Vol. 13(1), pp. 1-11, January-June 2021
DOI: 10.5897/JABSD2020.0381
Article Number: 163BDDD66145
ISSN: 2141-2340
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Journal of Agricultural Biotechnology and Sustainable Development

Full Length Research

Shorten the producing process of horse manure to fermented compost and appropriate fertilization on crops

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Received 13 November, 2020; Accepted 3 February, 2021

Horse manure composts may provide nutrients to crops as well as enrichment of good microorganisms for phytoprotection. Previous studies have shown their effectiveness against diseases but there are problems to overcome their composting procedures. The purpose of this experiment is to treat the horse manure starting from the stable to produce compost for crop growth. The results indicate that the manure can be enriched in its nutrient components after appropriate crushing. Biophase analysis of the microorganisms on manure composts during their fermentation showed that the main genus is *Bacillus subtilus* species which is characterized by higher temperature resistance and so has higher concentration after fermentation. Field experiment on cabbage growth shows that horse compost may improve soil property, nutrient components and cabbage quality more than the compost sold in the market.

Key words: Horse manure, plant nutrition, agricultural management, resource, product innovation.

INTRODUCTION

Horse is an herbivorous domestic animal originating in the central Asian grassland. It was migrated to the America and Australia along with immigrants after the 15th century and now widely spread worldwide. In the past horse mainly served for riding, pulling carts and transporting goods, especially during the war (Borioni et al., 2012). Based on investigations by scholars, there were about 60 million horses in 2012. Recently, horse is commonly used for recreation and sports in most countries (Edwards et al., 1999). In the central and northern Germany, more than 90% of the horses are confined individually in a stable averaging about 12 m^2 (Fleming et al., 2008). Each horse can excrete about 17 kg of feces and 9 L of urine (Wartell et al., 2012). As horse is sensitive to poor air quality, it may get sick easily if it stays constantly in a filthy environment. Therefore, the floor of the small stable is commonly matted with carbon-rich and porous materials to absorb the feces as well as the poor air. Generally, hays are used, however, the sawdust are more easily available in many country

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(Fleming et al., 2008). As a matter of fact, feces collected from the horse stable are valuable material for improving soil quality (Sigrid, 2013).

Horse manure is produced more than the total other feces in some US regions. The horse manures produced in these regions are treated as follows: (1) direct spreading on the field or composting before spreading; (2) combusting or heat treatment to reduce the volume (Lundgren and Pettersson, 2009); (3) being buried as trash; (4) as fertilizer for grass and pepper or serving as medium for mushroom cultivation (Wartell et al., 2012; Westendorf et al., 2010). In the past, horse manures were commonly applied directly to the field in Germany. Even now this method is still mostly used in the US and other developed countries.

However, this causes a great impact on soil environment (Airaksinen et al., 2007), such as acidification of the soil, water pollution and eutrophication (nitrate, nitrite, ammonium, nitrogen, etc.) (Garlipp et al., 2011). Shortly, after direct application to the field, nutrients and organic matters may easily flow into the nearby river by runoff. Nitrate may reach the groundwater and create serious problems in the long run. In the past 20 years, every country in the world has paid more attention to the improper treatment of feces and the associated environmental problems. As composting of horse manure can reduce the materials harmful to the environment, it has been recognized as one of the important methods of treatment (Edwards et al., 1999). Extracts from horse manure composts were considered effective in controlling *Phytopthora infectans* in potato and tomato (Weltzein, 1990). The extracts from compost of horse manures mixed with hay can effectively prevent *Fusarium oxysporum* of crops and *Sphaerotheca fuliginea* of cucumber from occurring (Kai et al., 1990). Horse manure compost was also studied for its use for raising earthworm as food staff (Hanc et al., 2019). Publication on how to produce horse manure compost are rare in Taiwan at present and problems remain to be solved in its composting procedure.

For example, there are abundant high-temperature, fiber-decomposing bacteria in horse manure because of its soft and loose texture and so it maintains at high temperature too long (often more than half a year) for field application. On average, horse manure with large granular can be composted in three to six months, because the microorganisms in the granular is active to decompost the organic matter that is involved in the maintenance of high temperature. The size of the materials will influence the duration of high temperature in the composting procedure (Fabian, 2019). Small particles decompose faster because they have more surface area for microbial activity. The grinder for coarse horse manure before proceeding compost pile is needed (Gina, 2018). This study was conducted to research on the crushing method for horse manure to shorten the duration of high temperature in the composting procedure.

MATERIALS AND METHODS

This study is a cooperative project between academics and industry aiming to produce high-quality manure compost for the production of vegetables, coffee beans, black beans and other crops in the field or gardens. The horse manure comes from Audenfurg Equastian Training Center located at Dashu district, Kaohsiung city. This stable mainly serves as a training ground for equestrian. There are 100 horses with 11 to 12 kg of manure production for each horse per day, so there are about 33 to 36 tons of manure produced in a month. Sawdust serves as the main floor coverings for collecting manure including urine. The experiment began in March, 2015. The experiment was designed with two different ratios between manure and sawdust under complete mixing: one at 1:3; the other at 1:5.

As a reference for comparison, manure only was piled up to 1.0-1.5 m high for composting. The pH values range from weak acidic to weak alkaline, Thee water content was about 55 to 60%, In the first week, it was completely mixed once in 3 to 4 days. Beginning at the second week, it was mixed only once. Temperature monitoring showed it was 73°C at the beginning but it was decreasing very slowly. After 3 months, it reminded above 50°C, and so the compost could not be used in the field directly. As sawdust are the main floor covering but grass is sometimes fed to the horse in addition to regular forage, the materials for compost include mainly sawdust plus dried rice stalks which form chunks that prevent micro-organisms from fermentation completely with the mixture of sawdust and dried rice stalks because of smaller surface contact area. As the manure chunks have smaller surface area, they are not easily dissociated while the sawdust were actively dissociated by bacteria, maintaining high temperature for the compost. This study intends to explore crushing of the manure trunks before composting to examine the changes of the compost.

Effects of machine-crushing together with addition of micro-organisms on horse manure compost

After crushing of the manure trunks, 0.2% of microorganisms were added (*Bacillus subtilis* strain). Those with no crushing were piled up to 1.0-1.5 m for composting with weak alkaline pH value and water content at 55to 60%. The compost is well mixed every 3 to 4 days and maintains 55 to 60% water content. Its temperature is monitored every 3 to 4 days. Samples are collected regularly for nutrient analysis.

Effects of different crushing techniques on compost

The materials for compost were crushed with machines and mixed sufficiently with the sawdust used as floor covering. At the same time, the materials without crushing were composted for comparison. Then they were mixed together with water to have 55 to 60% of water content. During the first week, the composts were mixed once in 3 to 4 days. The evaluation indices include temperature, order, nutrients and sprouting rate of vegetable.

Analysis of horse manure

The samples were collected and then oven-dried at 70°C for 1 day. The oven-dried samples were then grinded to obtain homogenous finer samples. Sulfuric acid was added at 350°C for the complete digestion and then K, Ca, Mg, Fe, Mn, Zn, and Cu were determined by Inductively Coupled Plasma (ICP) spectrophotometer. The oven-dried samples were analyzed for N using elemental analyzer, P by phosphomolybdate method.

Table 1. Recommended quantity of fertilizer used for cabbage (kg/acre).

Fertilizer	Organic fertilizer (Compost)	Ammonium sulfate (NH_4SO_4)	Calcium phosphate ($Ca_3(PO_4)_2$)	Potassium chloride (KCl)
Applying amount	400	120	55	25

Table 2. Distribution rate of chemical fertilizer at each stage (%).

Applied time	Organic fertilizer (Compost)	Ammonium sulfate (NH_4SO_4)	Calcium phosphate ($Ca_3(PO_4)_2$	Potassium chloride (KCl)
Basic	100	30	100	50
1st Addition	-	10	-	-
2st Addition	-	15	-	50
3st Addition	-	25	-	-
4st Addition	-	20	-	-

1st Addition: 7-10 days after planting by its side, the others: 14 days in between

Change of microorganism in horse manure before and after composting

Horse manure sample is diluted to ten times in series. Each diluted solution is then coated on potato cultivating plate to calculate bacteria of various kinds and their quantity.

Cabbage cultivation experiments in the field

Cabbage cultivation experiments were conducted on using crushed and non-crushed compost as well as compost of feces of other domestic animals available in market (match 5-09 standard). Chemical fertilizer only was also used for comparison with those containing organic fertilizer. During cultivation of cabbage, the applied quantity and distribution of chemical fertilizer were shown in Tables 1 and 2. Nutrient concentrations of the soil as well as its property were analyzed during planting, ball-like stage and harvesting. At harvesting, average weight of the cabbage, its average diameter and its sugar content and recoverable rate were analyzed.

RESULTS AND DISCUSSION

Temperature variations on different treatments of horse manure composts

Figure 1 shows temperature variations on horse manures treated in three different ways: crushing only, crushing with microorganism added, and non-crushing. Each compost was mixed and adjusted with water content normally. Within one and a half months (August 30 to October 11, 2015), the temperature was above 60°C for each compost. Subsequently, the temperature fall faster for those crushed with or without addition of microorganism. The temperature decreased slowly for the non-crushing compost. After two and a half months, the temperature for the crushing composts with or without adding microorganism already decreased to about 40°C while that for the non-crushing compost remained at about 50°C. After 3 months, the crushed composts dropped to about 30°C, but the uncrushed one stayed at about 35 to 40°C. This indicated that crushing was more effective for temperature drop regardless of presence of microorganisms. Figure 2 shows two different ways of crushing compared with non-crushing for composting. After a month, the crushing compost was more effective in reducing temperature than the non-crushing one. When horse manure and other organic matter are completely oxidized or degraded, they are termed “mature” compost. Compost maturity is crucial to quality assurance and quality control when marketing a compost product for agricultural or horticultural use. Hence, if the compost of horse manure is mature, the temperature should be reduced to 30 to 40°C (Auvermann et al., 1999).

Although low rates of recovery and utilization of nitrogen (N), phosphorus (P), and potassium (K) from livestock are a global problem, nutrients in horse manure is good for crops as fertilizer. Figure 3 shows nitrogen content variations with time for the three types of composts. The N concentration decreases faster for the crushed composts (regardless of microorganisms addition) than the uncrushed compost because the latter decomposed slower and so with higher N concentration. After 3 months, N concentrations are stable at higher level for all composts. P concentrations for all 3 composts are similar but the crushed composts are lower after half a month. The crushed compost with microorganisms has lower P concentration than the one without microorganisms during the middle and late stages. After 3 months, the P concentrations for all three composts are stable at higher level. The K concentration for crushed compost with microorganisms is lower at the early stage.

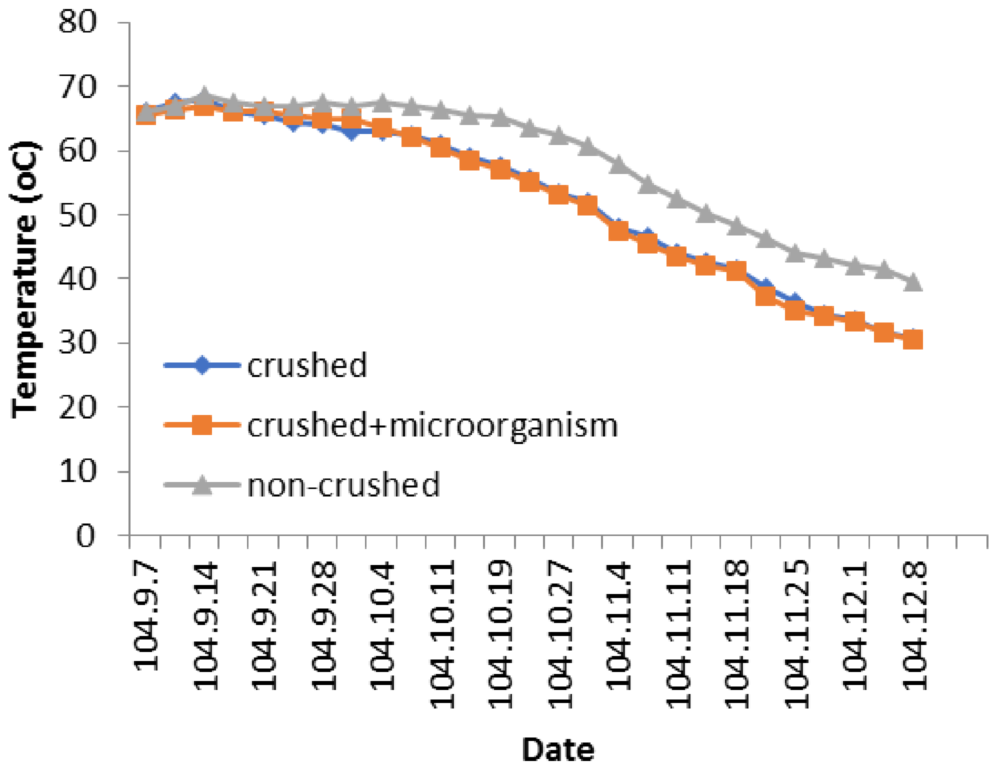

Figure 1. The variation of temperature after the different treatments.

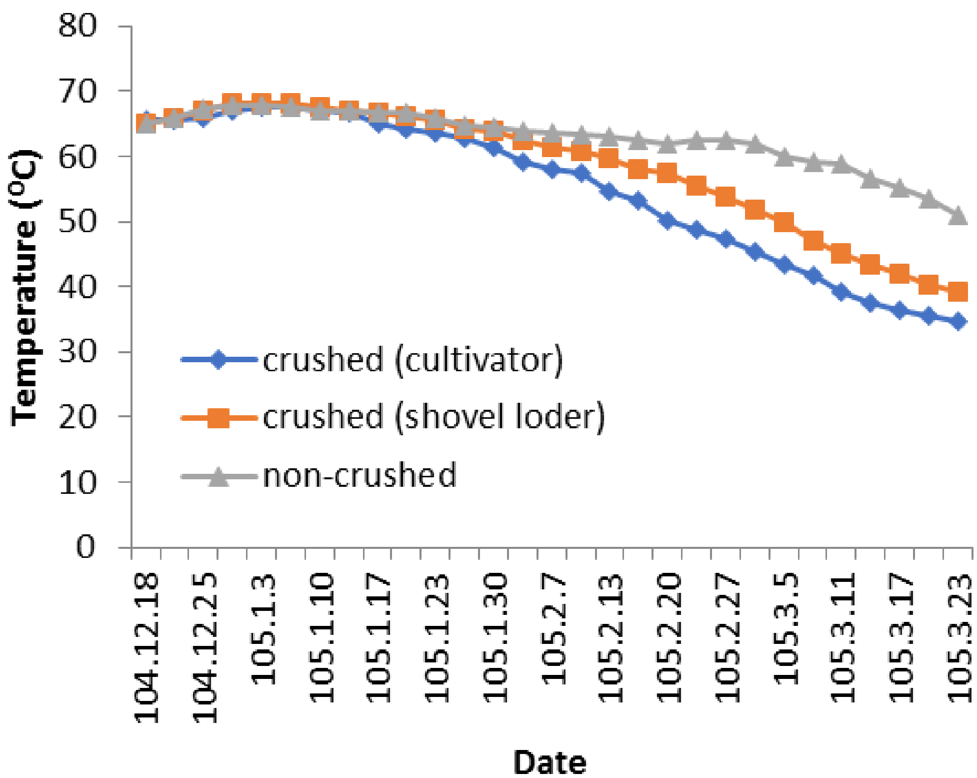

Figure 2. The variation of temperature after different methods of crushing.

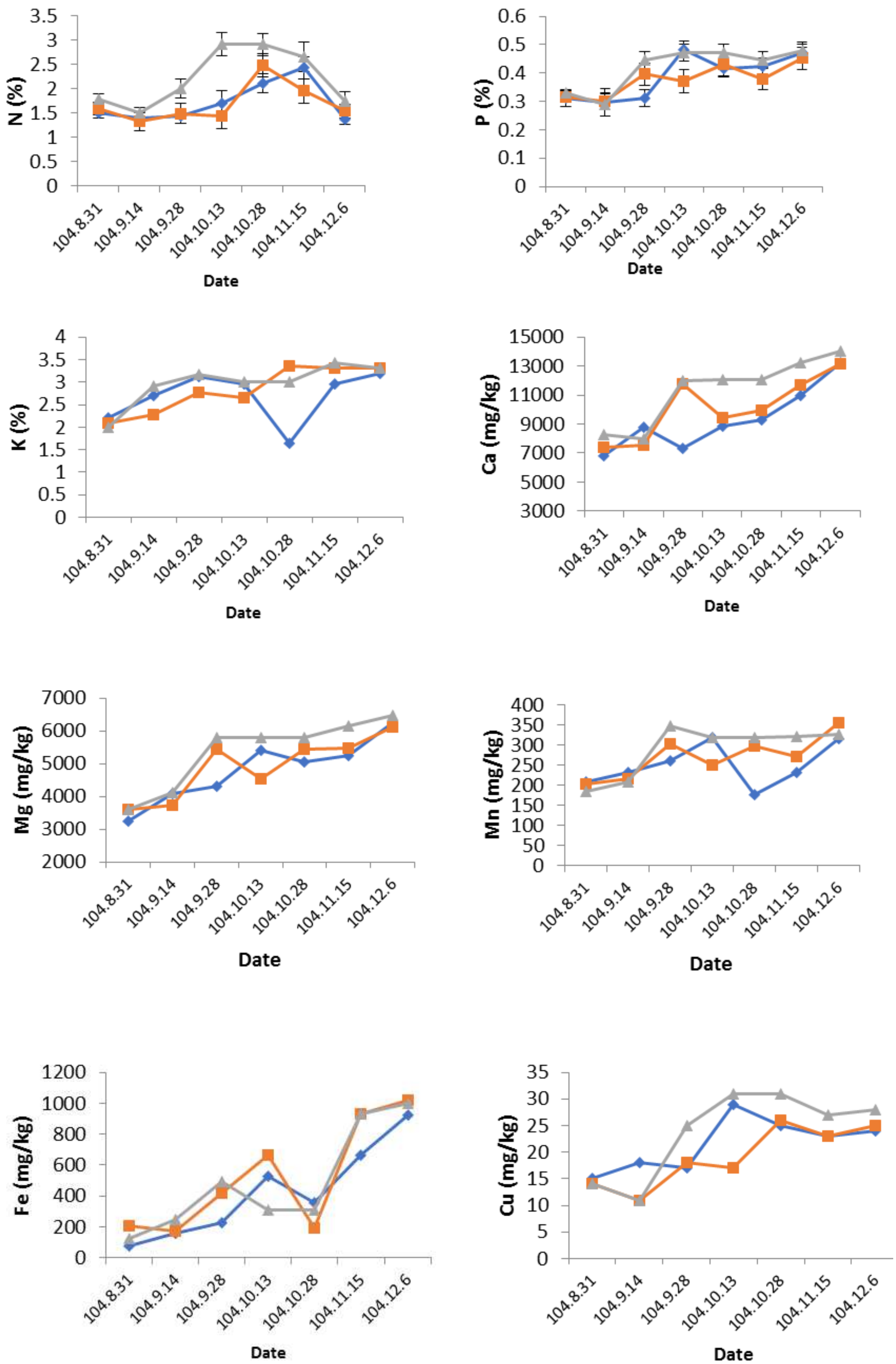

Figure 3. The nutrient concentrations (N, P, K, Ca, Mg, Mn, Fe, Cu and Zn) of cattle manure after different treatments.

Compost from horse manure has the ability to retain nitrogen (N) and phosphorus (P) under rainfall and capacity to release N when mixed with soil (Keskinen et al., 2017). The K concentrations are similar for both the crushed and uncrushed composts but at later stage the crushed compost has lower concentration. After 3 months, the K concentrations for all composts reach stable state. The concentrations of Ca, Mg, Mn, Cu and Zn have similar trend. At early stage, the crushed composts are lower but the crushed compost treated with microorganisms has no significant difference with the uncrushed one. After middle stage, the crushed-only manure has lower Ca, Mg, Mn, Cu and Zn concentrations than the other two with higher K for the uncrushed compost. Concentrations of Ca, Mg, Mn, Cu and Zn show slow increasing trend for all three composts. Fe concentration for all three composts is similar along with the composting time. In this experiment, the N concentrations in the composts from different treatments are all not high. Wheeler and Zajaczkowski (2001) showed that every 1000 kg of bedded horse manure contains about 6 kg of total-N, 2.5 kg of P_2O_5, and 4.5 kg of K_2O (Wheeler and Zajaczkowski, 2001). Horse manure also contains large amounts of carbon, organic matter, and many valuable minor plant nutrients, such as Ca, Mg, S, Zn, Cu, Mn, and Fe. However, little data is available in the literature concerning concentrations of minor plant nutrients in stall manure (Lawrence et al., 2003).

Variations of nutrient concentrations in the manure composts of different crushing

The size of the manure granular will cause continually high temperature in the composting pile (Fabian, 2019). There are much more surface areas on the small particles, so it decomposes faster because of contact with microbial activity. Therefore, the grinding of coarse granular for horse manure is needed for the procedure of composting (Gina, 2018). Figure 4 shows that N concentration of the compost crushed by running shovel loader back and forth is lowest while that of the uncrushed compost is higher than the crushed ones. As the surface area has been increased by crushing, the decomposed rate by organisms increases, leading to faster fermentation for the two crushed composts. The concentrations of P, K, Ca, and Mg are similar to that of N, that is, their concentrations are higher for the uncrushed compost than the crushed ones. However, P, Ca, and Mg concentrations are lower in the compost crushed by cultivator than that by shovel loader. K concentration is lowest in the compost crushed by shovel loader but not far off. Microelements such as Mn, Fe, Cu, and Zn concentrations have lowest concentrations in the compost crushed by cultivator. The compost crushed by shovel loader and the uncrushed compost have similar concentrations of Mn, Fe, Cu, and Zn, comparison of the grain size of the manure crushed by cultivator with that crushed by shovel loader shows that the former manure has finer grain size, resulting in faster fermentation for the compost due to more surface area for contact with the organisms.

Soil property changes of cabbage garden treated with different composts

The field to be grown with cabbage was treated with four types of fertilizer separately before planting: (1) horse manure compost; (2) compost of mixture with horse manure and sawdust at 1 to 3 ratio; (3) compost of poultry feces sold in market; (4) chemical fertilizer only. After cabbage was planted, the change of soil properties at different stage of cabbage growth while chemical fertilizer was designed to add accordingly and the results were shown in Figure 5. The pH of the soil treated with the three types of compost (types 1 to 3) is increasing slowly but more stable for the one treated with horse manure compost (type 1). The soil treated with chemical fertilizer only shows rapid acidification because no organic fertilizer to buffer the acidic material released by cabbage roots. Organic matter (OM) of the soil is higher and better for the horse manure compost (type 1). The organic contents of the soil are lower for the other fertilizers (types 2 to 4). In fact, due to this net N immobilization, horse manure is not a desired fertilizer. However, due to beneficial effects on soil structure and C content, it can be considered a valuable soil conditioner (Sweeten and Mathers, 1985). Phosphorus contents are higher for the organic compost sold in market (type 3), followed by composts of horse manure and mixture of manure and sawdust at 1 to 3 ratio (types 1 and 2). The soil with chemical only has lower phosphorus content. The potassium contents are higher, especially qt later stage, for the soil treated with horse manure composts (types 1 and 2), followed by the compost sold in market (type 3) and then the chemical fertilizer (type 4). Calcium and magnesium contents of the soil are the best for the one mixed with sawdust (type 2) and then the compost from market. The lowest concentration in the one treated with chemical fertilizer. To sum up, the soil treated with compost of horse manure (type 1) is better than the other fertilizers (types 2 to 4) in improving the soil properties as well as rationing nutrients for cabbage growth. The application of horse compost can work as amendments to reclaim acid mine soils (Walker et al., 2004; Clemente et al., 2006;). Mature horse composts will increase sorption of metals onto colloidal particle surfaces, and the formation of stable complexes with humic substances. These substances provide an important number of carboxylic (–COOH), hydroxylic (–OH) and phenolic (aromatic ring–OH) functional groups, which have a large affinity for metals l (Narwal and Singh, 1998; Shuman, 1999; Walker et al., 2004). The application of farmyard

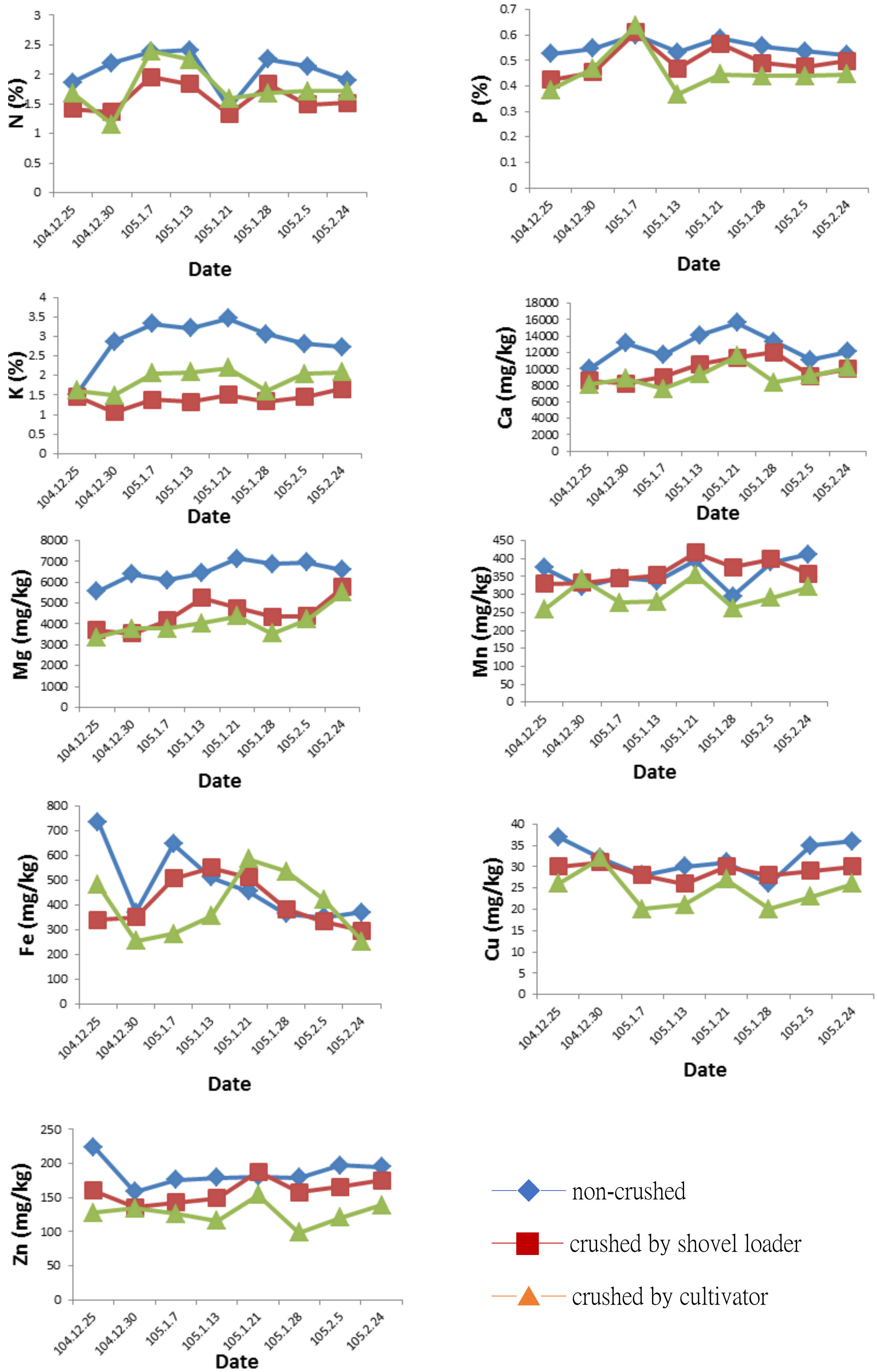

Figure 4. The nutrients concentrations (N, P, K, Ca, Mg, Mn, Fe, Cu and Zn) of cattle manure between different crushing treatments.

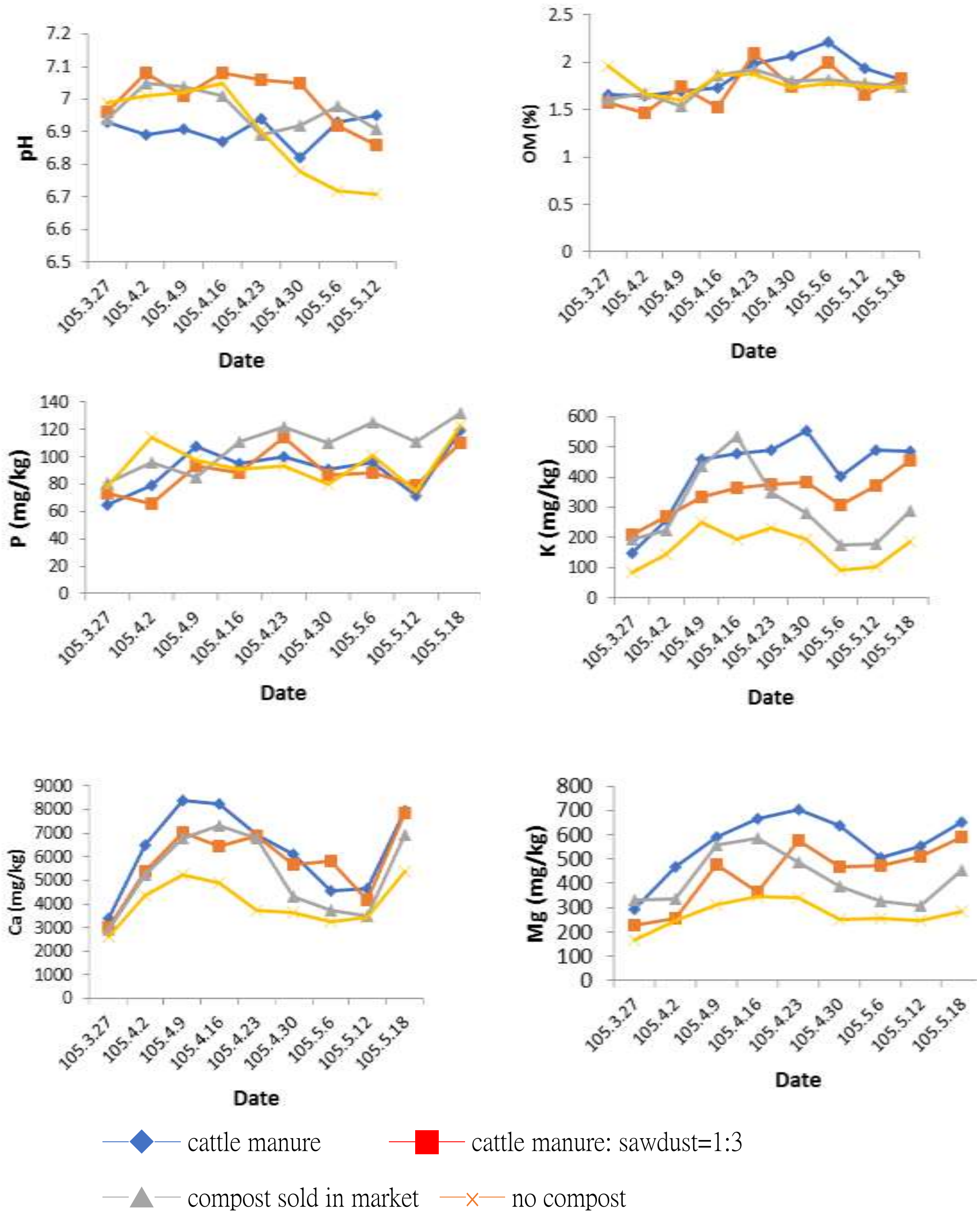

Figure 5. The soil properties between different application of organic fertilizers in the cabbage garden.

manure at a rate of 10 tha/year for 21 years increased soil organic carbon (SOC) and Zn contents by 28.9 and 46%, respectively, compared to CK (Parat et al., 2005).

Variations of element concentration in cabbage treated with different composts

Figure 6 shows elemental analyses on cabbage leaves grown in soils treated with four types of fertilizer as mentioned earlier, namely (1) the horse manure compost, (2) the compost mixed 1 to 3 between horse feces sold in market, and (4) chemical fertilizer only. It was found that nitrogen concentrations of cabbage leaves are higher for the soils treated with organic fertilizers (types 1 to 3) than for that treated without (type 4). The highest N concentration among the three organic fertilizers was found at the one sold in the market (type 3). The P

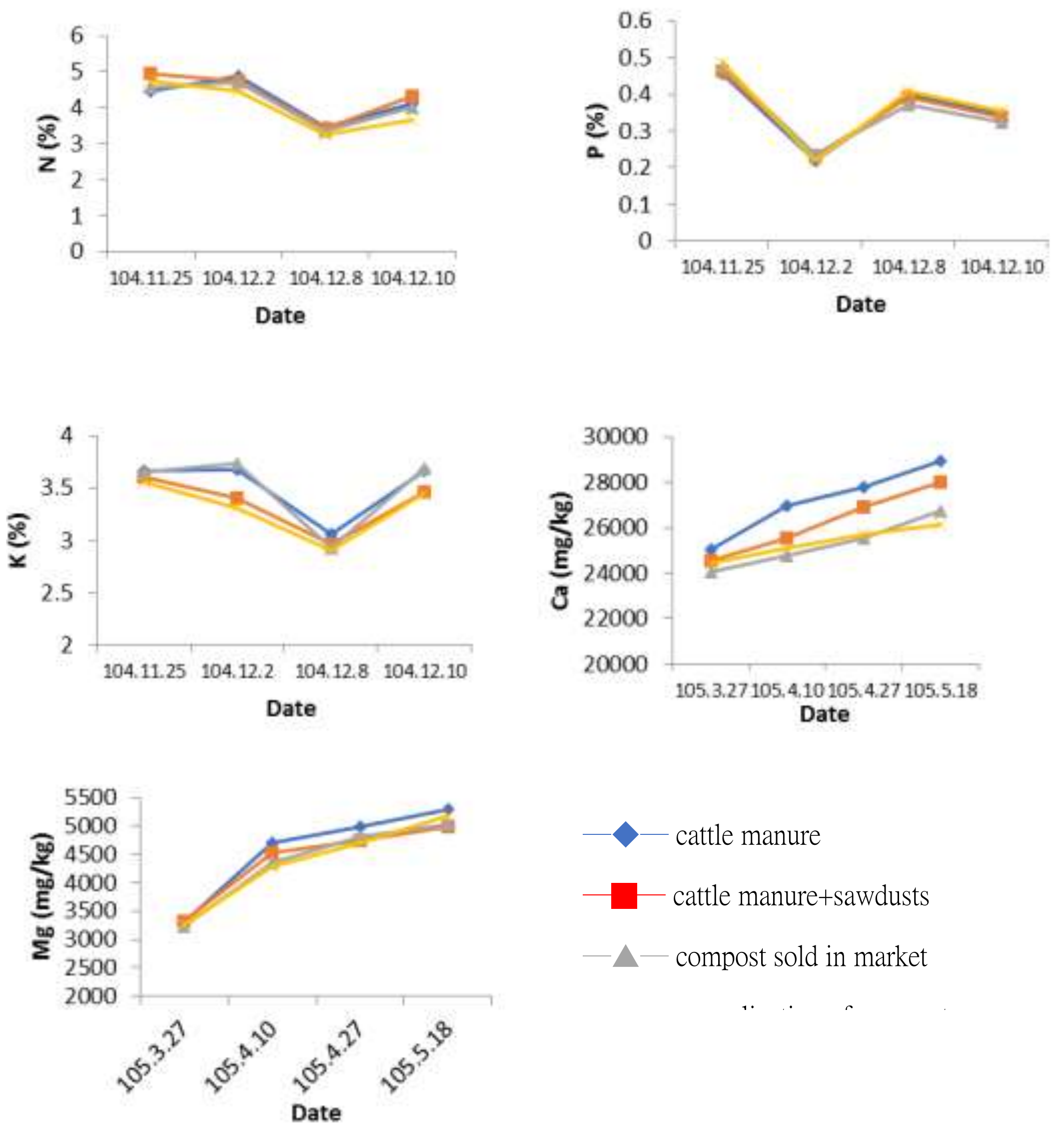

Figure 6. The nutrient concentrations in the leaves of cabbage between different treatments of organic fertilizers.

concentrations are similar for all types of fertilizer but higher concentration was found at the one without organic fertilizer (type 4) treatment. This might be due to P remaining from previous cultivation. The concentrations of K, Ca and Mg in the cabbage were higher for the manure compost and mixed one (types 1 and 2) than for the organic fertilizer sold in market and the chemical fertilizer (types 3 and 4). The results showed that manure composts (type 1 and 2) were helpful in raising the concentrations of Ca, Mg and K in cabbage leaves.

Microorganisms' variations in manure before and after composting

Separation and analysis of microorganisms in manure before and after composting show that bacteria are the main microorganisms but more abundant phases in the manure before composting, totaling 10 species (Table 3). Total amount of bacteria is about $1.7{\times}10^6$ CFU/g soil (colony forming unit/g soil). After fermentation and competitive interference among bacteria the manure after composting are reduced to 6 species with $2{\times}10^6$ CFU/g soil. Among them, 3 genus of *Bacillus* spp. (HS3, HS5 and HS6) may be found at about 10^4~10^5 CFU/g soil with increasing trend after composting. The concentrations of each species are shown in Table 3. In the composting process, *Bacillus* spp. genus is the main fermentation driver because they are temperature, they temperature resistant, resulting in higher concentration after composting. Decaying bacteria with less temperature resistance show less useful for composting and may die

Table 3. The variation of micro orgasms in horse manures before and after composting.

No.	Before composting (CFU/g soil)	After composting (CFU/g soil)
HS1	3.0×10^5	-
HS2	$< 10^3$	-
HS3	2.2×10^4	1.2×10^5
HS4	$< 10^3$	
HS5	3.2×10^5	3.3×10^5
HS6	3.0×10^5	7.2×10^5
HS7	2.8×10^5	-
HS8	2.3×10^5	-
HS9	1.5×10^4	-
HS10	2.3×10^5	-
HSF1	-	$< 10^3$
HSF2	-	$< 10^3$
HSF3	-	6×10^3

HS: *Bacillus subtilus* spp.,HSF: fungi.

Table 4. The quality of cabbage by the application of different compost.

Quality×Treatment	Average weight of cabbage (g/grain)	Average diameter of cabbage (cm/grain)	Average sugar degree (°Brix)	Yield rate (%)
HC	1031[a]	14.2[a]	4.1[a]	94.5[a]
HMS	723[b]	13.9[a]	4.1[a]	43.0[c]
PCM	1025[a]	14.2[a]	4.0[a]	54.7[b]
CK	596[c]	11.4[b]	3.9[a]	43.8[c]

HC: Horse manure compost; HMS: horse manure: sawdust=1:3; PCM: powder compost sold in market; CK: no application of organic fertilizer.

under fermentation heat. HSF1~3 (Fungi) appear only after fermentation of the manure, probably introduced from the environment after fermentation when temperature has dropped, and then concentrations are lower, about 6×10^3 CFU/g soil at maximum.

Effects on quality of cabbage by different composts

Livestock manure-derived amendments can be very beneficial for agricultural soil quality, as they increase the content of soil OM (thereby, improving porosity, aeration, water holding capacity, structural stability and nutrient availability) and stimulate microbial activity and biomass, thus enhancing crop yield (Hernández et al., 2016). Livestock manure can be applied directly (fresh) or after being subjected to a composting process. Table 4 shows cabbage grown with horse manure compost as fertilizer has the highest mean unit weight, average diameter, mean sweetness and quality yield. This is followed by the compost (powder form) sold in market. Ranking third is the compost at 1 to 3. The quality of cabbage is worst when the soil is not treated with organic fertilizer. This indicates that application of manure compost improves cabbage quality significantly. Desalegn et al. (2005) found that horse manure as growing media component promotes growth of cress seed. Presently, production of compost at composting field needs to conform to regulations on fertilizer classification (Chen et al., 1999). The horse manure compost should have to conform to the poultry compost sold in market.

Conclusion

These experiments showed that composting of horse manure requires suitable crushing before proceeding in order to complete the compost faster. During the composting process, high-temperature resistant *Bacillus* species serves as an active fermentative microorganism. The appropriate application of horse compost will be helpful for nutrient absorption of cabbage and increase its quality. This research proved that horse manure can be produced for high-quality compost via crushing.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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