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Copper and Zinc Uptake by Pakchoi and Rice as Affected by Applying Manure Compost with Different Levels of Cu and Zn Concentrations

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Abstract. Cu and Zn are frequently added to livestock diets as additives to increase feed efficiency and production. This practice resulted in the higher contents of Cu and Zn in excrement of livestock. The aim of this study is to evaluate the effect of Cu and Zn concentration of manure compost and its application rates on the production and quality of pakchoi and rice. The pot experiments were conducted and the six manure compost were applied at 3 rates (20, 40, and 80 ton/ha), including the control and chemical fertilizer treatments. Results showed that the yield of the crops was enhanced by the compost application, and the Cu and Zn concentration in the edible part of crops were in normal range (pakchoi: Cu 1.8-10.4 mg/kg, Zn 39-160 mg/kg; rice grain: Cu 0.6-4.0 mg/kg, Zn 58-79 mg/kg). The potential risk of long-term manure compost application on soil quality was also evaluated. The total Zn concentration in soils may reach the regulation standard after 22 years of manure compost application at the rate of 40 ton/ha/year.

Key words: Cu, Zn, manure, compost, pakchoi, paddy rice, bioavailability.

Introduction

Soil organic matter plays a critical role in the sustainability of agroecosystem and it is also an important indicator of the soil quality and productivity. Intensive agriculture system and subtropical climate in Taiwan accelerate the decomposition of soil organic matter. Chen and Hseu (1997) reported that the organic matter contents of commonly cultivated soils in Taiwan are generally low, ranged from 1.3% to 2.4%. Therefore, the application of organic fertilizer is important for the nutrient supply in soils and maintainance of soil quality. The use of organic fertilizer has received great attention from researchers who investigated the sustainability and productivity of rural soils in last two decades (Shu and Chung, 2006).

Lots of agriculutral residues and livestock wastes were recycled for composting in Taiwan. Hseu (2004) found that the concentration of Cu and Zn in manure compost were significantly higher than the regulation of metals in the composts in Taiwan. Excessive application of manure compost may cause negative effects on the environment, such as the accumulation of salts or heavy metals in soils (Diez et al., 2001).

The objectives of this study were (1) to find out the appropriate application rate of manure compost and (2) to evaluate the potential risk of long-term manure compost application on the soil quality and the crop quality .

Materials and Methods

Pot Experiment

The pot experiment was conducted in the phytotron of National Taiwan University. The humidity was 70 to 95%, and the temperature was maintained at 25/20□ during the day and night.

Air-dried silt clay soil (3.5 kg) was thoroughly mixed with the manure compost in the 1/5000 a Wager pot. The application rates were 20, 40, and 80 ton/ha, There were 20 treatments including 18 treatments with different compost rates and a non-fertilized control treatment (CK) and a conventional chemical fertilizer treatment (CF). Seedlings of pakchoi (*Brassica rape* L., leaf vegetable) were grown in pots until harvest and followed by the growth of rice (*Oryza sativa* L.). The soil moisture content was maintained at field capacity during the growth of pakchoi. For rice, pots were flooded with 3-5 cm of water above the soil surface during the whole rice growth period. All the treatments were 4 replicates by a completely randomized design.

The pakchoi and rice were harvested after the growth of 30 days and 120 days, respectively. The soils were sampled at the same time. The shoot of pakchoi and rice grain were washed with deionized water, oven-dried at 70℃ for 2 days. All the crop samples were ground to pass through a 40 mesh sieve (<0.5 mm).

Soil bioavailability of Cu and Zn was determined by extraction by using the reagent 0.01 *M* $CaCl_2$ (soil:water = 1:10). The pakchoi or rice grain powder (0.5 g dried weight) were digested by concentrated H_2SO_4 and 30% H_2O_2 and heated at 250℃ for 30 min. The concentrations of Cu and Zn of all solutions were determined by the ICP-AES.

Statistical Analysis

Data were analyzed by analysis of variance in a factorial design. The mean values of treatments were compared by Duncan's multiple range tests. Statistical significance level was defined at $p = 0.05$.

Results and Discussion

Characteristics of Manure Compost

Table 1 showed the chemical properties of the manure compost and the studied soil for the pot experiments. The main differences of studied compost are the concentrations of Cu and Zn. The concentrations of Cd, Cr, Ni, and Pb of all studied composts were meet the regulation of composts in Taiwan and acceptable for the application into the soils (data not shown).

Cu and Zn contents of the pakchoi and rice grain

The Cu and Zn concentrations of pokchoi (Cu: 1.8-10.4 mg/kg; Zn: 39-160 mg/kg) was higher than those of rice grain (Cu: 0.6-4.0 mg/kg; Zn: 58-79 mg/kg). Generally speaking, the Cu concentration of plants is below 25 mg/kg and the Zn concentration is on 20-400 mg/kg (Epstein, 1997). The regulations of Cu and Zn in crops around the world are 20 and 100 mg/kg (Lin et al., 2002). Cu and Zn are micronutrient for crops and human. The Zn concentration of pakchoi tissue was 123 mg/kg under the treatment of CF, which was similar to those of all other treatments of manure compost. Furthermore, no adverse effects were found on the growth and production of pakchoi. The Cu and Zn concentrations of rice grain were not enhanced by the application of manure compost, even the total Cu and Zn concentrations in soils was increased (Figure 1).

Soil bioavailability of Cu and Zn after compost application

After the compost application, the total Cu and Zn concentrations of soil were significantly increased (data not shown). The concentration of extractable Zn is positively correlated with the total Zn in soil (42-131 mg/kg) (Figure. 2a). A good correlation between the bioavailable Zn in soil and the Zn concentration in pakchoi is observed (Figure. 2b). This may be explained by the high mobility of Zn in soils. The same findings were reported in the previous study (Zhou et al., 2005). The Zn concentration in rice grain showed no correlation with the bioavailable Zn in soil. Rice was cultivated in the flooded system and the reduction reaction might increase soil pH. This may decrease the mobility of Zn in soils. Although the total Cu concentration in soil is elevated (15 – 52 mg/kg), the level of Cu in rice grain is at normal range (Figure 1b). The increase of soil pH in the flooded situation and the strong binding of Cu and the organic matter might contribute to the immobilization of Cu in soils.

The effect of long-term application on the soil quality and the food safety

The data supported the fact that the crop yield was enhanced by compost application, while the Cu and Zn concentrations in soils were also increased in those treatments. Therefore, it is necessary to assess the risk of long-term compost application on the crop safety and soil quality. Two approaches were taken in this study: (1) to evaluate the potential accumulation of Cu and Zn in pakchoi to evaluate the maximum compost application capacity of the soil and (2) to estimate the soil accumulative application capacity of the compost based on the Cu and Zn regulation standard of Taiwan rural soil.

(1) The Zn concentration in plant tissue is varieties dependent, 25-400 mg/kg is recognized as normal ranges (Pendias and Pendias, 2001; Epstein, 1997). Cu and Zn are microelements but essential elements for crops. We assumed the regulation value of pakchoi is 200 mg/kg (as y axis), then the regression formula can be listed as following:

$$y = 59.78x + 29.39 \text{ (Figure 2b)}$$

We got x= *2.85 mg/kg* as soil extractable Zn concentration. Furthermore, it may be reasonable to access the total Zn concentration (as x axis) in soil by applying 2.85 mg/kg (as y axis) into the formula subjecting to:

$$y = 0.0148x - 0.4497 \text{ (Figure 2a)}$$

We got x=*223 mg/kg*. The result implied that when the total Zn concentration of soil approached to 223 mg/kg by compost application, the $CaCl_2$ extractable Zn concentration in soil might around 2.85 mg/kg. This may result in Zn concentration in pakchoi reached to around 200 mg/kg, which is still recognized as safety.

(2) The soil function to attenuate the heavy metal toxicity should be taken into account. Therefore, the maximum loading capacity of compost can be estimated. According to the Soil and Groundwater Pollution Remediation Act of Taiwan EPA, the regulation of Cu and Zn of rural soil is 200 and 600 mg/kg, respectively.

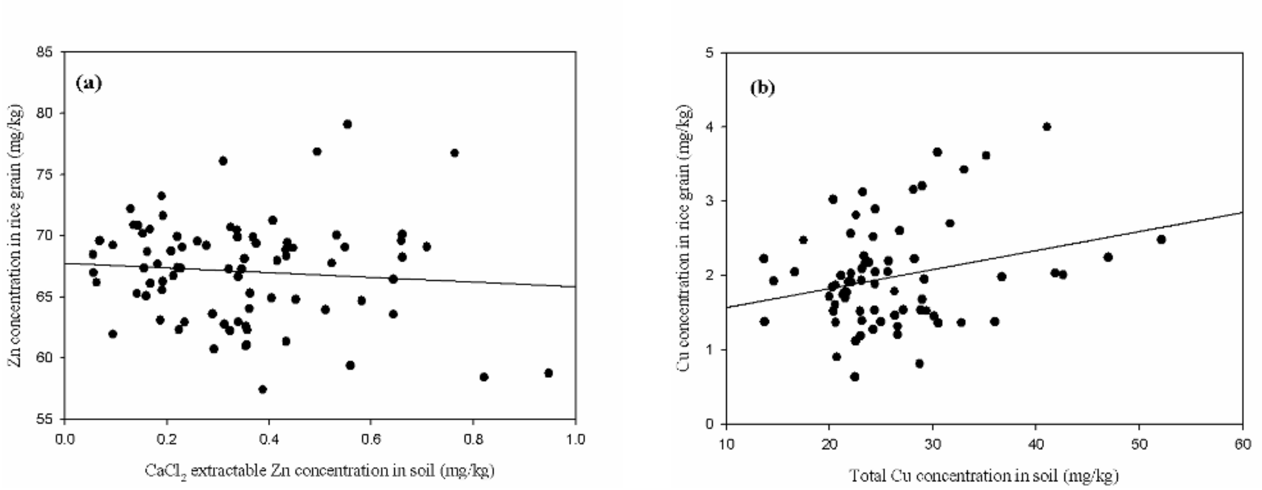

Fig. 1. The relationship between (a) $CaCl_2$ extractable Zn concentration in soil and Zn concentration in grain; (b) Total Cu concentration in soil and Cu concentration in grain. (All treatments in a plot).

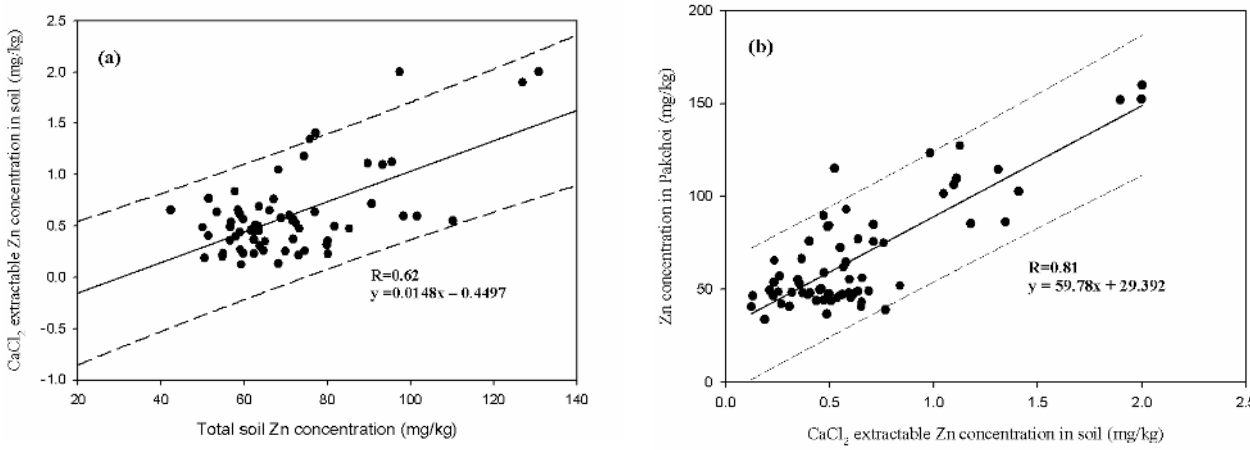

Fig. 2. The relationship between (a) Total Zn in soil and $CaCl_2$ extractable Zn concentration in soil; (b) $CaCl_2$ extractable Zn in soil and Zn concentration in pakchoi. (All compost treatment in a plot, the dash lines represent the prediction of interval.).

Table 1. The physical and chemical properties of the soil and the compost.

Composts/soil	pH	EC	OM†/OC‡	Cu	Zn	Texture
		dS m^{-1}	%	----- mg kg^{-1} ----		
Compost A	6.9	5.5	93.1†	34	104	-
Compost B	6.3	10.6	63.9†	111	398	-
Compost C	7.4	4.9	49.6†	136	312	-
Compost D	6.4	3.4	71.1†	156	520	-
Compost E	6.5	8.8	54.2†	560	766	-
Compost F	4.8	12.5	85.5†	321	1213	-
Soil	5.3	0.58	2.1‡	15	49	Silt clay

†: OM: organic matter; ‡: OC: organic carbon.

In this case, the maximum loading capacity of Cu is 185 mg/kg (200 subtracts 15) and Zn is 551 mg/kg (600 subtracts 49). Considering 2000 ton/ha soil in the agricultural soils (top soil 15 cm depth), the Maximum loading capacity of metals in soil for Cu is 370 kg/ha and Zn is 1102 kg/ha. Maximum application rate of compost can be calculated as followings:

Maximum application rate (ton/ha) = [Maximum loading capacity of metals in soil (kg/ha) / heavy metal concentration in the compost (mg/kg)] × 1000

For example, the compost F with Zn 1213 mg/kg, and the maximum application rate is thus 908 ton/ha. This implied that at the application rate of 40 ton/ha/year, it will take 22 years of application to increase the total Zn concentration in soils to reach the regulation standard.

Conclusion

Manure compost with the large range of Cu (34-560 mg/kg) and Zn (104-1213 mg/kg) concentration were applied at 20, 40, and 80 ton/ha/year. Both the yield of the pokchoi (leaves vegetable) and rice grain were enhanced by the application of manure compost. The yield of rice grain was further increased at higher application rate. The Cu and Zn concentration of crops were slightly increased by the application of manure compost, but they were still acceptable, pakchoi (Cu: 1.8-10.4 mg/kg; Zn: 39-160 mg/kg), rice grain (Cu: 0.6-4.0 mg/kg; Zn: 58-79 mg/kg). The mobility of Cu and Zn of the paddy soil was decreased, while the soil bioavailability of Zn was increased in the compost treatments in the rural soil. Our evaluation indicated that the total Zn concentration of soils may reach the regulation standard after 22 years of manure compost application by the application rate of 40 ton/ha/year.

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