Research article

Biofunctool® Approach Assessing Soil Quality under Conservation Agriculture and Conventional Tillage for Rain-fed Lowland Rice Systems in Cambodia

VENG SAR*
Provincial Department of Agriculture, Forestry and Fisheries, Pailin province, Cambodia
Conservation Agriculture Service Center, Department of Agricultural Land Resources Management, General Directorate of Agriculture, Cambodia
Faculty of Agriculture, Kasetsart University, Bangkok, Thailand
Email: sarveng@hotmail.com

KANNIKA SAJJAPHAN
Department of Soil Science and Center for Advanced Studies in Agriculture and Food, Kasetsart University, Bangkok, Thailand

WUTTHIDA RATTANAPICHAI
Department of Soil Science and Center for Advanced Studies in Agriculture and Food, Kasetsart University, Bangkok, Thailand

ALEXIS THOUMAZEAU
CIRAD, Systèmes de pérennes, University of Montpellier, Montpellier, France

VANG SENG
Department of Agricultural Land Resources Management, General Directorate of Agriculture, Phnom Penh, Cambodia

FLORENT TIVET
CIRAD, AIDA, University of Montpellier, Montpellier, France

Received 30 December 2020 Accepted 30 June 2021 (*Corresponding Author)

Abstract Rice productivity is often limited by soil fertility depletion, water availability and access. Conservation Agriculture (CA) cropping systems have been designed and tested with the main objectives of restoring soil fertility, increasing productivity and profitability. This study assessed changes in soil health under rain-fed lowland rice under (i) conventional tillage (CT), (ii) CA (CA7: 7 years under CA) and (iii) green manure management for one year (CGM1) and for two years CGM2). Biofunctool®, a multi-functional soil assessment approach based on a set of seven soil indicators, was used to evaluate changes in three main soil functions (C transformation, nutrient cycling, and soil structure). In addition, soil chemical analyses were conducted in the 0-5, 5-10, 10-20 and 20-40 cm soil layers to assess changes in nutrient contents. Our results emphasized positive impacts of CA on C transformation, soil structure and nutrient contents. Soil organic carbon and total N were significantly higher ($p < 0.05$) under CA7 in the 0-5 cm layer with up to +7.5 g C kg^{-1} and +0.74 g N kg^{-1}, respectively. Higher values of labile C and soil respiration ($p < 0.05$) were observed under CA in the 0-5 and 5-10 cm layers. More stable soil aggregates and improved VESS values ($p < 0.05$) were also observed under CA. CA and CGM had 2 to 3 times more available phosphorus than CT in the 0-5 cm layer, and higher values were observed under CA from a depth of 0-20 cm. Higher Ca, Mg and K contents were recorded under CA and CGM in the 0 to 40-cm soil layer. A SOC stabilization trend was observed in soils under CA (0-5 and 5-10 cm layers) while a SOC mineralization trend was observed under CT and CGM. These results emphasize the positive impacts of CA on maintaining and/or enhancing soil health and in contributing to SOC accumulation. A diachronic analysis is now needed to assess the long-term on-farm impacts of CA on soil health and crop performances.

Keywords soil organic carbon dynamic, sustainable intensification, climate change adaptation

INTRODUCTION

Cambodia produced over eight million tons of paddy for a total cultivated area of ~ 3.3 million ha (MAFF, 2018). Rice exports jumped from 100,000 tons in 2010 to ~ 540,000 tons in 2016. Based on topographic position, rice agroecosystems range from upland rice, rainfed lowland or upper sandy terraces, flooded rice in the plains, receding rice, and deep-water rice. Soil fertility across the rice agroecosystems ranges from medium to low (Biswas *et al.*, 2017). Yields are often limited by low levels of soil nutrients, fluctuating water levels in the paddy field and related impacts on the form and availability of nutrients in the soil (Pheav *et al.*, 2005). Despite the increase in rice yields over the last two decades, rice yield and profitability of farming systems around the Tonle Sap lake are still low. In addition, increasing use of chemical fertilizers and pesticides are recorded both in flooded and irrigated conditions raising concerns about environmental and health issues, and food safety. The low level of diversification, the increasing use of pesticides (Flor et al., 2018) and the combination of practices that deplete soil fertility (i.e., continuous ploughing, use of rotary tillers, low inputs of organic compounds, burning or removal of crop residue to feed cattle) call for the design and assessment of alternative rice-based cropping systems. There is an urgent need to promote diversified rice cropping systems to maintain and improve soil quality, increase farmers' incomes while simultaneously contributing to safer food production. Several studies have demonstrated the positive impacts of diversified conservation agriculture (CA) cropping systems which promote the accumulation of soil organic carbon (SOC) and improve soil fertility (Boddey *et al.*, 2010). Conservation agriculture (CA) is based on three technical principles with (i) minimum soil disturbance (i.e., no tillage), (ii) a permanent soil cover, and (iii) diversified cropping systems (FAO, 2014). Diversified CA cropping systems with high biomass-C inputs (Séguy et al., 2006) insure a continuous supply of fresh organic compounds, thereby improving soil aggregation (Tivet et al., 2013), increasing soil biodiversity (Lienhard *et al.*, 2013), and SOC content (de Moraes Sá et al., 2015) while enhancing production and ecosystem services (Pittelkow et al., 2015). Multifunctional soil assessments are needed to better understand the relationships between cropping system management and soil health. Thoumazeau et al. (2019 a, b) proposed an integrative, multifunctional approach, named Biofunctool®, that makes it possible to assess three main soil functions (i) carbon transformation, (ii) nutrient cycling, and (iii) soil structure, with a core set of in-field and low-tech indicators. Three indicators were used to assess the changes of the carbon transformation including the labile soil organic C fraction (permanganate oxidizable carbon: POXC) (Weil et al., 2003), the basal soil respiration (SituResp®) (Thoumazeau et al., 2017), and the soil biological activity using the bait lamina test (van Gestel et al., 2003). Then, three indicators were used for the soil structure maintenance function by assessing soil aggregate water stability (AggSoil) at 0-5 and 5-10 cm depths (Herrick et al., 2001), water infiltration (Beerkan) (Thoumazeau et al., 2019b), and visual evaluation of soil structure (VESS) at 0-30 cm depth (Guimarães et al., 2011). Finally, the nutrient cycling function was assessed by quantifying available N, P, Ca, Mg and K.

OBJECTIVE

We hypothesised that rice-based CA cropping systems have direct and positive effects on soil health, increase the main soil functions through C transformation, soil structure and nutrient contents. The overall objective of the study was to conduct an integrative and quantified assessment of the relationships between contrasted rice cropping systems (i.e., conventional plough-based tillage (CT), CA and green manure management) and soil health on the flood plains of Lake Tonle Sap using the Biofunctool® approach.

METHODOLOGY

Study site:

In 2011, an on-farm experimental design was implemented in the hydromorphic plains in Kropeur Kert village, Banan district, Battambang province (latitude 13°00′32.37″ N, longitude 103°04′27.31″E, 18 m elevation, no slope). The soil in the 0-20 cm layer comprised 511 g kg^{-1} clay, 339 g kg^{-1} silt, 150 g kg^{-1} sand and 5.19 pH (H_2O). The soil is classified as a Vertisol by the FAO and as clayey soil according to the USDA soil classification. Mean annual precipitation was 1,306 mm and the mean temperature was 27.5 °C.

Cropping systems:

Soil functions and soil physical-chemical characteristics were assessed for four main cropping systems (CA7, CGM1, CGM2 and CT). It should be noted that the on-farm assessment was based on an unequal number of fields under the same management, with two fields under CA management for 7 years (CA7), two fields under green manure management for one year (CGM1), three fields under green manure management for two years (CGM2), and seven fields under conventional plough-based management (CT). CA was based on no-tillage with a cover crop following wet season rice. Two main species were used, *Stylosanthes guianensis* (cv. Ubon Nina) and *Centrosema pascuorum* (cv. Cavalcade). Green manure management comprised ploughing the cover crop biomass into the soil a few weeks before rice was sown. Conventional tillage (CT) included ploughing (6-disc plough) and harrowing, and the residues of the previous crop were incorporated into the soil by ploughing or rotary tiller.

Soil quality assessment:

According to the integrative view of the soil quality, the indicators used to assess changes in soil quality should be the result of soil biota-physical-chemical property interactions (Thoumazeau et al., 2019). The Biofunctool® approach was chosen to provide this integrative view and to describe the impacts of contrasted practices on soil quality. This approach is based on three main soil functions (i) soil carbon transformation, (ii) nutrient cycling and (iii) soil structure.

Soil sampling and soil physical-chemical analysis:

Soil samples were collected on January 25th, 2018 in four soil layers (0-5, 5-10, 10-20, and 20-40 cm) with three replicates per field. The Biofunctool® approach was applied to the 0-5 and 5-10 cm layers. In addition, the same two soil layers (0-5 and 5-10 cm) were sampled per subplot to assess water-stable aggregates. Total C and N concentrations were analysed using a dry combustion method with an elemental CHN analyser (Wright et al., 2008), available P (Bray II method) (Bray and Kurtz, 1945), and available K, Ca, Mg (AAS method) (Pyle et al., 1995). Available N was quantified on samples sieved at 2-mm using the Kjeldahl method (Craft et al., 1991).

Data analysis:

Statistical analysis was performed using R software (Dessau and Pipper, 2008). Each Biofunctool® indicator was first studied separately using a linear-mixed effects model (lme4 package, (Bates et al., 2015). Treatment was defined as the fixed factor and replicates (plots and inner-replicates) as random factors. After checking the normality of the model residuals and the homoscedasticity of residual variance, ANOVAs were run using the car package (Fox and Weisberg, 2013). This was followed by post-hoc mean comparisons, using the Shapiro-Wilk test with Bonferroni adjustment (Hothorn et al.,