Title: Evaluation of long-term effects of nitrogen fertilizer and rice residue management on soil surface nitrogen budget in a lowland paddy rice

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Abstract

Soil surface nitrogen (N) budget is a useful tool for assessing soil fertility, crop productivity, and environmental quality but it is mainly dependent on farming management practices in agroecosystem. Hence, we evaluated long-term effects of N fertilizer and rice residue management on soil surface N budget in rice cropping system over 28-year using the constructed long-term data set of inputs, outputs, and change in total soil N. To evaluate rice N uptake (RN), loss N (LN), change in total soil N, and the N budget, five rates of N fertilizer (N 0, 100, 150, 200, 250 kg N ha^{-1} yr^{-1}) under non-rice residue (control) and rice straw (RS) and rice straw compost (RSC) incorporated plots were continuously applied. Results showed that long-term incorporation of RS and RSC contributed to higher RN compared to that under control regardless the given N rates. Although a relatively superior total soil N in RS and RSC other than control was accumulated, LN was increased and varied according to increasing N rates. Meanwhile, less LN from RSC was significant due to comparable accumulation of total soil N content. In determination of the N budget on 28-year average, continuous incorporation of RS and RSC obtained near zero (− 0.5 kg N ha^{-1} yr^{-1} and 0.7 ± 6.0 kg N ha^{-1} yr^{-1}), while control showed negative by − 54.0 ± 5.6 kg N ha^{-1} yr^{-1} due to greater difference in change in total soil N. In conclusion, both of RS and RSC could enhance and maintain total soil N reserve, rice production, and thus N balance, but the adverse impact of N fertilization on the risk of environmental pollutions required for minimizing N loss.

Key words: Rice residue management, Soil N reserve, Rice productivity, Environmental quality, Soil surface N budget

1. Introduction

Nitrogen (N) management is a crucial factor affecting the crop production in agriculture. Inherent soil N stock to produce profitable crop yield is not sufficient. Prior to the introduction of synthetic N fertilizer, organic manure has been applied for increasing crop production, but still has the limitation leading to need to the use of synthetic N fertilizer in order to achieve significantly productive crop harvests (Heffer, 2009). However, the utilization of synthetic N fertilizer has generated serious environmental issues like global warming by greenhouse gases emission and water contamination by runoff and leaching in soils (Mosier et al., 2004; White and Brown, 2010). The environmental issues caused from the synthetic N fertilizer require the need to improve N use efficiency through soil organic matter (SOM) management that contributes to increase crop production and reduce the N losses. One of the factors affecting SOM is the addition of crop residue to the soil, and its effects on maintaining sustainable crop production and reducing N losses are significant (Sánchez et al., 2017).

A promising N management using crop residue such as rice straw has been recommended in most rice-based cropping system. Many studies on the agronomic benefits on improvement of soil fertility and rice productivity have been demonstrated worldwide since the rice straw allows its utilization as an organic amendment that contributes to increase in soil organic carbon (SOC) and nitrogen (SON) and reduce synthetic N fertilizer application (Park, 1979; Yeon et al., 2007; Hai et al., 2010; Kim et al., 2012; Huang et al., 2013; Lehtinen et al., 2014; Wang et al., 2015). However, rice straw incorporation produced significant amount of methane (CH_4) emission under submerged soil condition (Gaihre et al., 2013). Since it consists of cellulose, hemicellulose, and lignin reacting as carbon (C) sink and source for microbial mineralization and production, the positive and negative impact changed the use of rice straw to an alternative environmentally friendly organic material such composting (Shilev et al., 2007; Pramanik and Kim, 2014; Sánchez et al., 2017; Jeong et al., 2018). The composted rice straw has the significant effects on increasing rice yield and reducing CH_4 emission under submerged soil condition, compared to rice straw incorporation (Yagi and Minami, 1990; Corton et al., 2000). In the context of the agronomic benefit and environmental issue affected by use of rice straw and the compost, a technical and practical assessment of N fertilizer and rice straw management is necessary for future food production.

A way of assessing crop productivity and environmental quality is to determine N balance (Leip et al., 2011; Kremer, 2013; Özbek and Leip, 2015; Ladha et al., 2016). Generally, N balance accounts for inputs and outputs N, and the difference estimates a size of various N pools, atmospheric N deposition, crop N uptake, and N losses to the environment in soil N cycle processes (Meisinger et al., 2008). In determination of N balance, a positive value indicates surplus N, leading to potential losses to the environment through volatilization, denitrification, and leaching, while a negative value indicates depletion in soil N, describing decline in soil fertility (Kremer, 2013). Leip et al. (2011) evaluated the method of calculating a N balance through different system boundaries, farm, land, or soil. They considered two key parameters of the N surplus (inputs N – outputs N) and N use efficiency (outputs N/inputs N) to assess agricultural productivity and environmental quality in each system boundary. Meanwhile, Ladha et al. (2016) included the total N stock in calculation of N balance because soil N stock has large N contribution to N management for next crop cultivation.

Since the continuous application of synthetic fertilizers or combined with organic material, especially crop residue or animal manure, alters rice productivity, environmental quality, and thereby N balance (Mosier et al., 2004; Lu and Tian, 2017), this study used a long-term rice field data over 28-year conducted at the Iksan experimental station, National Institute of Crop Science (NICS), Rural Development Administration (RDA) in order to assess N balance under continuous N fertilizer application and rice straw management. Specific objectives of this study were 1) to evaluate effects of different rates of N fertilizer with none, rice straw, and rice straw compost on rice N uptake, N loss, change in total soil N and 2) determine soil surface N budget using the constructed parameters of inputs, outputs, and total soil N content.

2. Materials and methods

2.1. Long-term mono rice cultivation

A long-term data set of 28-year (1981 to 2008) field experiment at the Iksan experimental station, National Institute of Crop Science (NICS) of Rural Development Administration (RDA) was used in this study. Soil texture in the field located at coastal plain adjacent to East Sea of South Korea was silt loam-rice paddy classified as *Aquepts* of *Inceptisols* (Ahn et al., 2012). Initial soil chemical property sampled at surface 20cm-depth was 6.4 in pH, 2.3 % in organic matter, 0.12 % in total soil N, 100 mg kg^{-1} in available phosphate (P_2O_5), and 11 $cmol_c$ kg^{-1} in cation exchangeable capacity.

The experimental field had a separate 45-plot (11.7 m^2, 3m width and 3.9 m length of a plot), and three rice straw incorporations: no incorporation (control), fresh rice straw (RS), and rice straw compost (RSC) as main-factor; five levels of nitrogen (N) fertilizer from urea: 0, 100, 150, 200, and 250 kg N ha^{-1} as sub-factor were allocated by split plot design with three replications (Table 1). RS and RSC were incorporated into each plot in the middle of November after harvest and in the middle of May before transplanting in a depth of 200 mm, respectively. Amount of total N contained in RS and RSC is shown in Table 1. Following to the local rice production practice, four split urea applications were done on basal (50 %), maximum tillering (20 %) and panicle initiation (20 %), and ripening stages (20 %) in the first 3 years. Thereafter, the split N applications were modified as 70 % in basal, 20 % in panicle initiation, and 10 % in ripening stage to the end of studied period. Phosphorus fertilizer (70 to 90 kg P_2O_5 ha^{-1}) was basally applied before transplanting, and potassium fertilizer (80 to 110 kg K_2O ha^{-1}) was applied 70 % on basal and 30 % on panicle initiation stages. The planted rice varieties showing a high yield with high-tillering capacity as 13 to 17 productive tillers $plant^{-1}$ were Pungsan (1981 to 1990), Hwachung (1991 to 2001), and Dongjin-1 (2002 to 2008) and manually transplanted in the middle to late of each May during the studied period (Park et al., 1982a; Park et al., 1982b; Mun-Hue, 1993). Three to four seedlings per hill were established with the density of 30 × 15 cm. During the rice growing season, water management practice was continuously flooded with mid-season drainage. The flooded depth was 100 mm above the soil surface. For effective weed control, herbicides were sprayed twice in early June and July. Harvest was done during the late September to early October. To determine rice grain yield (GY) we sampled 100 hills in each sub-plot, oven-dried at 70 ^{o}C for one week, and calculated the yield in kg ha^{-1}.

Table 1. Annual amounts and sources of fertilizer N input in the long-term experiment during 1981 to 2008.

Plot	Rice straw incorporation (kg N ha^{-1})	Urea (kg N ha^{-1})	Amount of N input (kg N ha^{-1})
C 0	Control	0	0
C 100	(N 0)	100	100
C 150		150	150
C 200		200	200
C 250		250	250
RS 0	Rice Straw	0	49.5
RS 100	(N 49.5)	100	149.5
RS 150		150	199.5
RS 200		200	249.5
RS 250		250	299.5
RSC 0	Rice Straw Compost	0	34
RSC 100	(N 34)	100	134
RSC 150		150	184
RSC 200		200	234
RSC 250		250	284

2.2. Determination of N balance

Inputs N includes inorganic and organic fertilizer (FN), irrigation (IN), atmospheric deposition (AN), seed (SN), and biological N fixation (BNF). Outputs N includes rice N uptake (RN) and loss N (LN) from the soil through volatilization, denitrification, leaching, and runoff. The change in total soil N (∂ soil N) at a depth of 0.3m by accounting final minus initial total soil N ($\partial \text{ soil N} = \text{final} - \text{initial}$) was considered as the independent component in determining soil surface N budget. Thus, N balance was calculated as follow (Greenland and Watanabe, 1982):

$$\text{N balance} = \text{Inputs N} - \text{Outputs N} \pm \partial \text{ soil N} \qquad (1)$$

Input sources and amounts of FN (urea, rice straw, rice straw compost) were listed in Table 1. Other inputs from IN (12.6 ± 2.1 kg N ha^{-1}), AN (8.2 kg N ha^{-1}), and SN (24 kg N ha^{-1}) during the rice growing season were obtained from national research report (NAIST, 2000). Biological N fixation (BNF) is uncertain and difficult to measure and not included in the calculation of N inputs. Instead, we considered BNF as part of the change in total soil N.

The N output from rice N uptake is simply measured N in aboveground biomass (grain plus stem) after harvest. For the long-term experiment, N removal by rice N uptake was determined in every year. Rice grain and stem at harvest from each plot were separately determined, air-dried at 65^{o}C for 7 days, and convert yield to dry matter basis. The dried samples were grinded for a subsamples of grain and stem to <1 mm and determined N concentration by using the Kjeldahl method (Bremner, 1996). Total N removal (kg N ha^{-1}) by multiplying crop yield by N concentration was calculated.

To determine soil organic N (SON), soil samples to a depth of 0.3m in each plot were collected after harvest, air-dried, and ground to 2mm which is used for N analysis. The SON concentration was determined by using the Kjeldahl method. And, total soil N (kg ha^{-1}) contents were calculated based on the following formula (Sainju, 2017):

$$\mathrm{TSN} = SON \times BD \times T \times 10{,}000 \qquad (2)$$

where, TSN is total soil N content (kg ha^{-1}), SON is soil organic N content (g kg^{-1}), BD is bulk density (Mg m^{-3}), T is thickness of the soil sampling layer (m), and 10,000 is conversion factor. The applied values of BD and T in calculating TSN were 1.25 Mg m^{-3} and 0.3m, respectively.

Finally, annual change in total soil N (kg ha^{-1} yr^{-1}) was calculated as the following formula:

$$\partial \text{ soil N} = TSN_{final} - TSN_{initial} \qquad (3)$$

where, ∂ soil N is the change in total soil N (kg ha^{-1} yr^{-1}), TSN_{final} is final total soil N after harvest (kg ha^{-1}), and $TSN_{initial}$ is initial total soil N (kg ha^{-1}) obtained from the previous year.

Loss N summed up of volatilization, denitrification, leaching, and runoff N was estimated as following equations:

$$RE_N = \frac{U_N - U_0}{FN} \qquad (4)$$

$$LN = FN \times (1 - RE_N) \pm \partial\, soil\ N \qquad (5)$$

where, RE_N is recover efficiency of fertilizer-N, U_N is total N uptake in aboveground biomass at maturity that received N (kg ha^{-1}), and U_0 is the total N uptake in aboveground biomass at maturity that received no N (kg ha^{-1}).

2.3. Statistical analysis

A two-way ANOVA was computed using statistical tool for agricultural research (STAR V. 2.0.1) and the differences between means were determined using least significant difference (LSD).

3. Results

3.1. Rice N uptake and RE_N

Rice N uptake (RN) in total aboveground biomass response to N fertilizer with and without rice residue incorporation was evaluated (Fig. 1a). In the results, RN showed increasing trends in response to increasing N rate under both non-residue (control) and rice residue incorporated plots (RS and RSC). On 28-year average, the long-term result showed that RS and RSC improved RN in all N rates, significantly.

Recovery efficiency of fertilizer N (RE_N) in total aboveground biomass that received each N fertilizer under control, RS, and RSC also showed increasing trends according to increasing N rate (Fig. 1b). Whereas, the difference in RE_N among control, RS, and RSC were comparable. As calculated by the differences from the inherent soil N (N 0 kg ha^{-1} under control), the total N harvested by rice that received N fertilizer under RS and RSC was higher than those under control in the given N rates at 0, 150, and 200 kg ha^{-1} yr^{-1}. However, rice received 100 kg N ha^{-1} yr^{-1} absorbed similar amounts of N both under control and RSC. At the highest N rate of 250 kg ha^{-1} yr^{-1}, no effect on RE_N between control, RS, and RSC was obtained.

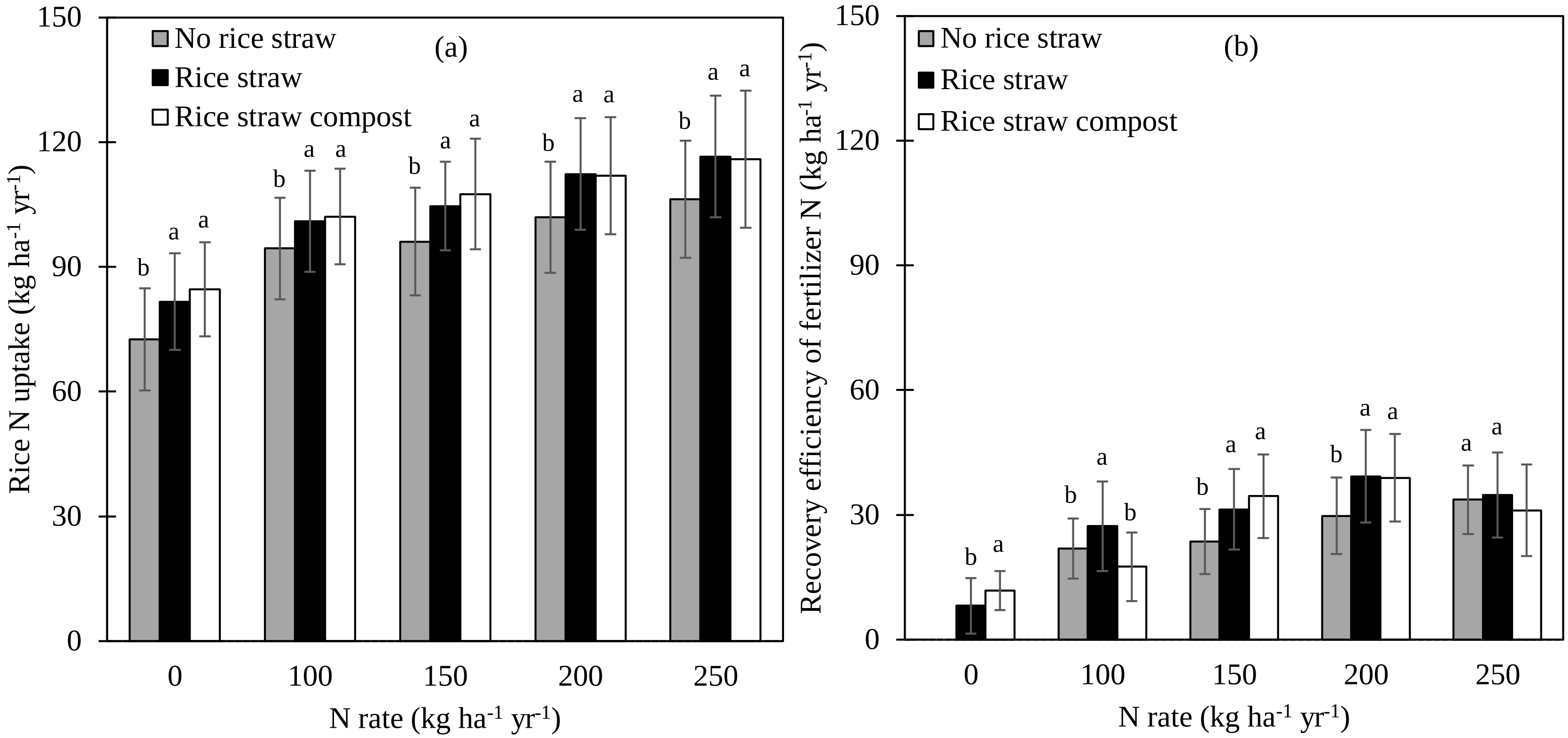

Figure 1. Rice N uptake (a) and recovery efficiency of fertilizer N (b) on 28-year average in the treatments that received N fertilizer under no rice straw, rice straw, and rice straw compost incorporations (Recovery efficiency of fertilizer N was calculated by the difference from N 0 kg ha^{-1} with no rice straw incorporation).

1.1. Change in total soil N

Based on data from the long-term field study, result showed that annual incorporations of RS and RSC contributed to enhance total soil N (TSN) contents as calculated by $TSN_{final} - TSN_{initial}$, while the soil growing rice under control showed negative values explaining decline in total soil N (Fig. 2). Mean comparison results showed that there were no differences of change in total soil N in the given N rates regardless rice residue incorporation. However, changes in total soil N under RS and RSC were significantly higher as 15.9 ± 1.4 and 17.7 ± 2.4 kg ha^{-1} yr^{-1} than that under control as –15.4 ± 0.97 kg ha^{-1} yr^{-1}. Therefore, incorporation of RS and RSC contributed to the significant accumulation of total soil N in the paddy soil.

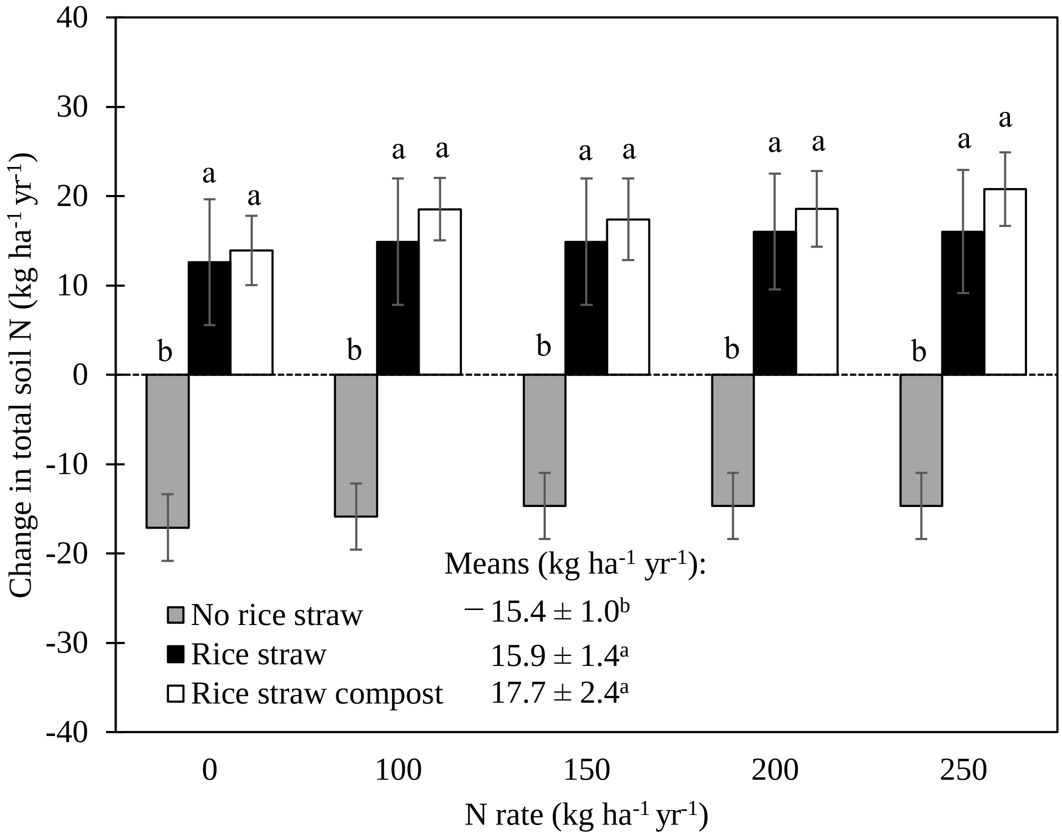

Figure 2. Change in total soil N contents that received the different rates of N fertilizer under no rice straw, rice straw, and rice straw compost incorporations on 28-year average (Means of each N rate under no rice straw, rice straw, and rice straw compost with the same letter are not significantly different at P < 0.05).

1.2. Estimation of Loss N

Estimated by RE_N and change in total soil N content against the total N input, increasing N fertilizer application caused for increased N loss (Fig. 3). Mean comparison results indicated that RS incorporated plots showed significantly higher loss N (LN) in the given N rates from 0 to 200 kg N ha^{-1} yr^{-1}, compared to those under control and RSC. However, at the highest N rate of N 250 kg ha^{-1} yr^{-1}, RS showed comparably lower LN than those under control and RSC. Meanwhile, there was no significant difference on LN between control and RSC in all N rates although RSC incorporated plot received more N than control. The result appeared that input N from N fertilizer with RSC may not elevate the risk of N loss to the environment because of relatively higher RN and change in total soil N than those under control.

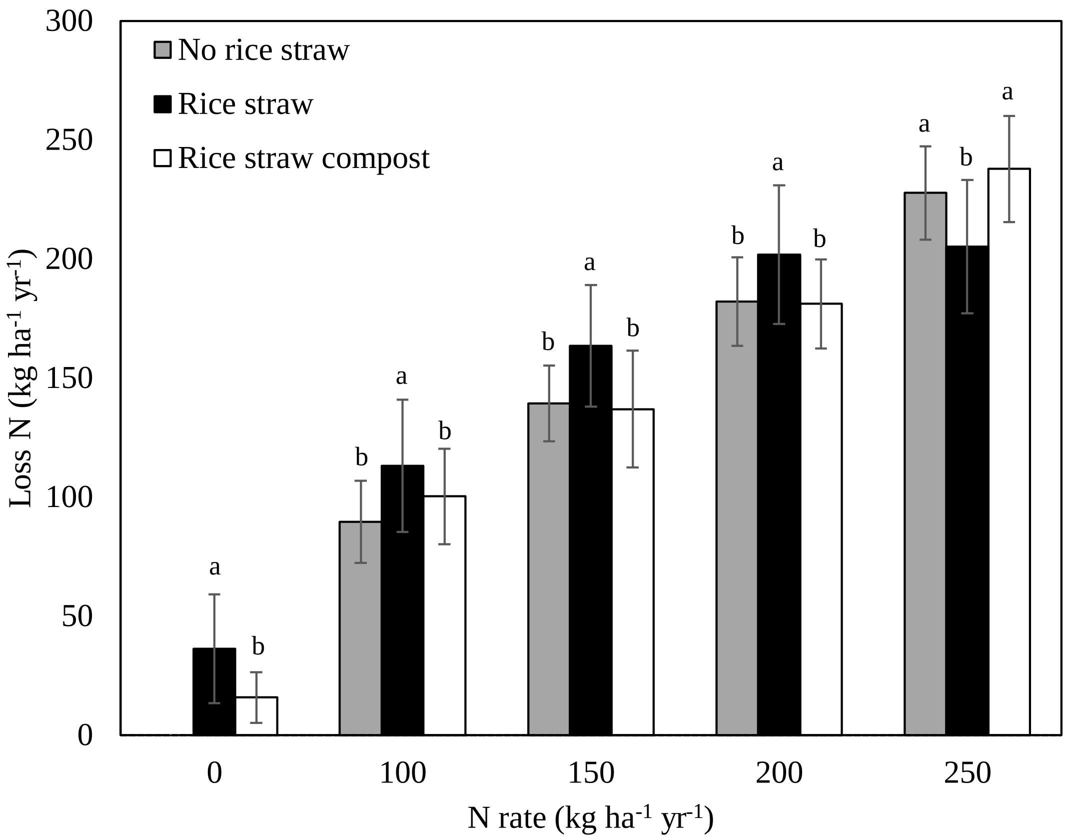

Figure 3. Mean values of loss N and its response to N fertilizer under no rice straw, rice straw, and rice straw treatments during 28-year (Loss N was calculated by the difference from N 0 kg ha^{-1} yr^{-1} with no rice straw).

1.3. Determination of soil surface N budget

Using the method in determination of soil surface N budget ($\text{Inputs N} - \text{Outputs N} \pm \partial\ \text{soil N}$), the 28-year average N budget showed that control obtained all negative while RS and RSC obtained around zero values, regardless N rates. Mean value of N rates under control was – 54.0 ± 5.6 kg N ha^{-1} yr^{-1}, while the values of N budget both under RS and RSC was close to zero showing as – 0.5 ± 4.5 for RS and 0.7 ± 6.0 kg N ha^{-1} yr^{-1} for RSC, respectively (Fig. 4). The results could be mainly due to the increased change in total soil N content, as shown in Table 2. Although the responses of N fertilizer application to RN, RE$_N$, and LN were highly significant (p<0.001), it did not increase total soil N content.

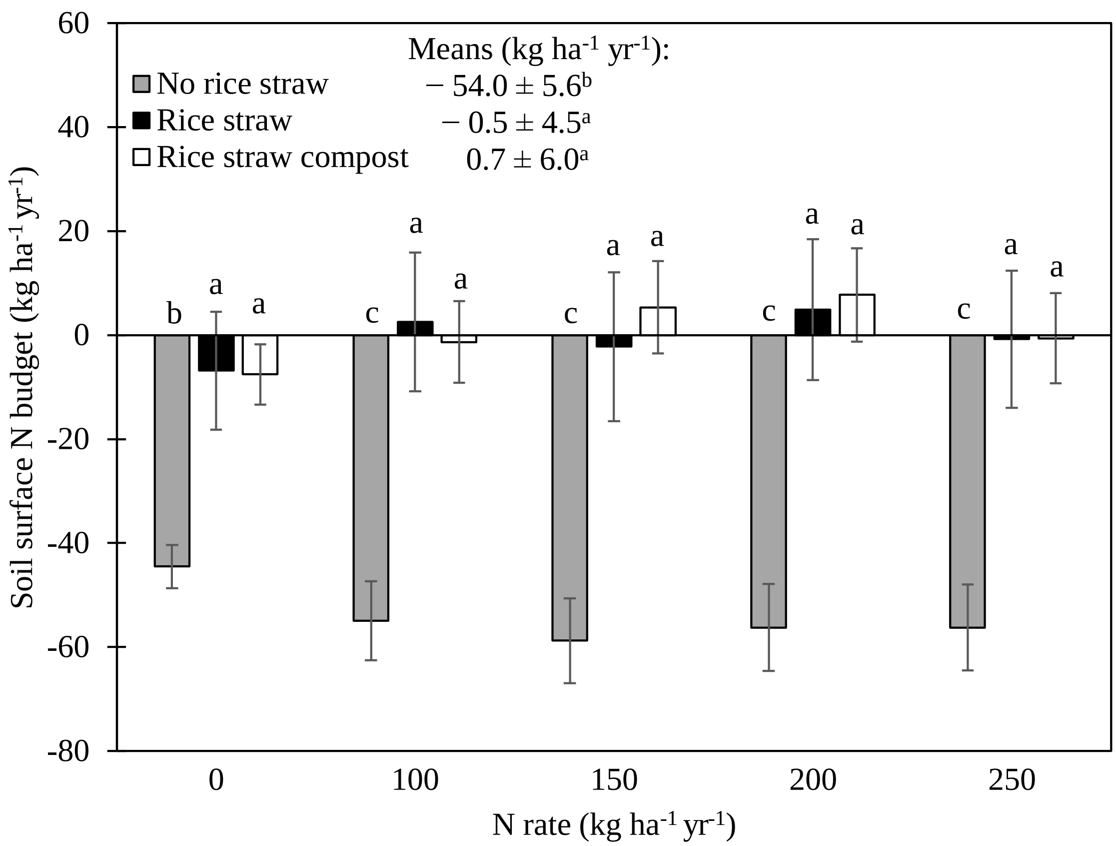

Figure 4. Mean comparison results of N balance on the 28-year average in each N rate under no rice straw, rice straw, rice straw compost (Means of each N rate under no rice straw, rice straw, and rice straw compost with the same letter are not significantly different at P < 0.05).

2. Discussion

N fertilizer application and its combined with rice residue incorporation as the major input N source to produce rice growth was significantly efficient, and rice growth response was following to a quadratic increase with increasing N rate. The varieties cultivated in the long-term experiment requires N rate around 200 kg N ha^{-1} to achieve high rice production and the N efficiency from soils was approximately ≥ 50 % (Park et al., 1982a; Park et al., 1982b). Our long-term study proved that the N rate to achieve the maximum RN was 250 kg N ha^{-1} in each rice residue treatment (Fig. 1a). Meanwhile, it appeared that the long-term incorporation of RS and RSC contributed to enhance RN compared to that under control due to additional crop available nutrients contained in RS and RSC when incorporated into the soil (Park, 1979). Previous studies addressed that organic matter amendment such as rice residue or organic manure is one of the practical ways of increasing rice production where soil fertility was low since rice straw contains a number of nutrients, such as N, phosphorous (P), potassium (K), silicate (SiO_2) and other micronutrients, improves the soil physical properties, and enhances functional and structural soil microbial diversity regulating biochemical processes such as organic matter decomposition and nutrient cycling (Park, 1979; Yadav et al., 2000; Yeon et al., 2007; Kim et al., 2010). Thus, the enhanced physical, chemical, and biological features of the soil after incorporation of RS and RSC could elevate availability of N, P, K, SiO_2, and other micronutrients for significant rice production in the field.

In response of N fertilization to RN, however, there was controversial relationship on that the annual N loss estimated over 1981 to 2008 was significantly increased and varied greatly according to N rates under control, RS, and RSC (Table 2). In our assumption, the magnitude of rice production and N loss were attributed to two reasons: 1) rice growth response is always following with the concept of diminishing return to N fertilizer application because the crop N utilization is limit and 2) soil has a limited N retention capacity although soil acts as a major sink for added N in agriculture. Increased N deposition from excess N fertilizer application with or without rice residue incorporation over crop N demand can result in N saturation and thereby being loss, depending on soil physical and chemical properties including soil texture, nutrients exchange capacity, and soil organic matter (SOM) level in soil (Weil et al., 2016). Additionally, the capacity of soil N retention may be affected by the interaction between added N to the soil and crop cultivation (Lu et al., 2011). In the pathway of N pools, part of added N being reactive mineral forms is assimilated to crop growth; another part is adsorbed to soil clay or incorporated in SOM; the other part remaining in soil profile is subject to loss within the agroecosystem (Havlin et al., 2007). Under control, data revealed that total soil N content was declined regardless N application rates in the limited crop N use (Fig. 1 and 2). Many long-term studies conducted in different climate conditions revealed that continuous rice cultivation depletes SOM, which are closely linked to the change in total soil N, without rice residue incorporation or organic manure amendment because continuous N fertilizer application generally releases more soil native N than unfertilized (Jenkinson et al., 1985; Zhang and He, 2004; Yeon et al., 2007; Kim et al., 2010). Thus, increasing N fertilizer application increases the risk of N loss to the environment (Hossain et al., 2012; Chen et al., 2015).

Table 2. Mean comparison results on 28-year average rice N uptake, recovery efficiency of fertilizer N, loss N, change in total soil, and N balance in kilogram N per hectare in the treatments for the 28-year duration

Main plot (A)	No rice straw (control)					Rice straw (RS)					Rice straw compost (RSC)				
Sub plot (B) (kg N ha^{-1} yr^{-1})	0	100	150	200	250	0	100	150	200	250	0	100	150	200	250
RN	72.6	94.4	96.1	101.9	106.3	81.6	101.0	104.6	112.3	116.5	84.6	102.1	107.5	111.9	115.9
RE_N	-	21.9	23.5	29.3	33.7	9.07	28.4	32.1	39.8	34.9	12.0	17.5	34.9	39.3	31.3
LN	-	89.6	139.3	182.1	227.7	36.2	113.0	163.3	201.8	205.4	15.8	100.3	136.8	181.0	237.8
∂ soil N	-17.0	-15.8	-14.8	-14.8	-14.8	12.6	14.9	14.9	16.0	16.0	13.9	18.3	17.2	18.3	20.6
N balance	-43.8	-54.9	-58.8	-56.2	-56.2	-6.8	2.5	-2.2	4.9	-0.8	-7.6	-1.3	5.3	7.7	-0.6

Statistical analysis	RN	RE_N	LN	∂ Soil N	N balance
LSD values	6.89	5.10	9.09	12.15	24.4
A	**	**	**	***	***
B	***	***	***	NS	NS
A × B	NS	***	***	NS	NS

Control, RS, and RSC indicate no rice straw, rice straw, and rice straw compost incorporation

RN: rice N uptake (kg N ha^{-1} yr^{-1}), RE_N: Recovery efficiency of fertilizer N (kg N ha^{-1} yr^{-1}), ∂ soil N: change in total soil N (kg N ha^{-1} yr^{-1}), and LN: loss N (kg N ha^{-1} yr^{-1})

NS means not significant F-values for $p < 0.05$, ** and *** indicate significant difference at $p < 0.01$, and $p < 0.001$, respectively.

Meanwhile, the more N loss occurred corresponding to additional input by RS other than control and RSC although a relatively superior total soil N content was accumulated both under RS and RSC (Fig. 3). Theoretically, N balance is always dependent on the principle of conservation of mass balance indicating that N inputs minus N outputs equals total soil N stock within the system (Meisinger et al., 2008). In agroecosystem, a different approach including total soil N stock as an independent component to derive an actual N balance has been suggested because farming management practices (e.g., fertilization and tillage) mainly affect soil N pools and N losses, or vice versa (Greenland and Watanabe, 1982; Ladha et al., 2016). Hence, total soil N stock inevitably plays a crucial role contributing to quantifying a crop yield and amount of N loss to the environment in continuous crop cultivation although it is also dependent on soil and climate conditions and farming management practices (Ross et al., 2008; Pieri et al., 2011). As well known, input N from synthetic N fertilizer or crop residue incorporation or combined N fertilization may improve total soil N content as well as crop yield. However, continuous N input to increase total soil N content is limit since rice residue incorporated in field gains or loses N simultaneously until an equilibrium soil N level is reached (Meisinger et al., 2008). If the mineralized from organic N is equal to organic N incorporated through the rice residue, the soil N level is attained at a steady state condition, as described by Zhang and He (2004) and Puget and Lal (2005). When the soil N level reached at a steady state, continuous input of RS over N fertilizer increased more N loss because of no more accumulation of total soil N content, as shown in Table 2. Thus, N fertilizer application to soil incorporated with RS stimulates microbial decomposition which promotes microbial N mineralization rate and releases more mineralized N species (NH_4^+, NO_3^-) being available for N loss to the environment (Havlin et al., 2007).

However, RSC showed smaller amounts of N loss but relatively higher total soil N reserve compared to RS (Fig. 3). In the use of RSC which is s transformed into stable humic substances through solid-state fermentation process, it is a stabilized-form of rice straw having low C/N ratio (20.3), while RS which is fresh rice straw has high C/N ratio (67.2). Generally, fresh rice straw comprised of cellulose, hemicellulose, and lignin prior to incorporation into soil. When the rice straw incorporated into soil, cellulase, hemicellulase, and lingniase are required to break down these components (Schiere and Ibrahim, 1989), and ≥ 90 % of cellulose and hemicellulose is rapidly decomposed due to easily decomposable carbohydrate, but lignin cannot be broken down due to the lack of ligninase in common soils (Sylvia et al., 2005). In addition with application of N fertilizer, the decomposed soluble substrates provided sufficient nutrients and energy for further microbial production and mineralization (Melillo et al., 1989). By contrast, a slowly decomposable humic substance such as RSC accumulated, and thus limited microbial growth and reduced the decomposition and mineralization in soil (Rivas et al., 2014). Since most component of RSC is humic substance which is resistant pool of SOM, it enhances soil nutrients retention capacity other than further microbial decomposition (de Bertoldi et al., 1983). Additionally, when labile N after application of N fertilizer is linked to the SOM, it improves total soil N reserve (Al-Bataina et al., 2016). Consequently, RSC with low C/N and high humic substance to carbohydrate (cellulose and hemicellulose) ratios may mineralize more slowly than RS with high C/N and low humic substance to carbohydrate ratios. Thus, the field incorporated with RSC obtained significant total soil N content and showed less N loss compared to RS.

1. Conclusion

Continuous inputs of N fertilizer and rice residue incorporation to ensure sustainable crop production contributed to the environmental problems. Using the constructed long-term data set of inputs, outputs, and change in total soil N content, we evaluated continuous N fertilizer with and without rice residue incorporation effect on soil surface N budget in a paddy rice. Our results indicated that increasing N fertilizer application responded to RN and LN. Additionally, the contribution of RS and RSC led to increased total soil N content and thereby higher RN compared to control. The difference on change in total soil N between no rice straw (control) and rice straw (RS and RSC) treatments attributed to the variation in N budget where RS and RSC showed around zero; control showed negative value on – 54.0 kg N ha^{-1} yr^{-1}. Although rice residue incorporation not only promoted total soil N and RN but also improved N budget, the risk of N loss to the environment was considerable. To sustain rice production and minimize N loss, this study suggested rice residue amendment. However, further study on best N management for ensuring crop productivity and environmental quality is required in line with a desired precision of inputs and outputs N in different soil and climate conditions.

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