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The Stratification of Organic Carbon and Nitrogen in Top Soils as Affected by the Management of Organic and Conventional Rice Cultivation

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Abstract

Organic and conventional management in rice cultivation have an impact on the nature of soil and the sustainability of agricultural system. This study aimed to determine the stratification of organic carbon and nitrogen in top soil from organic and conventional rice management. Top soil samples from organic and conventional rice management were taken before planting rice to find out the parameters of several soil characteristics. After rice was planted, top soil samples were taken at the depths of 0-4, 4-8, 8-12, 12-16, 16-20, 20-24 and 24-28 cm from organic and conventional rice fields, to determine the total organic carbon, total nitrogen and nitrate. The results show that organic rice management will provide better soil properties. Stratification of organic carbon and nitrogen was found in top soil from organic and conventional rice fields. Organic rice field appeared to have organic carbon content that was significantly higher than that of conventional rice field, and it is concentrated on top soil surface. The total nitrogen content in layers 0-4 cm and 4-8 cm in organic rice field was considerably higher than in conventional, but the content was different in layers 8-24 cm. Nitrate content was significantly different in top soil 12-16, 16-20 and 20-24 cm, significantly in top soil 8-12 cm, with nitrate in top soil of conventional rice field higher than in organic rice field. However, it was not significant in 0-4 cm and 4-8 cm top soils. This condition was influenced by organic and synthetic chemical fertilization, nitrification, denitrification and leaching.

Keywords: organic carbon; nitrogen; rice field; top soil layer

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INTRODUCTION

Rice agricultural intensification increases food production, but decreases the quality of soil, water and biodiversity resources (Pimentel et al., 1995). Organic farming, using manure, compost, crop rotation, without synthetic fertilizers and pesticides, is an alternative to maintain soil fertility and crop production. Organic farming is distinguished in terms of quality (Gąstoł et al., 2011) and higher carbon content (Anshori et al., 2019). Organic farming systems are being explored to improve soil health, agricultural sustainability and environmental quality (Poudel et al., 2002).

Organic farmers tend to apply large amounts of organic fertilizers, so that this prevents environmental degradation such as nitrate pollution (Maeda et al., 2003). Soil organic carbon is associated with better soil quality (Franzluebbers, 2002; Lal, 2004), increases crop productivity (Nusantara et al., 2014), upsurges soil organic carbon stocks (Anshori et al., 2018),

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significantly promotes sustainable production (Manna et al., 2005) and plays a role in the sustainability of agricultural system (Magdoff and Es, 2009).

Soil organic matter is a major concern in agricultural system. This includes soil biota, plant residues and microorganisms and derived organic products, which are important for soil fertility and ecosystems (Dikgwatlhe et al., 2014). Agricultural management influences soil organic matter (Lal, 2000; Xu et al., 2013). Decomposition of organic matter results in a balance of soil organic matter contents (Korschens et al., 1998).

Soil organic matter pools are created by processing and restoring crop residues (Hou et al., 2012), such rice straw, green manure and farm yard manure to improve soil productivity (Bhatia et al., 2005; Ramesh et al., 2009). The organic matter content varies according to the input of crop residues (Franzluebbers et al., 1998). Organic matter is also a source of nutrients (Bhandari et al., 2002; Magdoff and Es, 2009), including nitrogen (Tarkalson et al., 2009). Carbon and nitrogen are important for the condition of agricultural system (Gao et al., 2007), also C/N is important for plant growth (Yang et al., 2011).

The incorporation of organic residues into the soil increases biological activity (Ghosh et al., 2012) and organic carbon (Yagioka et al., 2014) plays a role in soil conservation, compaction and future soil fertility (Wienhold et al., 2013). Organic residue is utilized by soil microorganism and fauna as a source of nutrient and energy for better soil quality (House and Parmelee, 1985; Rasse et al., 2005).

Soil tillage plays a role in the accumulation of soil organic matter (Rasmussen and Collins, 1991; Pendell et al., 2007; Mishra et al., 2009), as well as impacts on the physical and chemical properties of soil (Bai et al., 2009). Conventional tillage increases soil erosion and degradation processes, causes losses in soil organic matter content and promotes the deterioration of the soil quality (Six et al., 1999). The organic matter content varies according to the cultivation system (Burke et al., 1989) and the cropping intensity (Franzluebbers et al., 1998) and includes in the rice cropping (Xu et al., 2013). The content of soil organic matter is different in rice and upland crops (Nishimura et al., 2008).

Depletion of soil organic carbon is a major process of soil degradation (van Noordwijk et al., 1997) and is largely related to the balance of carbon inputs and outputs. Organic matter may be managed as organic inputs (Nandwa, 2001). The quality and quantity of organic inputs affect the storage of organic matter and soil structure (Droogers and Bouma, 1997). Soil organic matter binds soil particles to form soil aggregates. Stable aggregates provide soil protection (Gupta and Germida, 1988).

Stratification of soil organic carbon at different depths occurring in various ecosystems is function of management practices (Franzluebbers, 2002; Dikgwatlhe et al., 2014; Zhang et al., 2016). The concentration of soil organic matter decreases in depth, and is influenced by tillage (Dikgwatlhe et al., 2014) and planting intensity (Lal, 2000). Soil organic matter decreases exponentially to a depth of 100 cm, 30-40% stored below a depth of 30 cm (Pan et al., 2008). However, the calculation of data on soil organic matter content usually reaches a depth of 20 cm to 30 cm (Schwager and Mikhailova, 2002).

Stratification of soil organic carbon and nitrogen at soil depth is caused by agricultural management practices (Álvarez et al., 2011; Zhao et al., 2015; García et al., 2016). Differences of total nitrogen in the soil depth can be influenced by several things, such as the provision of plant residues (Zhao et al., 2015), land use change (García et al., 2016) and soil tillage (Álvarez et al., 2011).

The content of soil organic matter and nitrogen is determined by the input of crop residues, cropping intensity and cultivation systems. This study aimed to determine the stratification of organic carbon and nitrogen in top soil from organic and conventional rice management.

MATERIALS AND METHOD

This research was conducted in Jayan Kebonagung Village, Imogiri Sub-district, Bantul Regency, Special Region of Yogyakarta, Indonesia, on the organic and the conventional rice fields, with three replications. The organic and conventional rice field are located at 7°56'01.22"N, 110°22'18.87"E and 7°55'57.08"N, 110°22'17.07"E, respectively. The altitude is 60 meters above the sea level. The soil type in this location is classified as Inceptisols. The dose of organic fertilizer in organic rice fields was 10 tons ha^{-1} $season^{-1}$ and rice stubble was incorporated in the top soil. Organic fertilizer was applied three times (before transplanting day, 15 and 30 days after transplanting). The rates of synthetic chemical fertilizers in conventional rice fields were 300 kg ha^{-1} $season^{-1}$ of phonska (NPK 15:15:15) and 150 kg ha^{-1} $season^{-1}$ of urea (46% N).

Before rice transplanting was carried out, samples of top soil were taken from organic and conventional rice fields. Soil samples were analyzed for pH (Eviati and Sulaeman, 2009), texture (Agus et al., 2006a), particle density (Agus and Marwanto, 2006), bulk density (Agus et al., 2006b) and permeability (Dariah et al., 2006).

After rice transplanting, samples of top soil were taken at the depths of 0-4, 4-8, 8-12, 12-16, 16-20, 20-24 and 24-28 cm from the organic and conventional rice fields. Soil samples were analyzed for the organic carbon, total nitrogen and nitrate (Eviati and Sulaeman, 2009) to find out the organic carbon and soil nitrogen stratification.

Data were examined statistically. The difference level of organic carbon, total nitrogen and nitrate between organic and conventional rice fields in each layer was determined using the T-test.

RESULTS AND DISCUSSION

Rice cultivation

Organic fertilizer is a source of nutrients for organic agriculture, while conventional agriculture relies on synthetic chemical fertilizers. In research area, the sources of organic fertilizer include compost, weeds and other plants, agricultural waste, agricultural processing waste and non-agricultural organic waste (Anshori et al., 2016). Urea and phonska were used as synthetic chemical fertilizers. The management of organic material and fertilizer can be seen in Table 1.

Table 1. Fertilizers in organic and conventional rice fields

Fertilizer	Management of rice fields	
	Organic	Conventional
Organic		
Rice stubble	Yes	Yes
Organic fertilizer	Yes	No
Chemical synthetic		
Urea	No	Yes
Phonska	No	Yes

The control of plant pests in organic rice fields utilized organic materials with the concept of environmental friendly control. Plant pests control in conventional rice fields applied synthetic chemicals. Tillage (hand tractor), planting (2:1 in row) and irrigation with about 2 cm flooded soil were applied in organic and conventional rice fields.

Characteristics of top soil

Organic carbon plays a role in soil properties (Sutanto, 2005; Hanafiah, 2012). Soil pH, particle density, bulk density, porosity and permeability in top soils are influenced by rice management. The soil properties of organic and conventional rice management are served on Table 2.

Table 2. Top soil properties from organic and conventional rice fields

Soil properties	Organic rice field	Conventional rice field
Texture	Loam	Loam
Total organic carbon (%)	2.27	1.16
pH	6.26	6.34
Particle density (g cm^{-3})	1.72	1.85
Bulk density (g cm^{-3})	1.16	1.26
Porosity (%)	32.56	31.89
Permeability (cm hr^{-1})	4.31	3.08

Total organic carbon, porosity and permeability in organic rice field were higher than those in conventional rice field, in contrast to particle density and bulk density. This shows that organic rice management leads to better soil properties.

Stratification of organic carbon

The organic carbon profiles in top soil from organic and conventional rice management during the study are presented in Figure 1. The distribution of organic carbon in top soils varied, influenced by organic fertilization.

The organic and conventional rice management causes a difference in organic carbon content in top soil layers. In all top soil layers, the organic carbon contents of organic and conventional rice fields were significantly different, 0-4 cm layer ($P<0.001$, n=3), 4-8 cm layer ($P<0.001$, n=3), 8-12 cm layer ($P<0.001$, n=3), 12-16 cm layer ($P<0.001$, n=3), 16-20 cm layer ($P<0.001$, n=3) and 20-24 cm layer ($P<0.005$, n=3). The organic carbon at all depths of top soil of organic rice field were significantly higher than the contents in conventional rice field, because of the application of organic fertilizer in organic rice management and synthetic chemical fertilizers in conventional rice management. Stratification of soil organic carbon content was also found by Franzluebbers (2002); Pan et al. (2008); Zhang et al. (2016); Mujiyo et al. (2017) and Anshori et al. (2018). Provision of organic fertilizer and plant residues, which are decomposed, produce soil organic carbon residues, causing stratification of organic carbon.

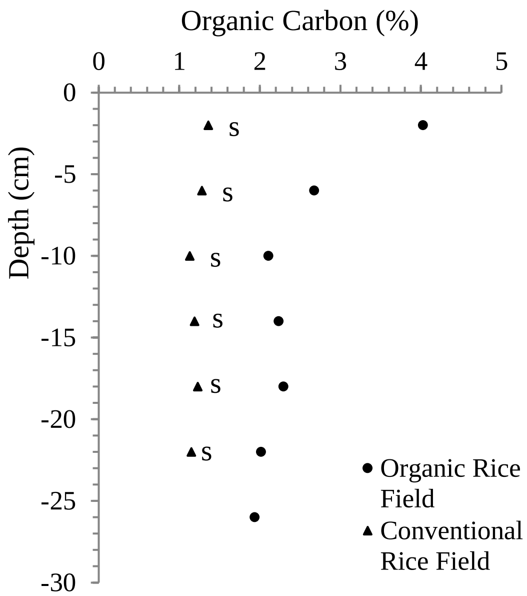

Figure 1. Stratification of organic carbon in top soil of organic and conventional rice fields

Note: The s notations show the significance of soil organic carbon contents in top soil layer of organic and conventional rice fields

The organic carbon contents in conventional rice field were relatively uniform in all layers because of the small input and high intensity of tillage. In organic rice field, the organic carbon contents were high in 0-4 cm and 4-8 cm layers because of high organic material input. The application of organic fertilizer using the spread method caused the concentration of organic carbon in top layer soil. Translocation process of organic carbon to the deeper layers was slow and the lack of incorporation into the deeper layer lowered the concentration in the deeper layer. In the depth of 16-20 cm, the soil organic carbon content tended to be high and this might be caused by high density of microorganisms in plant roots, as Mueller et al. (1992). The quantity and/or quality of soil organic matter and its fractions regulate microbial community composition and associated function (Murphy et al., 2011). The results of research by Hou et al. (2012) and Anshori et al. (2018) have shown that the soil organic carbon increased more rapidly in the upper soil layers.

Stratification of nitrogen

Total nitrogen content was high in soil 0-4 cm layer. The content in organic rice field was higher because the nitrogen was sourced from organic fertilizer. At the 8-24 cm depth layer, the total nitrogen content was small, as presented in Figure 2. Total nitrogen was concentrated in the upper layer soil allegedly due to the application of organic fertilizer by the spread method, slow translocation process of organic fertilizer and the lack of top soil incorporation. A similar condition was found by Hou et al. (2012) that in the surface soil layers, at 0-5 cm, total nitrogen increases more rapidly.

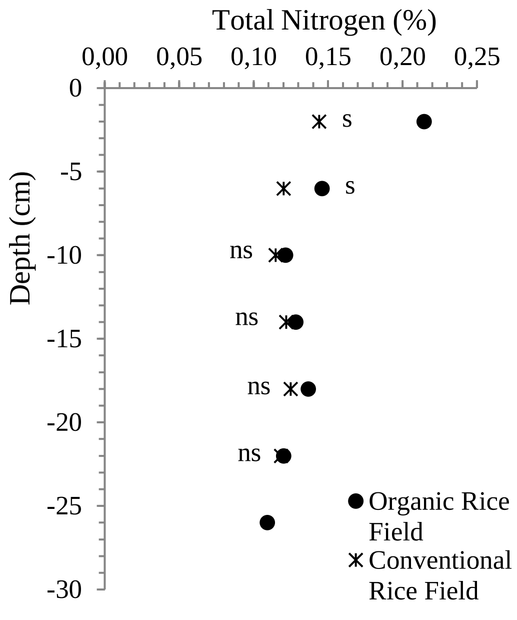

Figure 2. Stratification of total nitrogen in top soil in organic and conventional rice fields

Note: The s notations show the significance, while ns do not show the significance of total nitrogen in top soil layer of organic and conventional rice fields

In 0-4 cm and 4-8 cm layer, there were significantly difference in total nitrogen between organic and conventional rice fields, with 0-4 cm layer ($P<0.01$, n=3) and 4-8 cm layer ($P<0.01$, n=3). However, it were not significant on top soils 8-12, 12-16, 16-20 and 20-24 cm layer. Average total nitrogen in organic rice field was higher than conventional, because the spread of organic fertilizer in organic rice management.

The nitrate content showed the opposite condition (Figure 3). The deeper layer has higher nitrate content. Nitrate stratification in the soil layer was also found by Randall (1990), in line with this results. According to Singh et al. (1995) some of residual nitrogen was leached into the deeper layer. Nitrate leaching is the main route of nitrogen loss (Zhou et al., 2012), so nitrates accumulate in the deeper soil layers.

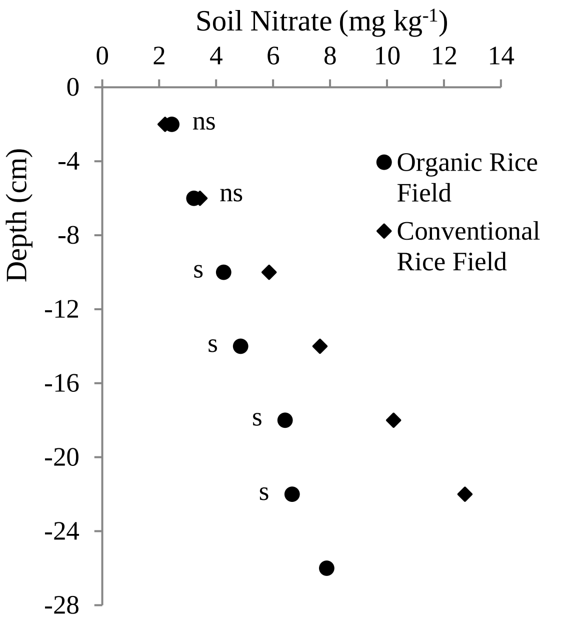

Figure 3. Stratification of soil nitrate in top soil from organic and conventional rice field

Note: The s notations show the significance, while ns do not show the significance of nitrate in top soil layer of organic and conventional rice fields

Nitrate contents were significantly different in 12-16 cm layer ($P<0.01$, n=3), 16-20 cm layer ($P<0.01$, n=3) and 20-24 cm layer ($P<0.01$, n=3), as well as significantly different in top soil 8-12 cm layer, with nitrates in top soil of conventional rice field higher than that in organic rice field. However, the contents were insignificant in both 0-4 cm and 4-8 cm layers. Nitrate are commonly leached and concentrated in the deeper layer of soil. Nitrates in conventional rice field were higher than those in organic rice field. This condition was due to the addition of synthetic chemical fertilizers to complement soil nitrate through nitrification reactions. This is line with Cooke et al. (1957) that the concentration of soil nitrate increases with the addition of fertilizer and nitrification reactions. Rice plants absorb N-urea of 20-40%, the rest undergo evaporation, denitrification and leaching (Singh et al., 1995). NPK fertilizer application increases nitrate concentration in the soil (Sunarminto et al., 2014). Nitrogen evaporation was not observed in this research. Furthermore, chemical synthetic fertilizer of nitrogen, organic fertilizer, nitrification, denitrification and leaching affects the nitrate content in the top soil layer and nitrate stratification occurs.

CONCLUSIONS

Management of both organic and conventional rice fields influences the stratification of organic carbon and nitrogen in the top soil layer. Organic rice field appeared to have higher total organic carbon and nitrogen contents than conventional rice field, and those substances were concentrated on the top soil surface. Nitrate content, on the other hand, was higher in conventional rice field than in organic rice field and was concentrated in the deeper layers.

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