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# Greenhouse gas emissions, soil carbon sequestration and crop yields in a rain-fed rice field with crop rotation management

Nittaya Cha-un[a,b], Amnat Chidthaisong[a,b], Kazuyuki Yagi[c], Shigeto Sudo[c], Sirintornthep Towprayoon[a,b,*]

[a] The Joint Graduate School of Energy and Environment (JGSEE) and Center of Excellence on Energy Technology & Environment, King Mongkut's University of Technology Thonburi (KMUTT), 126 Prachauthit Rd, Bangmod, Tungkru, Bangkok, 10140, Thailand
[b] Earth System Science Research and Development Center (ESS), King Mongkut's University of Technology Thonburi, 126 Prachauthit Rd, Bangmod, Tungkru, Bangkok, 10140, Thailand
[c] Institute for Agro-Environmental Sciences, National Agriculture and Food Research Organization (NARO), 3-1-3 Kannondai, Tsukuba, Ibaraki, 305-8604, Japan

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ABSTRACT

Field experiments of two consecutive years (2010–2011) were conducted to investigate the effect of crop-rice rotation systems on greenhouse gas (GHG) emissions, soil carbon sequestration, and rice yield. Rotation crops were cultivated in the dry season, while rain-fed rice was grown in the wet season. Four different treatments were investigated: fallow-rice (RF), rice–rice (RR), corn-rice (RC) and sweet sorghum-rice (RS). The closed-chamber method was used for flux measurements of methane ($CH_4$), nitrous oxide ($N_2O$) and carbon dioxide ($CO_2$) in the field. Parameters such as soil carbon budgets (SCBs), soil organic carbon (SOC) stocks, and crop yields were also measured. In this study, it was found that RC and RS rotations reduced $CH_4$ emissions by 78–84%, and reduced net $CO_2$ equivalent emissions ($CH_4$ and $N_2O$) by 68–78%, as compared with RR. After two consecutive years of crop cultivation, SCBs were reclaimed by positive values in the RC and RR treatments. The SOC stocks were maintained in the RR, RC and RS treatments, but decreased in the RF. Although RF also reduced the net $CO_2$ equivalent emissions by 72–84% as compared with RR, there were losses in soil carbon sequestration and agricultural land utilization. The rice grain yields of RC and RS were stable in both years, while RF fell slightly by 11%, and RR significantly reduced by 39% from the first year.

## 1. Introduction

Rain-fed agriculture is a major source of food production in many countries around the world (Wani et al., 2009). Approximately 165 million ha are cultivated for global rice productions, while approximately 52 million ha are cultivated for rain-fed lowland rice. Rice produced and consumed in Asia covers approximately147 million ha or almost 90% of the global rice harvested area (FAOSTAT, 2013; GRiSP, 2013). Rain-fed lowland rice in Southeast Asia covers approximately 20 million ha or approximately 38% of the global rain-fed rice area (Mutert and Fairhurst, 2002; FAOSTAT, 2013; GRiSP, 2013). Rice remains an important economic crop in Thailand. Its cultivation area covers approximately 11 million ha which is about 47% of the country's arable land, and 60% of this rice cultivation is rain-fed (OAE, 2012). The main factors affecting rain-fed rice production are rainfall variability, drought, submergence and poor soil fertility (GRiSP, 2013). In Thailand, many rain-fed rice areas have low soil fertility (Jongdee et al., 1997) and over 200,000 ha have been abandoned (LDD, 2010). In general, rice cultivation in rain-fed areas is conducted over approximately four months during the rainy season; thereafter, fields are left fallow for approximately eight months in the dry season (OAE, 2008, 2012). As a result of limited water and poor management during the fallow period, a loss of soil utilization, fertility and nutrition occur. It is therefore deemed inappropriate to grow the second rice crop. Hence, farmers that have rain-fed rice fields often lose the opportunity of doubling their annual cultivation, which is a general practice in irrigated rice

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[*] Corresponding author at: The Joint Graduate School of Energy and Environment (JGSEE) and Center of Excellence on Energy Technology & Environment, King Mongkut's University of Technology Thonburi (KMUTT), 126 Prachauthit Rd, Bangmod, Tungkru, Bangkok, 10140, Thailand.
*E-mail address:* sirin@jgsee.kmutt.ac.th (S. Towprayoon).

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fields. However, rice cultivation requires a great deal of water (DOAE, 2009). Therefore, the cultivation of rice in rotation with other crops that have low water consumption during the dry season is an interesting option.

Crop rotation in rice fields can improve the utilization of agricultural land. However, different crop rotation systems have been shown to have different effects on GHG emissions (Adhya et al., 2000; Zheng et al., 2000; Nishimura et al., 2008; Datta et al., 2011; Zhou et al., 2014). Methane ($CH_4$) is produced by methanogens in flooded soil and emitted to the atmosphere during the rice growing season (Le Mer and Roger, 2001). Nitrous oxide ($N_2O$) is produced by nitrification and denitrification processes mainly from agricultural soil management activities, i.e. organic matter application, fertilization and irrigation (Lal, 2007; Nishimura et al., 2008). FAOSTAT (2013) reported that the global paddy rice cultivation in 2000–2010 emitted 22–25 Mt $CH_4$ year$^{-1}$ or 472–518 Mt $CO_2$eq year$^{-1}$. In addition, the agricultural sector is the largest contributor to global anthropogenic non-$CO_2$ greenhouse gases (GHGs). The annual total non-$CO_2$ GHG emissions from agriculture in 2000–2010 was found to be between 4.6-5.1 Gt $CO_2$eq year$^{-1}$, accounting for 57% from $N_2O$ emission and 43% from $CH_4$ emission (FAOSTAT, 2013). In Thailand, agricultural emissions make up more than 22% (51.88 Mt $CO_2$eq) of the annual GHG emissions. These emissions are disaggregated into 57.7% from rice cultivation, 15.9% from enteric fermentation, 14.6% from agricultural soil, 9.8% from manure management and 1.9% from the field burning of agricultural residues (ONEP, 2010). As a result of this relatively large contribution to global GHG emissions, improving the field management of agricultural systems may substantially reduce their global warming potential (CAST, 2011).

Although rice cultivation under the different management practices affect $CH_4$ and $N_2O$ emissions, many references have indicated that the use of suitable crop rotation systems and crop residue management can reduce their emissions and increase soil organic carbon (SOC). These practices can reduce carbon loss to the atmosphere, leading to better soil fertility and improved crop productivity (Li and Feng, 2002; Qiu et al., 2005; Tang et al., 2006; Dawson and Smith, 2007; Al-Kaisi, 2008; Nishimura et al., 2008; Kukal et al., 2009; Singh et al., 2009; Ali et al., 2012). The rotation of upland crops in rice fields results in frequent switching between wetting under anaerobic conditions and drying under aerobic conditions, which has affected the nutrient balance in the plant and soil (Deog-Bae et al., 2005). These different cropping conditions affect the decomposition rate of organic matter, which controls soil organic carbon accumulation (Zhou et al., 2014).

In Thailand, due to limitations of water and soil quality, crop rotation in the fallow period after rain-fed rice cultivation is not generally practiced. During the fallow period, these areas cover 7 million ha, which are approximately 55% of the rice cultivation areas (OAE, 2012). The second rice cultivation in these fallow areas can increase rice yield by over 50% (average yield is 2.8 ton ha$^{-1}$) (OAE, 2012; GRiSP, 2013). However, increasing the rice cultivation period will also increase GHG emissions during the rice growing season (Adhya et al., 2000). Very few studies have been conducted in tropical areas on the impact of crop rotation in rice field, in terms of GHG emissions and SOC storage. Moreover, there is no evidence that such a study has been conducted in Thailand. The introduction of crop rotation in rain-fed rice fields has helped increase the utilization of poor land during the fallow period. Therefore, a short period of crop rotation is proposed in rice fields. Corn and sweet sorghum are of considerable interest as rotation crops in rain-fed rice fields, as a result of their short growing period (about four months), low water demand and drought resistance. These crops can also be used as feedstock for bio-ethanol production (Ban et al., 2008; Holou, 2010; Wu et al., 2010). The use of crop rotation in rice fields will not only reclaim the benefits of double cropping but also help farmers to gain more benefits from their annual activities, including a potentially higher income. These practices are regarded as sustainable agriculture and have the potential to reduce poverty, which are important pillars of sustainable development goals.

This study aims to verify the effect of crop rotation on GHG emissions, soil carbon sequestrations, and rice yields using corn, sweet sorghum and irrigated rice rotations. This study introduced alternative cultivation practices in the fallow period of rain-fed rice fields with crop rotations that maximize utilization of the rain-fed area in Thailand.

## 2. Materials and methods

### 2.1. Site description

The field experiments were conducted in 2010 and 2011 at King Mongkut's University of Technology Thonburi, Ratchaburi campus (13° 35′ N, 99° 30′ E) in Rang Bua, Chombung District, Ratchaburi Province, on an abandoned rice field that had laid fallow for 10 years prior to the experiments. The soil at this site was classified using the KhaoYoi (Kyo) soil series described as follows: a pinkish gray (7.5YR6/2) sandy loam, many fine distinct strong brown mottles, weak medium and coarse subangular blocky structure, soft, friable, slightly sticky, slightly plastic, and very few small soft Fe and Mn nodules (classification by Office of soil resources survey and research, Land Development Department). Other soil characteristics are as follows: 53% sand, 45% silt and 2% clay, pH 5.8, 1.75 g cm$^{-3}$ bulk density, 0.69% organic matter and 0.40% organic carbon.

The local climate during the experimental periods was observed from the Dry Dipterocarp Forest Site at KMUTT Ratchaburi station, which is 400 m from the experimental site. Daily air temperatures and rainfall are shown in Fig. 1. The means of daily air temperatures in 2010 and 2011 were 27.9 °C and 26.7 °C, respectively. The means of daily maximum and minimum air temperatures were 32.4 °C and 23.5 °C in 2010, and 30.9 °C and 22.4 °C in 2011, respectively. The annual rainfall accumulation amounts were 1063 mm in 2010 and 1022 mm in 2011. The maximum amounts of accumulated monthly rainfall were 243.4 mm in October 2010 and 256.9 mm in October 2011 (Sanwangsri et al., 2011).

### 2.2. Field experiment designs

The experiments were conducted in a field measuring 35 m × 22.5 m containing eight rectangular plots, each of size 5 m × 15 m as shown in Fig. 2. In all eight plots, rain-fed rice was grown during the wet season (August-December). To investigate the effects of crop rotation in the dry season (February-June), two replications of the following four treatments were made: 1) fallow land (RF), 2) irrigated rice (RR), 3) corn (RC), and 4) sweet sorghum (RS), with each treatment in two different plots as shown in Fig. 2.

The crop cultivars used in this study are Pathumthani 1 rice, Suwan 5 corn, and KhonKaen 40 sweet sorghum. The crop management practices are shown in Table 1. Rice was planted by direct sowing at a seed rate of 95 kg ha$^{-1}$. Corn and sweet sorghum were planted by direct seeding at a spacing of 75 cm × 25 cm and 50 cm × 10 cm, respectively.

### 2.3. Greenhouse gas sampling and analysis

At three points in each plot, sampling of the gas emitted from the field was performed by the closed-chamber method. Access to these sampling points in plots where rice was growing was by stainless steel frame bridges, suspended 25 cm above the soil, to avoid disturbing the rice field. Each gas sampling chamber