Research article

Impact of No-tillage on Rice Yield and Some Soil Properties in Tropical Flooded Transplanting Lowland Rice Cultivation

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Abstract Flooded transplanting rice with full tillage is a traditional rice production technique in Thailand. However, the intensity of soil tillage increased operation costs and affected soil fertility especially on soil organic carbon (SOC). No-till is widely used as a system to improve soil properties and reduce operation costs. However, the effectiveness of no-till to flooded transplanting rice needs further investigation. The aim of this study was to determine the effectiveness of rice yield response and the change of soil properties under flooded transplanting rice conditions after using a no-tillage system. A field experiment was conducted over three years on Typic Plinthaquults (Phen series) with 4 treatments including conventional tillage (CT), conventional tillage with green manure incorporation (CTG), no-till (NT) and no-till with green manure application (NTG). NT and NTG treatments showed a significant increase in SOC, soil total nitrogen, Bray II P and exchangeable K compared with CT. Under flooded transplanting rice, no-till had a negative effect on rice yield in the first 2 years. However, the NT yield significantly increased in the third crop and was comparable to the CT yield. Adequate application of green manure to no-till could improve yield reduction at early year of no-till adoption. The results in this paper reveal that no-till is more effective to use in a flooded transplanting rice system which improves soil properties and rice yield.

Keywords no-tillage, rice, soil organic carbon, soil properties, yield

INTRODUCTION

Rice is the principal food of more than half of the global population. The global estimated production area is 161 million ha with a production of 716 million metric tons of paddy rice in 2016, nearly all (87%) produced in Asia (IRRI, 2017). More than 90% of the global rice production is harvested from lowland paddy fields (Tuong and Bouman, 2003). In Thailand, where the world's largest rice exporter had a total area of 11.7 Mha of rice production, most of farmers use a paddy rice cropping system (Office of Agricultural Economics, 2015). Flooded transplanting rice is a traditional practice in Thailand rice production, especially in a rainfed area, and similarly in other rice production countries in South and Southeast Asia (Liese et al., 2014).

In general, the rice establishment in Asia with a lowland ecosystem and flooded transplanting rice involves hand transplanting followed by full tillage that consists of primary and secondary tillage and soil puddling. Soil tillage and puddling are mainly completed for weed control, easy transplanting and decreased water percolation which results in retained standing water in rice fields

(Rodrigues and Lal, 1985; Singh and Kaur, 2012). However, these techniques do increase the water requirement during land preparation, labor and energy consumption. The rice fields are continuously flooded during the period of crop growth until final drainage occurs around 7-10 days before harvest (Tuong and Bouman, 2003). Continuous flooding is a benefit for weed control, to make water management easier and to ensure that an adequate amount of water maintained during crop growth in an unstable rainfed area. However, regular tillage accelerates mineralization of soil organic matter (SOM) by increasing the contact of crop residues with soil, and thus consequently declining the SOM and deteriorating the soil quality (Wall, 2007). In general, soil quality is largely defined by the status of SOM; there are many confirmed reports of a decline in SOM in conventional tillage soil compared to no-tillage soil (Madari et al., 2005; Ogle et al., 2005). A decline in SOM leads to reduced soil fertility because SOM is an important source of plant nutrients. Sahrawat (2004) reported that 50-75% of nitrogen in paddy rice crops comes from organic matter.

SOM also greatly influences the biological, physical and chemical properties of soil. Johansen et al. (2012) concluded that a decline in SOM results in reduced soil particle aggregation, soil aeration, soil water holding capacity and an increase in the soil bulk density. Besides a decline in soil fertility, an increase in the production cost is another concern in rice production. The production cost of transplanting rice increased by 50-200% in developing countries in Asia from 1990 to 2010 (Liese et al., 2014; Papademetriou et al., 2000). In Thailand, the growth rate of rice production costs steadily increased by about 19% since 2001 until it increased to 54% in 2008 while increased from 73 US$ per Mt in 2001 to 201 US$ per Mt in 2008 (Poramacom, 2014). This increase in the cost of rice production was due to an increase in the input prices including fuel, fertilizers, wages of labor and land preparation cost. Traditional land preparation including full tillage and soil puddling accounted for 10-15% of the total production cost (Poramacom, 2014).

No-tillage in the context of conservation agriculture is widely adopted; data reported in 2010 indicated that the adoption area of no-tillage is over 115 Mha. More than 96% of the total no-tillage area is in North and South America and Australia, while less than 3% is found in Asia (Derpsch et al., 2010). The advantages of conservation tillage over conventional tillage includes reduced cultivation costs, increased SOM, an improvement to the physical and chemical properties of soil and an improvement to soil microbial ecology (Hobbs et al., 2008; Mathew et al., 2012). For rice production, many reports have shown the improvement to soil and economic benefits of no-tillage in a rice-wheat system, but less information has been presented on tropical flooded transplanting rice ecosystem. Moreover, the effectiveness of no-tillage on crop and soil properties evolves over time. Yield reduction after no-tillage adoption found in several cases due to an imbalance between mineralization and immobilization of SOM (Pittelkow et al., 2015; Soratto et al., 2014). Therefore, the duration of transitional period should be determined for design fertilizer recommendation before no-tillage adoption. The present study has the following objectives: 1) to determine the effectiveness of no-tillage on flooded transplanting rice in a tropical environment; and 2) to determine rice yield response and the change in soil properties under no-tillage conditions.

METHODOLOGY

Experimental Description

Experiments were conducted during three growing seasons (2010-2012) in the Sakon Nakhon province of Thailand, in a tropical savannah climate (17_08°N, 104_04°E). According to weather data collected from the Kasetsart University Chalermphrakiat Sakonnakhon Province Campus weather station from 2010 to 2012, the annual precipitation was between 1,350 and 2,014 mm, and most of the rainfall was between May and October (Fig. 1). The soil was a Typic Plinthaquults **(**Phen series**)**, being loamy-skeletal in texture. At the beginning, soil contained 3.60 g kg^{-1} of soil organic carbon (SOC), 430 mg kg^{-1} total nitrogen, 0.92 mg kg^{-1} Bray II P and 47.97 mg kg^{-1} exchangeable K.

The field experiments were arranged in randomized complete block design with 4 replications consisting of 4 treatments: (1) conventional tillage (CT), included disc ploughing followed by secondary tillage and puddling; (2) conventional tillage with green manure incorporation (CTG), green manure was applied before primary tillage; (3) no tillage (NT) and (4) no tillage with green manure application (NTG). Green manure (*Crotalaria juncea*) was grown ex-situ outside of the experimental plot. After Crotalaria flowering, the above ground biomass was harvested and applied to the plot by treatment at a rate of 3,750 kg ha^{-1} (dry weight). Rice cultivar Chai Nat 1 was transplanted in spacings of 20 × 20 cm with 3 seedlings per hill in a 35 m^2 plot. 30 days after emergence, the seedlings were used. Nitrogen at a rate of 30 kg ha^{-1}, phosphorus at a rate of 30 kg P_2O_5 ha^{-1} and potassium at a rate of 15 kg K_2O ha^{-1} were applied 7 days after transplant and top dressed at a rate of 60 kg N ha^{-1} at the booting stage.

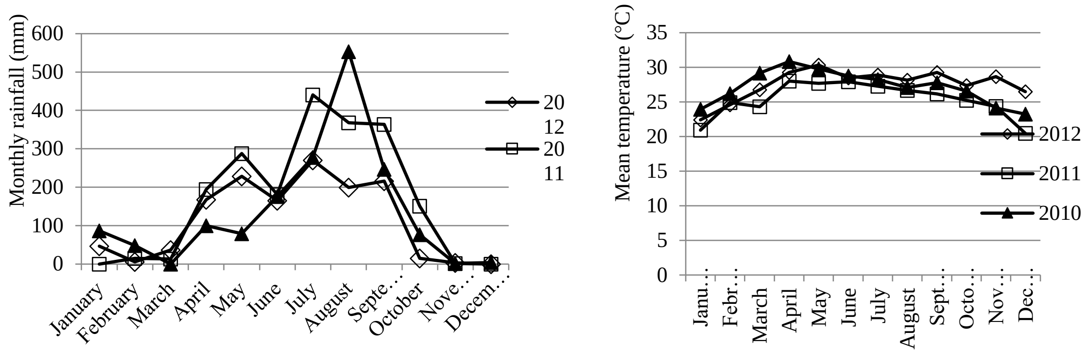

Fig. 1 Monthly rainfall and mean temperature during experiments in 2010, 2011 and 2012

In green manure treatment (CTG and NTG), the N fertilizer addition rate was calculated by subtracting the N received from the organic materials while each plot had the same amount of N at the rate of 90 kg N ha^{-1}. In the first crop, the Crotalaria green manure contained 2.0% N and 46.7% C. In the second crop, Crotalaria contained 1.98% N and 51.0% C, while the third crop, the Crotalaria contained 1.83% N and 47.5% C. The rice residue was left on the soil surface after harvest of each crop. The water level in the experimental field was maintained at a depth of 10-15 cm throughout maturity. The first crop started in July 2010, the second crop started in July 2011 and the third crop started in March 2012.

Sampling and Analyses

Soil samples were taken after the rice harvest in each crop for analysis of the nutrients including SOC, total N (micro Kjeldahl), available P by Bray II extraction and ammonium acetate (NH_4OAc) extraction for exchangeable K. Whole rice shoots from 5 hills were collected at harvest on 115 Day After Transplanting (DAT) to determine N uptake using the micro Kjedahl method followed by a flow injection analyzer (FIA); to determine the amount of P colorimetry was used (Murphy and Riley, 1962) and for the amount of K, flame emission spectroscopy was used. Grain yield and the dry weight of shoots were determined from a 2 m^2 area. Statistical analysis was completed using one way analysis of variance (ANOVA) and the significant difference among means was determined by using least significant difference (LSD) at $\alpha = 0.05$. All of data were analyzed using program STATISTIX (version 8).

RESULTS

The Change in Soil Properties

In the first crop, SOM in all treatments increased to 6.20 - 6.86 g kg^{-1} from the initial soil, but there was no significant difference between the treatments (Table 1). Green manure application in the

CTG and NTG treatments increased SOC to 0.37 and 0.13 g kg^{-1} relative to CT, respectively, but the level was less than CT in NT without green manure addition (Table 2). In the second year, SOC increased to 11.8 - 25.8% over the first year with highest level observed using the NTG treatment (8.33 g kg^{-1}) and the lowest level observed using the CT treatment (7.26 g kg^{-1}), while SOC in the NT treatment increased to the same level as CT and CTG (Table 1). Table 2 shows an accelerated SOC accumulation in NTG compare to CT. No-tillage without green manure addition also increased SOC to 0.39 g kg^{-1} relative to CT. No-tillage with green manure gave the highest SOC level (10.44 g kg^{-1}) in the third crop, but this level was not significantly different to NT, while the lowest level was found with CT (Table 1). An increased SOC was found in the no-tillage treatments (NT and NTG) with 13.0% and 23.1% greater than CT, respectively (Table 2). Soil total nitrogen (STN) after harvest in the first year was highest with the NT treatment (861.3 mg kg^{-1}) equivalent to 18.5% relative to CT (Table 2). The lowest level of STN was found with the CT treatment (721.3 mg kg^{-1}), but this was not significantly different to the CTG and NTG treatments (Table 1). Using no-tillage with a green manure application, STN was significantly greater than CT in the second crop, equivalent to an increase of 158.6 mg kg^{-1} compared to CT (Table 2). Despite this, there was no significant difference in the STN values among the CT, CTG and NT treatments (Table 1). In the third crop, the highest level of STN was found in the CTG treatment equivalent to an increase of 152.7 mg kg^{-1} compared to CT (Table 2). However, STN, using the NTG treatment, declined to same level as using the NT treatment (655.7 mg kg^{-1}), but the STN value remained significantly higher than that found with the CT treatment (Table 1).

Table 1 Effect of tillage method and green manure application on soil organic carbon, total N, available P and exchangeable K after harvested in 2010, 2011 and 2012

Tr.	SOC (g kg^{-1})			Total N (mg kg^{-1})			Bray II P (mg kg^{-1})			Exch. K (mg kg^{-1})		
	2010	2011	2012	2010	2011	2012	2010	2011	2012	2010	2011	2012
CT	6.49	7.26 c	8.48 c	721.3 b	563.2 b	578.6 c	1.33	2.58	3.62 b	157.5	122.5 b	97.5 b
CTG	6.86	7.80 b	9.35 b	756.6 b	622.8 b	731.3 a	1.38	2.60	3.96 b	155.5	137.5 a	127.5 a
NT	6.20	7.65 bc	9.58 ab	861.3 a	610.3 b	621.3 bc	1.27	3.01	5.62 a	162.5	140.0 a	115.0 a
NTG	6.62	8.33 a	10.44 a	766.7 b	721.8 a	655.7 b	1.30	2.53	4.44 b	162.5	152.5 a	122.5 a
F-test	ns	*	*	*	**	*	ns	ns	**	ns	**	**
CV (%)	12.91	9.82	11.9	11.93	13.5	16.91	7.13	19.24	22.6	17.02	18.11	18.73

Means labeled with the same letter in each column are not different as determined by LSD (P < 0.05)

The tillage and green manure method were not affected by available P in the first two years after the experiment (Table 1). Soil analysis showed Bray II P was in the range of 1.27 - 1.38 mg kg^{-1} in 2010 and 2.53 - 3.01 mg kg^{-1} in 2011. However, a significant increase in available P was found in 2012 with the NT treatment, which was higher than CT by 2.00 mg kg^{-1} (Table 2). There was no significant difference in available P among the CT, CTG and NTG treatments, which were between 3.62 and 4.44 mg kg^{-1}.

Soil results showed a three-fold increase in exchangeable K in 2010 compared to the initial soil, but there was no significant difference among treatments that ranged from 155.5 - 162.5 mg kg^{-1}. Tillage methods and green manure incorporation affected the exchangeable K in soil in 2011. High levels of K were found with CTG, NT and NTG resulting in values between 137.5 and 152.5 mg kg^{-1} (15.0 - 30.0 mg kg^{-1} greater than the CT treatment). The same response pattern of soil exchangeable K was also found in 2012, with the higher level of K found in CTG, NT and NTG treatments than that of the CT treatment. Among CTG, NT and NTG, there was no significant difference in the exchangeable K that ranged from 115.0 - 127.5 mg kg^{-1} equivalent to an increase of 17.5 - 30.0 mg kg^{-1} compared to CT (Table 2).

Table 2 Soil organic carbon, total N, Bray II P and Exchangeable K in soil after harvest relative to CT

Tr.	SOC (g kg^{-1})			Total N (mg kg^{-1})			Bray II P (mg kg^{-1})			Exch. K (mg kg^{-1})		
	2010	2011	2012	2010	2011	2012	2010	2011	2012	2010	2011	2012
CTG	0.37	0.54	0.87	35.3	59.6	152.7	0.05	0.02	0.34	-2.00	15.0	30.0
NT	-0.29	0.39	1.10	140.0	47.1	42.7	-0.06	0.43	2.00	5.00	17.5	17.5
NTG	0.13	1.07	1.96	45.4	158.6	77.1	-0.03	-0.05	0.82	5.00	30.0	25.0

Yield and Nutrient Uptake

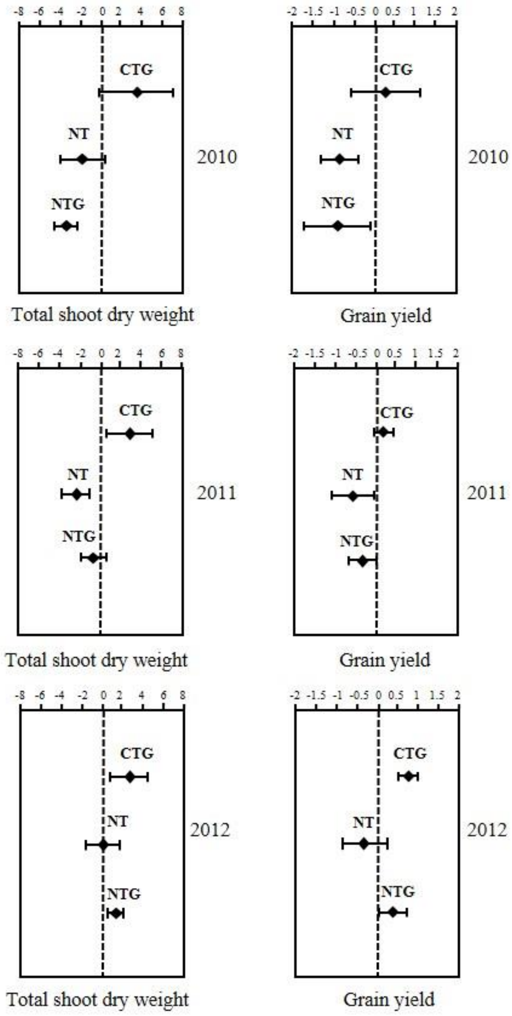

Fig. 2 Total shoot dry matter and grain yield of different tillage method relative to conventional tillage. Error bars represent LSD (P < 0.05)

The tillage system had a significant effect on grain yield especially early in the experimental year. In 2010, NT resulted in lower total shoot dry weight and grain yield than CT, even though green manure was applied (NTG). The highest grain yield was obtained with CTG but was not significantly different to the CT treatment (Table 3). The highest shoot dry weight was also found in CTG and the lowest one was found in NTG. However, there was no significant difference between the CT and NT treatments in the first year. In 2011, the highest grain yield was obtained with CTG (3.52 Mg ha^{-1}), but the yield was not different to the CT method (3.34 Mg ha^{-1}). However, NTG did increase the grain yield and shoot dry weight to the same level as CT. The grain yield was 3.01 Mg ha^{-1} and the shoot dry weight was 10.27 Mg ha^{-1} with NTG, while CT produced 3.34 and 10.83 Mg ha^{-1} for grain yield and shoot dry matter, respectively. The no-tillage treatments (NT and NTG) increased the grain yield and shoot dry weight to the same level as the conventional tillage treatments (CT and CTG) in 2012. The highest grain yield and shoot dry weight were found with CTG (4.29 and 12.70 Mg ha^{-1}, respectively), but the yield and shoot dry weight were not significantly different with NTG (3.94 and 11.41 Mg ha^{-1}, respectively). Moreover, NT also increased the grain yield and shoot dry weight to the same level as CT (Table 3). With the use of conventional tillage to provide a benchmark level of yield, the no-till reduced the yield in the first year by 22.2% and 23.5% for NT and NTG, respectively (Fig. 2). In the second crop, NTG can increase the yield to same level with CT. Both NT and NTG produced similar yields to conventional tillage yield in the third crop (Fig. 2).

Table 3 Effect of tillage method and green manure application on above ground dry weight, grain yield and shoot N uptake in 2010, 2011 and 2012

Tr.	Grain yield (Mg ha^{-1})			Total shoot dry weight (Mg ha^{-1})		
	2010	2011	2012	2010	2011	2012
CT	3.91a	3.34ab	3.62ab	15.46b	10.83b	10.17b
CTG	4.18a	3.52a	4.29a	18.84a	13.55a	12.70 a
NT	3.04b	2.78c	3.26b	13.86bc	8.45c	10.18b
NTG	2.99b	3.01bc	3.94ab	12.24c	10.27b	11.41ab
F-test	*	*	*	**	**	*
C.V.(%)	14.62	8.73	11.53	11.21	9.6	8.93

Means labeled with the same letter in each column are not different as determined by LSD (P < 0.05)

Table 4 Effect of tillage method and green manure application on shoot nutrients uptake in 2010, 2011 and 2012

Tr.	Shoot N uptake (kg ha^{-1})			Shoot P uptake (kg ha^{-1})			Shoot K uptake (kg ha^{-1})		
	2010	2011	2012	2010	2011	2012	2010	2011	2012
CT	84.6a	72.2b	72.0b	7.3b	7.7b	4.7	104.4	84.7b	61.4b
CTG	82.4a	96.2a	82.7a	14.6a	9.4a	4.2	112.2	101.3a	63.6b
NT	59.6b	60.8b	73.6b	7.5b	7.0b	5.6	94.9	81.2 b	72.6a
NTG	62.5b	73.1b	78.2ab	6.3b	7.1b	6.2	95.1	77.5 b	70.3a
F-test	**	**	*	**	*	ns	ns	**	*
C.V. (%)	9.4	13.9	5.0	32.6	12.2	21.7	17.3	12.5	9.1

Means labeled with the same letter in each column are not different as determined by LSD (P < 0.05)

The uptake of nutrients was affected by the tillage methods. In 2010, there was a lower N uptake with NT and NTG than CT and CTG by 24.1 - 9.6% (Table 4). With CTG, the shoot P uptake increased by over 48.7% when compared with CT, NT and NTG. However, there was no significant difference in the K uptake among treatments with values ranging from 94.9-12.2 kg ha^{-1}. In 2011, NT and NTG increased N uptake to the same level as CT, whereas the highest level of N uptake was found with CTG. For P and K uptake, CTG had a greater level than CT, NT and NTG.

In 2012, CTG had the highest N uptake, but this was not significantly different to NTG. There were no significant differences in P uptake among treatments, with values ranging from 4.2 - .2 kg ha^{-1}. The highest K uptake was found with the NT treatment, but this was not different to that from the NTG treatment with values ranging from 70.3 - 2.6 kg ha^{-1} (Table 4).

DISCUSSION

According the results given in this paper, we have found that SOC increased to 9.58 g kg^{-1} with NT treatment to the same level as the CTG treatment in the third year; equivalent to an increase of 12.97% over that which was found with the CT treatment. Moreover, an increase in SOC of 23.11% over the CT treatment was found with the NTG treatment in same year. This indicates that the no-till treatments improve SOC in flooded transplanting rice production. Likewise, several previous studies have reported an increase in SOC or SOM in no-till systems (Al-Kaisi et al., 2004(.

Bhattachayya et al. (2008) reported that SOC in a rice-wheat zero-tillage system was higher than that found with conventional tillage. In general, SOC plays an important role in maintaining soil structure and providing soil nutrients, which affects crop production. Accumulation of organic carbon was generally found in long term no-till treatments more than in conventional tillage treatments (Kushwaha et al., 2001). An increase in SOC under no-tillage was due to remaining plant residue on the soil surface which reduced the contact of residues with the soil (Singh and Kaur, 2012). Plant residues on the soil surface tend to decompose slower than soil incorporated residue. In the present study, SOC in the plot with no-tillage and without green manure addition (NT) was not significantly different compared to CT in the first 2 years, while significantly higher amounts of SOC was found with NT compared to CT in the third-year crop. However, green manure addition in NTG treatment can accelerate the rate of SOC accumulation to a higher level than CT within 2 years. Lal et al. (1999) concluded that the SOC dynamic is related to land use and management practices.

Adoption of conservation tillage resulted in a 56% increase in SOC over a 10-year period compared to conventional tillage, while SOC slightly increased within five years, then a large increase occurred in the next five to ten years (Lal et al., 1998). Duiker et al. (1999) reported that the SOC accumulation rate was lower in plough-till compared to no-till. The tillage system also affects the content of nutrients in soil. The current study found that no-till increased the total N, Bray II soil P and exchangeable K after the second crop compared to CT. In general, a no-till system favors organic material accumulation on the soil surface that usually advocates recycling of nutrients and enhances soil fertility. Nevertheless, the SOM mineralization rate in no-till is lower than that of CT, which reduced the availability of nutrients to crops as during the period from system carry out to equilibrium (Soratto et al., 2014).

Application of the no-till system to flooded transplanting rice seems to have an equilibrium between immobilization and mineralization within three crop years that can be explained by rice grain yield and nutrients uptake. In this study, no-till produced rice grain yield equivalent to CT within three consecutive years. However, a declined grain yield, below the control in the NT and NTG treatments, was found in the first crop after adopting the no-till system. In the second crop, the grain yield and above ground dry weight from the NTG treatment was similar to that of CT but lower than that of CTG. In the third crop, the grain yield with the NTG treatment increased to the same level as the CTG and CT treatments. The results indicated that the grain yield, related to soil properties, changed by using no-tillage.

Several previous reports showed that no-till reduced crop productivity, especially in the first few years after adoption (Sa et al., 2014; Soratto et al., 2014). Haque et al. (2016) reported that minimum tillage and unpuddled transplanting rice gave yields of the same level as conventional puddling within three years after adoption. The reduction in yield in the first few years after implementation of no-till caused by soil, takes time to benefit the soil properties, such as an increased in SOC, availability of nutrients from SOM, mineralized and re-established desirable soil structure taking time to develop (Haque et al., 2016; Pittelkow et al., 2015; Soratto et al., 2014).

Not only grain yield but the uptake of nutrients by rice shoots can also explain the relationship between the change in soil properties and the response of rice in a no-till system.

No-till treatment showed lower N, P and K uptake than CT in the first crop, while in the third crop no-till with green manure addition showed increased N, P and K uptake, to the same level as CT and CTG. The results of this research relating to the change in soil properties, rice grain yield responses and the uptake of nutrients, revealed a three-year transition period from conventional tillage to a no-till system in a flooded transplanting rice system. However, this transition period of yield reduction can reduce or prevent soil management strategies such as nitrogen fertilization and organic matter addition (Lundy et al., 2015; Singh and Kaur, 2012; Sorattao et al., 2014).

CONCLUSION

A no-till system has quite a high effect on soil properties and rice yield under flooded transplanting conditions. The yield of rice declined with a no-till system in the first two years after adoption. However, the yield increased on the same level as CT treatment after the third year of no-till adoption. No-tillage had a positive impact on soil properties in flooded rice conditions. Under flooded transplanting rice conditions, no-till treatments were more beneficial than conventional tillage in terms of SOC, total N, available P and exchangeable K. Green manure applications to no-till systems can improve yield reduction at an early stage of no-till adoption and is beneficial to the improvement of soil properties in the long-term, also decreasing the operation costs.

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