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ARTICLE

Estimating Carbon Capture Potential of Fallow Weeds in Rice Cropping Systems

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ABSTRACT

Weeds occurred during the fallow season can well perform the function of carbon (C) capture due to receiving little human disturbance. This study aimed to evaluate the C capture potential of fallow weeds in rice (*Oryza sativa* L.) cropping systems. A six-region, two-year on-farm investigation and a three-year tillage experiment were conducted to estimate C capture in fallow weeds in rice cropping systems. The on-farm investigation showed that the average mean C capture by fallow weeds across six regions and two years reached 112 g m^{-2}. The tillage experiment indicated that no-tillage practices increased C capture by fallow weeds by 80% on average as compared with conventional tillage. The results of this study not only contribute to an understanding of C capture potential of fallow weeds in rice cropping systems, but also provide a reference for including fallow weeds in the estimation of vegetative C sink.

KEYWORDS

Carbon cycling; fallow weeds; no-tillage; rice cropping system; vegetative carbon sink

1 Introduction

Global mean surface temperature has increased by more than 1°C from the pre-industrial era and this warming is projected to reach 1.5°C by 2030 and 2°C by 2045 [1]. 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 [2]. 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 [3–5]; one approach to achieve this goal is to increase carbon (C) capture by terrestrial vegetation [4].

Weeds are an important component of terrestrial vegetation. However, C capture in weeds is generally not included in estimating the C sink of terrestrial vegetation [6–8], and limited information is available on the C capture 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 well perform the function of C capture.

Rice (*Oryza sativa* L.) 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 [9]. Planting green manure crops, e.g., Chinese milk vetch

(*Astragalus sinicus* L.), during the winter season is a traditional practice used in rice production in China due to its benefits of improving soil fertility [10]. 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 [11]. As a result, the planting area of green manure has sharply decreased since 1970s [12], and more and more rice paddies are left fallow during the winter season [13]. These winter fallow paddies provide a huge opportunity for the occurrence of weeds (Fig. 1).

Figure 1: Fallow weeds dominated by Japanese foxtail (*Alopecurus japonicus* Steud.) in a rice field nearby the famer's house in Anren County, Hunan Province, China. The photo was taken by the corresponding author on 11 March 2020

However, there is limited information available on the C capture potential from fallow weed occurrence in rice cropping systems. Vegetative C capture 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 capture [14–16]. This relationship also indicates that increasing vegetative biomass is a major path toward increasing vegetative C capture. For the weeds in croplands, biomass is affected by several agronomic practices including soil tillage as a main factor [17]. As compared with conventional tillage (CT), no-tillage (NT) can increase weed population density and biomass through reducing weed seed movement to deeper soil layers [18,19].

In this study, we estimated C capture by 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 capture potential of fallow weeds in rice cropping systems.

2 Materials and Methods

2.1 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 [9]. 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 CT with varied management practices in these fields. The dominated fallow weed in these fields was Japanese foxtail (*Alopecurus japonicus* Steud.). 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 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 m^2. 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-day-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 in both the early and late seasons. In the early season, 67.5, 30, 30, and 15 kg N ha^{-1} were applied at basal (1 day before transplanting), early tillering (7 days after transplanting), panicle initiation, and booting, respectively. In the late season, 75, 30, 30, and 15 kg N ha^{-1} were applied at basal, early tillering, panicle initiation and booting, respectively. In both the early and late seasons, 67.5 kg P_2O_5 ha^{-1} were applied as basal, and 135 kg K_2O ha^{-1} were split equally at basal and panicle initiation. 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. [20]. The C capture in fallow weeds was estimated by multiplying the measured biomass by the assumed C content.

2.2 Statistical Analysis

The data of estimated C capture by 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.

3 Results

The on-farm investigation showed that Yiyang and Yongzhou, respectively, had the highest and lowest mean C capture by 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 capture by 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 capture by fallow weeds across six regions and two years was 112 g m^{-2}.

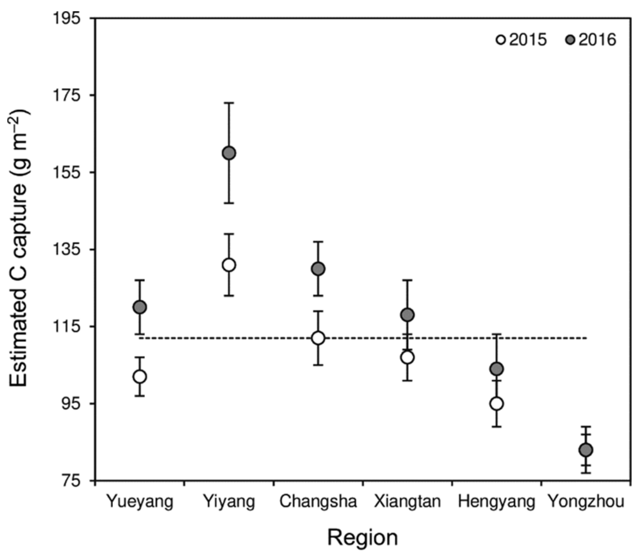

Figure 2: Estimated carbon (C) capture in fallow weeds in rice cropping systems in six regions of Hunan Province, China in two years. Points and bars represent means and 95% confidence intervals (CIs) of 30 fields, respectively. Means are considered to be significantly different from each other if their 95% CIs do not overlap. The horizontal dashed line shows the average value across regions and years

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

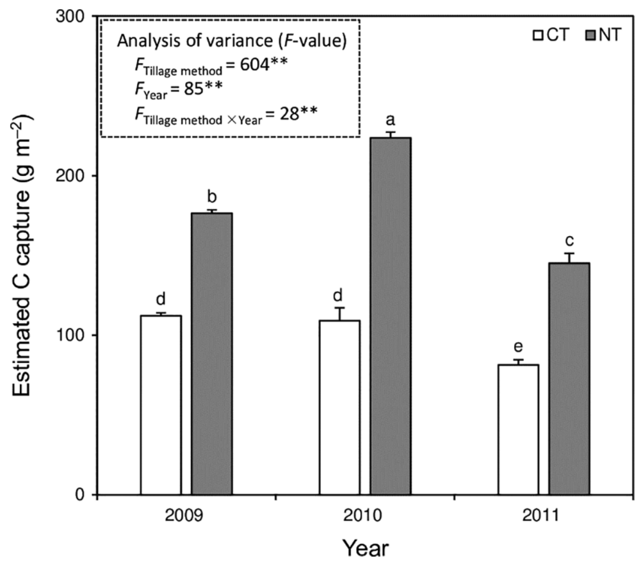

Figure 3: Estimated carbon (C) capture in fallow weeds in conventional tillage (CT) and no-tillage (NT) rice cropping systems over three consecutive years. In the dashed box, *F*-values marked with an asterisk sign (*) indicate significance at the 0.05 probability level. Columns and bars represent means and standard errors of 4 replications, respectively. Means sharing the same letters are not significant at the 0.05 probability level

4 Discussion

This study estimated C capture 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 capture by fallow weeds in rice cropping systems can exceed 110 g m^{-2} $season^{-1}$ 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 capture 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. [21], we found that the C capture 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 g CO_2 equiv. m^{-2} $season^{-1}$ or 141 g C equiv. m^{-2} $season^{-1}$. 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 capture by fallow weeds is dependent on the region where they are grown; C capture by 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 prefers 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 capture by 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. Apart from the temperature, the growth of Japanese foxtail should be also affected by other climatic factors such as solar radiation. In addition, soil properties must also be important factors that influence the growth of Japanese foxtail. Further investigations are required to identify the critical environmental factors and how they affect the growth of Japanese foxtail.

The NT effect on weed growth has been researched for many years, 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 [18,19]. Consistently, the tillage experiment of this study showed that the weed population density was approximately 50% higher under NT (5247 plants m^{-2}) than under CT (3500 plants m^{-2}) in 2011 (data not shown). Wu et al. [22] 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 capture by 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 are two limitations concerning this study that need to be acknowledged. First, the results of this study only represent the C capture potential of fallow weeds dominated by Japanese foxtail, ignoring the effect of weed diversity. Second, this study only estimated the C capture potential of fallow weeds in rice cropping systems. However, the captured 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 CO_2 and CH_4 emissions. In addition, fallow weed C input may alter the emission of other greenhouse gases such as N_2O. Therefore, further studies are required to investigate (1) the C capture potential of different fallow weed species and (2) 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.

5 Conclusion

Fallow weeds dominated by Japanese foxtail have great C capture potential (more than 110 g C m^{-2} $season^{-1}$) in rice cropping systems especially under NT practices.

Author Contribution: Min Huang conceived the study, collected the data, analyzed the data, and wrote the manuscript. Ge Chen analyzed the data and wrote the manuscript. Yuling Kang analyzed the data. Fangbo Cao and Jiana Chen collected the data. All authors have read and approved the final manuscript.

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