Kasetsart J. (Nat. Sci.) 46 : 24 - 32 (2012)

Effects of Swine Manure Extract by Foliar Application and Soil Drenching on Soil Chemical Properties and Variable Soil Strength of Cassava Planted Soils

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ABSTRACT

The effects were investigated of swine manure extract (SME) application on soil chemical properties and on soil strength, which are essential to soil management for cassava. The results of one cropping study revealed that an application of SME to the soil (SSME) or a combination of soil and foliar application of SME (FNSSME) tended to increase soil organic matter, cation exchange capacity and extractable Zn, but reduced soil strength. Nine split applications of SME in both the foliar or soil regimes had no effect on soil pH, but markedly reduced electrical conductivity indicating the depletion of soluble salts. FNSSME significantly decreased available P and exchangeable K while foliar application of SME decreased exchangeable K and exchangeable Mg. FNSSME significantly increased extractable Cu, and a similar result on extractable Mn was noted in the SME-treated soil. SME improved the availability of these two micronutrients. Chemical fertilizer (standard NPK) and FNSSME treatments reduced both exchangeable Ca and Mg. Soil strength calculated from penetration energy was maintained by a soil application of aqueous swine manure extract, SSME and FNSSME but not by an application of NPK fertilizer. The long term effects of SME application as a soil drench on the chemical properties of the soil and on soil strength over longer periods should be investigated.

Keywords: swine manure extract, foliar application, soil drench, soil properties, cassava

INTRODUCTION

Modern, commercial, intensive swine farms in Thailand produce a large amount of swine waste causing serious public health difficulties (Department of Livestock Development, 2008). The greatest problem facing all developing countries in the conversion of small or backyard swine production to commercial-scale operations is the enormous amount of animal waste produced. Improper swine farm waste treatment and utilization always leads to environmental pollution and poor hygienic conditions in the community. To solve these problems, swine waste must be properly treated and utilized to ensure swine farms are viewed as environmentally friendly.

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Received date : 03/05/11 Accepted date : 18/10/11

Swine farm waste may be used as fertilizer and in soil amendments or to provide renewable energy (biogas, liquid fuels and electricity). The fertilizer value of swine manure can be optimized by carefully matching application rates and timing with crop nutrient needs.

Swine manure extract (SME) is a liquid form of plant nutrient developed by the Suwanvajokkasikit Animal Research and Development Institute, Kasetsart University, Kampaengsaen, Nakhon Pathom, Thailand. It is derived from steeping dried swine manure in water for 24 hr and contains full profiles of both macronutrients and micronutrients required by plants. Monthly foliar application of SME increased tuber yield of cassava cultivar Rayong 5 grown on acid sandy soil (Momngam, 2002). The extract has also been shown to increase the yields of rice, vegetables and ornamental plants under practical farm conditions in Thailand (Kanto, U. and Jattupornpong, S., personal communication).

Field application of swine manure extract is primarily by foliar and soil application. The technique can be directly effective for leaf nutrient absorption and minimizing NH_3 volatilization, thereby increasing leaf expansion and chlorophyll content (Kanto *et al*., 2009). Understanding the soil chemical and physical properties that are changed by application of swine manure extract is essential to formulate best management practices for crop production. Several studies have reported the impact of pig slurry application on soil chemical properties; for example, changes including phosphorus pools and movement (Hountin *et al*., 2000; Gessel *et al*., 2004; Marshall and Laboski, 2006), heavy metal exchangeable fraction (Doelsch *et al*., 2010), N transformation (Petersen *et al*., 2003), nitrate leaching (Mantovi *et al*., 2006) and soil organic matter and humic substances (Plaza *et al*., 2006). Studies have also been made on changes in soil physicochemical properties using pig slurry and the results have been compared with the use of dry swine manure for the effect on water infiltration into the soil profile (Petersen *et al*., 2003). The increased soil organic C as a result of waste applications can reduce bulk density, surface sealing and crust formation (Jokela *et al*., 2009), but the effects of swine manure extract (SME) on soil strength, which influences root growth and distribution, were not well elucidated. As noted by King *et al*. (1985), an increasing load of swine lagoon effluent increased soil phosphorus and nitrates. Furthermore, King *et al.* (1985) found that long-term application of pig slurry had similar effects to short-term application. There is evidence that swine manure extract can significantly influence the growth and productivity of plants (Kanto *et al*., 2009), but its effects on soil properties should also be elucidated.

The main objectives of the current experiment were: 1) to characterize the changes in the chemical properties and soil strength of soil planted with cassava after receiving nine different split applications of swine manure extract; and 2) to compare soil characteristics from using conventional, chemical fertilizer (NPK) with using swine manure extract as foliar and soil fertilizer. The information obtained will assist the understanding of the effect of swine manure extract as an organic fertilizer on changes to the chemical and physical properties of soil.

MATERIALS AND METHODS

Cultural practices and experimental site

Four treatments with 16 experimental plots were arranged in a randomized complete block design with four replications on a Chatturat soil series (fine, mixed, active isohyperthermic Typic Haplustalfs; Land Development Department, 2003) in U-Thong district, Suphan Buri province, Thailand (latitude 14°24′N, longitude 99°51′E). Particle size distribution determined by a pipette method (Gee and Bauder, 1986) indicated that the surface soil consisted of sand (31.6%), silt (45.82%) and clay (22.58%) and was classified as having a loamy texture. The experimental site had been previously planted with corn (*Zea mays*), and had no known history of manure application. Soil preparation involved using conventional tillage that consisted of moldboard plowing followed by disk harrowing. Each of the 16 experimental plots (6 m wide and 16 m long) was composed of six raised-up ridge type planting beds, 1 m apart for ease of drainage. The 8-month-old cassava stakes (cultivar Hauybong 60) were planted in the middle of the ridge at 1 m spacing in late January 2007 with a final population of 10 000 plant.ha^{-1}. Four separate fertilizer treatments were randomly applied to experimental plots: 1) chemical fertilizer (NPK) application, formula 21-10-10 at 250 kg.ha^{-1}, with 52.50 kg N, 25 kg P_2O_5 (10.94 kg P), and 25 kg K_2O (20.81 kg K) per hectare; 2) nine foliar applications of swine manure extract (FSME) with 2.50, 0.5 and 3.96 kg.ha^{-1} of N, P and K, respectively, plus secondary elements and micronutrients contained in SME; 3) nine soil applications of SME (SSME) with 17.81, 3.56 and 26.69 kg.ha^{-1} of N, P and K, respectively, plus secondary elements and micronutrients contained in SME; and 4) nine foliar and soil applications of SME (FNSSME) with 20.25, 4.06 and 30.38 kg.ha^{-1} of N, P and K, respectively, plus secondary elements and micronutrients contained in SME (Table 1). Chemical fertilizer (NPK) was applied on day 45 after planting and SME as foliar (FSME and FNSSME) or soil fertilizer (SSME and FNSSME) was applied every 30 d from day 45 until day 245 after planting. The application rate of SSME was 2.5 L.plant^{-1}.month^{-1}. The total amount of SME applied for FSME, SSME and FNSSME treatments throughout the study were 24,869, 178,000, and 202,878 L.ha^{-1}, respectively (Table 2).

Soil chemical analysis

Before planting and after harvesting of the plants, soil samples were collected at a depth of 15 cm from the soil surface of each plot. The samples were air-dried, ground and passed through a 2 mm stainless steel sieve. Soil organic carbon was determined by the Walkley and Black method (Walkley and Black, 1934). Soil pH was measured in water at a soil-to-water ratio of 1:1. Electrical conductivity of soil saturation extract (ECe) was determined by EC meter. Available P and exchangeable K in the soil were determined by colorimetry in Bray-II extracts (Bray and Kurtz, 1945) and atomic absorption spectrometry, respectively. Soil exchangeable Ca^{2+} and Mg^{2+}

Table 1 Rate of macronutrients and micronutrients added to the soil in the four treatments.

Nutrient	Treatment			
(kg.ha^{-1})	CF	FSME	SSME	FNSSME
N	52.50	2.50	17.81	20.25
P	10.94	0.50	3.56	4.06
K	20.81	3.69	26.69	30.38
Ca	na	0.28	20.54	23.39
Mg	na	2.96	21.31	24.27
Fe	na	0.03	0.24	0.27
Cu	na	0.35	2.50	2.85
Mn	na	0.04	0.31	0.35
Zn	na	0.01	0.08	0.09

CF = conventional fertilizer; FSME = foliar application of swine manure extract; SSME = soil application of swine manure extract; FNSSME = foliar and soil application of swine manure extract; na = not applicable.

Table 2 Soil and foliar application rate of swine manure extract throughout the study.

Time	FSME ($L.ha^{-1}$)	SSME ($L.ha^{-1}$)
1	1,562.5	19,780
2	1,562.5	19,780
3	1,562.5	19,780
4	2,604.2	19,780
5	2,604.2	19,780
6	3,906.3	19,780
7	2,604.2	19,780
8	5,208.3	19,780
9	3,255.2	19,780
Total	24,869.85	178,020

FSME = foliar application of swine manure extract; SSME = soil application of swine manure extract.

were extracted using ammonium acetate at a pH of 7.0. Soil cation exchange capacity (CEC) was measured using the analytical method described by Jones (2001). Exchangeable Fe, Cu, Mn and Zn were extracted with diethylenetriaminepentaacetic acid (DTPA) solution (Jones, 2001).

Soil strength measurement

The soil strength parameter was determined by mechanical measurement using a dynamic cone penetrometer as described by Herrick and Jones (2002). The principal use of the penetrometer was to calculate the soil resistance from the work done to raise a hammer (mass M) lifted to a height h above an anvil. Before the mass is dropped on the anvil, the penetromenter is assumed to be at equilibrium with the indented soil surface. When the hammer hits the anvil, the hammer and the shaft (mass m) move together into the soil. The energy applied by the action of dropping the hammer against the force of gravity is described in Equation 1:

$$F = Mgh \quad (1)$$

where F is the energy (in J), and g is the gravity-acceleration constant. By assuming that all the energy loss is absorbed by the shaft, there is negligible friction between the penetrometer and the soil. From the basal area of the cone and the distance of penetration, the penetration resistance (PR) is obtained using Equation 2:

$$PR = Mgh/(Ax) \times [M/(M + m)] \quad (2)$$

where PR is the resistance to penetration (Pa), x is the penetration distance (m), and A is the basal area of the cone (m^2). The energy available for penetration through the soil depth (z) was evaluated as the penetration energy (PE in MJ m^{-2}) from Equation 3:

$$PE = \int_0^z PRdz \quad (3)$$

After harvesting, the soil strength from one sample site on each of the 16 plots was measured.

Statistical analysis

Chemical properties of the soil from the experimental plot before and after the trial were compared. The mean values of soil chemical property parameters from each treatment were analyzed using analysis of variance, and the differences among treatment means were determined by the SAS program (SAS Institute, 2003). Means that differed at $P < 0.05$ were considered to be significant.

RESULTS AND DISCUSSION

Swine manure extract application and chemical properties of soil before planting and after harvest

The chemical properties of soil samples before and after the experimental period are shown in Table 3. The soil pH in the top 15 cm of soil of every treatment at the start of the experiment ranged from pH 7.6 to 7.7, but then tended to decrease toward harvest to pH 7.2 to 7.5, but the differences between the various fertilizer treatments were not statistically significant. Although there were no significant differences in soil organic matter before planting and after harvest, the FNSSME treatment increased soil organic matter by 10.05%. Soil organic matter tended to increase toward harvest which was probably attributable to the tendency for an increase in soil organic matter content from the microbial degradation of the fallen leaves and the production of organic acid returned to the soil, as well as the cation uptake by the plants (Havlin *et al*., 2005). Peterson *et al*. (2003) studied the utilization of pig slurry on degradable C and N after slurry injection and suggested that dissolved compounds and suspended particles from the slurry liquid of pig manure would be carried along with the aqueous phase, but slurry components may interact with the soil. Ammonium ions can adsorb to negatively charged surfaces, and metabolizable C can be taken up by soil microorganisms. The importance of mechanisms for C and N turnover of FNSSME or only SSME will depend upon both the swine manure extract concentration and the soil properties. Electrical conductivity of the soil in every treatment significantly decreased toward harvest except those treatments involving chemical

Table 3 Field soil sample test properties before planting and after harvesting cassava[a].

Treatment	pH (1:1)		EC_{se} (dS.m^{-1})		CEC (c mol.kg^{-1})		OM (mg.g^{-1})	
	Before	After	Before	After	Before	After	Before	After
CF	7.7	7.3	0.42	0.31	16.77	15.59	18.1	18.6
FSME	7.7	7.5	0.43	0.33 *	17.59	18.06	17.7	18.3
SSME	7.6	7.4	0.40	0.30 *	17.42	17.58	18.3	18.7
FNSSME	7.6	7.2	0.51	0.30 *	16.93	18.06	17.9	19.7
	Available P (mg.kg^{-1})		Exchangeable (g.kg^{-1}) K		Ca		Mg	
	Before	After	Before	After	Before	After	Before	After
CF	13.43	11.31	0.16	0.13	4.03	2.93 *	0.17	0.14 *
FSME	16.56	10.71 *	0.22	0.17	4.33	3.37 *	0.18	0.15 *
SSME	10.53	7.97	0.17	0.14	3.50	3.26	0.18	0.16
FNSSME	11.62	7.51 *	0.14	0.10 *	3.44	3.28	0.17	0.14 *
	Extractable (mg.kg^{-1}) Fe		Cu		Mn		Zn	
	Before	After	Before	After	Before	After	Before	After
CF	7.41	9.45 *	0.79	0.88	16.75	34.83 *	0.31	0.47
FSME	7.75	9.03	0.96	0.98	19.43	31.71 *	0.36	0.41
SSME	9.10	8.85	0.93	0.94	20.38	30.87 *	0.39	0.50
FNSSME	8.24	9.06	0.74	1.00 *	19.28	27.51	0.28	0.43

OM = organic matter; CEC = cation exchange capacity; EC_{se} = Electrical conductivity.

[a] = Statistical *t*-test, between before planting (n = 2) and after harvesting (n = 4).

* = Significantly different before planting and after harvesting ($P < 0.05$).

CF = conventional fertilizer; FSME = foliar application of swine manure extract; SSME = soil application of swine manure extract; FNSSME = foliar and soil application of swine manure extract.

fertilizer, which was probably due to the high water content and soil matrix potential during the growth period (data not shown). This was the result of salt leaching to the subsoil and tile drain, as well as the nutrient uptake by the plants (Fageria, 2009). The swine manure extract surprisingly did not increase soil electrical conductivity probably because the extract was highly diluted and a well-drained field was used for the study.

Table 3 shows that every soil sample that was taken before planting contained medium organic matter, medium available P and high exchangeable K (Department of Agriculture, 2005). Exchangeable Ca and Mg in the soil samples of all treatments were classified as high while the extractable Cu content was low to medium. The levels of extractable Fe and Zn in this soil were low (Department of Agriculture, 2005). The macronutrients content tended to decrease after harvest, which was mainly due to crop removal (Table 3). The depletion of nutrients during the experiment varied among the treatments with the following nutrient reductions being significant: NPK—exchangeable Ca and Mg; FSME—available P, exchangeable Ca and Mg; and FNSSME—available P, exchangeable K and Mg. Significantly lower exchangeable Ca and Mg in the soil in the NPK and FSME plots after harvest indicated a remarkable removal of exchangeable Ca, Mg and available P from the soil, when compared to the values before planting. This could have been due to the low application rates of these nutrients to the soil (only foliar application of SME). The soil samples where NPK fertilizer and foliar application of SME (FSME) treatments were used showed significantly decreased exchangeable Ca and Mg, which was caused by there being no Ca and Mg supplied in the fertilizers. In the plots treated with FNSSME, there was significant depletion of available P, exchangeable K and Mg that probably was due to the influence of the foliar and soil application of swine manure extract on biomass production enhancement. Hence, nutrient uptake from the soil in FNSSME showed predominant depletion of these minerals (Kanto *et al.*, 2009). The contents of extractable Cu, Mn and Zn in the soil were moderate (Howeler, 1996) at the beginning of the experiment but increased toward the end of the experiment which might have been caused by the lowering of soil pH (Table 3) that tended to increase the availability of these nutrients in the soil (Brady and Weil, 2008). However, SME is a source of micronutrients, especially Cu, which may have increased their availability in the soil. The soil application of Cu-rich SME was likely to have increased available Cu in soils, in the same manner as using farm effluent (Bolan *et al.*, 2003). Nevertheless, the CEC of soil samples before and after the study was not significantly different in all treatments. Kaiser *et al.* (2008) demonstrated that the CEC of soils depends on the amount and composition not only of clay minerals but also of soil organic matter (SOM). The content and composition of SOM depends on both the input from the live roots and from root residues (Francisco *et al.*, 2000) and the process of organic matter decomposition, which is controlled by soil type, climatic conditions and management practices including soil cultivation, fertilization and crop rotation. The available P of the soil in the FSME treatment significantly decreased at harvesting indicating that only the foliar application of SME was unable to provide adequate, available P uptake by the cassava plants cv. Hauybong 60. FNSSME promoted high growth in the cassava plants which resulted in the high uptake of available P from soil. However, Gessel *et al*. (2004) reported that application of liquid swine manure at the highest rate, resulted in lower runoff volume and sediment loss than in the control plots without manure.

Swine manure extract and soil strength parameter

The soil strength parameter (PE) of each treatment is shown in Figure 1. The average penetration through the soil was affected by the fertilizer application. Soil strength was lower for FNSSME than for the SSME, FSME and NPK treatments. The PE at harvest time varied with soil depth and was lowered by the soil application of aqueous swine manure extract (SSME and FNSSME). It does not appear that the differences in soil strength parameters, due to soil application of SME, were responsible for the observed differences in the soil matric potential. Alternatively, the observed reduction in PE was a result of improved soil infiltration rate (Gessel *et al*., 2004), minimizing soil compaction and enhancing root distribution. This implies that the improvements in soil structure were due to the gradual accumulation of organic substances through the mass flow of soil water with each application of SME (Or, 1996), or swine manure extract particles could have been transported into the soil matrix, contributing to an increased water retention capacity (Olesen *et al*., 1997). As discussed above, soil organic matter increased when swine manure extract was applied to soils, so it is not surprising that the soil physical properties also improved. The finding that SSME decreased soil strength is in agreement with Khaleel *et al*. (1981) and Haynes and Naidu (1998) who observed that increases in soil C as a result of waste applications can reduce bulk density, surface sealing and crust formation but increase biological activity (Jokela *et al*., 2009). Thus, additions of SME to soils normally cause an increase in the size and amount of water-stable aggregates. Hence, the other soil physical properties should be determined over a range of water regimes to evaluate the effects of various long-term fertilization treatments (Munkholm *et al*., 2002).

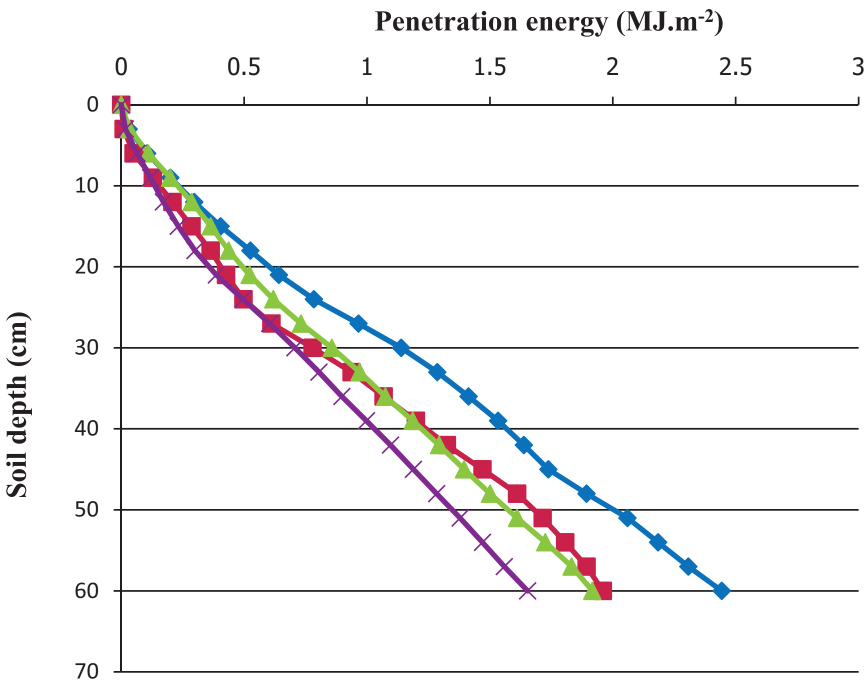

Figure 1 Penetration energy against soil depth of four fertilizer treatments.
CF = conventional fertilizer (◆); FSME = foliar application of swine manure extract (■); SSME = soil application of swine manure extract (▲); FNSSME = foliar and soil application of swine manure extract (×).

CONCLUSION

Direct application to soil or a combination of soil and foliar application of SME tended to improve soil organic matter, cation exchange capacity, extractable Zn and to decrease soil strength. Nine split applications of SME in both foliar or soil regimes had no effect on the electrical conductivity and soil pH in the short term, but FNSSME significantly decreased available P and exchangeable K, while a foliar application of SME decreased exchangeable K and exchangeable Mg. FNSSME significantly increased extractable Cu and a similar result with extractable Mn was noted in the SME-treated soil, which revealed the beneficial effects of SME applications on the availability of these two micronutrients. The reduction in soil strength calculated from the penetration energy was affected by the soil application of aqueous swine manure extract (SSME and FNSSME). The long-term effects of SME application as a soil drench on the chemical and physical properties of cassava growing soils should be further studied.

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