Impact of Composted Dairy Manure on pH Management and Physical Properties of Soilless Substrate

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Abstract

Dairy cow manure compost (DMC) was evaluated as a soilless substrate substitute for dolomitic limestone and peat moss in two experiments. The objectives were 1) to quantify the impact of DMC on substrate pH establishment and stabilization throughout crop time and 2) to test the effect of DMC on physical properties of substrate. Peat moss plus DMC (at 5 to 30% by volume) was held constant at 75% volume and perlite at 25% without limestone. Two additional control treatments of 75% sphagnum peat moss and 25% perlite were formulated with and without agricultural dolomitic limestone. Pot chrysanthemum 'Kory' plants were transplanted into 16.5-cm diameter (1.4 L) plastic pots and fertilized at each irrigation with 17N-2.2P-14.1K neutral fertilizer. Additions of 0 to 30% DMC resulted in initial substrate pH levels of 3.1 to 6.5. Although pH declined during plant production, the decline was similar in the agricultural limestone and the 20 to 30% DMC treatments that had similar initial pH levels. Thus, pH buffering capacity of DMC was similar to the limestone. The initial EC levels for all substrates were within the acceptable range for seedlings and bedding plants. Magnitude of shrinkage did not relate to addition of DMC and was of little commercial significance. Irrespective of time in the cropping cycle, DMC resulted in increased dry bulk density (D_b), decreased total porosity (TP) and container capacity (CC), and little effect on air space (AS). AS levels were in a good range of 15% and above for the 7.6 cm tall test cylinders. End of crop tissue analysis indicated that DMC resulted in higher leaf concentrations of potassium, sulfur, copper, iron, and manganese, lower, but adequate, calcium and magnesium, and similar nitrogen, phosphorus, boron, and zinc concentrations. Maximum plant growth (dry weight) occurred with 15% DMC in Experiment 1 and with 10% DMC in Experiment 2. All limestone and a portion of peat moss were effectively replaced with DMC.

INTRODUCTION

Use of dairy manure compost (DMC) has contributed to sustainable agricultural production through recycling of animal waste and improving chemical and physical properties of soil (Klausner et al., 1998; Eghball et al., 2004; Butler and Muir, 2006; Butler et al., 2008). Composting of manure benefits the handling of manure waste by reducing volume, weight, and odor, and can kill weed seeds and pathogens (Rynk et al., 1992). Application of compost to soil significantly increased pH, organic matter content, and soil-water holding capacity (Murray, 1981; Butler and Muir, 2006; Butler et al., 2008, 2009). The effects of compost residuals lasted up to four years by guarding against soil acidification and nutrient depletion problems in corn production (Eghball et al., 2004). DMC and similar composted materials such as fiber from digested slurry or composted cattle slurry fiber were shown to serve as a substitute for peat moss in a growing mix for a number of crops (Bradley el al., 1996; Chen et al., 1986; Prasad, 2008). Information is lacking on the effects of compost on pH stabilization in container root substrates as well as on the impact compost could have on the physical properties of these substrates. The

objectives of this study were 1) to quantify the impact of DMC on substrate pH establishment and stabilization throughout crop time and 2) to test the effect of DMC on physical properties of substrate.

MATERIALS AND METHODS

Plant Culture

Two experiments were conducted in a glass greenhouse at 35°N latitude in Raleigh, NC. The experiments were initiated in August 2007 (Expt. 1) and May 2008 (Expt. 2) and were conducted for 12 and 11 weeks, respectively. Five rooted cuttings of pot chrysanthemum 'Kory' (*Dendranthema* × *grandiflora* (Ramat.) Kitam.) were transplanted into green plastic pots containing 1.4 L of root substrate and measuring 16.5 cm in diameter at the top and 11.2 cm deep. Fertilizer formulated in deionized water was applied to the top of the substrate at each irrigation with approximately 20% leaching. Fertilizer consisted of 17N-2.2P-14.1K neutral water soluble fertilizer (Greencare 17N-5P2O5-17K2O, Kankakee, IL). It was applied at a concentration of 300 mg L^{-1} N in Experiment 1 and 250 mg L^{-1} N in Experiment 2. Frequency of irrigation ranged from twice a week at the beginning to daily at the end of the experiments. At 14 days after transplanting (DAT), all plants were pinched to leave an average of 9 leaves per plant. In Experiment 1, black cloth was applied from 7:00 pm to 7:00 am beginning at 14 DAT and was continued for 9 weeks to induce flowers. In Experiment 2, incandescence light was applied at an intensity of 2 μmol m^{-2} s^{-1} for the first two weeks. After two weeks, plants were shaded with black cloth from 6:00 pm until 7:00 am daily until color was well developed in buds. Plants were sprayed with daminozide plant growth regulator at a concentration of 2,500 mg L^{-1} 21 DAT in Experiment 1 only.

Compost

A stable mature compost of dairy cow manure plus spoiled-silage (DMC) adjusted initially to a C:N of 30 (Woods End Laboratories, Inc., Mt. Vernon, Maine) was prepared by turned-pile method, using a tractor front-end loader to lift and mix a conical-shaped pile (dimensions 4.3 m d×1.8 m H) 5 times in the course of 90-days. Temperature in the core of the pile rose within 7-days of mixing to 57-60°C and remained very warm (49-57°C) for 6-weeks. After cooling to less than 30°C piles were stored outdoors by covering with Compostex® compost fabric, a polypropylene spun fabric permeable to air but which sheds water. Prior to use, a cubic meter sample of DMC was sieved through a 13 mm screen and mixed in a Twister™ II Batch Mixer, (Bouldin & Lawson, McMinnville, TN). Compost samples were tested by the North Carolina Department of Agriculture and Consumer Services (NCDA&CS) waste analysis lab. Total dry weight concentrations of nutrients are presented in Table 1. Other measurements include a cation exchange capacity of 36.7 meq 100 cm^{-3} determined by summation of cations; a base saturation of 100%; a pH level of 8.0 measured in a 2:1 deionized water filtrate; a saturated paste EC level of 5.1 mS cm^{-1}, a C:N ration of 13.3; and calcium carbonate equivalence 1.67% (dry weight bases).

Treatments

Root substrate treatments had fixed volumes of 25% perlite and 75% sphagnum peat moss (Sun Gro Horticulture, Bellevue, WA) plus DMC (at 5, 10, 15, 20, 25 or 30% by volume). No limestone was applied in these treatments. Additionally, two control treatments of 75% sphagnum peat moss and 25% perlite were formulated with and without agricultural dolomitic limestone (6 g L^{-1}). All treatments included wetting agent (AquaGro 2000 G, Aquatrols, Paulsboro, NJ) at the label rate of 0.6 g L^{-1}. Anhydrous calcium sulfate ($CaSO_4$) at 0.9 g L^{-1} was added into all treatments in Experiment 2.

Data

Root substrate pH and EC were measured in substrate solution extracted using the

pour-through technique (Wright, 1986) in Experiment 1 and the Rhizon Soil Moisture Sampler in Experiment 2 (Soil Moisture Equipment Corp., Santa Barbara, CA, www.soilmoisture.com). Both tests were designed to sample unaltered bulk solution. The Rhizon sampler consisted of a 10 cm long hollow, hydrophilic polymer PVC tube that was inserted diagonally into the pot from 0.5 cm below the substrate surface to the bottom of the pot. Substrate solution was drawn through the sampler and into a collection vial under a vacuum of -138 kPa.

Root substrate shrinkage during the crop production period in Experiment 1 was measured as the difference in depth of the substrate below the pot rim at day 1 and harvest date. Prior to the first measurement, plants had been transplanted and watered to settle the substrate. Substrate depth was determined as the average of three measurements of the distance from the pot rim to the substrate surface.

In Experiment 1 the five plants in each pot were cut at the substrate surface, dried to a constant weight in a forced draft oven at 70°C, and the combined weight of the five plants was measured. In Experiment 2, leaves one third of the distance from the terminal end of lateral shoots were harvested. These leaves were washed in 0.2 N HCl for 1 min, rinsed in deionized water, dried in a forced draft oven at 70°C, and weighed. Total dry shoot weight was determined as the sum of the weight of sampled leaves plus the weight of the remainder of the combined five shoot in each pot. The dry leaf samples were ground in a Thomas-Wiley Intermediate Mill (Arthur H. Thomas Co., Swedesboro, NJ 08085) with a stainless steel cutting chamber to pass a 20 mesh sieve (1 mm particle size). A 0.15 g sample was digested in a microwave digester (MARS; CEM Corp, Matthews, NC) using a modified EPA method (EPA method 3051 with additional peroxide step). Nutrient concentration, except N, was determined with inductively coupled plasma optical emission spectroscopy (ICP-OES; Model IRIS Intrepid II, Thermo Corp., Waltham, MA). Total nitrogen was determined with a combustion analyzer (model 2400, Perkin Elmer, Waltham, MA).

Average substrate physical properties in a 7.6 cm tall column were measured in Experiment 2 at the beginning and the end of the experiment. Measurements included dry bulk density (D_b, g cm^{-3}), total porosity (TP, % substrate volume), container capacity (CC, % substrate volume), and air space at CC (AS, % substrate volume) using the NCSU porometer method (Fonteno, 1996). At the initial date, three 7.6 diameter by 7.6 cm tall cylinders were taped together end to end. This combination cylinder was filled with substrate and was compacted by dropping it a distance of 15 cm three times. The center cylinder with its substrate was used for physical properties testing. At the end of the experiment (77 DAT), substrate was removed from the center of pots by coring. Three 7.6-cm diameter cylinders were taped together end to end. The bottom cylinder was 3.8 cm tall and had a beveled cutting edge while the two cylinders above it were each 7.6 cm tall. This compound cylinder was hammered through the substrate in the pot to the pot bottom. The center cylinder with its substrate was used for physical properties testing.

Experimental Design and Analysis

Both experiments were arranged in a randomized complete block design with five blocks. Each plot consisted of one complete row of three pots across the 122 cm wide bench. Initial substrate pH and EC values of each substrate were regressed using the PROC REG to determine the best-fit, linear or quadratic model. Terms of the model were evaluated for significance based on a comparison of F values at α=0.05. Means of plant tissue nutrient concentrations were separated by T-test at $P \leq 0.5$.

RESULTS AND DISCUSSION

Substrate pH

Initial substrate pH in Experiments 1 and 2, measured after watering newly transplanted plants with deionized water, was 5.8 and 6.0 in the control treatment with limestone but no DMC and 3.2 and 3.1 in the control treatment without both limestone

and DMC, respectively (Fig. 1). Initial substrate pH increased with each increase in DMC in a quadratic fashion ($P<0.0001$). At 30% DMC initial substrate pH was 6.3 and 6.6 in Experiments 1 and 2, respectively. The initial substrate pH declined over time in all treatments with the exception of the un-limed 0, 5, and 10% DMC treatments in Experiment 1 and 0% DMC in Experiment 2 (Fig. 2). Substrate pH in these latter treatments was always below 5.0 and rose slightly by the end of the experiments. Substrate pH in the limestone control treatment over time was between the 20 and 30% DMC treatments in Experiment 1 and between the 20 and 25% treatments in Experiment 2. The declines in substrate pH over time in the limestone control and 20 to 30% DMC treatments were fairly parallel, indicating that the pH buffering capacity of DMC was of a similar magnitude to the agricultural limestone. A downward shift in pH was anticipated because applied fertilizer was neutral, there was no alkalinity in the irrigation water, and plant root respiration was expected to have an acidifying effect. The residual component of limestone was inadequate to counteract acidification.

Substrate EC

The EC of DMC, as determined by the saturated media extraction procedure, was 5.1 mS cm^{-1}. The EC of substrate solutions in Experiment 1, obtained through the pour-through extraction procedure one hour after watering the newly transplanted plants with deionized water ranged from 2.0 to 3.0 mS cm^{-1} (Fig. 3). The EC levels in all substrates were within the safe range for seedlings and bedding plants as set forth for the pour-through technique by Whipker et al. (2000).

Plant Growth

The 15 and 10% DMC treatment in Experiments 1 and 2, respectively, produced the largest plant dry weight which is significantly greater growth compared to both control treatments that did not contain DMC (Fig. 4). Similarly, the addition of composted separated fiber from cattle manure improved the growth of tomato seedling (Prasad, 2008).

Substrate Physical Properties

Because the procedures for sampling substrate were, out of necessity, different at the beginning and end of the experiment, comparison of physical properties between the two times would not be valid. Consequently, interpretation of physical properties is limited to the impact of DMC within each of the initial and final treatment series.

Initial and final substrate dry D_b increased from 0.10 to 0.23 g cm^{-3} and from 0.11 to 0.19 g cm^{-3}, respectively, with DMC increases from 0 to 30% (Fig. 5A). These are in the range found by Chen et al. (1986). Initial TP decreased from 87.5 to 79.6% with DMC increases from 0 to 30% (Fig. 5B). Final TP likewise decreased from 91.2 to 85.2% with increased DMC. Substrate CC followed a similar pattern to TP (Fig. 5C). Initial CC declined from 70.0 to 62.7% and final CC from 75.2 to 70.0% with increases of 0 to 30% DMC. Initial AS increased slightly up to 10 to 15% DMC and then declined moderately at higher DMC levels (Fig. 5D). Final AS was random across DMC treatments without fitting any significant regression line. Irrespective of time in the cropping cycle, DMC resulted in increased D_b, decreased TP and CC, and little effect on AS. AS levels were in a good range of 15% and above for a 7.6 cm tall column of substrate.

Nutrient Uptake

The control substrate with limestone and the substrate with 20% DMC were selected in Experiment 2 for a comparison of leaf nutrient concentrations because the substrate pH levels in these treatments were similar and in the desired range. Plants grown in the substrate with 20% DMC contained significantly higher concentrations of K, S, Cu, Fe and Mn and lower concentration of Ca and Mg than plants in the limestone control treatment (Table 2). Higher Ca and Mg concentrations would be expected in the limestone control treatment plants due to the supply of these nutrients in dolomitic

limestone. Higher concentrations of the other nutrients were reasonable given the supply of these in manure compost.

CONCLUSIONS

This study demonstrated that DMC can be used in the place of limestone to set initial substrate target pH and buffer it as well as limestone over 77 days of production. Air space at container capacity did not differ and substrate volume shrinkage was insignificant in the DMC substrates. However, bulk density was higher and container capacity was lower in the DMC substrates. Substrate EC values increased with DMC addition but remained in acceptable levels.

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Tables

Table 1. Total nutrient concentrations in dairy manure compost.

	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B
	(%)						(mg kg^{-1})				
Mean	1.77	0.42	0.76	1.80	0.56	0.23	3486.33	351.67	134.67	758	24.63
S.E. [1]	0.11	0.01	0.01	0.03	0.01	0.00	147.74	6.69	1.86	9.45	0.37

[1] Standard error (n=3).

Table 2. Nutrient concentrations with standard errors (n=5) in chrysanthemum leaves grown in 0% DMC with lime (Control) and in the substrate with 20% DMC without lime (20% DMC) at the end of Expt. 2 (77 days after transplant).

Treatment	Macro nutrients (% of dry weight)					
	N	P	K	Ca	Mg	S
Control	6.40±0.17	0.78±0.11	5.21±0.16	2.15±0.12	0.56±0.02	0.19±0.02
20% DMC	5.81±0.11	0.59±0.01	5.98±0.27	1.77±0.04	0.44±0.01	0.27±0.00
Significance[1]	NS	NS	*	*	**	**
	Micro nutrients (mg kg^{-1} of dry weight)					
	B	Cu	Fe	Mn	Zn	Na
Control	65.3±10.5	9.1±1.5	155.1±18.3	308.8±23.6	38.4±1.7	883.9±21.0
20% DMC	53.4±2.80	15.8±1.3	269.6±42.2	462.4±28.2	58.8±9.9	412.8±51.0
Significance	NS	*	*	**	NS	***

[1] T-test significance *, ** and *** at P≤0.05, 0.001 and 0.0005, respectively.

Figures

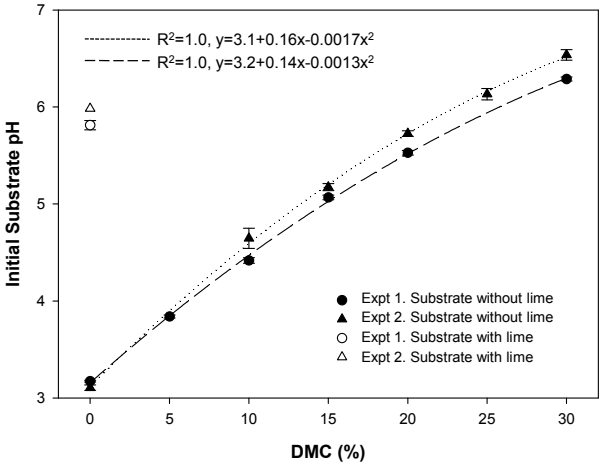

Fig. 1. Response of initial substrate pH to volumetric quantity of dairy manure compost (DMC) in Experiments 1 and 2.

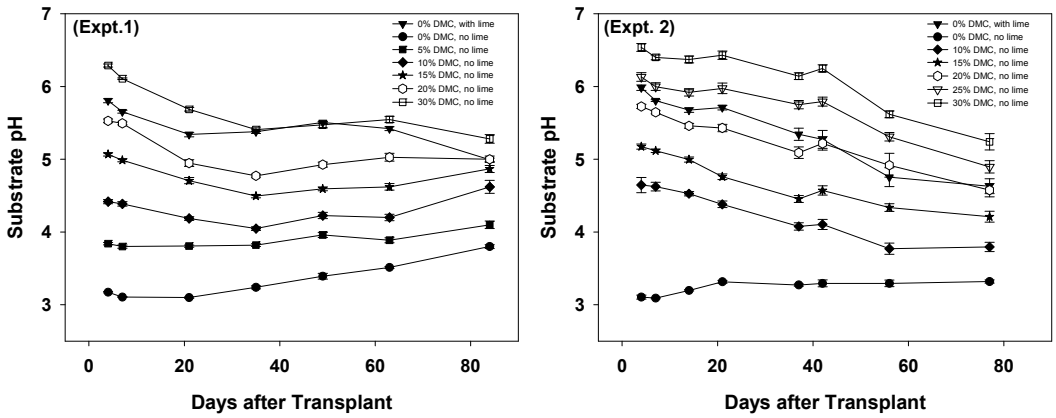

Fig. 2. Substrate pH levels over time in treatments with and without limestone or dairy cow manure compost (DMC) in Experiments 1 and 2.

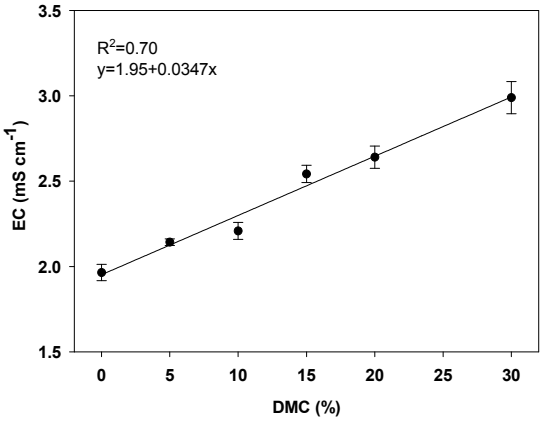

Fig. 3. Average EC (±standard error, n=5) of substrates containing 0 to 30% dairy cow manure compost (DMC) in Experiment 1 after transplanting by the pour-through method.

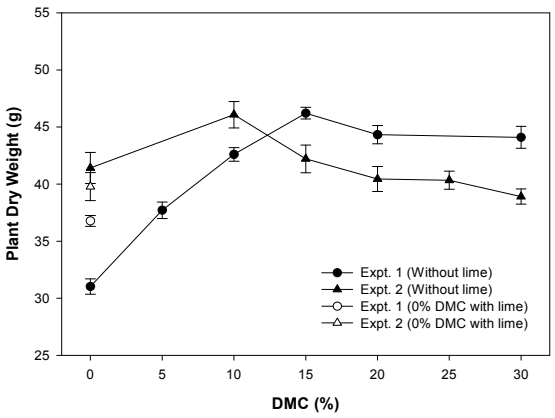

Fig. 4. Plant shoot dry weight with increasing dairy cow manure compost (DMC) from 0 to 30% without lime and 0% DMC with lime.

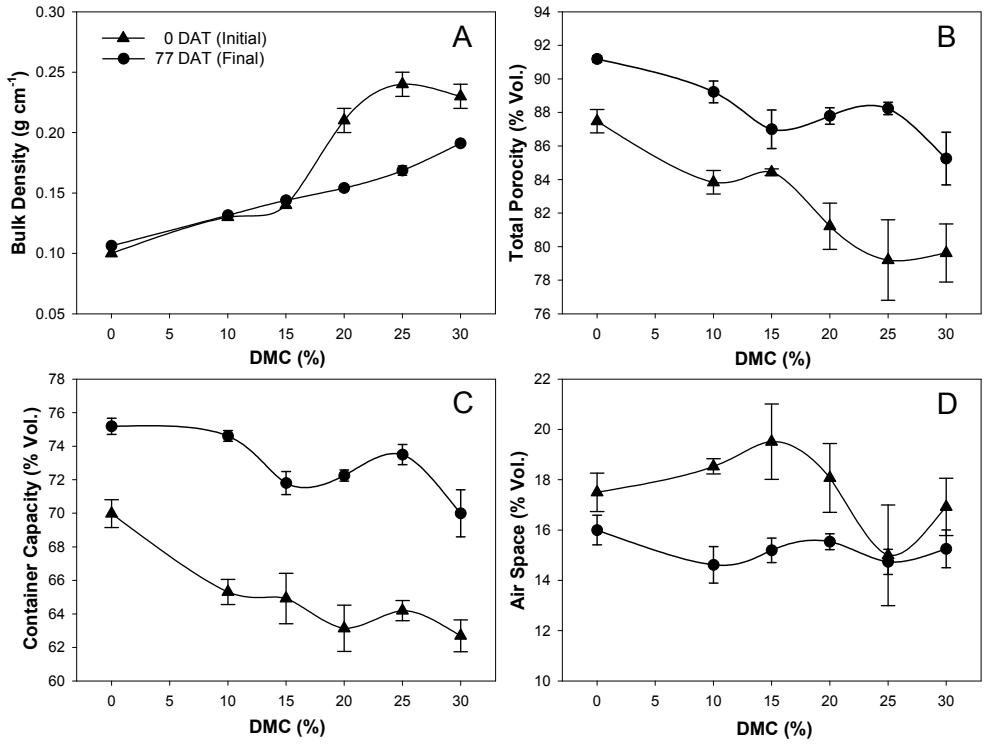

Fig. 5. Average substrate physical properties in a 7.6 cm tall column at the beginning and the end of Experiment 2, including A) dry bulk density (D_b), B) total porosity (TP), C) container capacity (CC), and D) air space (AS).