

## Nitrogen and Phosphorus Content Changes in Paddy Soil and Water As Affected by Organic Fertilizer Application

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### Abstract

**BACKGROUND:** With increasing public awareness to environment-friendly agriculture, many efforts have been run to develop organic farming technologies in Korea as of late 90s. The objective of this study was to investigate the effects of different organic farming practices on soil chemical properties and water quality in paddy fields.

**METHODS AND RESULTS:** Total nitrogen (TN) and total phosphorus (TP) were monitored for a two-year period (2006 to 2007) from the study organic paddy fields located in Wanju, Jeonbuk Province in Korea. TN and TP of organic paddy water were gradually increased for 2~3 weeks after organic manure application and then gradually decreased afterward. The overall variation of TP in the paddy fields was much greater than that of TN. The phosphorus content in organic paddy field appeared to increase with the organic farming period.

**CONCLUSION(s):** This indicates that long-term organic farming is likely to cause phosphorus accumulation in soils and increase vulnerability to rainfall runoff. Thus, appropriate phosphorus management needs to be implemented, particularly, to reduce excessive phosphorus supply owing to nitrogen-based determination of organic manure application amount.

**Key Words:** Organic farming, Paddy fields, TN, TP, Nonpoint source pollution

### Introduction

As environmental friendly agriculture has gained more public attentions in Korea, increasing investment has been made to convert the conventional high input (high rate application of fertilizer and pesticides) agricultural practices for the agricultural productivity to environmentally sustainable ones.

Between 2000 and 2005, the number of farmers who adopted environment-friendly agricultural practices has been increased about 25 times from 2,000 to 53,000 (MAF, 2006). Subsequently, organic farming area has also enlarged about 24 times from 2,000 ha in 2000 to 50,000 ha in 2005. The fraction of environment-friendly agricultural product sold in the market has grown from 0.4 to 4.0% (about 19 times increase). There has been increasing efforts of the Korean government to encourage environment-friendly agriculture and scale up the size from a village level to the broad complex within a city or large water basins.

However, there is little information regarding the effect of organic farming on the changes of soil and water qualities. The objective of this study is to investigate the changes of the chemical properties of paddy soil and stream sediments as affected by organic farming practices through monitoring TN and TP con-

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centrations in paddy and stream water.

## Materials and Methods

### Farming practices

The study site was located at Wanju-gun, Jeollabuk-do Province in Korea (Fig. 1). Organic rice farming practices included rice-duck farming (5.9 ha), rice-pond snail farming (1.8 ha), and other organic farming practices for weed control (1.4 ha) (Gil et al., 2008). The sites have been under organic farming practices for 4–15 years. Depending on the length and type of organic farming practices, four different organic farms were selected including 15 years rice-duck farming (OF1), 3 years rice-duck farming followed by 2 years rice-pond snail farming (OF2), and 4 years rice-duck farming followed by 1 year rice-pond snail farming (OF3), and 6 years rice-duck farming (OF4) (Table 1). The OF1 treatment was investigated only in 2006 because of the site incorporation into a rice processing plant.

The OF1 site was fertilized once a year with livestock manure as basal fertilizer for 15 years. The livestock manure was applied at the rate of N-P<sub>2</sub>O<sub>5</sub>, 8.8–12.5 kg/10a. The OF2 and OF3 sites were fertilized twice a year. Chinese milk vetch (*Astragalus sinicus* L.) was sown at the sites and used as the green manure. Livestock manure was applied as basal fertilizer when the sites with grown milk vetch was plowed. Then oil-cake was applied at the panicle initiation stage. About 17 to 23 duck heads per 10 a dwelled in the rice-duck farming sites of OF1 and OF3. According to Isobe et al. (2005), the duck excretion is equivalent to 0.15–0.35, 0.21–0.49 kg/10a in N and P<sub>2</sub>O<sub>5</sub>, respectively, which is minimal contribution to the farm nutrient supply. In other words, majority of nutrients was supplied as organic sources of the livestock manure, Chinese milk vetch, and oil cake. Water resources used for irriga-

tion included a nearby small stream of the Mankyeong river and groundwater in complex.

### Sampling and analysis

The soil of the organic farms was classified as Seok-cheon series, which is silty loam. The paddy soil samples were collected from the study sites after harvest in 2006. Stream sediments were also collected from the upstream inlet, middle inlet, middle outlet, and downstream outlet in Jan, Apr, Jun, Aug, and Dec in 2007 (Fig. 1). These soil samples were wind dried and sieved through a 2 mm mesh grid before soil chemical analysis following the protocol provided by the National Institute of Agricultural Science and Technology (NIAST, 1988). Available P of soil and stream sediment samples was measured by Lancaster method. Each form of inorganic P in the soil and stream sediment samples was determined by the ascorbic acid method as described by Zhang and Kova (2004).

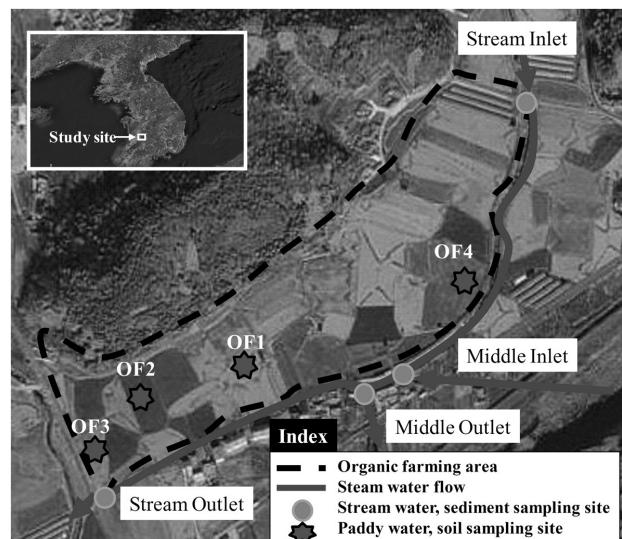


Fig. 1. Location of the study organic farm and sampling sites.

Table 1. Cultivation methods of the study organic farming area

Site	Weed control method			Fertilizer type
	before	2006	2007	
OF1	Rice-duck farming for 14 years	Rice-duck farming	-	Livestock manure
OF2	Rice-duck farming for 3 years	Rice-pond snail farming	Rice-pond snail farming	Livestock manure, milk vetch, oil-cake
OF3	Rice-duck farming for 3 years	Rice-duck farming	Rice-pond snail farming	Livestock manure, milk vetch, oil-cake
OF4	Rice-duck farming for 6 years	Rice-duck farming	Rice-duck farming	Livestock manure

Paddy water samples from the selected fields were collected once a week during the rice growing seasons and analyzed for the TN and TP concentrations from 2006 to 2007. The inflow and outflow water samples of the study site were collected from the same locations where sediment soil samples were taken. Water quality analyses followed the APHA (1992) methods.

## Results and Discussion

### Soil chemical properties

Table 2 summarized the soil properties of the study sites. The organic matter (OM), and P concentrations were higher in OF fields than national average values (RDA, 2007). Fertilization amount for the organic farms were determined based on the crop N requirement and thus excessive amount of P might have accumulated in the soils and resulted in higher P concentrations in the organic farming fields (Jin and Yoo, 1999). According to Chung and Hong (1977) and Jung *et al.* (2003), accumulation of P in paddy soils may be smaller than in plastic film house, however, the reduced environment of paddy field due to flooding may increase P availability substantially. Thus P attached to the suspended matter became susceptible to paddy runoff with rainfall events increasing P loading to the surface water bodies. Shin *et al.* (1988) reported that P in paddy soils may begin dissolving into water when soil P concentration is greater than 232 mg P<sub>2</sub>O<sub>5</sub>/kg. In this study, the P concentrations for all the organic farming soils appeared to exceed this concentration.

Figure 2 shows concentration changes for each phase of phosphorus in paddy soils. The mean TP concen-

trations of OF1, OF2, and OF3 soils were 1110, 776, and 811 mg/kg, respectively. OF1 of which organic farming period was 15 years showed much greater P content compared to those of the other two sites of five years organic farming. This indicates that P may accumulate in paddy soils with longer organic farming practices.

The inorganic P concentration of organic farm soil was higher in the order of Fe-P (317~445 mg/kg), residual-P (256~402 mg/kg), Al-P (123~194 mg/kg), Ca-P (51~61 mg/kg), and soluble and loosely bound P (2.2~2.8 mg/kg). The greatest Fe-P content was consistent with the previous study by Chang and Chu (1961). This study has reported that Al-P content is greater than Fe-P at the fertilization and then tends to decrease while Fe-P content increases with time.

A reduced condition when paddy field is flooded renders P combined with Fe readily soluble and thus increases dissolved P content in paddy water (Nriagu,

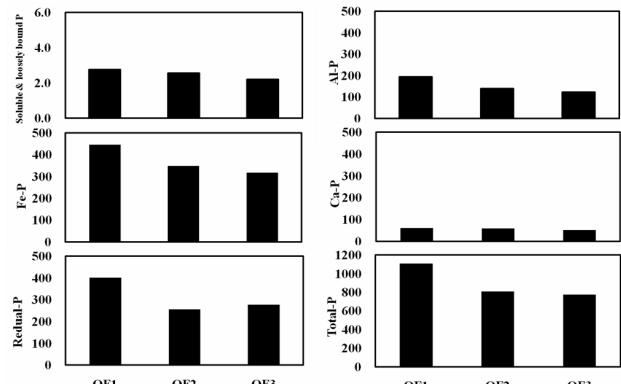


Fig. 2. Fractionation of inorganic phosphorus in organic paddy farm soil (unit: mg P/kg).

Table 2. Soil chemical properties of the study paddy fields

2006 year	pH (1:5)	EC (dS/m)	TN (g/kg)	OM (g/kg)	Avail. P (mg P <sub>2</sub> O <sub>5</sub> /kg)
OF1	5.9	0.27	2.52	28.1	477
OF2	6.0	0.30	2.51	35.9	258
OF3	5.9	0.27	2.41	27.1	328
2007 Year	pH (1:5)	EC (dS/m)	TN (g/kg)	OM (g/kg)	Avail. P (mg P <sub>2</sub> O <sub>5</sub> /kg)
OF2	5.9	0.29	3.27	36.9	259
OF3	5.9	0.45	2.64	31.7	272
OF4	5.8	0.28	1.79	28.2	258
National Average*	5.8	-	-	24.0	132

\*RDA (2007)

1972). Thus Fe-P increase in paddy soils due to long-term livestock manure application may elevate P content in paddy water.

A substantial amount of accumulated P seemed to exist as residual-P, which is the amount of TP subtracted by inorganic P (Jun and Park, 1989). The residual-P for the organic farm soils varied from 256 to 402 mg/kg. The accumulated residual-P over long-term application of the applied livestock compost and organic fertilizer seemed to serve as P source to supply inorganic P for paddy water through a time-rated mineralization process.

### Stream sediment chemical properties

Sediment runoff from agricultural fields can affect water quality as well as aquatic ecosystems through attached nutrient dissolution by various processes of decomposition, diffusion, re-suspension, and biological disturbance (Lee and Lee, 2000).

The mean OM concentrations of stream sediment were 15.9, 18.9, 9.5, and 33.9 g/kg for stream inlet, middle inlet, middle outlet, and stream outlet, respectively (Table 3). The mean TN were 1.0, 1.0, 0.6, and 2.0 g/kg, correspondently, showing lowest in the middle

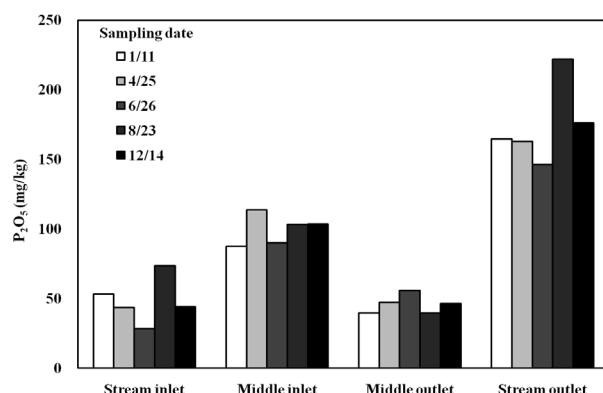
outlet and the highest in the stream outlet. The mean values of available P were 49, 100, 46, and 174 mg P<sub>2</sub>O<sub>5</sub>/kg for stream inlet, middle inlet, middle outlet, and stream outlet, respectively, indicating P accumulation at the stream outlet. This phenomenon probably resulted from the gate regulation of water flow at the middle outlet. The gate was closed for most of time and opened during rainfall events. High flow velocity occurring during rainfall discharge entailed suspended matter as well as sediment runoff at the outlet. As the runoff water reached the stream outlet where the stream slope becomes slow, much of suspended loads settled down along with particle-adsorbed matter including P (Fig. 3). This proves why sediment at the steam outlet was observed to contain high P content. The P content from OF paddy soils was discharged with paddy water runoff and accumulated in the drainage waterways causing a more slow flow near the stream outlet.

### Paddy water quality

The concentrations of TP and TN in OF paddy water increased gradually at the first 2-3 weeks after rice transplanting and then decreased gradually during the following rainy season (Fig. 4). This trend was different from that of conventional farms, which in general demonstrated rapid increase in TN and TP concentrations over a short period time after chemical fertilization (Cho *et al.*, 2006; Hong and Kwun, 1998; Seo *et al.*, 2002).

After flooding paddy field, the paddy environment with increased water temperature and pH and decreased redox potential seemed to facilitate the dissolution of P combined with Fe or Al and thus increase P content in paddy water (Koski-Vahala and Hartikainen, 2001; Kim *et al.* 2010).

Overall TN concentrations for the organic paddy fields ranged from 0.28 to 5.95 mg/L and the mean concentrations varied from 1.72 to 2.55 mg/L depend-



**Fig. 3. Seasonal change of available phosphorus content in sediment.**

**Table 3. Chemical properties of sediments in the stream inlets and outlets**

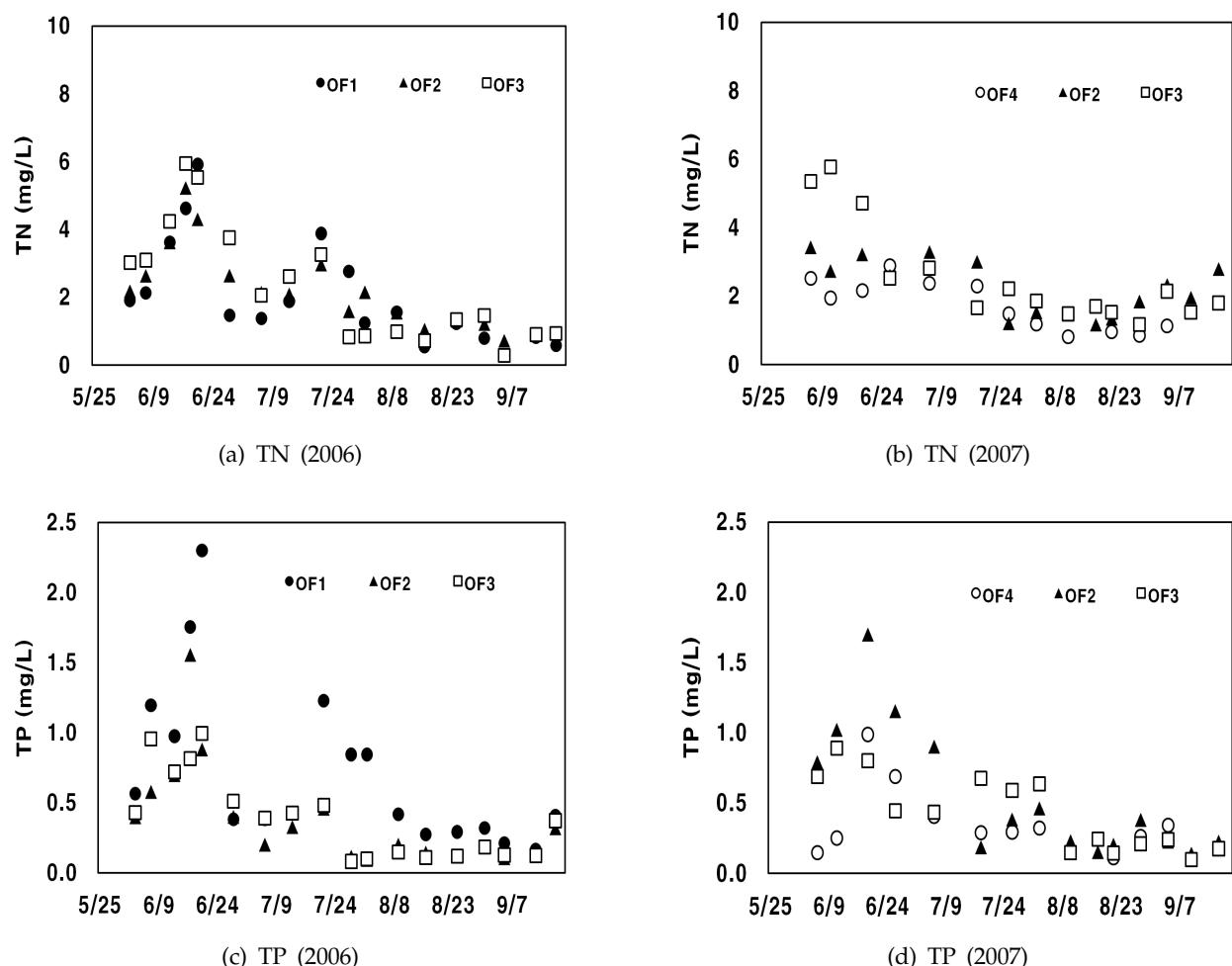
Sample locations	pH (1:5 H <sub>2</sub> O)			EC (dS/m)			TN (g/kg)			OM (g/kg)			Avail. P (mg P <sub>2</sub> O <sub>5</sub> /kg)		
	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
Stream inlet	6.8	7.3	6.6	0.30	0.43	0.16	1.0	1.7	0.6	15.9	29.8	6.4	49	73	28
Middle inlet	6.7	7.2	6.4	0.18	0.28	0.10	1.0	1.8	0.3	18.9	29.4	6.3	100	114	87
Middle outlet	7.3	7.4	7.2	0.10	0.20	0.05	0.6	1.0	0.2	9.5	16.8	2.8	46	56	40
Stream outlet	6.5	7.0	6.2	0.38	0.62	0.24	2.0	2.2	1.4	33.9	39.9	29.2	174	222	146

**Table 4.** TN and TP concentrations of water from the study paddy sites over the two-year period (unit: mg/L)

2006 year	TN			TP		
	Avg	Max	Min	Avg	Max	Min
OF1	2.04	5.92	0.30	0.72	2.30	0.17
OF2	2.17	5.22	0.72	0.38	1.55	0.09
OF3	2.32	5.95	0.28	0.39	0.99	0.08

2007 year	TN			TP		
	Avg	Max	Min	Avg	Max	Min
OF2	2.26	3.43	1.16	0.43	0.89	0.10
OF3	2.55	5.77	1.17	0.54	1.70	0.14
OF4	1.72	2.89	0.81	0.35	0.99	0.11

**Fig. 4.** Temporal change in TN and TP concentrations for the organic paddy water (2006-2007).

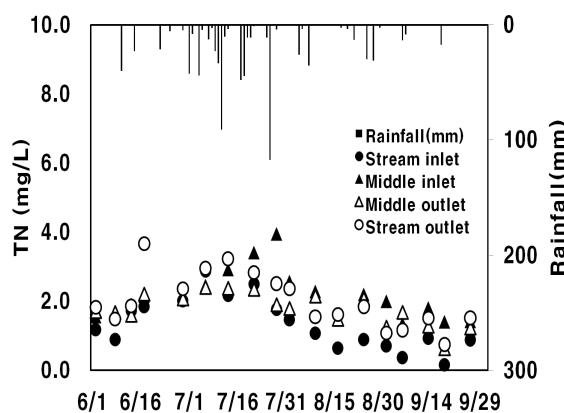
ing on the cultivation years and methods (Table 4).

The TP concentrations of paddy water varied from 0.08 to 1.70 mg/L (0.35 to 0.54 mg/L on average) and from 0.17 to 2.30 mg/L (0.72 mg/L on average) in fields after 4 and 15 years organic farming, respectively. The

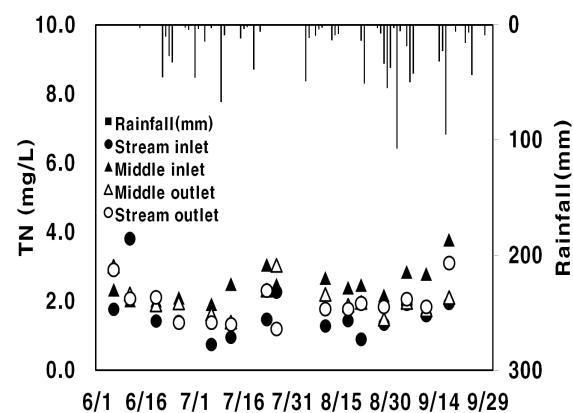
TP concentration after 15 years organic farming was nearly twice as high as that of 4 years organic farming which implies that P has accumulated in paddy soils with continuous application of livestock-compost manure over a long period of time.

**Table 5.** TN and TP concentrations in stream water during the growing seasons in 2006 and 2007 (unit: mg/L)

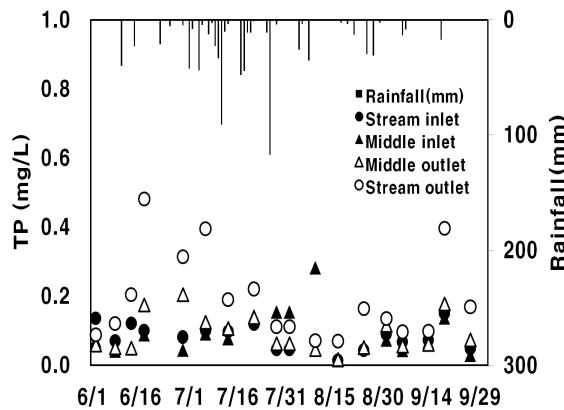
Sampling location	2006					2007						
	TN		TP		TN		TP					
	Avg	Max	Min									
Stream inlet	1.34	2.88	0.16	0.08	0.15	0.02	1.60	3.81	0.74	0.06	0.11	0.04
Middle inlet	2.15	3.95	1.35	0.09	0.28	0.01	2.46	3.07	1.91	0.07	0.14	0.02
Middle outlet	1.77	2.40	0.63	0.09	0.21	0.02	2.04	3.04	1.40	0.07	0.15	0.04
Stream outlet	2.01	3.67	0.75	0.19	0.48	0.07	1.90	2.91	1.20	0.16	0.38	0.05



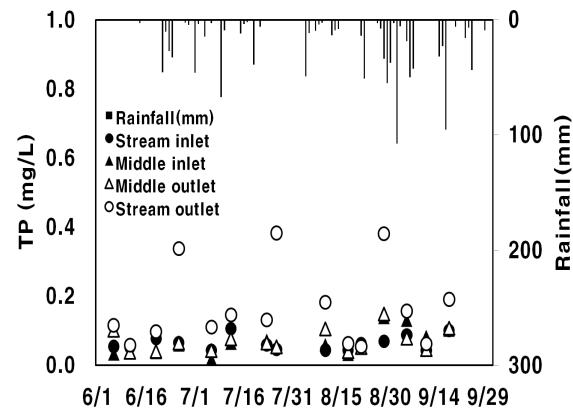
(a) TN (2006)



(b) TN (2007)



(c) TP (2006)



(d) TP (2007)

**Fig. 5.** Temporal change in TN and TP concentrations for the site inlets and outlets.

### Stream water quality

The mean TN concentrations of stream water ranged 1.34~1.60, 2.15~2.46, 1.77~2.04, and 1.90~2.01 mg/L for respective stream inlet, middle inlet, middle outlet, and stream outlet (Table 5). As shown in Fig. 5, overall TN concentration was highest at the middle inlet where the Mankyeong river water diverted into the study area as irrigation water. This indicates that organic farming has a minimal effect on stream TN concentration.

However, TP concentrations at the stream outlet ranged from 0.16 to 1.19 mg/L which was substantially elevated probably owing to organic farming practices. This was approximately two-fold higher than 0.06~0.08, 0.07~0.09, and 0.07~0.09 mg/L from stream inlet, middle inlet, and middle outlet, respectively. The TP concentrations at the stream outlet appeared to be closely related with rainfall events. In other words, TP concentrations were rapidly elevated during major rain-

fall events (see the peaks in Fig. 5) and decreased rapidly afterward. During rainfall events, suspended matter and sediment runoff became the major source of the stream TP elevation. Continuous application of livestock compost or similar organic material may result in TP accumulation in paddy soils and thus runoff water containing high P content should be fully taken into consideration. Application of compost containing lesser P with N complementation could be a good fertilizer management option for organic farming paddy fields.

## Conclusion

Phosphorus content of paddy soil and water in organic farming fields increased with organic farming period. Phosphorus accumulation in surface paddy soil was observed and resulted in the elevation of P concentrations in sediment and water at the stream outlet during rainfall runoff event.

Long-term application of livestock compost for organic farming may cause P accumulation in farm soils, which could be discharged with rainfall runoff of containing suspended matter and sediments. Thus P management application should be considered in order to minimize the environmental problems as affected by excessive accumulation of P in organic farming soils.

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