

Estimating carbon fixation potential of fallow weeds in rice cropping systems

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Research Letter

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Abstract

Fallow weeds are more and more common in Chinese rice cropping systems, but are always excluded in studies of vegetative carbon (C) sinks. This study aimed to evaluate the C fixation potential of fallow weeds in rice cropping systems. A six-region, two-year on-farm investigation and a three-year tillage experiment were conducted to estimate C fixation in fallow weeds in rice cropping systems. The on-farm investigation showed that the average mean C fixation in fallow weeds across six regions and two years reached 112 g m^{-2} . The tillage experiment indicated that no-tillage practices increased C fixation in fallow weeds by 80% on average as compared with conventional tillage. The results of this study not only contribute to an understanding of C fixation potential of fallow weeds in rice cropping systems, but also provide a reference for including fallow weeds in the estimation of vegetative C sink. Further investigations are required to determine the effect of C input from fallow weeds on C balance of rice paddies in order to comprehensively evaluate the role of fallow weeds in C cycling in rice cropping systems.

Introduction

Global mean surface temperature has increased by more than $1 \text{ }^{\circ}\text{C}$ from the pre-industrial era and this warming is projected to reach $1.5 \text{ }^{\circ}\text{C}$ by 2030 and $2 \text{ }^{\circ}\text{C}$ by 2045 (Xu et al. 2018). Global warming has and will continue to harmfully affect many human beings by increasing the frequency and severity of extreme weather events such as heatwaves and the incidence of climate-sensitive diseases such as malaria (IPCC 2018). Since carbon dioxide (CO_2) is the major contributor to the global warming, reducing atmospheric CO_2 concentrations has been the main goal for developing strategies to mitigate global warming (Batjes 1998; Yamasaki 2003; Kumar et al. 2011); one approach to achieve this goal is to increase carbon (C) fixation in terrestrial vegetation (Yamasaki 2003).

Weeds are an important component of terrestrial vegetation. However, C fixation in weeds is generally not included in estimating the C sink of terrestrial vegetation (Fang et al. 2007; Piao et al. 2009; Tang et al. 2018), and limited information is available on the C fixation potential of weeds. In crop production systems, although weeds that occurred during the crop-growing season are always controlled to avoid yield losses, those occurrences during the fallow season receive little human disturbance and hence can perform the function of C fixation.

Rice (*Oryza sativa*) is one of the most widely grown crops around the world and China is the largest rice grower with an area of about 30 million ha (IRRI 2020). Planting green manure crops (e.g., Chinese milk vetch) during the winter season is a traditional practice used in rice production in China due to its benefits of improving soil fertility (Yang et al. 2014). However, because rapid urbanization has led to a labor shortage and an increase in labor wages in rural areas of China, many Chinese rice farmers have had little enthusiasm to plant green manure crops (Huang et al. 2019). As a result, the planting area of green manure has sharply decreased since 1970s (Cao et al. 2017), and more and more rice paddies are left

fallow during the winter season (Wang et al. 2014). These winter fallow paddies provide a huge opportunity for the occurrence of weeds (Fig. 1).

Vegetative C fixation is a function of vegetative biomass and C concentration within said biomass. As C concentration is relatively stable in vegetative biomass, a given value of biomass C concentration is often assumed to estimate the vegetative C fixation (Coomes et al. 2002; Howard et al. 2004; Houghton et al. 2009). This relationship also indicates that increasing vegetative biomass is a major path toward increasing vegetative C fixation. For the weeds in croplands, biomass is affected by several agronomic practices including soil tillage as a main factor (Petit et al. 2011).

In this study, we estimated C fixation in fallow weeds in rice cropping systems based on measured biomass data from a six-region, two-year on-farm investigation and a three-year tillage experiment. Our objective was to evaluate the C fixation potential of fallow weeds in rice cropping systems.

Materials And Methods

Data collection

An on-farm investigation was carried out in six regions of Hunan Province, China, including Yueyang (28°31'–29°32' N, 112°39'–113°02' E), Yiyang (28°27'–29°01' N, 112°18'–112°25' E), Changsha (28°12'–28°18' N, 113°13'–113°49' E), Xiangtan (27°45'–27°55' N, 112°13'–112°38' E), Hengyang (26°32'–27°02' N, 112°13'–112°47' E), and Yongzhou (25°46'–26°36' N, 111°29'–111°59' E), before land preparation for rice cultivation in 2015 and 2016. The Hunan Province is one of the major rice-producing provinces in China, contributing more than 10% of the total national rice production (IRRI 2020). The investigated regions represent a broad geographical distribution covering northern (Yueyang and Yiyang), central (Changsha and Xiangtan), and southern areas (Hengyang and Yongzhou) of the province. The temperature generally tends to decrease from northern to southern regions. Thirty rice fields with a dense vegetation of fallow weeds were selected in each region. Rice crops were grown under conventional tillage (CT) with varied management practices in these fields. The dominated fallow weed in these fields was Japanese foxtail (*Alopecurus japonicus*). Six sampling points (0.6 m × 0.4 m) were chosen along the diagonal of each field. Fallow weed plants were sampled from each sampling point and mixed to get a representative sample for each field.

A tillage experiment was conducted in Changsha (28°11'N, 113°04'E), Hunan Province, China from 2008 to 2011. The soil of the experimental field was a Fluvisol (FAO taxonomy), and had the following properties at the upper 20 cm layer: pH 5.83, 27.7 g organic matter kg⁻¹, 1.59 g total N kg⁻¹, 12.6 mg available P kg⁻¹, and 107 mg available K kg⁻¹. In each cropping cycle, two seasons of rice crops (*i.e.*, early- and late-season rice) were grown within a given year and then a fallow season (*i.e.*, end-October to mid-April) was followed until the first rice-growing season in the next year. Rice crops were grown under two tillage methods: CT and no-tillage (NT). The CT operation was performed by rotary ploughing. For the NT operation, no soil disruption was implemented and herbicide (paraquat) was applied before rice

cultivation to avoid the occurrence of weeds during the rice-growing season. The tillage methods were laid out in a randomized complete block design with four replications and a plot size of 45 m². The plots were separated from each other by ridges (30 cm width) or irrigation ditches (50 cm width). The plots were fixed at the same place throughout the duration of the experiment. Rice crops were managed according to the locally-recommended practices for achieving high grain yields. Briefly, seedlings (approximately 30-days-old) were transplanted with two seedlings per hill at a hill spacing of 20 cm × 16.7 cm for early-season rice and 20 cm × 20 cm for late-season rice. Synthetic fertilizers (urea, superphosphate, and potassium chloride) were applied at rates of 142.5 kg N ha⁻¹, 67.5 kg P₂O₅ ha⁻¹, and 135 kg K₂O ha⁻¹ for early-season rice, and 150 kg N ha⁻¹, 67.5 kg P₂O₅ ha⁻¹, and 135 kg K₂O ha⁻¹ for late-season rice, respectively. The practice of alternating wetting and drying was employed for water management. Pesticides and fungicides were used to prevent biotic damages as needed. Fallow weeds, predominately Japanese foxtail, were naturally grown without any management activities. Two sampling points (0.4 m × 0.6 m) were randomly chosen in the middle of each plot before land preparation for rice cultivation in 2009–2011. Fallow weed plants were sampled from each sampling point and mixed to get a representative sample for each plot.

All fallow weed samples were oven-dried at 70 °C until they reached a constant weight to determine biomass. The C content in fallow weed biomass was assumed as 43% according to Toriyama et al. (2020). The C fixation in fallow weeds was estimated by multiplying the measured biomass by the assumed C content.

Statistical analysis

The data of estimated C fixation in fallow weeds were subjected to statistical analysis using Statistix 8.0 (Analytical Software, Tallahassee, FL, USA). For the on-farm investigation, descriptive statistics were employed to calculate the mean and the 95% confidence intervals (CIs) for each region-year, and means were considered to be significantly different from each other if their 95% CIs did not overlap. For the tillage experiment, an analysis of variance (ANOVA) was performed followed by the least significant difference test. The statistical model of the ANOVA included replication, tillage method, year, and the interaction between tillage method and year. The statistical significance was set at the 0.05 probability level.

Results

The on-farm investigation showed that Yiyang and Yongzhou, respectively, had the highest and lowest mean C fixation in fallow weeds in both 2015 and 2016 (Fig. 2), which were significantly different from the other four regions (*i.e.*, Yueyang, Changsha, Xiangtang, and Hengyang). A significant yearly difference in mean C fixation in fallow weeds was observed in Yueyang, Yiyang, and Changsha, but not in the other three regions (*i.e.*, Xiangtan, Hengyang, and Yongzhou). The average mean C fixation in fallow weeds across six regions and two years was 112 g m⁻².

The tillage experiment indicated that C fixation in fallow weeds was significantly affected by tillage method, year, and their interaction (Fig. 3). NT had a significantly positive effect on C fixation in fallow weeds in all three years, but the magnitude of the effect varied by year. NT increased C fixation in fallow weeds by 57%, 105%, and 78% in 2009, 2010, and 2011, respectively, as compared with CT.

Discussion

This study estimated C fixation in fallow weeds, as fallow weeds commonly occurred in Chinese rice cropping systems but are always ignored in studies of vegetative C sink. From the results of this study, it is known that C fixation in fallow weeds in rice cropping systems can exceed $110 \text{ g m}^{-2} \text{ season}^{-1}$ under CT practices across a wide range of regions and can be further increased by an average of approximately 80% by adoption of NT rather than CT practices. This does not only contribute to an understanding of C fixation potential of fallow weeds in rice cropping systems, but also provides a reference for including fallow weeds in the estimation of C sink of terrestrial vegetation.

By comparing the results of this study with those of a meta-analysis by Feng et al. (2013), we found that the C fixation potential of fallow weeds is comparable to the average value of total emission of the greenhouse gases methane (CH_4) and nitrous oxide (N_2O) during the rice growing season across different rice cropping systems (double rice, rice-upland crop, and single rice cropping systems) in China: $516 \text{ g CO}_2 \text{ equiv. m}^{-2} \text{ season}^{-1}$ or $141 \text{ g C equiv. m}^{-2} \text{ season}^{-1}$. This finding suggests that fallow weeds are capable of playing an important role in C cycling in rice cropping systems.

The results of our on-farm investigation also indicated that C fixation in fallow weeds is dependent on the region where they are grown; C fixation in fallow weeds tended to decrease from northern to southern regions (Fig. 2). This might be due to several reasons: (1) the dominant weed in the investigated fields was Japanese foxtail, which is indigenous to northern regions and prefer relatively low temperatures; or (2) northern regions generally have a shorter rice-growing season but a longer winter fallow season than southern regions. Also, the on-farm investigation showed that C fixation in fallow weeds was generally lower in 2015 than in 2016 (Fig. 2). This might be partially because the winter season of 2014–2015 was the second warmest winter season in the Hunan Province since record collection began in 1951 (Hunan Meteorological Bureau, <http://hn.cma.gov.cn>), which might not be favorable for the growth of Japanese foxtail that prefers relatively low temperature as mentioned above.

The NT effect on weed growth has been researched for many years (Buhler and Mester 1991; Yenish et al. 1992), and it has been well documented that NT can reduce weed seed movement to deeper soil layers and consequently increase weed population density and biomass as compared with CT. Wu et al. (2016) investigated the effect of burial depth on germination and emergence of Japanese foxtail, the dominant fallow weed in the tillage experiment of this study. They observed that increasing burial depth decreased the germination index of Japanese foxtail. Accordingly, we speculated that the increased C fixation in fallow weeds under NT compared with CT in the present study might be attributable to more fallow weed

seeds distributed in shallow soil depths. This highlights the need for an understanding of the effect of NT on seed bank characteristics of Japanese foxtail in rice paddies.

There is a limitation concerning this study that needs to be acknowledged. This study only estimated the C fixation potential of fallow weeds in rice cropping systems. However, the fixed C will be released to soils as fallow weeds decompose during the rice-growing season, and not all of the released C will be sequestered in the soil; some C will be lost to the atmosphere through CO₂ and CH₄ emissions. In addition, fallow weed C input may alter the emission of other greenhouse gases such as N₂O. Therefore, further studies are required to investigate the effect of C input from fallow weeds on C balance of rice paddies in order to fully evaluate the role of fallow weeds in C cycling in rice cropping systems.

Conclusions

Fallow weeds have great potential to play an important role in the C cycling in rice cropping systems. Fallow weeds in rice cropping systems can fix more than 110 g C m⁻² season⁻¹ under CT practices across a wide range of regions, which can be further increased by approximately 80% by adoption of NT rather than CT practices. Additional investigations are needed to determine the change in C balance of rice paddies induced by returning fallow weed to soils.

Declarations

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Authors' contributions

MH conceived the study, analyzed the data, and wrote the manuscript. GC, FC & JC performed the experiment. All authors read and approved the final manuscript.

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Availability of data and materials

The research data of this study can be obtained upon by requesting the corresponding author.

Competing interests

The authors declare that they have no conflict of interests.

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Figures



Figure 1

Fallow weeds dominated by Japanese foxtail in a rice field nearby the farmer's house in Anren County, Hunan Province, China. The photo was taken on 11 March 2020.



Figure 1

Fallow weeds dominated by Japanese foxtail in a rice field nearby the farmer's house in Anren County, Hunan Province, China. The photo was taken on 11 March 2020.

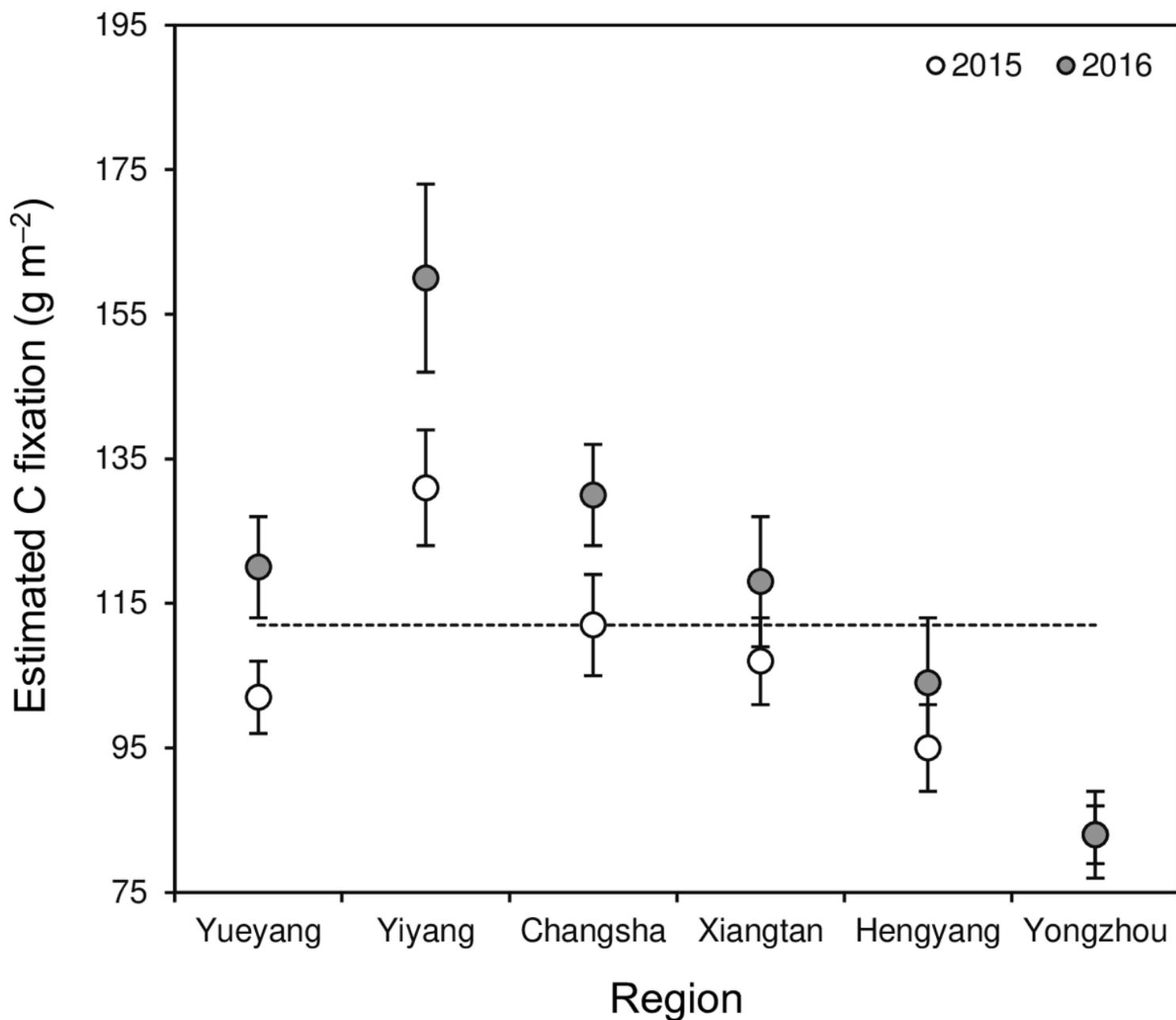


Figure 2

Estimated carbon (C) fixation in fallow weeds in rice cropping systems in six regions of Hunan Province, China in two years. Points and bars represent means and 95% confidence intervals (CIs) of 30 fields, respectively. Means are considered to be significantly different from each other if their 95% CIs do not overlap. The horizontal dashed line shows the average value across regions and years.

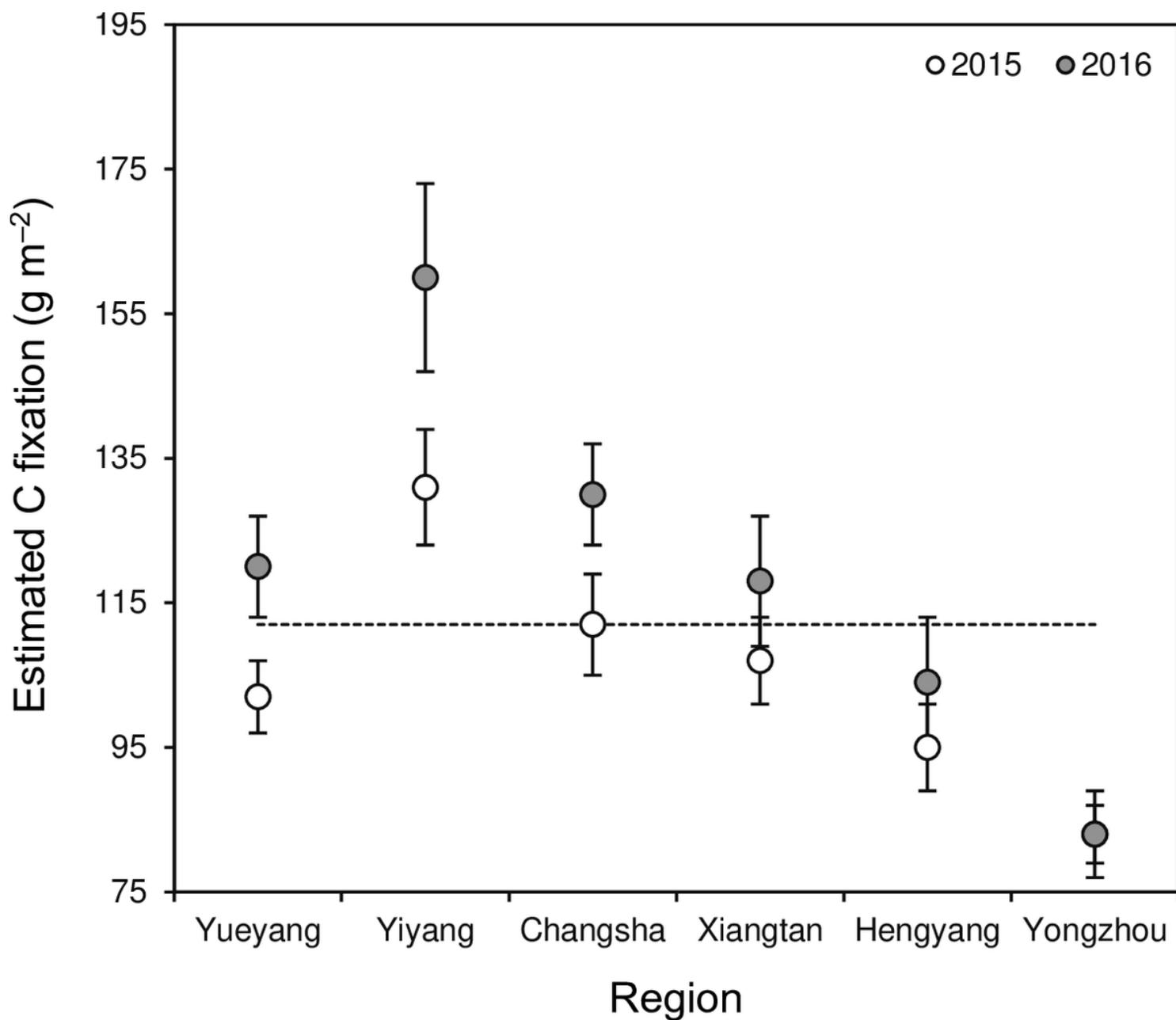


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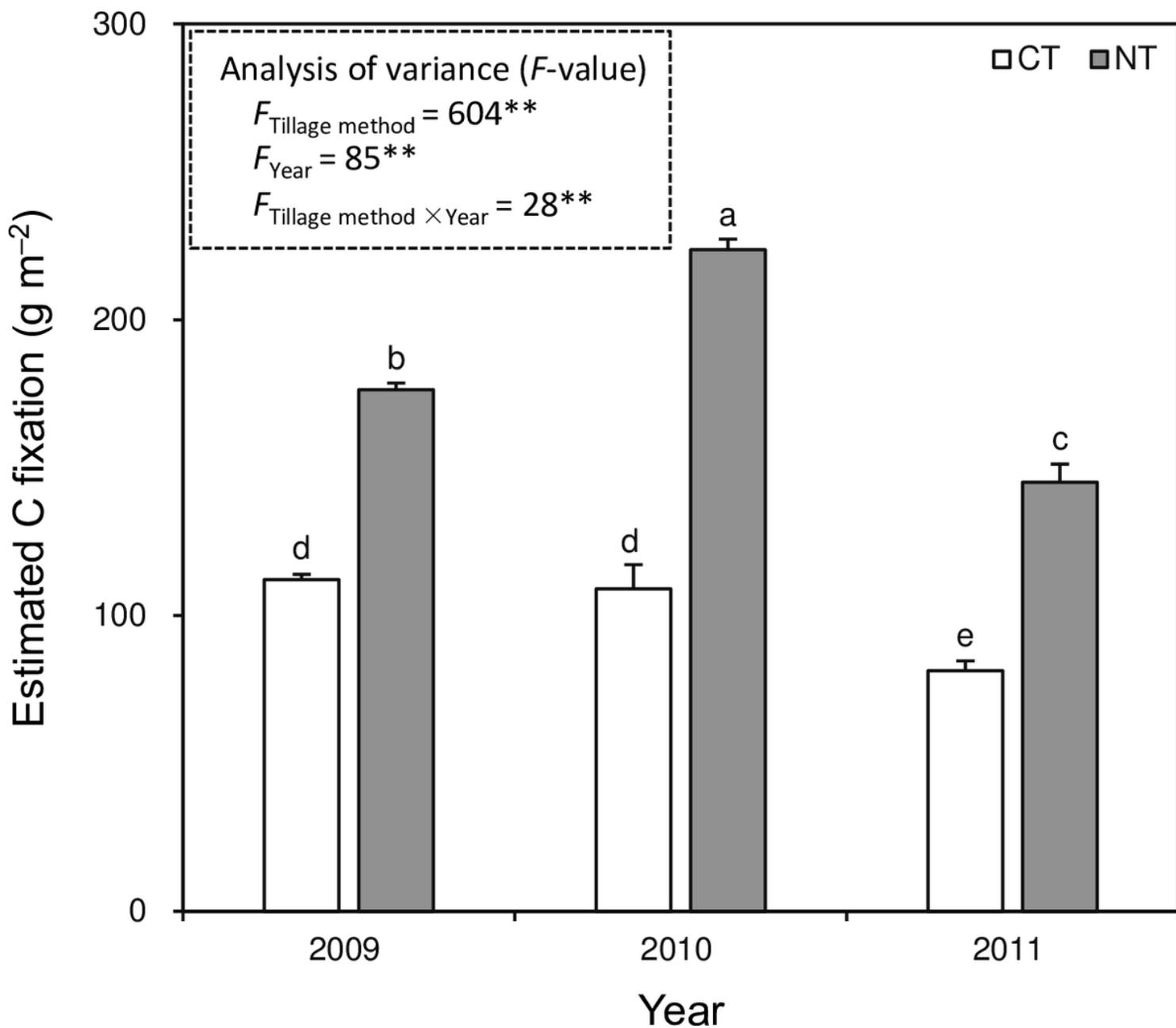


Figure 3

Estimated carbon (C) fixation in fallow weeds in conventional tillage (CT) and no-tillage (NT) rice cropping systems over three consecutive years. In the dashed box, *F*-values marked with an asterisk sign (*) indicate significance at the 0.05 probability level. Columns and bars represent means and standard errors of 4 replications, respectively. Means sharing the same letters are not significant at the 0.05 probability level.

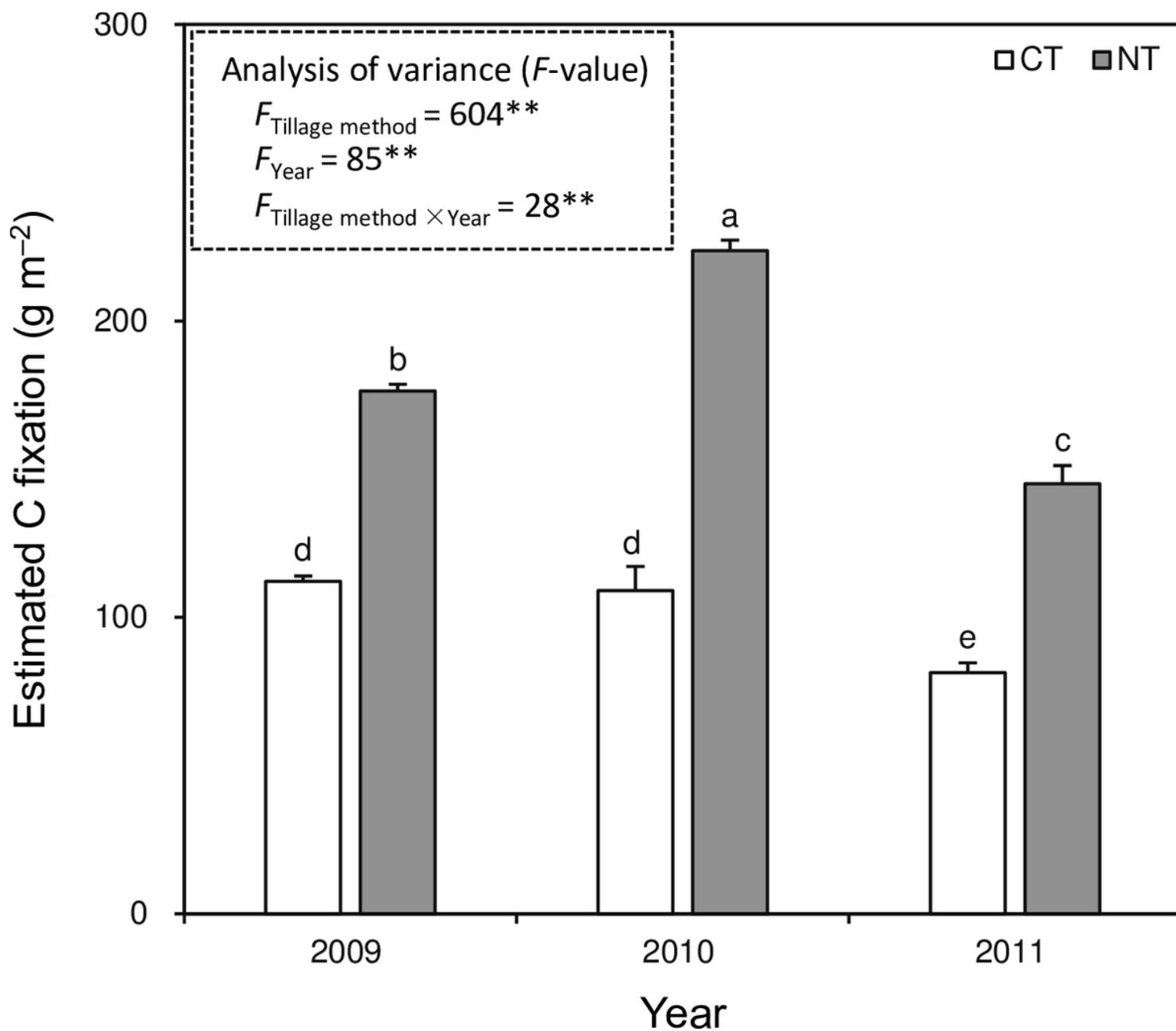


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