Nitrogen-based Composted-Manure application: Implications for Phosphorus balance and changes in Soil quality in the Pot Experiment

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Abstract
A 2-yr pot experiment with nitrogen (N) based one-time application of composted manure evaluated phosphorus (P) balance and changes in soil quality. Treatments consisted of compost, compost + urea, urea, all applied at 250 kg N ha^{-1} and a Zero Control to the first crop. Inorganic water soluble P (WSP) leaching was monitored 28 times adding 83 and 62 mm of water fortnightly to cabbage and corn, respectively. Crops were grown in annual rotation and monitoring of WSP leaching was limited to growing seasons. The concentrations of WSP leaching from any treatments were mostly below water quality threshold value of 0.1 mg L^{-1}. Soil quality index (SQI) correlated well with dry matter yields of cabbage (r^2 0.45, $P < 0.01$) and corn (r^2 0.71, $P < 0.001$). Despite widely reported for limited application, encouraging results obtained from this pot experiment appear to be promising. However, field verification of other forms of inorganic P leaching and result of SQI is suggested for improved compost management in agriculture.

Key words
High rainfall, coarse-textured soil, P balance, acid soil, environment, Taiwan

Introduction
Leaching of plant available P following manure or compost application can pollute the ground water and N-based compost application adds more P than P based application (Eghball, 2003). In Taiwan, increasing swine manure production (approximately 27400 tons per day) and related regulations encourage farmers to apply composted swine manure to reduce water pollution and improve crop productivity (Chen and Yang 1996). In practice, however, once compost is applied, most farmers heavily rely on chemical fertilizers for subsequent crops due to difficulty in handling and/or slow nutrient availability in manure/compost. Huang (1994) asserted that such practices in high rainfall areas have changed soil nutrient balance and soils are degrading due to nutrient leaching. Although government's current policy encourages use of composted manure, study of compost effects on soil P balance including P leaching and soil quality still remains undocumented. While P balance can be used to quantify the flow of P nutrition in agroecosystems, articulating soil quality analysis can further help develop an understanding of relative sustainability of management practices arising from composted manure application and decision making in agriculture.
With the above in mind, this study was aimed at examining whether a one-time application of N-based composted manure would i) leach environmentally objectionable concentrations of inorganic WSP -a crucial part of P balance, and iii) relate soil quality to dry matter (DM) yields of cabbage and corn under high rainfall and warm tropical conditions of Taiwan.

Methods
Pot experiments offer suitable alternatives to avoid possible adverse weather effects such as from repeated typhoons and high variations in the field conditions. To avoid this uncertainty, an experiment was conducted in the pot at the Department of Agriculture Chemistry, National Taiwan University, Taipei from April 2006 to June 2008. The standard Wagner's pots (the largest size) were filled with 12.9 kg of soil on dry weight basis. The soil samples were collected from a nearby Taoyuan upland agricultural area and sieved through 10 mesh screen prior to filling. Soil texture was sandy clay loam, clay 25%, pH 4.5 (1:1 soil water ratio), EC 0.6 dS m^{-1}, Bray-1 P 29 mg kg^{-1}. Compost contained total N 3.7% and total P 3.6%. Locally made industrial compost was used made of swine manure and mushroom growing media (5:1 by vol.). Three combinations of N sources designed to meet agronomically recommended rate of N (250 kg ha^{-1}) were applied to the 1st crop cabbage (Table 1). Treatments

were randomly attributed to 16 Wagner's pots. In order to optimize crop growth, treatments other than control received a uniform rate (hereafter referred to as *blanket application*) of NPK from urea, MCP and KCl, respectively, from 2nd to 4th crop (data not shown).

Table 1. Actual quantities of compost, urea, MCP, and KCl applied to 12.9 kg dry weight of soil per pot before the 1st crop cabbage in the 1st-yr rotation

Treatment[†]	Compost[‡]	N from compost[¶]	P from compost[¶]	Urea[§]	MCP[§]	KCl[§]
	-----------	-----------	-----------	g pot^{-1}	-----------	-----------
Ctrl	0	0	0	0	0	0
U250	0	0	0	2.71 (1.25)	0.71 (0.40)	1.2 (0.80)
U125C125	40	1.25	1.21	1.30 (0.62)	0	0.9 (0.60)
C250	80	2.50	2.43	0	0	0.6 (0.40)

[†]Ctrl = Control, prefixes ‘U and C’ indicate N sources as urea and compost, respectively. Suffixes “250 or 125”indicate kg of N ha^{-1} added to the 1st crop cabbage in the 1st-yr rotation. Four treatments replicated four times (4 x 4 = 16).
[‡]Values “40 and 80 g pot^{-1}” correspond to 8 and 16 Mg ha^{-1} of compost for the respective treatments in column 1.
[¶]Values of “N and P from compost” shown are the actual total N and total P quantities that “40 and 80 g pot^{-1}” composts would automatically supply to the soil.
[§] Reagent grade chemicals. Values in parenthesis indicate elemental nutrients, not the fertilizer. KCl = Potassium chloride.

Quantity of compost application assumed 50% N availability which agrees with Passoni and Borin (2009). One plant pot^{-1} was grown in both cabbage (*Brassica oleracea* L.) and corn (*Zea mays* L.) and harvested 4 crops in 2-yr. WSP leaching was monitored 28 times in 2-yr adding 83 and 62 mm of water fortnightly to cabbage and corn, respectively corresponding to 4.1 and 3.1 L water per leaching event and analyzed spectrophotometrically (Murphy and Riley 1962). Flow-weighted means of WSP concentrations were computed and total P uptakes and DM yields recorded. Phosphorus uptake and leaching were measured directly, whereas quantities unaccounted for were approximated by deducting the sum of P uptake and leaching from the total applied in 2-yr. Apparent P recovery (henceforth simply referred to as *P recovery*) in P balance (i.e., uptake, leaching, and soil retention) was calculated using the difference method.

Two-yr after the experiment, samples of these leached soils were analyzed for selected indicators of soil quality (Table 2). Developing soil quality indices (SQI) using indicators then followed the soil management assessment tool (see details in Andrews *et al.* 2001). Theoretically, SQI is developed by integrating physical, chemical, and biological indicators. However, owing to homogenized pot-soil environment, the SQI model in this case excluded the use of physical indicators. Since assigning weights to indicators is largely subjective, distribution of relative weights to the selected indicators was based on unbiased weights allotment criteria. For conversions of indicators into unitless scores (0-1), threshold values were modified to suit the soil condition (data not shown).

Table 2. Soil quality model used for assigning weights to soil functions

Indicators		Soil indicators		Weighted Index (W)
	Weight_1	Properties	Weight_2	(Wt1 x Wt2)
1. Chemical	0.50	pH	0.20	0.10
		EC	0.20	0.10
		Nitrate N	0.20	0.10
		Bray-1 P	0.20	0.10
		Mehlich-1 K	0.20	0.10
2. Biological	0.50	Pot. mineralizable N	0.33	0.17
		Microbial carbon	0.33	0.17
		Organic carbon	0.33	0.17
Totals	1.00			1.00

SQI was calculated as Σ(W X S); where, W = Weighted index of each indicator which equals to Wt1 X Wt2, and S = Scored indicator value. For further details on how S is derived, refer to Lee *et al.* (2005).

Results

Phosphorus balance

Cumulative P uptake by crops combined, in 2-yr between C250 and U125C125 were not different from each other; however, uptakes in these two treatments were significantly higher than in Ctrl and U250 and percent recovery increased almost twice the amount in U250 (Table 3). On the other hand, unlike greater differences in P uptake and recovery between with and without compost applied soils, WSP leaching was detected only in trace amounts in all treatments. Irrespective of treatment type, a large fraction of applied P (81.6 to 89.5%) was retained (unaccounted for) in the soil. Event based flow-weighted mean of WSP concentrations (mg L^{-1}) showed slightly higher peak concentrations (0.2 to 0.6 mg L^{-1}) in the initial two measurements after compost application to the first crop in all treatments including the control. In rest of monitoring events in 2-yr they were always below critical water quality threshold of 0.1 mg L^{-1} (data not shown).

Table 3. Two-yr P balance for cabbage and corn in annual rotation, April 2006 to June 2008.

Treatment†	P added	Crop uptake		Leaching¶		Unaccounted for§	
	mg pot^{-1}	mg plant^{-1}	% recovery‡	mg pot^{-1}	% leaching¶	mg pot^{-1}	%
	------------------------------------Total of 4 crop seasons--------------------------------------						
Ctrl	0	374 b	-	4.96 ab	-	-	-
U250	800	458 b	10.6	4.05 b	-0.11	716	89.5
C250	2830	893 a	18.3	5.75 a	0.03	2311	81.6
U125C125	1610	714 a	21.1	4.24 b	-0.04	1271	78.9
P > f		0.001		0.05			
CV, %		14		15			
r^2		0.88		0.55			

In a column, means followed by the same letter across the treatments are not significantly different (Tukey test, *P* = .05).
†See Table 2 for treatment definitions.
‡% Crop recovery or % leaching = (Uptake or leaching from treatment - control)/P added x 100.
¶Leaching = Sum of P (mg pot^{-1}) from 28 leaching events during four crop seasons in 2-yr; §Unaccounted for P = 100 – (sum of P recovered in uptake and leaching).

Soil quality

One-way ANOVA showed that treatment application increased SQI significantly (*P* = 0.05). But mean comparison by Tukey test indicated indistinct differences in SQI within three treatments other than control (Tabular data not shown). However, as hypothesized a good correlation occurred between SQI and DM yields of both crops ($r^2 = 0.45$, $P < 0.01$ for cabbage; $r^2 = 0.71$, $P < 0.001$ for corn) (Figure 1).

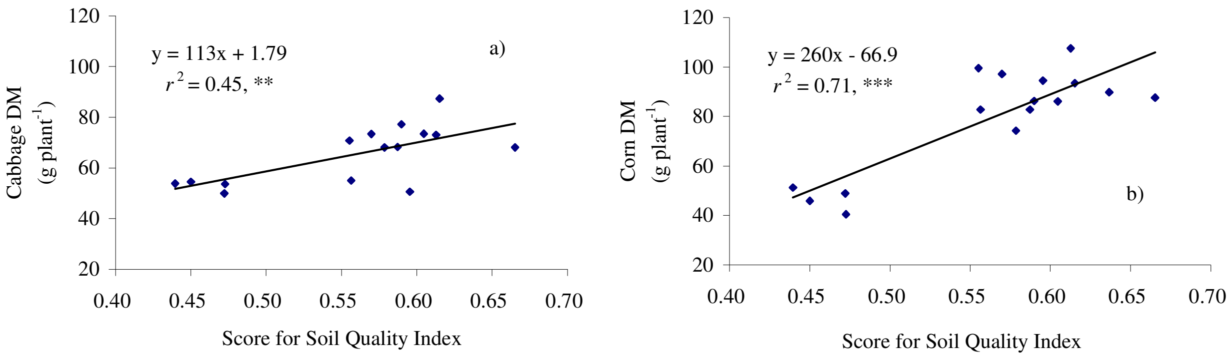

Figure 1. Linear correlations for score of soil quality index with a) cabbage DM and b) corn DM yields. Point data in the figures indicate cumulative of both years DM (g plant^{-1}) for that crop. Corn DM combines grain and biomass.

Discussion

Very high P retention in this soil agrees with those reported by many including Kuo (1990) where strong P retention occurred in strongly acid soils rich in sesquioxides. Generally speaking, more weathered the soil is greater would be the P adsorption and greater the rainfall more would be the P leaching. It points to a question that the soil in hand was neither from a highly weather site, nor did it receive a low rainfall. To minimize preferential flow through the inner walls of the pot, experimental set up was maintained well which we believed that it allowed sufficient time for interaction between applied compost and the soil constituents in the pot. Regarding leaching, inorganic water soluble fraction of P in compost samples was 8% of the total P. If we compare this with that in Table 3, leached P was only in trace amounts (< 0.03%) which supported that leaching does not pose a risk in this soil. However, we did not measure other forms of inorganic P in leachate samples. Results also clearly indicated that adding compost would increase P desorption in acid soils as shown by greatly improved crop uptake from compost applied soils relative to that without compost (10.6 to 21.1%) (Table 3).

It should be relatively new that concept of soil quality was evaluated in the potted-soil environment for severely leached soil. The principal reason behind was a hypothesis that not only in natural state, but soils still function in the pot. The results were encouraging that compost with or without urea and MCP, improved soil quality relative to the Control. Although with limitations of physical indicators, improved SQI in terms of other measured parameters (Table 2) correlated well with DM of cabbage and corn (Figure 1). Non-significant differences between composted and non-composted treatments (data not shown) was thought primarily due to severe leaching, primarily N and soluble salts such as K, and hardened soil conditions which reduced vital power of compost for non-repeated and low level of compost application. We considered 16 Mg compost ha^{-1} for C250 'high' for this study is usually in the lower range relative to the quantities used by other studies.

Conclusions

One-time application of composted swine manure up to 16 Mg ha^{-1} with or without MCP in 2-yr: 1) did not pose risk of inorganic WSP leaching for water quality, and 2) SQI based on the performance of indicators showed significant and strong correlation with crop DM yields. Despite widely reported for limited application, encouraging results obtained from this pot experiment appear to be promising. However, field verification of other forms of inorganic P leaching and SQI is suggested for improved compost management in agriculture.

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