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The fate of nitrogen compounds and heavy metals in studied semi-closed organic paddy fields

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ABSTRACT

Agricultural development, cultivation management, and the application of fertilizer have affected the environment to such extent that organic farming has become an adopted trend to reduce the negative impact of all these factors. For a paddy field system, implemented activities in cultivation management are the essential factors that build up man-made materials such as nitrogen compounds and heavy metals. In this paper, we studied a non-polluted, low population density farming area, which is located within a semi-closed like valley where dry/wet deposition is the only natural source of nitrogen compounds and heavy metals. However this source can be ignored if it is compared to an applied organic fertilizer used in farming activities at the studied site. Cultivation management and field sampling in three organic paddy fields were conducted to investigate the outcome of organic farming. During the three-year study, concentrations of nitrogen compounds and heavy metals in the paddy fields, after a certain stage of cultivation, were reported. Seasonal soil and water samples were taken from the studied site to compare the trends of nitrogen compounds and heavy metals in both organic and conventional farming. The results indicated a higher ammonium nitrogen transfer rate by using an organic fertilizer, and the detected heavy metals in the soil were matched with the constituents of the applied fertilizer.

Keywords: Organic rice farming; Fertilizer; Nitrogen compounds; Heavy metals

1. Introduction

Fertilizers are classified in two categories: one is chemical (synthetic) and the other is organic. A chemical fertilizer is synthesized, which is of low cost and is easy to use. It has been well studied that a chemical would cause fertilizer depletion of trace minerals in soil, acidified soil, and contaminate water resources. Organic farming has been developed after concerns were voiced against the widespread use of synthetic agrochemicals by conventional farming spraying synthetically manufactured pesticides. Synthetic agrochemicals have been reported with potentially high toxicity to human beings and animals and they persist in the environment. The definition of organic farming by the International Federation of Organic Agriculture Movements is "Organic farming is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects." In general, organic fertilizers are used for organic farming only when it is

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necessary to improve soil biodiversity and to gradually increase soil productivity. An organic fertilizer has been proved to be of the slow-release type and is more effective over a long period of use than a chemical fertilizer. On the contrary, conventional farming is conducted using pesticides or insecticides to augment production. According to the US Department of Agriculture, Natural Resources Conservation Service, it was estimated that conventional farming corporations gained a fourfold return on their money using pesticide controls in the US.

Rice paddy fields are the largest man-made wetlands on earth and such fields are the most common crops used for cultivation in Taiwan and Asia. In a conceptual mass balance model, precipitation, irrigation, fertilizers, and agrochemicals are the major input into the paddy fields, and rice production is the expected output [1]. In the paddy field system, the nitrogen balance, either in the soil, water or atmosphere was reported [1–4]. The analysis of nitrogen (NH_4^+, NO_3^-, and NH_3) that had gone through chemical or biological mechanisms, such as nitrogen fixation, denitrification and leaching was also performed [2].

Two rice-growing seasons were studied and it was reported that high concentrations of nitrate–N (NO_3^-–N) in the irrigation water had contributed to the high input of nitrogen at the studied site. The nitrification process in the paddy field took place in the rhizosphere; however, in the monsoon season or flooding stage, leaching or biochemical processes in the soil may have induced losses of nitrogen and fertilizer [5,6].

To save inputs and to shorten the lag period in farming management, a comparison study between the conventional soil puddling management and an achievable amount of cultivation by reusing the pre-harvested crop residue without removing it (i.e. zero tillage) was reported [7]. Moreover, due to the overuse of synthetic fertilizers and agrochemicals, organic farming is becoming more popular in the cultivation of rice. In a study of 25 samples of agricultural soil surface in India, the organic amendments, such as livestock manure and inorganic fertilizer, were the two major input sources of nitrogen which had contributed up to 77% of the total nitrogen concentration followed by atmospheric deposition and nitrogen fixation [8]. Organic amendments, such as animal compost, straw management, and organic fertilizer, were the major factors for soil fertility and may usually enhance crop yields, while applying animal compost could achieve the highest annual surplus of nutrients [3,9,10].

Besides nitrogen, heavy metals are the other input materials of concern into the paddy field system. Most of the heavy metals in the paddy soil may come from organic/inorganic amendments or fertilizer, which contains a mixture of heavy metals with dissimilar concentration. Other sources may come from agrochemicals, anthropogenic pollutants, or may occur due to different soil textures. Either chemical or organic fertilizers that were used in intensive and extensive farming contain not only the primary nutrients (N, P, K), but also have some concentrations of heavy metals as the secondary or micronutrients [11–13]. Unlike the foliar application, the fertilizer that was classified as "BT NPK" was used for basal, top-dressing, and in extensive farming, which contained nutrients (N, P, K) and heavy metals [13]. The researchers analyzed eight kinds of "BT NPK" whole fertilizers and reported that Cu, Zn, Cd, Cr, and Pb had concentrations (in $mg\,kg^{-1}$) ranging between 9–261, 12–650, <0.3–8.1, <5–95, and <3–4, respectively. However, heavy metals tend to accumulate in the soil due to absorption or chemical reactions and are hard to be completely biodegraded, absorbed by plants, or removed by weathering effects. An input–output balance of cadmium in a contaminated paddy field was studied and a negative balance reported for Cd; they concluded that the major factors involved in input and output were the applied fertilizer, manure compost, uptake by rice plants, and water management [14].

Most of the organic amendments were composted manure, straw materials, and agricultural waste that may contain heavy metals. The applied composted amendments reacted with humic substances in the field forming insoluble, stable complexes that reduced the mobility of metals. However, many researchers reported that heavy metal accumulation in a contaminated paddy soil may be absorbed by the exposed crops and different species of rice [15–19]. In a study conducted on semolina samples, the researchers reported that, in the top soil (0–20 cm), heavy metals, such as Cd, Cr, Cu, Pb, and Zn, had average concentrations (in $mg\,kg^{-1}$) of 0.3, 16.6, 43.4, 38.1, and 82.6, respectively [20]. Li et al. [3] reported that in agricultural soils of the Pearl River Delta, China, Pb concentrations were 20% higher than in natural soil. They conducted a study about the content of Pb in paddy soil and reported that the top soil (0–20 cm) of the studied sites had total Pb concentrations of 56.8 and $46.3\,mg\,kg^{-1}$ in Ultisol and Inceptisol in the Zhejiang province, respectively [21].

Other researchers have also conducted tests on experimental plots with different designated levels of heavy metal concentrations and studied their distribution in different rice growth periods in which they reported wide ranges of heavy metal distribution in the soil or plants [22]. Due to geographical differences, most of the researchers conducted their studies over a vast area of land [23–26]. However, the outcome of nitrogen compounds and heavy metals for organic farming in a small and semi-closed like valley was seldom reported. Therefore, to investigate the fate of these compounds, we conducted the study in the Ce-Tao Creek community to learn of the possible environmental influences caused by organic farming, which is an organic rice producing valley in eastern Taiwan.

2. Materials and methods

2.1. Study site

The experiments were conducted in the paddy fields at the Fongnan Village in Fuli Township, Hualien County, Taiwan. This village is located at the foothills of the highest peak of the Central Mountain Range whose altitude is above 3,900 m, and the slope of the studied area is 30˚. Moreover, the area has a prevailing northeast wind, so it can be assumed that any long-range transportation of material from the western part of Taiwan or China can be ruled out. The annual precipitation is reported to be more than 2,400 mm by the Central Weather Bureau, Taiwan. Rice cultivation was carried out twice a year during the years 2006–2008.

The population of the studied site is only about 800 people and agricultural cultivation is their major economic activity. Fig. 1(a) shows the mountainous terrain of the Ce-Tao Creek catchment which has an area of only 9.08 km^2, while the contours range from 300 m (west) up to 1,686 m height (east). The studied community is located in the southwest corner of the catchment and their only water source for irrigation comes from the catchment. Fig. 1(b) shows the sloping terrain (about 30˚) of the studied rice cultivation area, which is located along the Ce-Tao River that runs downstream to the farming community. During our study period (2006–2008), 14 rice cultivation plots were located within this site, seven cultivaors were contracted for organic rice cultivation and the other seven cultivators were conventional rice planters located on the eastern side of the Ce-Tao River. These 14 organic cultivation plots are located at the catchment of the Ce-Tao River, and the total cultivation area is 5 ha. The studied plots A, B, and C are organic cultivation plots having their very own irrigation facility. The color of the surface soil in the studied plots is darker, implying a certain level of organic component. The subsoil was mixed with yellow and gray hues, which reflect good aeration and drainage for the activity of aerobic organisms in soil. The soil is mostly composed of clay and mixed with a little silt in a location where rice is being commonly grown for decades. The average pH of the soil is 5.79, which is slightly acidic. The organic matter content is in the range of 3–4% in the nearby area.

In Taiwan, rice is generally harvested twice a year. For each harvest, the rice production rates in these plots are about 5,400–6,000 kg ha^{-1}, regardless of organic or conventional cultivation. However, organic cultivation is being promoted to reduce the release of synthetic agrochemicals that are used against any pests in the environment. In addition, Fig. 1 shows three organic studied plots (A, B, and C) where the soil samples were taken. Water samples were taken from the sites upstream and downstream (C1, C2, and C3) along the irrigation channel. There are several conventional cultivation plots located at the eastern side of the Ce-Tao River. Therefore, there are different irrigation systems for both organic farming and conventional farming in the studied area. In order to make a comparison of the water quality between organic and conventional rice cultivation, water samples were taken from three sites (R1, R2, and R3) in separated irrigation water sources for conventional rice cultivation, which is the Ce-Tao River as shown.

2.2. Cultivation management

Based on the geographical location of the studied area, we concluded that the major sources of input elements to the paddy fields were the applied organic fertilizers, while nutrient sources from natural dry/wet deposition can be discounted. Cultivation management records were important sources of information to discover the related input materials in the system. The organic fertilizer and amendments were the main sources of primary nutrients (N, P, K) and secondary nutrients (heavy metals) for rice cultivation. There were two cultivation stages each year that were January–June and July–December, unless they were affected by natural calamities. Table 1 shows a typical organic rice cultivation sequence of the studied plots. The adopted organic management practices after plowing were in the sequence of first time basal fertilization before transplanting followed by a double sequence of topdressing fertilization on the 20th and 40th days and panicle fertilization on the 60th day.

However, depending on the in situ conditions, 4–6 times of topdressing fertilization might be implemented; generally, there was about 4,500 kg $ha^{-1}year^{-1}$ of organic fertilizers applied. It should be noted that there were no identical brands of fertilizers used by farmers and thus we were unable to track down the chemical contents of all the different kinds of fertilizers. However, according to the reported categories of fertilizers [27], the most commonly used fertilizers in

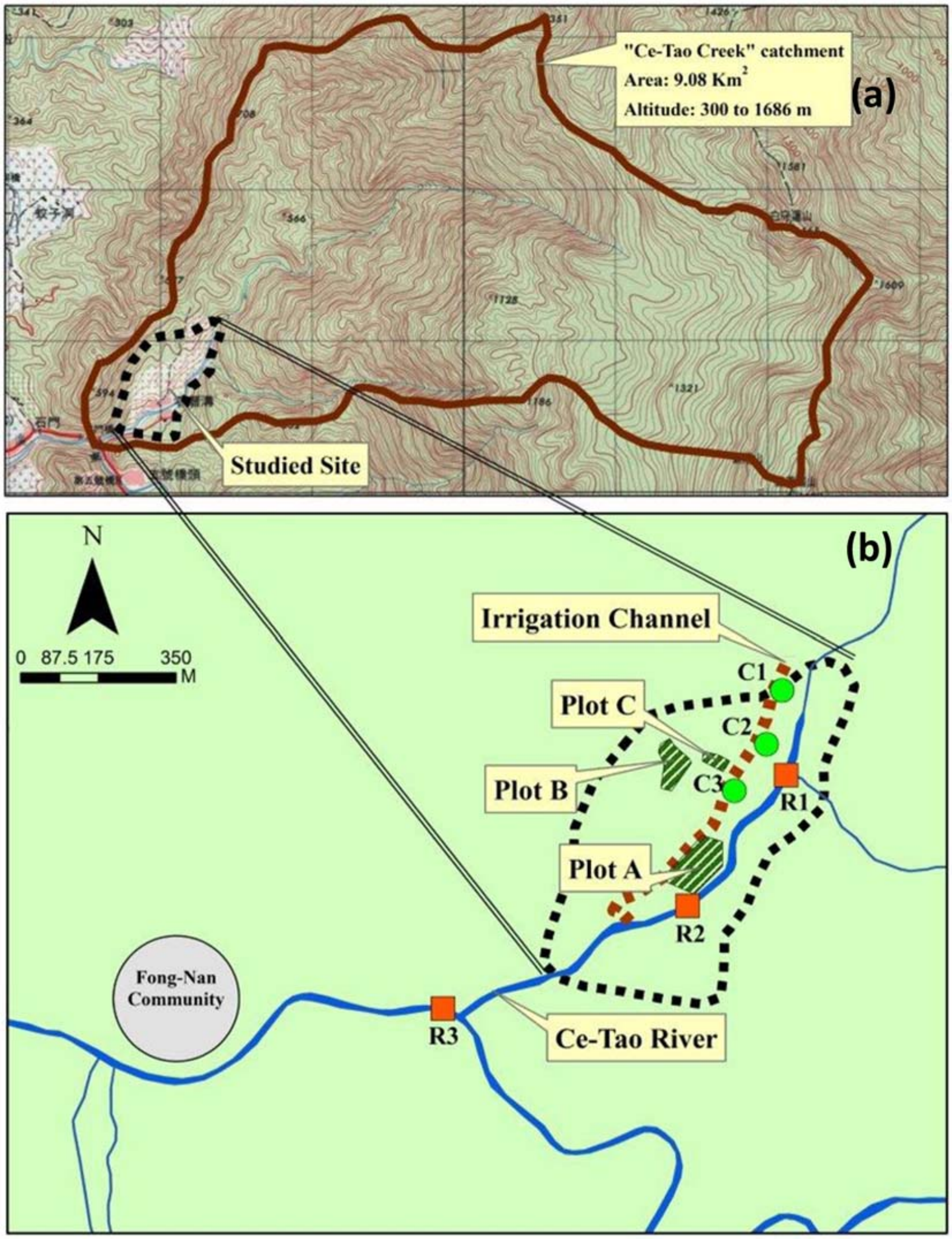

Fig. 1. (a) The mountainous terrain of the Ce-Tao Creek catchment and (b) the studied rice paddy fields.

this area, such as Fu-So™ or Fu-So #7™, were officially named "miscellaneous compositing material, No. 5-11." For example, the major content of the listed fertilizer (Fu-So #7™) are wood chippings, residues of sugarcane and soybean oil extraction, rice bran, and wood chippings for mushroom cultivation. Table 2 lists the chemical content of fertilizer Fu-So #7™ that was analyzed on three different occasions, which shows minor differences but all within the range of legal limitations. The heavy metal contents are in the sequence of Zn > Cu > Cr > Ni, the results of which are similar to those of the reported organic fertilizers of Hasegawa et al. [9] who studied the on-farm assessments of organic amendments.

Table 1
Typical organic rice cultivation sequence of the studied plot

Month	Implemented process	Flooded water level (cm)
January (1st stage)	• Plowing • Fertilizing: 1. (Green manure (12 kg, Brassica capestris or Brassica napus) 2. Basal (Fu-So^{TM} 2000 Kg) • Weeding • Transplanting • Pesticide control of "Pomaceacanaliculata" (using "Oil tea residue")	Max. 25 Min. 10
February	• Irrigation • Weeding	Max. 25 Min. 20
March	• Irrigation • Weeding • Topdressing: 1. Fu-So ^{TM}600 Kg	Max. 20 Min. 15
April	• Irrigation • Panicle fertilization: 1. Fu-So-*zu-yo*^{TM}600 Kg	Max. 20 Min. 15
May	• Pesticide control of "Rice blast" (using "Sugar-acetate") • Irrigation	Max. 15 Min. 10
June	• Pesticide control of "Naranga aenescens (Moore)" (using "Tobacco liquid")	Max. 10 Min. ~5
July (2nd stage)	• Harvesting (1st stage) • Plowing (2nd stage) • Fertilizing: 1. Basal (Fu-So 7#^{TM} 2000 Kg)	Max. 25 Min. 20

2.3. Sampling and analysis

Table 3 lists the investigated cultivation sequence of the studied plots during the sampling time (2007–2008), which indicated similar but not identical stages of cultivation, plotting area, and applied fertilizer. Water samples were collected by using a 1 l high density polyethylene bottle, stored at low temperature, and analyzed within 24 h. A single gravity corer and sludge sampler (AMS, Inc.) were used to collect about 1 kg of topsoil and two samples were randomly taken from each studied plot (the average area of each plot is 0.35 ha). Water samples were analyzed according to the published methods, which are the ammonia-selective electrode method (NIEA W446.52C) and spectrophotometer method (NIEA W419.50A) for ammonia–N and nitrate–N, respectively [28].

Soil samples were pre-washed by using ultrapure water and air-dried within a hood before analysis. The analysis methods for ammonium–N, nitrate–N, and heavy metals in soil samples were conducted using the salicylate–hypochlorite method [29], the chromotropic acid spectrophotometer method [30], and the aqua regia digestion method (NIEA S321.63B), respectively. Heavy metals in the digested soil samples were analyzed using atomic absorption spectroscopy (PerkinElmer AA-400), an ammonia electrode

Table 2
Analyzed chemical content of fertilizer Fu-So #7™*.

Primary nutrients (% w/w)								
	T–N		T–P_2O_5		T–K_2O		Organic content	
Data 1	4.2		3.5		1.8		78.5	
Data 2	4.3		3.4		1.7		76.9	
Data 3	3.93		3.4		2.03		75.7	
Limitation	>0.6		>0.3		>0.3		50	
Secondary nutrients (mg kg^{-1})								
	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Data 1	1.8	0.0,007	19	21	0.045	10	0.0,064	59
Data 2	3.0	0.33	17	19	0.29	11	2.3	63
Data 3	2.33	1.47	14.9	18.5	0.02	5.8	1.22	75.8
Limitation	<50	<5	<150	<100	<2	<25	<150	<800

*Recommendations and Regulations of Domestic Organic Fertilizer Products. Council of Agriculture, Executive Yuan, Taiwan ROC.

(Suntex, SP-2200), a spectrophotometer (Hitachi, U-1800), and ultrapure water (≧18 MΩ-cm) device (Millipore purity, Suntex Ec-410) were routinely maintained and used to make up a standard solution. The R^2 value of calibration for NH_3–N, NO_3^-–N in the analysis of water samples was greater than 0.995; also the R^2 values for NH_4^+–N and NO_3^-–N in the analysis of soil samples were greater than 0.991 and 0.995, respectively.

3. Results and discussion

3.1. Ammonia–N and nitrate–N in irrigation water

According to the cultivation sequence in Table 3, seven series of water sampling, W1–W7, in the irrigation channel and Ce-Tao River were from January 2007 to July 2008. Fig. 2 shows the three ammonia–N and three nitrate–N concentrations in each instance of sampling for locations C1, C2, C3 and R1, R2, R3. The figure shows a similar development for these nitrogen compound concentrations, which indicated that the water quality was related to the cultivation sequence; while W4, which was the time after the panicle fertilization, had the highest concentrations of nitrogen. Sampling site C3 is located downstream of the major rice plots of organic farming areas, where two points of high NH_3–N concentrations at sampling times W4 and W7 (Fig. 2(a)) are revealed, which were 0.17 and 1.17 mg L^{-1}, respectively. In particular, W7 showed dramatically high levels of ammonia–N, which may be due to the water sample being taken only after five days of basal fertilization at Plot C.

In addition, the flooded water levels in the paddy fields, which were verified in the rice cultivation sequence (Table 1), were especially high in January and July. The seasonal variations are not significant in the area compared to the western part of Taiwan, as the overall record of stream flow in the Ce-Tao River has been stable for the past four decades. Sheen [31] showed that the average monthly flow rate was higher from July to September in Hualien County due to the typhoon season in Taiwan. The dilution of nitrogen compounds by precipitation in the water at the studied area could be ignored. The study was performed in a semi-closed organic paddy field. The characteristics of the study area showed an abundance of precipitation in July, which is the time to start the second stage of rice cultivation sequence. Therefore, the detected high-nitrogen concentration might prove influential in overfertilization and might have been caused by the overuse of fertilizers in these plots by the time of panicle and basal fertilization.

Other than that, the detected NH_3–N and NO_3^-–N concentrations in the channel were around 0.00049–0.04 and 0.06–0.52 mg L^{-1}, respectively, while the detected NH_3–N and NO_3^-–N concentrations in the river were around 0.00052–0.06 and 0.04–0.34 mg L^{-1}, respectively. The results indicated no significant difference; however, the Ce-Tao River, which was used in conventional cultivation, had higher ammonia–N concentrations, which might indicate the dissimilarity between using chemical and organic fertilizers. Fig. 2 (b) shows that R3 is located downstream of the conventional farming rice plots, where it presented higher levels of NH_3–N and NO_3^-–N than the results in R1 and R2. In addition, the concentrations of ammonia–N and nitrate–N in water samples show higher concentrations of nitrate–N in the irrigation channel, which might indicate a higher transfer rate when using an organic

Table 3
Cultivation activities of the studied plots at time of sampling

Plot	Description	Date	Samples		Cultivation activities
			Water	Soil	
A	Plotting area 1.4784 ha	2007/07/19	W3		Basal (2007/07/07): 1,200 kg
		2007/10/15	W4	S1	Tillering stage/14 days after panicle fertilization: 200 kg
		2008/01/04	W5	S2	Harvested; no fertilization
		2008/05/30	W6	S3	14 days after panicle fertilization
		2008/07/17	W7	S4	Basal (2008/06/07); 10 days after fertilization
B	Plotting area: 0.58 ha at the time of 2007/01/27 and 2007/04/26 and 3.3696 ha after that	2007/01/27	W1		Basal (2007/01/26): 720 kg
		2007/04/26	W2		Topdressing (2007/03/10): 720 kg
		2007/07/19	W3		Harvested (2007/06/29)
		2007/10/15	W4	S1	Tillering stage/ panicle initiation stage (2007/09/30): 800 kg
		2008/01/04	W5	S2	Harvested (2007/12/18); no fertilization
		2008/05/30	W6	S3	Tillering stage/14 days after panicle fertilization (2007/04/16): no record
		2008/07/17	W7	S4	Harvested; no fertilization
C	Plotting area: 3.3357 ha at the time of 2007/01/27 and 2007/04/26 and 1.6309 ha after that	2007/01/27	W1		Basal (2007/01/20): 1,040 kg
		2007/04/26	W2		Topdressing (2007/04/14): 400 kg
		2007/07/19	W3		Basal (2007/07/15): 1,500 kg
		2007/10/15	W4	S1	Tillering stage/14 days after panicle fertilization (2007/09/17): 200 kg
		2008/01/04	W5	S2	Harvested; no fertilization
		2008/05/30	W6	S3	Tillering stage/14 days after panicle fertilization(2008/04/21): 500 kg
		2008/07/17	W7	S4	Basal (2008/07/13); five days after fertilization

fertilizer. However, the data strongly suggested that the N formed in the water would be dominated by nitrate–N, which may imply that rapid leaching has taken place in paddy soils. Therefore, overfertilization may become routine in rice cultivation periods.

3.2. *Ammonium–N and nitrate–N in paddy soils*

To learn more about nitrogen compounds in the soil during the reported cultivation activities, we also took two soil samples from each studied plot at four sampling times; they were S1, S2, S3, and S4 which corresponded to the dates of water sampling W4, W5, W6, and W7, respectively. In the meantime, the pH of soils was tested to analyze the acidity levels in the study fields. The pH data were in the range of 5.44–6.34, and the mean was 5.79, which was slightly acidic. Bacteria are most active for nutrient transformation in slightly acid to alkaline conditions. Therefore, the pH value in this study has no negative influence on the formation of nitrogen compounds. Fig. 3 shows the results of ammonium–N and nitrate–N concentrations in the soil for those sampling dates. In general, the trends of ammonium–N and nitrate–N were similar in Plots A and B, the results of which were consistent with the cultivation activities reported in Table 3. All the studied plots show pairs of high concentrations of ammonium–N and low concentrations of nitrate–N at the time of two weeks after panicle fertilization, which were S1 and S3; however, S2, which was the time of no fertilizer application, shows the opposite results. The results indicate the progress of absorbing the primary nutrients by the rice crop; however, guidance in the proper application of fertilizer was needed. As shown in Figure 3, S1 and S4 were times when panicle and basal fertilization had higher concentrations and that may be a sign of overfertilization. If we ignore the data of S4 in Plot C, the results show S1 had the highest NH_4^+–N and the lowest NO_3^-–N concentrations in the soil, which were

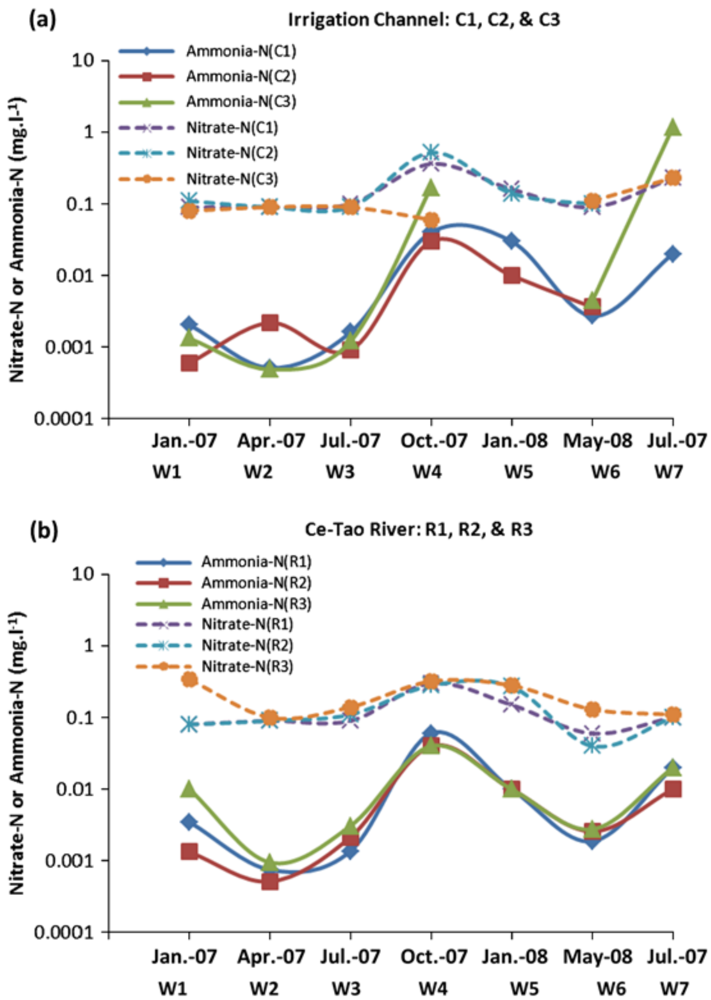

Fig. 2. Detected nitrogen compound concentrations in the irrigation water for (a) the organic and (b) conventional paddy fields.

around 5.04–8.93 and 0.61–1.24 mg kg^{-1}, respectively. Overfertilization could cause a nitrate-rich soil and will lead to a measurable amount of nitrate leaching into the aquatic system.

The results shown in Figs. 2 and 3 confirm the nitrogen cycle in irrigation water and paddy soils. These results might be related to the water sample at W4, which was the time after panicle fertilization and when higher concentrations of nitrogen compounds were detected. This thought might also confirm the detected high nitrogen concentration downstream of the irrigation channel, which was C3, at sampling times of W4 and W7. Based on the record of the cultivation activities in Table 3, we compared the monitored data of nitrogen compounds in the soil and water. The results showed the applied fertilizer may have completed the nitrification process in two weeks. Consequently, it could be used as a monitoring factor in the aquatic system near farmlands for farmers to determine the fertilization progress.

3.3. *Heavy metals in paddy soils*

To investigate the presence of accumulated heavy metals in these plots, we also conducted six runs of soil sampling, which corresponded to sampling times W2–W7. Two soil samples were collected in each plot and five heavy metals, such as Pb, Zn, Cu, Cr, and Cd, were analyzed. However, the cadmium concentration was below the detection limit for all samples, which indicated that the amount of Cd in the applied fertilizers was within acceptable limits that had been reported by previous researchers. Fig. 4 shows the box plots that illustrate the concentrations of each detected heavy metal for these three plots at different locations. The figure shows an irregular distribution of

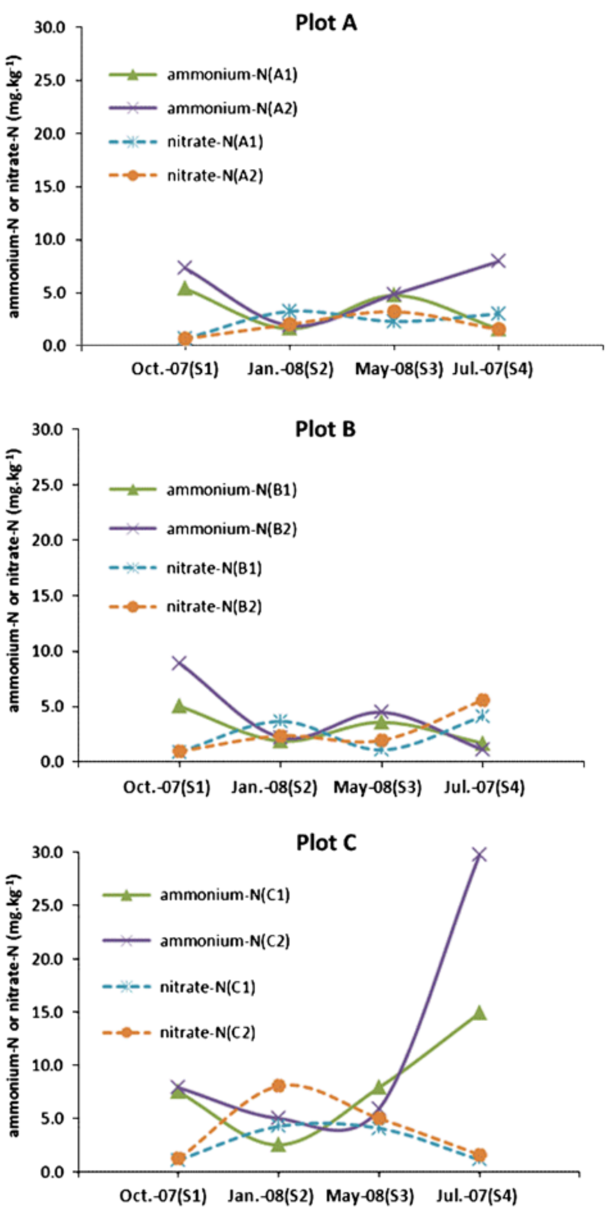

Fig. 3. Detected nitrogen compound concentrations in the soil of the three organic plots.

concentrations among plots; nevertheless, most of the detected metals illustrated similar concentration ranges at the same plot in their two sampling locations; these results indicate the dissimilarity of organic planters. Fig. 4 also shows that Zn had the highest concentration among all detected metals, which was up to about 90 mg kg^{-1} at the 75th percentile; while Cr, Cu, and Pb had detected concentrations up to about 35, 30, and 20 mg kg^{-1} at the 75th percentile, respectively. The results matched with the analyzed concentrations for Zn, Cu, and Cr in Table 2, which were 59–75.8, 18.5–21, and 14.9–19 mg kg^{-1}, respectively. Thus, we may conclude that metal concentrations in the plots were related to the applied fertilizer, which was a major input element in the system.

This thought may also be confirmed by the study of "BT NPK" fertilizer that was conducted by Otero et al. [13]. In addition, Chen [32] reported the background total concentration of heavy metals in rural soils in Taiwan, in which the result of this study is in the range of Chen's [32] report. However, the detected Pb concentration in the soil was up to about 20 mg kg^{-1}, which did not match the analyzed concentration in Table 2 which was 0.006–1.22 mg kg^{-1}. In Chen's [31] study, the mean concentration of lead in the rural soil of Taiwan was 32.6 mg kg^{-1}, which is close to our results. Zaccone et al. [20] found that topsoil (0–20 cm) from organic farming systems had a mean Pb concentration of 38.3 mg kg^{-1}. This result indicated that possible sources of this metal might have come from other organic amendments as reported by Zaccone et al. [20] and Li et al. [21].

4. Conclusions

The fate of nitrogen and heavy metal compounds in this studied semi-closed organic paddy field system had the following findings. The monitored nitrogen compound concentrations in the water indicated no significant difference between organic and conventional farming. However, the irrigation water used by conventional farming cultivation had a higher ammonia–N and a lower nitrate–N concentrations, which might indicate a distinction between chemical and organic fertilizers. It might suggest a higher transfer rate when using organic fertilizers. The nitrogen compounds in the soil and water had indicated the progress of absorbing the primary nutrients by the rice crop. Higher concentrations of nitrate–N in the water will lead to an increased denitrification rate and form more nitrous oxide, which is known to contribute to the greenhouse effect. Therefore, guidance in proper application of fertilizer was needed to avoid overfertilization. The results suggest a long-term monitoring of the dissolved inorganic nitrogen (i.e. ammonia and nitrate) in irrigation systems by the government sector may assist farmers in achieving more effective cultivation management.

The detected heavy metals in the organic plots confirmed that applied fertilizer was a major input source of heavy metals into the system and other organic amendments might also be a possible source of metal compounds. Consequently, it was concluded that appropriate fertilization management accompanied with an irrigation water monitoring system may reduce the greenhouse effect in paddy fields.

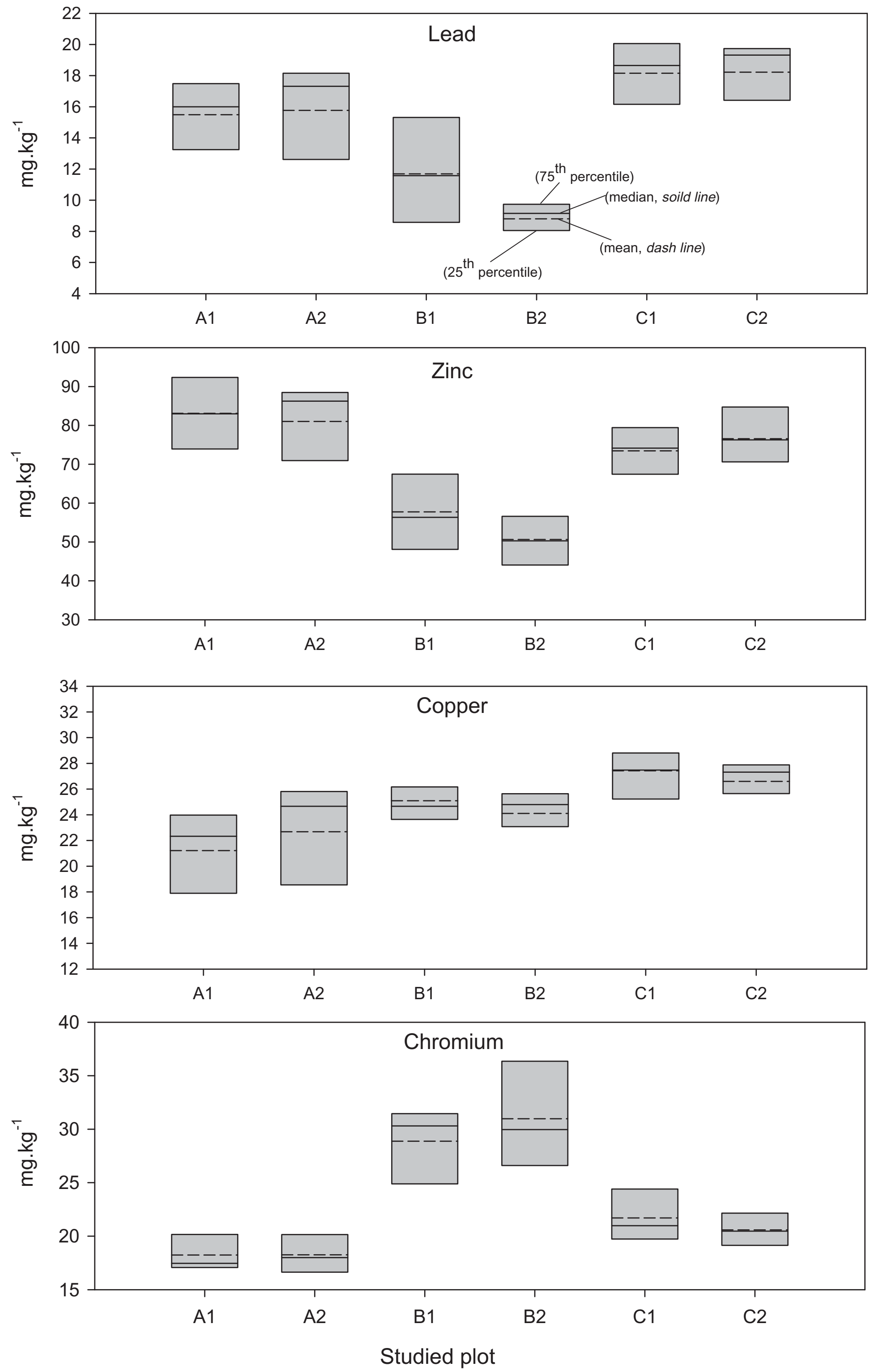

Fig. 4. Detected heavy metal concentrations in the soil of the three organic plots.

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