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# Microbial responses to temperature sensitivity of soil respiration in a dry fallow cover cropping and submerged rice mono-cropping system

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ABSTRACT

Soil heterotrophic respiration (SHR) increases exponentially with temperature and this general information has been incorporated into soil carbon models. However, the positive feedback of warming to SHR remains uncertain, mostly due to the differential response of soil microbial community to warming under dry and flooded conditions in a rice mono-cropping system. In this study, we aimed to evaluate the relationship between SHR and microbial functional groups during the fallow and flooded rice cultivation seasons under changing temperature in a rice mono-cropping system. Field experiments were conducted to investigate SHR, soil microbial functional groups and biomass, and temperature sensitivity of SHR ($Q_{10}$) under dry fallow conditions during the cover cropping season and under flooded conditions during the rice cropping season. We found that SHR increased with increasing air and soil temperature, carbon availability, and soil microbial community composition and biomass in the fallow season, whereas a decrease in SHR in spite of an increase in temperature and carbon availability was observed under flooded conditions during the rice cropping season. Furthermore, a nonlinear response of microbial community composition and biomass with SHR was noticed during the flooded rice cropping season. This suggests that flooding could be the limiting factor for temperature sensitivity of SHR as well as microbial community composition in a rice mono-cropping system. Flooding the soil significantly ($p < 0.01$) decreased $Q_{10}$. We therefore conclude that temperature, moisture region and carbon availability, rather than only soil microbial community composition are responsible for the spatiotemporal variation in SHR in a rice mono-cropping system in this region.

## 1. Introduction

Soil heterotrophic respiration (SHR) is a major source of carbon dioxide ($CO_2$) in terrestrial ecosystems (Wieder et al., 2013). Carbon dioxide released by microbial activities in association with soil organic matter decomposition (soil heterotrophic respiration) in soils is governed by abiotic and biotic components. Although abiotic components, primarily temperature, and moisture are well recognized as important variables for predicting organic matter decomposition and thus soil $CO_2$ efflux, the importance of soil microorganisms (biotic factor) as a determinant of SHR is not being critically examined, probably due to enormous diversity and different capacities of individual microbial groups in soil to degrade available and complex form of C (Waring et al., 2013). Moreover, the role of individual microbial groups on SHR under changing temperature and moisture regime in an ecosystem remains uncertain and widely debated (Curiel Yuste et al., 2007).

Several studies have shown that SHR increases exponentially with temperature and this general relationship has been incorporated into soil-carbon and Earth-system models (Wieder et al., 2013; Karhu et al., 2014). However, the positive feedback of warming to SHR remains uncertain, because the response of soil microbial communities to changing temperatures has the potential to either decrease or increase (Karhu et al., 2014). These inconsistent responses of soil microbial communities to the temperature sensitivity of SHR could be due to the influence of other environmental variables primarily soil moisture, which could markedly affects SOM decomposition (Suseela et al., 2012). Unlike, forest ecosystems, the role of microbial community response in controlling the temperature sensitivity of SHR in agricultural systems is not clearly understood due to different cropping practices and field management, which strongly influence not only the microbial community but also the SHR (Tian et al., 2013; Tang et al., 2017). Among agricultural systems, rice mono-cropping systems are unique ecological systems which comprise both flooded and dried soil conditions. For example, in Korean paddy fields, soils are kept under water submergence for almost three months during the rice cultivation season and under dry, aerobic conditions for more than six months during the

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fallow season. This dramatic change in ecological conditions of mono-rice paddies within a year could substantially influence soil microbial dynamics and temperature sensitivity of SHR. In particular, the role of soil microorganisms in the spatial dynamics of SHR under a wide range of temperature variation and moisture regimes in a rice mono-cropping system is not reported earlier and our understanding on whether the soil microbial community is one of the main factors controlling SHR in a rice mono-cropping system is, however, elusive.

Microorganisms play an integral role in virtually all the soil processes, including organic matter decomposition and nutrient mobilization (Tian et al., 2013). Microbial community composition and activity are directly affected by soil abiotic factors such as soil temperature, soil moisture and nutrient availability, and indirectly affected by plant biomass and diversity (Zhao et al., 2016). Furthermore, soil quality and field management practices also affect the microbial community and activity (Garcia-Orenes et al., 2013). Based on the importance of the functional group-specific sensitivity to the nutrient in particular C and water availability, the change in microbial communities could lead to the changes in ecosystem functions (Romaniuk et al., 2011; Zhao et al., 2016). For example, fungi are known to have higher C use efficiency and slower biomass turnover rates than bacteria (Six et al., 2006), which advocates that the difference in relative abundance of fungi and bacteria present in arable soils have the ability to affect SOM decomposition and subsequently the SHR. Besides, fungi are considered to have higher tolerance to drought conditions than bacteria and can well flourish in non-flooded conditions as compared to that of flooded conditions (Tian et al., 2013). However, it has also been previously reported that fungal biomasses and fungal to bacteria ratio could be enhanced with the increase in water availability in moist arable soils because of high input of recalcitrant carbon through plants (Drenovsky et al., 2004; Williams and Rice, 2007). Therefore, more experimental evidences should be gathered regarding fungal and bacterial community composition of mono-rice paddies in order to understand the response patterns of soil microorganisms in rice mono-cropping systems.

The objectives of the study were to evaluate the relationship between SHR and microbial community composition and biomass during the fallow and flooded rice cropping seasons under changing temperature, moisture regimes and C availability in a rice mono-cropping system and to elucidate the temperature sensitivity of SHR under dry fallow and flooded rice cropping seasons in a rice mono-cropping system. Such observations will be helpful to provide empirical supports to include soil microorganism in ecosystems or soil process models for predicting C-cycling in a rice mono-cropping system in this region.

## 2. Materials and methods

### 2.1. Experimental design, treatments and soil analysis

The experiment was conducted at the Gyeongsang National University experimental station (36°50′N and 128°26′E), in Jinju, South Korea. The region has a temperate climate conditions. The annual mean air temperature and precipitation were 13 °C and 1499 mm, respectively (Fig. 1). The soil texture was silt loam and was classified as typic Haplaquents. The chemical properties of soil were characterized as pH (1: 5 with $H_2O$) 6.5, total organic C (TOC) 14 g $kg^{-1}$, total nitrogen (TN) 1.3 g $kg^{-1}$, and available P 72 mg $kg^{-1}$.

The field experiment comprised of three treatments (Chemical fertilizer (NPK), Barley and Hairy vetch), and a total of 9 plots with three replications were arranged in a fully randomized block design. Each experimental plot has a size of 10 $m^2$. Two different cover crops were cultivated in the organic matter (OM) amendment treatments during the fallow season. For example, barley (*Hordeum vulgare* L) and hairy vetch (*Vicia villosa* L) at the recommended rate of 180 kg $ha^{-1}$ and 90 kg $ha^{-1}$, respectively were sown. In addition, a mineral fertilizer treatment, i.e., NPK treatment was installed in the field for comparison. The mineral fertilizer (NPK) plot was maintained under the same conditions, however no cover crops were cultivated in the NPK plot during the fallow season. Cover crop seeds were broadcasted in the early November 2013, and cultivated without the addition of mineral fertilizer. The aboveground biomasses of cover crops were harvested in the mid-maturity stage of barley in early June of the following year. After harvesting, biomasses were chopped into small pieces (5–10 cm) and were incorporated into the soil at a depth of 0.2 m manually one week before the rice transplanting. The total N biomass applied by the two cover crops were 50 kg N $ha^{-1}$ for barley and 102 kg N $ha^{-1}$ for hairy vetch, while the mineral fertilizer was applied in control treatment at the recommended rate of N-$P_2O_5$-$K_2O$ = 90-45-57 kg $ha^{-1}$ (RDA, 1999). Twenty-one day-old rice (*Dongjinbyeo* cultivar, Japonica) seedlings were transplanted (three plants per hill) by hand with a spacing of 15 cm × 30 cm on June 15th, and harvested on October 20th. The rice field was kept under water submergence (depth of 5–7 cm) throughout the cropping season and drained one month before the rice harvesting (RDA, 1999).

For soil chemical analysis, the soil samples were air-dried, ground and passed through a 2-mm sieve. Total organic C (TOC) and total nitrogen (TN) in soil were measured according to Bremner and Mulvaney (1982) and Yeomans and Bremner (1988), respectively. The available P in soil was extracted with $NaHCO_3$ and determined using the molybdenum blue method (Watanabe and Olsen, 1965). Dissolved organic C (DOC) was extracted by using the hot water extraction method (Kim et al., 2017) and quantified using an elemental analyzer (TOC-VCPN, Shimadzu, Japan). Soil temperature and soil moisture contents were monitored simultaneously by using data logger (EM50 Data logger, Decagon Devices, WA, USA) during the investigation period.

### 2.2. Soil heterotrophic respiration

In order to measure SHR, $CO_2$ fluxes were monitored over the experimental period of a whole year using a closed static chamber method (Chen et al., 2017). Three cylindrical static chambers with an internal diameter of 24 cm and height of 20 cm were permanently installed into the soil surface in each individual plot before broadcasting of the cover crops and left undisturbed throughout the course of the experiment. All of the living plants inside the chambers were removed by hand to exclude the plant respiration. Care has been taken to prevent weed regrowth inside the chambers at each sampling time.

The gas samples were collected once in a week using 50 ml gas-tight syringes at 0 and 30 min intervals after the chambers were closed manually. Gas was sampled three times a day (08:00, 12:00 and 16:00 h) throughput the two cropping periods to obtain the mean respiration rates (Haque et al., 2015; Chen et al., 2017). The collected gas samples were immediately transferred into 20 ml air-evacuated glass vials sealed with a butyl rubber septum for gas analysis. Carbon dioxide concentrations of the collected air sample were measured using a gas chromatograph (Shimadzu, GC-2010, Japan) equipped with a Porapak NQ column (Q 80-100 mesh). Quantification of $CO_2$ was done by using a thermal conductivity detector. The temperatures of the column, injector, detector and methanizer were adjusted at 80, 100, and 110 and 350 °C respectively. Helium was used as the carrier gas. $CO_2$ emission rates were calculated from the increase in gas concentration per unit surface area of the chamber for a specific time interval.

The following equation was used to estimate seasonal $CO_2$ fluxes from each treatment (Matsuura et al., 2011).

$$F = \rho \times (V/A) \times (\Delta c/\Delta t) \times (273/T) \quad (1)$$

where F (mg $m^{-2}$ $hr^{-1}$) is the soil respiration rate, ρ is the gas density of $CO_2$ under a standardized state (mg $cm^{-3}$), V is the volume of the chamber ($m^3$), A is the surface area of the chamber ($m^2$), Δc/Δt is the rate of $CO_2$ increase inside the chamber (mg $m^{-3}$ $hr^{-1}$) and T (absolute temperature) is 273 + mean temperature in °C inside the chamber.

The temperature sensitivity of SHR ($Q_{10}$) was derived from the exponential relationship between SHR and temperature using the