature inside the sampling chamber, soil water content, and soil temperature at 10 cm depth were measured simultaneously using a portable thermometer (JM624) and a right-angle soil thermometer.

### 1.4 Calculation Formulas

Greenhouse gas emission flux was calculated using a linear model. The linear model employed a linear regression equation of gas concentration (c) changing with time (t). The calculation formula is:

$$F = \rho \times \frac{V}{A} \times \frac{\Delta c}{\Delta t} \times \frac{273.15}{273.15 + \theta}$$

where: $F$ is the emission flux of greenhouse gases ( $\mathrm{g \cdot m^{-2} \cdot h^{-1}}$ or $\mathrm{mg \cdot m^{-2} \cdot h^{-1}}$); $\rho$ is the gas density in the chamber ($\mathrm{kg \cdot m^{-3}}$); $V$ is the internal space volume of the sampling chamber ($\mathrm{m^3}$); $A$ is the soil area covered by the sampling chamber ($\mathrm{m^2}$); $\Delta c/\Delta t$ is the linear change rate of greenhouse gas concentration per unit time; and $\theta$ is the average temperature inside the chamber during sampling (°C).

The cumulative emission of greenhouse gases $R_c$ was calculated as:

$$R_c = \sum_{i=1}^{n-1} \frac{F_i + F_{i+1}}{2} \times (t_{i+1} - t_i) \times 24 \times 0.01$$

where: $n$ is the number of observations during the growing season; $F_i$ and $F_{i+1}$ are the greenhouse gas emission fluxes at the $i$-th and $(i+1)$-th samplings; and $t_i$ and $t_{i+1}$ are the sampling times at the $i$-th and $(i+1)$-th samplings.

This experiment is based on the fact that $CO_2$, $CH_4$, and $N_2O$ emissions from farmland soil are anthropogenic greenhouse gas sources. When calculating the global warming potential (GWP) of farmland, only the warming effects of $CH_4$ and $N_2O$ were calculated. The 100-year global warming potentials of $CH_4$ and $N_2O$ are 28 and 265, respectively. Therefore, the GWP of farmland was calculated as:

$$GWP = CH_4 \times 28 + N_{2O} \times 265$$

with the conversion coefficient to standard carbon.

### 1.5 Data Processing

Data were processed using Excel 2010 and Origin software. SPSS 19.0 software was used for repeated-measures analysis of variance to compare differences in soil greenhouse gas emissions among treatments. One-way ANOVA and independent samples t-test were used to compare differences in soil temperature, water content, and soil greenhouse gas emission fluxes ($\alpha = 0.05$). Regression analysis was used to explore the relationship between soil temperature, water content, and soil greenhouse gas emission fluxes.

## 2. Results

### 2.1 Effects of Mulching on Soil Environmental Factors

Analysis of hydrothermal factors in mulched and non-mulched soils within the same crop plots revealed that mulching had significant effects on soil hydrothermal factors in both crop systems ($P<0.05$). Compared with non-mulched soils, mulched soils showed temperature increases of 17.10%-54.71% and water content increases of 90.41%-332.43% in maize plots, and temperature increases of 17.12%-50.65% and water content increases of 91.35%-298.80% in cotton plots. These results demonstrate that mulching can significantly enhance soil temperature and water content beneath the film (Fig. 3).

### 2.2 Dynamics of Greenhouse Gas Emissions from Different Farmlands

$CH_4$ emissions mainly showed absorption characteristics with occasional emissions. Both maize and cotton plots exhibited higher absorption intensity during the observation period. Mulched soils showed increased $CH_4$ emission frequency compared to non-mulched soils. The highest $CH_4$ emission fluxes in maize plots were 63.47 $g \cdot m^{-2} \cdot h^{-1}$ (MM) and 28.65 $g \cdot m^{-2} \cdot h^{-1}$ (MN), while in cotton plots they were 16.67 $g \cdot m^{-2} \cdot h^{-1}$ (CM) and 6.28 $g \cdot m^{-2} \cdot h^{-1}$ (CN). The highest $CH_4$ absorption fluxes were 40.27 $g \cdot m^{-2} \cdot h^{-1}$ (MM) and 34.85 $g \cdot m^{-2} \cdot h^{-1}$ (MN) for maize, and 27.32 $g \cdot m^{-2} \cdot h^{-1}$ (CM) and 23.16 $g \cdot m^{-2} \cdot h^{-1}$ (CN) for cotton. Overall, mulching increased the frequency of $CH_4$ emissions, with maize plots showing more emission events than cotton plots.

$N_2O$ emission fluxes showed smaller fluctuations between mulched and non-mulched soils within the same crop plots. The highest $N_2O$ emission fluxes appeared in July, with maximum values of 616.70 $g \cdot m^{-2} \cdot h^{-1}$ (MM) and 369.97 $g \cdot m^{-2} \cdot h^{-1}$ (MN) for maize plots, and 244.92 $g \cdot m^{-2} \cdot h^{-1}$ (CM) and 208.33 $g \cdot m^{-2} \cdot h^{-1}$ (CN) for cotton plots. Thus, mulching did not affect the $N_2O$ emission pattern, though peak timing and intensity differed between maize and cotton plots.

$CO_2$ emission fluxes in all treatments showed an initial increase followed by a decrease. The highest $CO_2$ emission fluxes occurred in June, reaching 848.32 $g \cdot m^{-2} \cdot h^{-1}$ (MM) and 680.67 $g \cdot m^{-2} \cdot h^{-1}$ (MN) for maize plots, and 505.93 $g \cdot m^{-2} \cdot h^{-1}$ (CM) and 440.30 $g \cdot m^{-2} \cdot h^{-1}$ (CN) for cotton plots. The dynamic patterns of $CO_2$ emission fluxes were similar across treatments, with all showing a peak in mid-growing season (Fig. 4).

### 2.3 Response of Greenhouse Gas Emissions to Mulching and Hydrothermal Factors

Analysis of the relationship between soil hydrothermal conditions and greenhouse gas emissions revealed that in the maize system, $CH_4$ emission fluxes under MM treatment were significantly correlated with soil water content ($P<0.05$), while $N_2O$ and $CO_2$ emission fluxes showed extremely significant correlations with soil water content ($P<0.01$). $CH_4$ emission fluxes were significantly correlated with soil temperature ($P<0.05$), while $N_2O$ and $CO_2$ emission fluxes were extremely significantly correlated with soil temperature ($P<0.01$). In the cotton system, soil temperature and water content had significant effects on $N_2O$ and $CO_2$ emissions from mulched soils ($P<0.05$), while only soil temperature significantly affected $CH_4$ emissions. For non-mulched soils, only $CO_2$ emissions showed significant correlations with soil temperature and water content.

Repeated-measures ANOVA indicated significant differences in $CH_4$, $N_2O$, and $CO_2$ emissions between maize and cotton plots ($P<0.05$). No significant differences were observed between mulched and non-mulched treatments within the same crop system for $CH_4$ and $N_2O$ emissions. However, crop species and film mulching had interactive effects on $CO_2$ emissions (Table 1). The dynamic patterns of $CO_2$ emission fluxes were similar across treatments, primarily influenced by crop root systems (Fig. 5).

### 2.4 Cumulative Greenhouse Gas Emissions and Global Warming Potential

During the observation period, both maize and cotton plots showed $CH_4$ uptake (negative emissions). Cumulative $CH_4$ uptake was significantly higher in mulched soils than in non-mulched soils ($P<0.05$). Compared with non-mulched soils, mulched maize soil reduced cumulative $N_2O$ emissions by 35.37%-40.00%, while mulched cotton soil reduced them by 57.46%-63.55%. Cumulative $CO_2$

emissions from mulched maize soil were 13.43% higher than from non-mulched soil, while mulched cotton soil showed 6.75% higher emissions (though not statistically significant).

Among all treatments, mulched maize soil exhibited the highest global warming potential (GWP) at 818.85 $kg \cdot hm^{-2}$, while non-mulched cotton soil had the lowest GWP at 440.30 $kg \cdot hm^{-2}$. Compared with non-mulched soils, the GWP of mulched maize soil increased by 19.78%, while that of mulched cotton soil increased by only 6.10%. These results indicate that maize plots have a higher warming effect (Table 2).

## 3. Discussion

### 3.1 Effects of Mulching on Soil Greenhouse Gas Emissions

Film mulching can significantly affect the hydrothermal conditions of soil beneath the film. Changes in soil hydrothermal conditions can have different effects on greenhouse gas emissions. In this study, soil water content was found to be the key factor affecting $N_2O$ emissions from mulched soils, with a stronger influence than soil temperature. This is because increased soil water content beneath the film changes soil heat capacity, and soil moisture also hinders gas diffusion in soil, which together limit the regulatory effect of soil temperature, making water content the critical factor for $N_2O$ emissions.

Soil temperature is the main factor controlling the mineralization of organic matter and plant root respiration rates. Fierer et al. [?] found in their study on soil respiration and temperature that changes in soil temperature cause significant variations in $CO_2$ emissions, which is consistent with our results. Meanwhile, Wang et al. [?] suggested that soil respiration is jointly affected by soil temperature and water content, which aligns with our findings for mulched soils but differs for non-mulched soils. Temperature can regulate various aspects of soil respiration, but its influence has certain limits [?]. In this study, non-mulched soil temperatures were significantly lower than those beneath the film. Crop root respiration and microbial metabolism are the main sources of soil $CO_2$, and lower soil temperatures may lead to decreased temperature sensitivity of microbial metabolic rates, resulting in reduced $CO_2$ emissions.

Under mulched conditions, the regulatory control of hydrothermal factors on greenhouse gas emissions increases significantly. For mulched farmland in Xinjiang's arid region, $CH_4$ emissions are only significantly affected by soil moisture; $N_2O$ emissions are jointly influenced by soil moisture and temperature; and soil temperature can also significantly affect $CO_2$ emissions from non-mulched soils.

Crop species is an important reason for differences in greenhouse gas emissions from different farmland soils, as the respiration of different crop roots indirectly affects greenhouse gas production and emissions [?]. This study showed that soil temperature was significantly correlated with $CH_4$ emission fluxes from mulched maize soil, but no such significant correlation was observed with mulched cotton soil. This may be due to different temperature sensitivities of root respiration between crops, leading to methanogens and methanotrophs in maize and cotton plots being in different soil environments, causing differential responses to soil temperature changes.

For maize and cotton crops, maize is a $C_4$ plant while cotton is a $C_3$ plant. The difference between $C_3$ and $C_4$ plants means their photosynthesis and respiration respond differently to temperature and $CO_2$ concentration. The $CO_2$ compensation point differs between them, so their respiration responds differently to temperature and $CO_2$ changes. In this study, the dynamic patterns of soil $CO_2$ emissions were mainly affected by crop species, and mulching significantly reduced cumulative $N_2O$ emissions from cotton plots but had no significant effect on maize plots. Mulching has a barrier effect, causing $CO_2$ accumulation in soil beneath the film. $C_4$ plants can utilize higher $CO_2$ concentrations, while $C_3$ plants (cotton) have higher $CO_2$ compensation points. Under high $CO_2$ concentrations, $C_4$ photosynthesis is already saturated, so its response to $CO_2$ is not strong, leading to different effects of mulching on $CO_2$ emissions between crop systems. This also results in interactive effects between crop species and mulching.

Under the same study area, climatic conditions, and observation period, both mulched and non-mulched soils in maize plots showed higher warming effects than cotton plots. Therefore, if maize planting area could be appropriately reduced during farmland structure adjustment in Xinjiang, it would play an important role in greenhouse gas mitigation in arid region farmland.

## 4. Conclusions

1) Under the same crop system, mulching increased the frequency of soil $CH_4$ emissions but did not significantly affect the emission patterns of $N_2O$ and $CO_2$. Throughout the growing season, soil greenhouse gas emission characteristics differed significantly between maize and cotton systems.

2) Mulching only significantly reduced cumulative $N_2O$ emissions in cotton plots. Soil hydrothermal factors are key factors affecting greenhouse gas emissions from mulched soils, with soil water content being the primary factor regulating $N_2O$ emissions from mulched soils.

3) Crop species significantly affect soil greenhouse gas emissions, and there are interactive effects between crop species and mulching on $CO_2$ emissions. The global warming potential of maize plots is significantly higher than that of cotton plots.

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## Figures

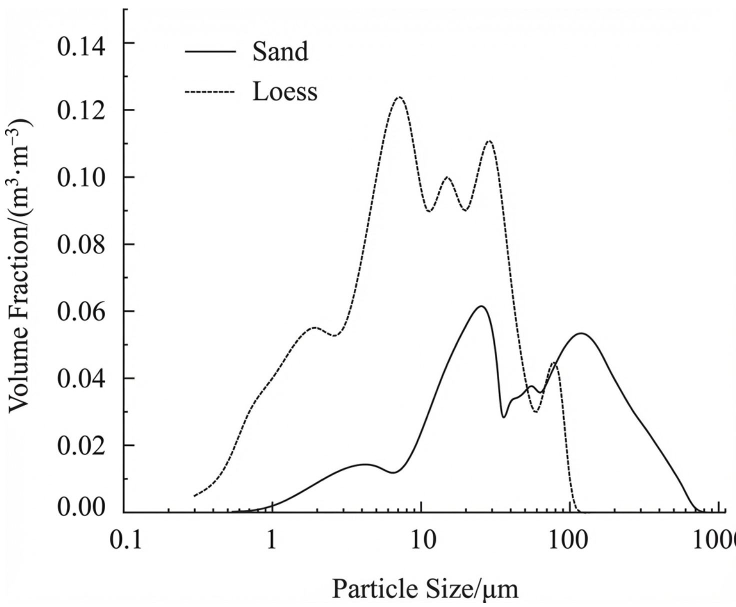


Figure 1: Figure 3

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