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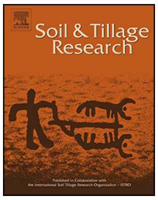

Combining no-tillage, rice straw mulch and nitrogen fertilizer application to increase the soil carbon balance of upland rice field in northern Benin

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ABSTRACT

Agricultural management practices are frequently non conservative and can lead to substantial loss of soil organic carbon and soil fertility, but for many regions in Africa the knowledge is very limited. To study the effect of local agricultural practices on soil organic carbon content and to explore effective ways to increase soil carbon storage, field experiments were conducted on an upland rice soil (Lixisol) in northern Benin in West Africa. The treatments comprised two tillage systems (no-tillage, and manual tillage), two rice straw managements (no rice straw, and rice straw mulch at 3 Mg ha^{-1}) and three nitrogen fertilizer levels (no nitrogen, 60 kg ha^{-1}, 120 kg ha^{-1}). Phosphorus and potassium fertilizers were applied to be non-limiting at 40 kg P_2O_5 ha^{-1} and 40 kg K_2O ha^{-1} per cropping season. Heterotrophic respiration was higher in manual tillage than no-tillage, and higher in mulched than in non-mulched treatments. Under the current management practices (manual tillage, with no residue and no nitrogen fertilization) in upland rice fields in northern Benin, the carbon added as aboveground biomass and root biomass was not enough to compensate for the loss of carbon from organic matter decomposition, rendering the upland rice fields as net sources of atmospheric CO_2. With no-tillage, 3 Mg ha^{-1} of rice straw mulch and 60 kg N ha^{-1}, the soil carbon balance was approximately zero. With no other changes in management practices, an increase in nitrogen level from 60 kg N ha^{-1} to 120 kg N ha^{-1} resulted in a positive soil carbon balance. Considering the high cost of inorganic nitrogen fertilizer and the potential risk of soil and air pollution often associated with intensive fertilizer use, implementation of no-tillage combined with application of 3 Mg ha^{-1} of rice straw mulch and 60 kg N ha^{-1} could be recommended to the smallholder farmers to compensate for the loss of carbon from organic matter decomposition in upland rice fields in northern Benin.

1. Introduction

Concerns about rising atmospheric CO_2 levels have prompted considerable interest in recent years regarding the potential of soil organic carbon (SOC) as sink for atmospheric CO_2 (Baker et al., 2007). Soil organic carbon is the largest terrestrial carbon pool, containing approximately twice as much carbon as the atmospheric CO_2 pool (Paustian et al., 1997). Because of the important role of SOC in terrestrial ecosystems and its large stock, minor changes in SOC as a result of perturbations, such as changes in land use or climate (Houghton et al., 1999), may influence both

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long-term ecosystem functions and the global atmospheric carbon budget (Mu et al., 2008).

Cropland soils contain approximately 170 Pg C, slightly more than 10% the total SOC pool (Paustian et al., 1997). Decomposition of SOC in cultivated soils has contributed to the emission of approximately 50 Pg C to the atmosphere (Paustian et al., 2000). SOC also helps maintaining soil fertility for sustainable crop production (Nishimura et al., 2008). Some activities, including agricultural practices, are proposed by the Kyoto Protocol, an international agreement for reducing CO_2 emission by 5.2% compared to the 1990 emission level, for slowing down the rise of atmospheric carbon dioxide (Lu et al., 2009). The French Government has proposed to the Conference of Parties (COP)21 of the United Nations Framework Convention on Climate Change (UNFCCC) in December 2015 that SOC concentration be increased globally at 0.4% per year to offset atmospheric CO_2 increases and advance food security (Lal et al., 2015). Therefore, an increasing attention is paid to carbon sequestration in agricultural soils.

In Benin, rainfed upland rice ecosystems account for about 27% of the total rice area (Diagne et al., 2013). Rice is typically grown under intensive tillage in slash-and-burn systems, and farmers have relied on extended fallow periods to restore soil fertility. However, rapid population growth and increased demand for land have led to shortened fallow periods, which in turn have resulted in declining soil organic carbon and rice yield (Saito et al., 2010).

A previous study has suggested that introducing no-tillage management may reduce the emission of CO_2 from upland rice soils in Benin (Dossou-Yovo et al., 2016). This was attributed to a reduction of tillage effects that generally increase soil carbon losses by increasing the availability and oxidation of SOC shortly after tillage (Al-Kaisi and Yin, 2005), and destruction of aggregates that physically protect SOC from microbial activities (Six et al., 2000). It has also been suggested that increases in nitrogen fertilization levels may promote soil carbon sequestration due to increases in aboveground biomass and especially root biomass, which can contribute to more stable SOC than aboveground residues (Rasse et al., 2005). However, potential increases in carbon input from increases in nitrogen fertilization level could be counter balanced by increases in carbon mineralization and CO_2 emissions (Zhou et al., 2014). Application of plant residues as mulch, instead of burning, has beneficial effects for replenishing soil organic carbon (Al-Kaisi and Yin, 2005), and the return to the soil of 1 Mg ha^{-1} of straw (rice, wheat or maize) each year can sequester about 130 kg C ha^{-1} yr^{-1} (Lu et al., 2009). Although it is clear that management practices can significantly affect soil carbon storage through carbon inputs and losses, the detection of SOC changes is often difficult due to the small magnitude of changes relative to the total stock, except in long-term studies (Conen et al., 2003). The calculation of the soil carbon balance from carbon inputs (aboveground residues, root biomass, management-related input of carbon) minus carbon outputs (carbon loss via heterotrophic respiration (R_h)) provides valuable insights into the processes contributing to changes in SOC on a finer temporal scale (Duiker and Lal, 2000).

The primary way of quantifying carbon loss from soils is by measuring soil CO_2 emission (Mu et al., 2008). Most of the soil CO_2 emission is a product of decomposition of plant litter and soil organic matter via heterotrophic respiration (R_h) and from root respiration (R_r) (Raich and Mora, 2005; Rochette et al., 1999). These two components can have different responses to soil moisture and temperature which can stimulate or reduce R_h and R_r and also slow down oxygen diffusion and the release of CO_2 (Guzman and Al-Kaisi, 2014). Thus, the contributions of these components need to be understood in order to quantify carbon losses from soil.

Information on potential changes in soil organic carbon due to management practices is vital for Benin in order to suggest sustainable farming strategies (i.e. associated with no net loss or even an increase of soil carbon) to the upland rice farmers. The objectives of this study were to (1) assess the effects of tillage systems, rice straw mulching and nitrogen application on soil moisture and soil temperature, (2) evaluate the effects of these farming management practices on soil CO_2 fluxes, R_h and R_r, and (3) calculate the soil carbon balance to suggest combination of factors to reduce net loss of carbon.

2. Material and methods

2.1. Experimental site

The study was conducted from June 2014 to May 2015 on an upland rice soil in the Tetonga catchment in northern Benin. The catchment is located between 1°01′ E and 1°14′ E, and 10°42′ N and 10°57′ N, and belongs to the Sudanian Savannah agro-ecological zone in West Africa. The climate is semi-arid with one rainy season (May-October) and one dry season (November–April) (Fig. 1).The mean annual air temperature, rainfall and potential evapotranspiration are 27 °C, 1177 mm and 1484 mm, respectively (data from 1985 to 2014). According to FAO soil taxonomy, the soil of the experimental site was a Lixisol (Youssouf and Lawani, 2000). Soil samples (0–20 cm soil layer) were collected before the onset of the experiment for particle size distribution, pH, SOC content, total nitrogen, extractable phosphorus and extractable potassium. The particle size distribution was determined based on the hydrometer method (Bouyoucos, 1951). The soil pH was determined using a soil-to-water ratio of 1–2.5. The soil organic carbon content was determined by chromic acid digestion, and the total nitrogen by

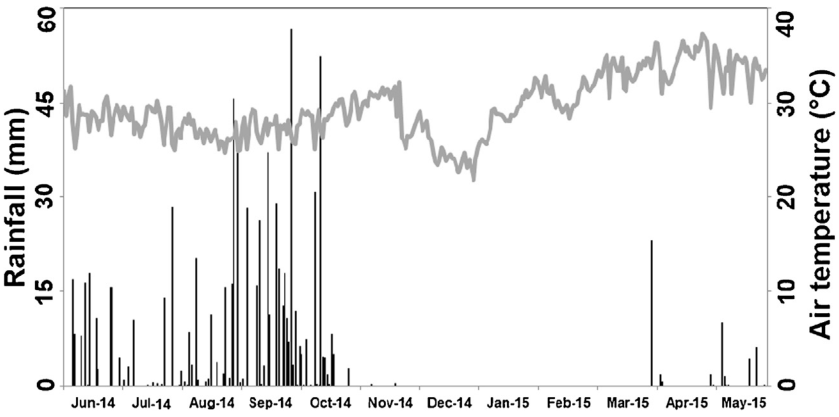

Fig. 1. Seasonal evolution of daily rainfall (dark vertical bars) and daily average air temperature (grey continuous line) from 01 June 2014*31 May 2015.