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Changes in Physical and Chemical Properties of a Loamy Sand Soil When Amended With Composted Poultry Litter[1]

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Abstract

The objective of this study was to determine the effects of composted poultry litter (CPL) on the physical and chemical properties of a loamy sand soil. To accomplish this, a loamy sand soil, amended with 0, 10, 20, 30, 40 and 50% by volume with CPL, was placed in 3.8-liter (#1) container for 13 weeks. Substrate pH increased with increasing rates of CPL. For most landscape plants, pH was in the recommended range ($5.5 \leq pH \leq 6.5$) at 10% to 30% CPL incorporation. Cation exchange capacity, available P, exchangeable K, Ca, and Mg increased linearly with increasing rates of CPL. The 20% amendment rate raised the available P, exchangeable K, Ca, and Mg to levels within the recommended range for landscape plants (N.C. Dept. of Agr.). Total porosity and unavailable water increased linearly with increasing rate of CPL amendment from 42% to 55.5% and 4% to 30.2%, respectively. Bulk density decreased linearly with increasing CPL concentration. Water content and available water capacity increased with increasing CPL rates. CPL amended soil had a 100% to 116% increase in available water capacity, compared to unamended soil. Amending soil with CPL reduced air space 3% to 36% with the largest decrease occurring between 20% and 30% CPL. This data supports the use of composted poultry litter to improve the chemical and physical properties of a loamy sand soil.

Index words: soil water, soil fertility, soil amendments.

Significance to the Nursery Industry: Twenty percent CPL amendment (by vol) modified all measured chemical properties to levels within the range specified for landscape plants. In addition, available water capacity was increased about 0.5 times over unamended soil within the upper 60 cm (24 in), which contains the majority of the root systems of most landscape plants. Available water capacity was increased with only a 6 to 9% decrease in air space.

This data supports the use of composted poultry litter to improve the chemical and physical properties of a loamy sand soil. It would be possible to apply higher rates, however, the increased pH and decreased air space might become limiting for optimal plant growth.

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Introduction

Sandy soils have low water- and nutrient-holding capacity. Therefore, landscape plants growing in a sandy soil are dependent upon frequent irrigation and fertilizer applications (4). Unfortunately, during drought or other water-limiting situations, one of the first steps taken is to ban or restrict watering landscape plants (21). To improve the water- and nutrient-holding capacity of sandy soils, current recommendations include amending soils with organic matter (6, 21). However, supporting data on the effectiveness of this treatment is limited (25).

Manure is a desirable soil amendment and reports of its effects on soil chemical properties are numerous (8, 23, 25, 30). Manures can increase organic matter content, pH, cation exchange capacity, and level of plant nutrients. The effects of manures on soil physical properties are not well documented (8, 25). Beneficial effects are decreased bulk density, improved soil water-holding capacity, enhanced hydraulic conductivity, and increased size and amount of water-stable aggregates. However, changes in soil physical properties may depend upon soil texture (12). Little research has been conducted to determine the effects of composted animal manure on the physical and chemical properties of soil (9).

In most cases, raw manure is unsuitable for use in the urban environment; however, after composting, manure could be an excellent source of organic matter (7, 29). Therefore, the objective of this study was to determine the effects of composted poultry litter (CPL) on the physical and chemical properties of a loamy sand soil.

Materials and Methods

The experiment, a completely randomized design with 19 replications, was conducted at North Carolina State University, Raleigh. A loamy sand (82.2% sand, 12.2% silt, 5.7% clay) was amended with 0, 10, 20, 30, 40 or 50% (by vol) CPL and placed into 3.8-liter (#1) containers. The CPL had a particle size distribution of 18% less than 0.05 mm (0.02 in), 39% between 0.05 and 2.0 mm (0.08 in), and 43% between 2.0 and 6.3 mm (0.25 in). The containers were placed in a greenhouse at 24/18°C (75/65°F) day/night temperature and watered daily.

Chemical properties. After 13 weeks, soil samples were collected from four replications in each soil x CPL treatment, dried at 105°C (221°F) for 24 hr, crushed to pass a 2-mm sieve, and volumetrically sampled. Using Mehlich-III extractant (15), exchangeable levels of K, Ca, and Mg were determined and reported as milliequivalents per 100 cm^3. Levels of P were determined and reported as milligrams per cubic decimeter. Exchangeable acidity and pH were determined using the procedure outlined in Mehlich (14). Cation exchange capacity (CEC) was obtained by summing exchangeable acidity and the quantity of K, Ca, and Mg extracted. Organic matter was determined using the procedure outlined in Mehlich (16). All analyses were conducted by the North Carolina Dept. of Agriculture, Agronomic Division, Raleigh. All variables were subjected to analysis of variance and regression analysis (22). Initial chemical properties of CPL and loamy sand soil are listed in Table 1.

Physical properties. All analyses were conducted at the Horticultural Substrates Laboratory, Dept. of Hort. Sci., N.C. State Univ., Raleigh. After 13 weeks, an intact, naturally compacted 347.5 cm^3 sample was taken from the center

Table 1. Initial chemical properties of composted poultry litter (CPL) and loamy sand soil.

Property	CPL	Soil
pH	7.5	4.2
CEC (meq/100cm^3)	33.0	3.4
Available P (mg/dm^3)	199.2	3.6
Exchangeable K (meq/100cm^3)	2.5	0.11
Exchangeable Ca (meq/100cm^3)	25.1	1.17
Exchangeable Mg (meq/100cm^3)	5.0	0.19

of each of 7 containers per treatment using an aluminum cylinder [7.6 cm (3 in) diameter, 7.6 cm (3 in) high] following the procedures of Fonteno et al. (5). The remaining substrate in each of the sampled containers was used to determine unavailable water content.

Total porosity (TP) was determined for each soil × CPL combination using a base plate attached to each of the aluminum cylinders used for sampling. The aluminum base plate consisted of an inner and outer plate with 8 holes in each plate. The plates fit together so the holes could be aligned in the open position for drainage through the plates or rotated to a closed position to prevent drainage. Each unit (cylinder with attached base plate) was placed in a Buchner funnel that had been modified to accept the unit into a fixed position where the outside plate would not move. Rubber stoppers were inserted into the bottom of the Buchner funnels to prevent drainage.

Each unit was rotated into the open position and distilled water was added between the aluminum cylinder and the Buchner funnel walls to allow water to be absorbed through the base plate. Water was added slowly in a step-wise fashion, as outlined by Karlovich and Fonteno (10), to prevent air entrapment. Water level was eventually brought to the top of the substrate; units were allowed to equilibrate for an additional 15 min before drainage. The base plate was closed and the rubber stoppers removed from the Buchner funnel allowing water to drain away from around the units. A graduated cylinder was placed under each funnel, the base plate opened and the sample allowed to drain for 60 min. After drainage, wet weights of the samples were recorded, then dried at 105°C (221°F) for 24 hr before recording dry weight. Total porosity was defined as [((wet weight – dry weight) + drainage water) / volume of sample]. Unavailable water (UW) was defined as the amount of water held at 1.5 MPa, using procedures of Milks et al. (17). TP and UW are properties of the substrate alone, and independent of container size and depth, provided bulk densities are similar in various containers (2, 18).

Soil moisture characteristic curves. Eight replications of each soil x CPL treatment were packed (2) in aluminum cylinders [7.6 cm × 7.6 cm (3 in × 3 in)]. Data were collected for moisture retained at 10 moisture tensions from 0 to 30 kPa using a pressure plate apparatus and procedures of Fonteno et al. (5), Karlovich and Fonteno (10) and Milks et al. (17). Each sample was then removed and bulk density determined by calculating the volume and weighing each sample after drying 24 hr at 105°C (221°F) (11).

A nonlinear, five-parameter function developed for soils by Van Genuchten and Nielsen (27) and adapted to horticultural media by Milks et al. (17) was used to describe the moisture retention data. The function is defined as

$$\Theta = \Theta_r + (\Theta_s - \Theta_r) / [1 + (ah)^n]^m \quad [1]$$

where Θ_s is the mean percent moisture at saturation, Θ_r is the mean percent moisture at asymptotic residual (taken to be 30 kPa), h is the log of moisture tension, and a, n and m are predicted through iteration. Model parameters of soil × CPL treatments are listed in Table 2.

Landscape soil profile model. To determine the effects of CPL addition on the soil at various depths, a landscape soil profile model was developed. TP and UW were equal to the volume wetness (Θ) at saturation and 1.5 MPa, respectively. Water content (WC) was predicted using procedures outlined by Karlovich and Fonteno (10). This model was based on the Equilibrium Capacity Variables (ECV) model described by Bilderback and Fonteno (2) and refined by Milks, et al. (18). The 90 cm (35 in) soil column was mathematically sectioned into 10 cm (4 in) tall increments. The nonlinear equation [1] was used to predict the moisture content (%) at the midpoint of each 10 cm (4 in) section. Multiplying the percentage of water value by the volume of each soil column section gave the water volume held in that section at field capacity. This model assumes that at field capacity the matrix tension is equal to the height of the column with 0 kPa [0 cm (0 in)] at the bottom and 0.9 kPa [90 cm (35in)] at the top. The water volumes of all zones were summed to provide the total water volume in the soil column at field capacity. Air space (AS) was calculated as the difference between TP and WC. Available water capacity (AW) was calculated as the difference between WC and UW.

Table 2. Parameter values, mean square errors (MSE), and coefficients of determination (r^2) for the nonlinear function[z] for composted poultry litter (CPL) amended soils.

CPL	Model Parameters						
(by vol)	Θ_s	Θ_r	a	n	m	MSE	r^2
0	41.95	9.45	0.43	4.22	10.97	4.23	0.995
10	45.22	12.08	1.04	8.06	0.52	1.08	0.999
20	46.92	15.29	0.34	2.89	11.09	4.27	0.997
30	46.97	20.43	0.77	3.23	1.28	0.77	0.999
40	49.39	24.42	0.23	2.00	9.73	1.03	0.999
50	55.45	28.82	0.04	1.81	211.63	1.06	0.999

[z] $\Theta = \Theta_r + (\Theta_s - \Theta_r)/[1 + (ah)^n]^m$

Table 3. Effect of composted poultry litter (CPL) amendment on pH, CEC, available P, exchangeable K, exchangeable Ca, and exchangeable Mg in a loamy sand soil.

CPL	pH	P	CEC	K	Ca	Mg
(% vol)		(mg/dm³)	(meq/100cm³)			
0	4.2	3.4	3.6	0.1	1.2	0.2
10	5.6	5.5	21.1	0.6	2.4	1.1
20	6.2	8.9	38.6	0.9	3.5	2.1
30	6.4	12.6	69.8	1.5	7.3	3.4
40	6.6	17.8	84.3	2.1	10.4	4.9
50	6.8	19.5	95.1	2.5	11.6	5.0
Significance[z]						
Linear	***	***	***	***	***	***
Quadratic	***	*	*	***	***	***

[z]NS, *, **, *** Nonsignificant or significant at 0.05, 0.01, or 0.001 level, respectively.

Results and Discussion

The pH increased with increasing rates of CPL (Table 3). This was expected since the pH of the CPL was 7.5 and past research utilizing poultry (28) or cattle manure (25) reported similar results. For most landscape plants, pH was in the recommended range ($5.5 \leq pH \leq 6.5$) at the 10% to 30% CPL rate (26). The 40% and 50% amendment rates raised pH higher than the recommended level.

Cation exchange capacity, available P, exchangeable K, Ca, and Mg increased linearly with increasing rates of CPL amendment (Table 3). Increasing the CEC should improve soil fertility (4). Hileman (9) working with poultry litter compost, and Mathers and Steward (13) utilizing cattle manure reported similar results. The 20% amendment rate raised the available P, exchangeable K, Ca, and Mg to levels within the recommended range for most landscape plants (26).

Somewhat surprisingly, CPL did not affect the organic matter level (data not shown). Several studies have shown that manure increases the organic matter level. However, it may take regular applications over a long period of time to have a significant impact (3, 20).

Total porosity increased linearly with increasing rate of CPL amendment, from 42% to 55.5% (Table 4). All of the soil × CPL treatments were greater than the minimum 35% pore space proposed by Craul (4).

Bulk density decreased linearly with increasing rate of CPL amendment (Table 4). Similar results were reported with cattle (24, 25), horse (8) and poultry manure (28). Decreasing bulk density is a reflection of increasing total porosity since bulk density is inversely related to pore space. Twenty percent and higher CPL rates were within the proposed ideal bulk density range of 1.35 Mg/m³ or less (4).

Water content increased with increasing CPL rate to a depth of 55 cm (22 in) (Fig. 1). Sommerfeldt and Chang (24) working with cattle manure and Tester (25) working with composted sewage sludge also reported that WC increased with increasing amendment rates. CPL increased WC 176% to 240% in the upper 35 cm (14 in). Most organic materials have a very high water retention capacity. However, much of the water is held at potentials > 1.5 MPa and is unavailable to plants. This is reflected in the increasing UW with increasing

Table 4. Effect of composted poultry litter (CPL) amendment on total porosity, unavailable water, and bulk density of a loamy sand soil.

CPL amendment	Total porosity	Unavailable water	Bulk density
(% vol)	(% soil volume)		(Mg/m³)
0	42.0	4.0	1.48
10	45.2	7.1	1.39
20	46.9	8.9	1.33
30	47.0	14.4	1.29
40	49.4	21.3	1.20
50	55.5	21.4	1.08
100	77.5	30.2	0.50
Significance[z]			
Linear	***	***	***
Quadratic	NS	NS	NS

[z]NS, *, **, *** Nonsignificant or significant at 0.05, 0.01, or 0.001 level, respectively. 100% CPL not included in the regression analysis.

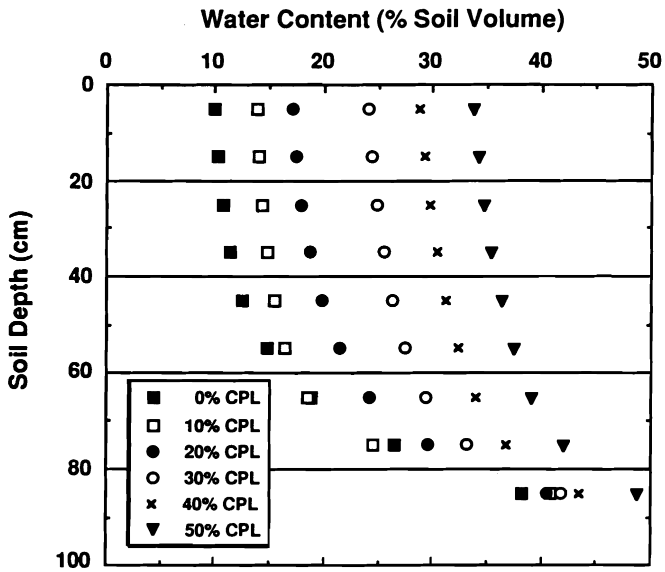

Fig. 1. Effect of composted poultry litter (CPL) on water content of a loamy sand soil.

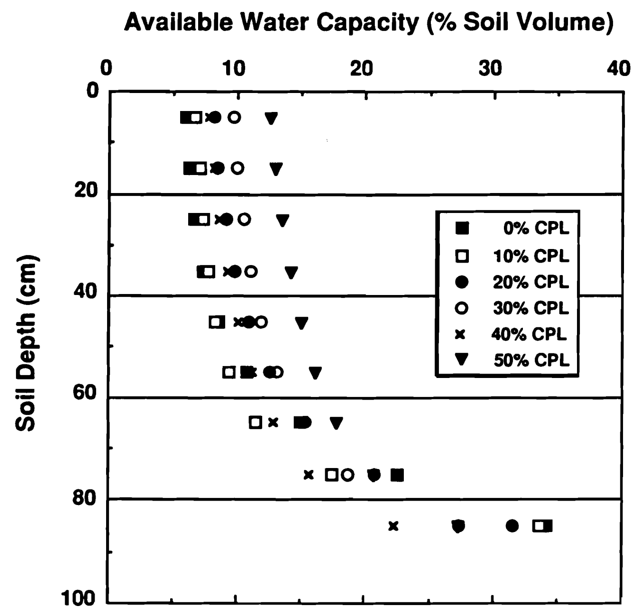

Fig. 2. Effect of composted poultry litter (CPL) on available water capacity of a loamy sand soil.

CPL rates (Table 4). Unavailable water increased linearly with increasing rate of CPL from 78% to 435% compared to unamended soil. Sommerfeldt and Chang (23), working with a clay soil, reported that AW decreased with increasing amendment rates of manure. Any increase in water content should be divided into available and unavailable water before the value of the organic amendment can be evaluated. With this loamy sand, CPL increased AW from 100% to 116% compared to unamended soil (Fig. 2). Available water capacity increased with increasing CPL to a depth of 35 cm (14 in). This is supported by MacRae and Mehuys (12) who reported that organic matter only increased available water in soil with less than 15% clay. From 35 to 85 cm (14 to 34 in) depth, AW in unamended soil (0% CPL) increased until it had the highest AW content. Available water capacity in

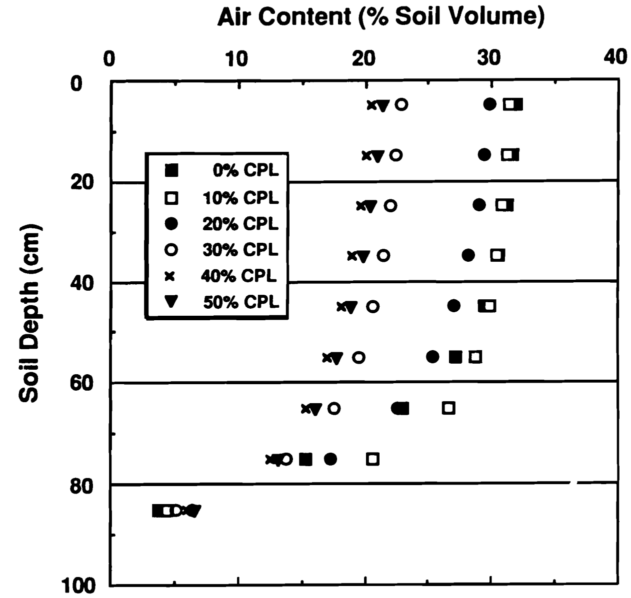

Fig. 3. Effect of composted poultry litter (CPL) on air space of a loamy sand soil.

40% CPL did not increase in line with the other CPL rates due to the increase in UW between 30% and 40% CPL.

CPL reduced AS 3% to 36% compared to unamended soil (0% CPL) to a depth of 35 cm (14 in) (Fig. 3). Below 35 cm (14 in), 10% CPL maintained the largest AS. Forty percent CPL had the lowest AS to a depth of 75 cm (30 in). The largest decrease in AS occurred between 20% and 30% CPL amendment. Twenty to 24% AS should be maintained to provide the pathways for O_2 to move into the soil and CO_2 to move out (1). All soil x CPL treatments maintained adequate AS to a depth of 20 cm (8 in). Below 20 cm (8 in), 40% and 50% CPL dropped below 20% AS. At a depth of 55 cm (22 in), 30% CPL dropped below 20%. At a depth of 75 cm (30 in), all soil × CPL treatments except 10% CPL were below 20% AS. Based on the assumption of the model a perched water table occurred at a depth of 90 cm (35 in). Therefore, increasing the depth of the model would increase AS throughout the soil profile.

The 20% CPL rate modified all measured chemical properties to levels within the range specified for landscape plants (26). In addition, AW was increased about 0.5 times over unamended soil within the upper 60 cm (24 in), which contains the majority of the root systems of most landscape plants (18). Furthermore, AW was increased with only a 6 to 9% decrease in AS. This data supports the use of composted poultry litter to improve the chemical and physical properties of a loamy sand soil. It would be possible to apply higher rates; however, the increased pH and decreased AS might become limiting for optimal plant growth.

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