Available online at www.sciencedirect.com
SCIENCE DIRECT
Scientia Horticulturae 102 (2004) 91–103
SCIENTIA HORTICULTURAE
www.elsevier.com/locate/scihorti

N and P uptake by strawberry plants grown with composted poultry litter

P.L. Preusch[a,1], F. Takeda[b], T.J. Tworkoski[a,b,*]

[a] *Department of Biology, Hood College, Frederick, MD 21701, USA*
[b] *United States Department of Agriculture, Agricultural Research Service (ARS), Appalachian Fruit Research Station, 2217 Wiltshire Road, Kearneysville, WV 25430-2771, USA*

Accepted 15 December 2003

Abstract

Composted poultry litter (CPL) can be used for horticultural crops as a source of organic matter and stabilized N. Recent studies indicated that P was not stabilized by composting and that excess P could be released into the environment when CPL was applied to land on N-based plant requirements. This experiment determined the effect of CPL and fresh poultry litter (FPL) from two sources on leaf N and P concentrations in strawberry plants grown in three soil types. Leaf N was higher in plants grown with FPL than CPL at 6 weeks after planting (WAP), but leaf N was not different by 12 WAP. By 12 WAP strawberry plants grown in soils amended with CPL had higher leaf P than those grown in soils amended with FPL. Applying CPL on a plant N-use rate may contribute to over application of P and higher P uptake by strawberry plants.

Keywords: Composting; *Fragaria* × *ananassa*; Nitrogen; Phosphorus

1. Introduction

The large number of high density chicken (*Gallus gallus domesticus*) farms near the headwaters of the Potomac River in West Virginia, USA (39°04′N, 78°58′W) and near rivers along the eastern shore of the Chesapeake Bay in Maryland (39°15′N, 76°39′W) have been the focus of attempts to solve water quality problems associated with excess applications of poultry litter to farm land (Lipton, 1997; Sims, 2000). Animal manure can be a plentiful

Abbreviations: CPL, composted poultry litter; MD, Maryland; FPL, fresh poultry litter; N, nitrogen; P, phosphorus; WV, West Virginia

* Corresponding author. Tel.: +1-304-725-3451; fax: +1-304-728-2340.
E-mail address: ttworkos@afrs.ars.usda.gov (T.J. Tworkoski).
[1] Present address: University of Maryland, College Park, MD 20740, USA.

0304-4238/$ – see front matter
doi:10.1016/j.scienta.2003.12.005

source of organic soil amendments but proper management is imperative to prevent adverse environmental effects that can result from application of manure to soil. Poultry wastes contain higher concentrations of N, Ca, and P than wastes from other farm animals (Stephenson et al., 1990). Organic mulches made with manures that are rich in nutrients may release significant quantities of nutrients if they are not managed properly (Anonymous, 1999).

Composting may provide a beneficial alternative method for handling poultry litter due to immobilization of nutrients and a reduction in litter volume. Compost is easier to handle, store, transport and apply than non-composted organic residues (Millner et al., 1998). Studies have shown that the composting process immobilizes N in the litter and produces humus, a source of organic materials and slow release-nutrients (Paul and Clark, 1996). The slow release of nutrients from composted poultry litter (CPL) may lessen adverse environmental effects from leaching of N in run-off from farmlands (Chang and Janzen, 1996). N mineralization rates for poultry litter provide the basis for field application rates, but do not guarantee that the amount applied to the soil is fully utilized by the crop. Laboratory and field work has indicated that P may become increasingly available to plants grown in CPL-amended soil (Preusch et al., 2002; Preusch and Tworkoski, 2003). Plant analysis is necessary to document that soil nutrient estimates correlate with nutrient uptake by plants (Munson and Nelson, 1990).

Organic amendments, such as poultry litter, are often applied to supplement soil N. In strawberry plants, the critical foliar N concentration is 2.8% (Ulrich et al., 1992) and CPL could be used to increase soil N. However, applications of CPL to supply N needs may result in over application of other nutrients. The objective of this experiment was to determine the growth and leaf concentrations of several mineral nutrients in strawberry plants grown in soil amended with CPL to increase soil N. Strawberry plants were grown in three soil types to contrast the effects of CPL amendments.

2. Materials and methods

2.1. Soils

Sassafras sandy loam (fine-loamy, siliceous, mesic, typic hapludults) is a typical soil on the eastern shore in Maryland. Hagerstown silt loam (residuum from limestone, fine, mixed, mesic, typic hapludalfs) and Hagerstown clay (residuum from limestone, fine, mixed, mesic, typic hapludalfs) are typical soils in the Piedmont region extending from Maryland into Pennsylvania and West Virginia. The Hagerstown silt loam was collected at the USDA Appalachian Fruit Research Station in Kearneysville, WV and had not been treated with organic or inorganic fertilizers for the previous 10 years. The Hagerstown clay was also from Kearneysville but had been in an actively managed orchard that was fertilized 2 years prior to soil collection. The sandy loam was collected from Caroline Co., on the eastern shore in Maryland from the edge of a field that had not received organic or inorganic fertilizer in 2 years. The soils were air-dried, sieved to pass through a 2 mm screen, and stored at room temperature until use. Analysis of soil chemical and physical characteristics (Table 1) was performed by the Agricultural Analytical Services Laboratory of the Pennsylvania State University, University Park, PA.

Table 1
Chemical characteristics of soils used in the present experiment[a]

Soil	pH	Organic matter (%)	C:N (w/w)	C:P (w/w)	CEC (meq per 100 g)	Nutrients (mg kg^{-1} DW)				
						P	Zn	Fe	Mn	Cu
Sand	4.4	1.1	13:1	78:1	4.0	53	8.9	73	13	1.8
Silt	5.4	1.7	10:1	495:1	6.1	22	2.2	81	190	1.0
Clay	5.4	2.4	11:1	300:1	8.5	38	8.1	50	45	1.0

[a] Analysis performed at the Agricultural Analytical Services Laboratory of the Pennsylvania State University, University Park, PA.

2.2. Litter

Composted and fresh litters were obtained from Moorefield, WV and from Dorchester County, on the eastern shore of Maryland, two major poultry production areas. Throughout this study we refer to “fresh” litter as litter that has no further processing between the chicken house and the field, even though some decomposition of litter probably occurs in the poultry house. Both fresh poultry litters (FPL) had been removed from poultry houses within 1 week prior to our collection.

The fresh and composted litters obtained from the WV composting site were a mixture of turkey (*Meleagris gallopavo*) and chicken litter. In preparation for composting, the turkey and chicken litter mixture was combined with hardwood chips to adjust the C:N ratio to 60:1. The wood chips were about 5 mm long × 3 mm wide × 1 mm thick. The composting mixture was kept under a roofed structure in windrows that were turned and mixed for aeration once a week. The moisture level in the mixture was maintained at 50% (on a dry weight basis) for 3 months through periodic additions of water as necessary.

Both fresh and composted litter obtained from MD was from chicken production. In preparation for composting, the fresh poultry litter was mixed with pine sawdust to adjust the C:N ratio to 60:1. Composting was conducted in uncovered windrows for 12 months with monthly turning.

Fresh poultry litter and CPL from both locations were passed through a 2 mm screen and stored in uncovered plastic jars at 5 °C until use. Litters were used within 2 weeks of collection. Water content was established with 2 g fresh litter dried at 65 °C for 48 h and then re-weighed. Litter samples were analyzed for mineral content and pH (Table 2). Ten

Table 2
Nutrient and pH analysis of fresh and composted poultry litter from Dorchester County, MD and Moorefield, WV

Litter source	Litter treatment	Nutrient ratios (w/w)			pH
		C:N	C:P	N:P	
MD	Fresh	9:1	12:1	1.4:1.0	–
	Compost	11:1	6:1	1.0:1.8	7.0
WV	Fresh	8:1	9:1	1.0:1.0	–
	Compost	15:1	25:1	1.7:1.0	6.0–7.0[a]

[a] Ken Haig, pers. commun., Moorefield, WV.

Table 3
Rates of application of litter treatments to add enough N to bring content to 0.12 g N kg^{-1} of soil

Treatment	Application rate (g litter kg^{-1} soil)		
	Sand	Silt	Clay
West Virginia FPL	5.02	4.70	4.82
West Virginia CPL	8.99	8.43	8.63
Maryland FPL	6.03	5.65	5.78
Maryland CPL	12.42	11.64	11.92
Synthetic fertilizer	1.39	1.30	1.33

grams of litter were combusted in a muffle furnace (400 °C) to gravimetrically determine total carbon content (Ben-Dor and Banin, 1989; Davies, 1974). Total N was determined with a LECO FP 228 Nitrogen Determinator (LECO Corp., St. Joseph, MI). Total P in litter was measured colorimetrically (Murphy and Riley, 1962) after digestion with $HClO_4$ (Adler and Wilcox, 1985).

2.3. *Soil/litter amendment*

Fresh and composted poultry litter from both locations was mixed with each soil to obtain a final N content of 0.12 g N kg^{-1} soil or 151.2 kg N ha^{-1} (assuming incorporation depth of 10 cm and a bulk density of 1.3 Mg m^{-3}). The rates of application (g litter kg^{-1} soil) varied due to differences in total N in the treatments (Table 3). The initial amount of added N was assumed to be high enough to meet strawberry plant N requirements (i.e. above 134 kg N ha^{-1}, Ulrich et al., 1992). Actual organic N also varied among soil–litter mixtures. The amount of organic N g^{-1} soil was ∼91 μg organic N g^{-1} soil in Maryland FPL (MD-FPL) and West Virginia FPL (WV-FPL), 107 μg organic N g^{-1} soil in Maryland CPL (MD-CPL), and 99 μg organic N g^{-1} soil in the West Virginia CPL (WV-CPL). Phosphorus concentration in the soil–compost mixtures varied due to different P concentrations in the litter. At the N-based rate of application, the amount of P in the litter was highest in MD-CPL (236.9 kg P ha^{-1}) and lowest in MD-FPL (106.2 kg P ha^{-1}). WV-FPL and WV-CPL had nearly equivalent initial P concentration (∼170.8 kg P ha^{-1}). Fertilizer with KNO_3, NaP_2O_5, and K_2O (8% N, 5.2% P, 26.6% K) was mixed with the three soils to provide N content of 0.12 g N kg^{-1} soil and was used as a control treatment.

2.4. *Plants and experimental layout*

Six replicate dormant 'jewel' strawberry (*fragaria* × *ananassa* Duch.) plants were planted into each source–compost–soil combination and grown in 15 cm diameter plastic pots (one plant per pot). Strawberry plants were planted on 2 June 1998, and the first leaves elongated within 2 weeks of planting. Strawberry plants were grown in the greenhouse under natural daylength (average midday intensity of 550 μE s^{-1} m^{-2}; 26±6 °C) for 12 weeks and flowers were removed. Plants were watered as needed, usually at least once each day. There were three soils, two poultry litter sources (Maryland and West Virginia), and two poultry litter treatments (fresh and composted). Untreated control and fertilizer-treated plants were also included in each soil type. There were 24 treatments (including controls) and a total of 144 plants.

In a related experiment strawberry plants were planted in pots with silt loam that was amended with CPL or FPL as described above and strawberry plants also were planted in pots with silt loam not amended with CPL or FPL. Poultry litter then was applied as mulch to strawberry plants planted in unamended soil. The same rates and sources of CPL and FPL described previously were applied as mulch or by mixing with the soil. This experiment compared effects two poultry litter sources (Maryland and West Virginia), two poultry litter treatments (fresh and composted), and two application locations (mix and mulch) on strawberry plant growth and leaf mineral content. There were eight treatments and a total of 48 plants.

Each plant was an experimental unit. Total leaf N was analyzed as described previously from one leaf of each plant at 6 weeks after planting (WAP). The remaining leaves were collected at 12 WAP and were analyzed for N, P, K, Ca, Mg, Mn, Fe, Cu, and Zn at the Agricultural Analytical Services Laboratory of the University of Maryland, College Park, MD. At final harvest, 12 WAP, growth and dry weight distribution of each plant was measured.

2.5. Experimental design and data analysis

The experimental design was completely randomized with soil, source of litter, composting, and location of litter application in factorial arrangements. Three analyses were conducted. First, soil (clay, sand, and silt), source (MD and WV), and compost (CPL and FPL) effects were analyzed as a $3 \times 2 \times 2$ factorial without untreated control and synthetic fertilizer treatments. Because of minimal effects of poultry litter source, a second analysis with soil and fertilizer (CPL, FPL, synthetic fertilizer, and untreated control) effects were analyzed as a 3×4 factorial. Third, location of application (mix or mulch), source of litter (MD or WV), and compost treatments (CPL and FPL) in silt loam were analyzed as a $2 \times 2 \times 2$ factorial. Three analyses were performed to maintain balanced treatment effects and evaluate treatment interactions. Analysis of variance was conducted using the general linear models procedure of the statistical analysis system and individual mean separations (least squares means procedure) was performed (SAS/STAT, 1991). There were six replications of each treatment.

3. Results

3.1. Growth and dry weight distributions of plants

In general, soil and compost treatments affected strawberry plant growth and dry weight but source of litter did not (Table 4). Strawberry plants grown in sand had the most leaves and leaf dry weight. Strawberry plants in clay had the most runner weight and least root weight. Fresh compost increased leaf area and runner, leaf, and crown dry weights compared with CPL. Few interactions occurred but compost treatments did interact with soil and source to affect total plant weight (Table 4; compost × soil and compost × source, $P > F = 0.01$ and 0.05, respectively).

Table 4
Treatment means and analysis of variance of dry weight distribution in strawberry plants grown in a greenhouse in three soils mixed with composted (CPL) or fresh (FPL) poultry litter from two sources in Maryland (MD) and West Virginia (WV)

Treatment	Leaf no.	Leaf area (cm^2)	Crown no.	Dry weight (g)				
				Runner	Leaf	Crown	Root	Total
Soil								
Clay	9 b	552 ab	1.3 a	7.1 a	4.5 b	1.7 a	1.1 b	14.4 a
Sand	11 a	594 a	1.5 a	4.6 b	5.4 a	2.0 a	2.2 a	14.2 a
Silt	9 b	491 b	1.3 a	4.4 b	4.2 b	1.5 a	1.9 a	12.0 b
Source								
MD	9 a	532 a	1.3 a	5.2 a	4.7 a	1.6 b	1.7 a	13.2 a
WV	10 a	559 a	1.5 a	5.5 a	4.7 a	1.9 a	1.7 a	13.8 a
Compost								
CPL	9 a	491 b	1.3 a	4.6 b	4.3 b	1.5 b	1.7 a	12.1 b
FPL	10 a	600 a	1.5 a	6.2 a	5.1 a	2.0 a	1.8 a	15.1 a
$P > F$								
Soil (SL)	0.02	0.04	0.20	0.01	0.01	0.15	0.01	0.01
Source (SC)	0.26	0.41	0.23	0.60	0.86	0.03	0.88	0.29
Compost (C)	0.06	0.01	0.09	0.01	0.01	0.01	0.52	0.01

Within each column and treatment, means followed by the same letter do not differ based on least squares means procedure.

A second analysis of treatment effects averaged growth and dry weights from both litter sources and compared litter effects with synthetic fertilizer and untreated control (Table 5). Only two significant soil-by-fertilizer interactions occurred and main effects were compared. Strawberry plants grown with FPL had the greatest number of crowns and leaf, crown, and total dry weights (Table 5). Strawberry plants grown with synthetic fertilizer had more runner and total dry weight than strawberry plants grown with CPL or untreated control. Strawberry plants grown with CPL had less leaf area, number of crowns, and total dry weight than strawberry plants grown with FPL and did not differ from untreated control.

Location of litter application affected strawberry plant growth and dry weight distribution. Poultry litter mixed with soil increased leaf number, area, and dry weight compared to poultry litter applied to soil as mulch (Table 6). Number of crowns and crown dry weight were also greater in soil mixed with litter. In contrast, runner dry weight was less in soil mixed with poultry litter. Significant interactions of source × compost and treatment location × source × compost occurred with total plant dry weight ($P > F = 0.03$ for both).

3.2. Nitrogen

In the analysis of variance of leaf mineral concentrations, significant interactions occurred with the type of soil and other treatment effects (Tables 7 and 8). Consequently, interaction means were presented for each soil. At 12 WAP, there was no difference in leaf N due to soil, source, or compost treatments (Table 7). A fertilizer–soil interaction was observed (Table 8). Leaf N was less in strawberry plants grown with CPL and FPL than

Table 5
Treatment means and analysis of variance of dry weight distribution in strawberry plants grown in a greenhouse in three soils mixed with composted (CPL), fresh (FPL) poultry litter[a], and synthetic fertilizer

Treatment	Leaf no.	Leaf area (cm^2)	Crown no.	Dry weight (g)				
				Runner	Leaf	Crown	Root	Total
Soil								
Clay	9 a	566 a	1.3 a	7.0 a	4.5 ab	1.8 a	1.2 c	14.5 a
Sand	10 a	531 ab	1.3 a	4.4 b	4.8 a	1.7 a	2.0 a	12.9 b
Silt	9 a	467 b	1.3 a	4.5 b	3.9 b	1.3 b	1.7 b	11.4 c
Fertilizer								
CPL	9 a	492 b	1.3 b	4.6 b	4.3 b	1.5 b	1.7 a	12.1 c
FPL	11 a	601 a	1.5 a	6.2 a	5.1 a	2.0 a	1.8 a	15.1 a
Synthetic	9 a	527 ab	1.1 b	6.6 a	4.0 b	1.4 b	1.5 a	13.5 b
Untreated	9 a	464 b	1.2 b	3.8 b	4.1 b	1.5 b	1.6 a	11.0 c
P > *F*								
Soil (SL)	0.17	0.02	0.95	0.01	0.02	0.04	0.01	0.01
Fertilizer (F)	0.15	0.01	0.04	0.01	0.01	0.01	0.46	0.01
SL × F	0.27	0.19	0.70	0.55	0.09	0.64	0.02	0.01

Within each column and treatment, means followed by the same letter do not differ based on least squares means procedure.

[a] Poultry litter treatment is the average of composted and fresh poultry litter from two sources in Maryland and West Virginia.

Table 6
Treatment means and analysis of variance of dry weight distribution in strawberry plants grown in a greenhouse in silt loam with composted (CPL) or fresh (FPL) poultry litter from two sources in Maryland (MD) and West Virginia (WV) applied by mixing with soil (mix) or to the soil surface (mulch)

Treatment	Leaf no.	Leaf area (cm^2)	Crown no.	Dry weight (g)				
				Runner	Leaf	Crown	Root	Total
Location								
Mix	9 a	491 a	1.3 a	4.4 b	4.2 a	1.5 a	1.8 a	11.9 a
Mulch	7 b	390 b	1.1 b	5.2 a	2.8 b	1.1 b	1.8 a	10.9 a
Source								
MD	8 a	446 a	1.3 a	4.7 a	3.6 a	1.3 a	1.9 a	11.5 a
WV	8 a	434 a	1.2 a	4.9 a	3.5 a	1.3 a	1.8 a	11.5 a
Compost								
CPL	8 a	380 b	1.2 a	3.3 b	2.9 b	1.1 b	1.6 b	8.9 b
FPL	9 a	502 a	1.3 a	6.4 a	4.1 a	1.5 a	2.1 a	14.1 a
P > *F*								
Location (L)	0.01	0.01	0.02	0.05	0.01	0.01	0.58	0.06
Source (SC)	0.74	0.73	0.73	0.62	0.69	0.95	0.39	0.93
Compost (C)	0.30	0.01	0.73	0.01	0.01	0.01	0.01	0.01

Within each column and treatment, means followed by the same letter do not differ based on least squares means procedure.

Table 7
Treatment means and analysis of variance of mineral concentration in leaves of strawberry plants grown in a greenhouse in three soils mixed with composted (CPL) or fresh (FPL) poultry litter from two sources in Maryland (MD) and West Virginia (WV)

Treatment	Leaf macronutrients (% DW)				Leaf micronutrients (mg kg^{-1} DW)				
	N	P	K	Ca	Mg	Mn	Zn	Cu	Fe
Clay									
MD CPL	0.82 a	0.28 a	1.76 a	2.65 ab	0.35 ab	108 a	25 b	6.0 a	37 a
FPL	0.82 a	0.25 ab	1.67 a	2.47 b	0.34 ab	101 a	27 ab	5.8 a	41 a
WV CPL	0.82 a	0.27 a	1.69 a	2.53 ab	0.32 b	110 a	62 a	5.3 a	40 a
FPL	0.84 a	0.23 b	1.67 a	2.79 a	0.38 a	70 a	40 ab	5.5 a	39 a
Sand									
MD CPL	0.72 a	0.26 ab	0.94 b	2.25 a	0.41 ab	114 a	31 a	6.3 b	34 b
FPL	0.77 a	0.24 b	0.93 b	2.51 a	0.42 a	99 a	78 a	7.8 a	33 b
WV CPL	0.73 a	0.28 a	1.36 a	2.27 a	0.35 c	90 ab	98 a	8.2 a	32 b
FPL	0.79 a	0.23 b	1.00 b	2.36 a	0.38 bc	40 b	87 a	7.3 ab	47 a
Silt									
MD CPL	0.75 a	0.23 b	1.39 ab	2.27 b	0.34 a	200 b	43 a	6.5 a	42 a
FPL	0.83 a	0.16 b	1.09 b	2.53 ab	0.36 a	305 a	22 a	7.0 a	37 a
WV CPL	0.90 a	0.35 a	1.50 a	2.74 a	0.38 a	226 b	24 a	6.7 a	35 a
FPL	0.81 a	0.19 b	1.01 b	2.62 ab	0.38 a	210 b	36 a	7.2 a	36 a
$P > F$									
Soil (SL)	0.06	0.09	0.01	0.01	0.01	0.01	0.03	0.01	0.54
Source (SC)	0.27	0.06	0.35	0.13	0.54	0.01	0.15	0.56	0.75
Compost (C)	0.44	0.01	0.01	0.16	0.04	0.68	0.92	0.15	0.35

Within each column and soil, means followed by the same letter do not differ based on least squares means procedure.

synthetic fertilizer in sand and silt but leaf N was the same in plants grown in clay. Leaf N was greater in strawberry plants grown in silt that was amended with CPL and FPL than untreated silt but there were no differences in leaf N in strawberry plants grown in clay and sand.

3.3. *Phosphorus*

At 12 WAP leaves from strawberry plants grown with both sources of CPL compared to FPL tended to have higher P in all three soil types (Tables 7 and 8). This coincides with findings from the related mineralization study that P levels increased in soil treated with CPL that was applied on an N-use rate (Preusch et al., 2002). Leaf P was highest in strawberry plants grown in silt amended with CPL from WV (Table 7). Leaf P was greater in CPL than in synthetic fertilizer treatments in clay and silt but not in sand (Table 8).

Leaf P in strawberry plants treated with the litter applied as mulch to the top of the soil (silt loam) was higher from CPL than from FPL applications (Table 9). Availability of P from mulch-like application of litter appeared significant, similar to previous work with CPL applied as mulch beneath peach trees (Preusch and Tworkoski, 2003).

Table 8
Treatment means and analysis of variance of mineral concentration in leaves of strawberry plants grown in a greenhouse in three soils mixed with composted (CPL) and fresh (FPL) poultry litter[a] and synthetic fertilizer

Treatment	Leaf macronutrients (% DW)					Leaf micronutrients (mg kg^{-1} DW)			
	N	P	K	Ca	Mg	Mn	Zn	Cu	Fe
Clay									
CPL	0.82 a[b]	0.28 a	1.72 a	2.59 b	0.34 ab	109 b	43 a	5.7 b	39 b
FPL	0.83 a	0.24 b	1.56 a	2.63 b	0.36 a	86 b	33 a	5.7 b	40 b
Synthetic	0.89 a	0.20 c	1.74 a	3.02 a	0.36 a	289 a	28 a	7.0 a	60 a
Untreated	0.84 a	0.23 b	1.57 a	2.50 b	0.31 b	116 b	33 a	6.3 ab	46 b
Sand									
CPL	0.73 b	0.27 a	1.15 b	2.26 a	0.38 a	102 ab	64 a	7.3 a	33 c
FPL	0.78 b	0.23 b	0.97 c	2.43 a	0.40 a	70 b	83 a	7.6 a	40 b
Synthetic	1.01 a	0.26 a	1.78 a	2.19 ab	0.33 b	105 ab	24 a	7.5 a	52 a
Untreated	0.77 b	0.19 c	0.85 c	1.99 b	0.37 a	141 a	21 a	7.3 a	32 c
Silt									
CPL	0.82 b	0.29 a	1.44 b	2.50 a	0.36 b	213 b	33 a	6.6 a	38 a
FPL	0.82 b	0.17 b	1.05 c	2.58 a	0.37 ab	257 ab	29 a	7.1 a	36 a
Synthetic	0.99 a	0.17 b	1.90 a	2.24 a	0.30 c	256 ab	27 a	6.4 a	42 a
Untreated	0.67 c	0.13 b	1.09 c	2.59 a	0.40 a	283 a	29 a	5.5 b	37 a
$P > F$									
Soil (SL)	0.78	0.01	0.01	0.01	0.13	0.01	0.78	0.01	0.01
Fertilizer (F)	0.01	0.01	0.01	0.18	0.01	0.01	0.14	0.17	0.01
SL × F	0.01	0.07	0.01	0.01	0.01	0.01	0.38	0.01	0.05

[a] Poultry litter treatment is the average of composted and fresh poultry litter from two sources in Maryland and West Virginia.
[b] Within each column and soil, means followed by the same letter do not differ based on least squares means procedure.

3.4. K, Ca, Mg, and micronutrients

Like leaf P, leaf K was greater in CPL than FPL-amended sand and silt treated with litter from West Virginia (Table 7). Few differences occurred in leaf Ca, Mg, Zn, Cu, and Fe. Compost source affected leaf Mn and source interacted with compost treatments ($P > F = 0.01$ for both two-way interactions). Leaf Mn tended to be greater in strawberry plants grown in CPL than FPL except where they were grown in silt amended with litter from MD. Strawberry plants grown in litter-amended sand and silt had less leaf K and more Mg than soil treated with synthetic fertilizer (Table 8). In clay, litter-amended soil had less leaf Mn and Fe than soil treated with synthetic fertilizer. Leaf concentrations of most minerals were not affected by location of litter application (Table 9). However, leaf K, like leaf P, was greater in strawberry plants receiving litter as mulch.

4. Discussion

Strawberry plant growth was greater in soils amended with FPL than CPL and synthetic fertilizer. It is difficult to attribute this growth to leaf mineral concentration at 12 WAP

Table 9
Treatment means and analysis of variance of mineral concentration in leaves of strawberry plants grown in a greenhouse in silt loam with composted (CPL) or fresh (FPL) poultry litter from two sources in Maryland (MD) and West Virginia (WV) applied by mixing with soil (mix) or to the soil surface[a] (mulch)

Treatment	Leaf macronutrients (% DW)					Leaf micronutrients (mg kg^{-1} DW)			
	N	P	K	Ca	Mg	Mn	Zn	Cu	Fe
Location									
Mix	0.82 a	0.23 b	1.24 b	2.54 a	0.37 a	235 a	32 a	6.8 a	37 a
Mulch	0.76 a	0.27 a	1.74 a	2.50 a	0.37 a	232 a	27 a	6.1 b	39 a
Source									
MD	0.77 a	0.23 b	1.41 b	2.51 a	0.37 a	245 a	30 a	6.4 a	41 a
WV	0.81 a	0.28 a	1.57 a	2.53 a	0.36 a	223 a	28 a	6.5 a	36 a
Compost									
CPL	0.82 a	0.30 a	1.64 a	2.47 a	0.36 a	234 a	33 a	6.4 a	42 a
FPL	0.76 a	0.21 b	1.35 b	2.57 a	0.36 a	234 a	25 a	6.5 a	34 b
$P > F$									
Location (L)	0.08	0.01	0.01	0.60	0.48	0.85	0.38	0.01	0.45
Source (SC)	0.22	0.01	0.03	0.87	0.37	0.13	0.72	0.46	0.10
Compost (C)	0.16	0.01	0.01	0.20	0.73	0.99	0.14	0.46	0.01

Within each column and soil, means followed by the same letter do not differ based on least squares means procedure.

[a] Poultry litter treatment is the average of composted and fresh poultry litter from two sources in Maryland and West Virginia.

because leaf mineral content in FPL-treated strawberry plants was generally the same or lower than in CPL and synthetic fertilizer treatments. Time of mineral availability and the molecular form of minerals may have affected growth.

At 6 WAP, leaf N was greatest in plants treated with synthetic fertilizer (2.53%), lower in plants treated with FPL (1.94%), and lowest in plants treated with CPL (1.32%) and in untreated controls (1.43%). There were few differences in leaf N by 12 WAP. In a related incubation study, there was nearly two times more NH_4^+-N in soil mixed with FPL than CPL within 20 days of mixing (Preusch et al., 2002). NO_3^--N was approximately three times greater in fresh than compost-treated soil (sandy loam and silt loam) by 40 days after mixing. The greater availability of N in fresh litter/soil mixtures probably resulted in higher leaf N at 6 WAP in this strawberry experiment. However, Preusch et al. (2002) found NH_4^+-N dropped to near zero in soils amended with either fresh or composted poultry litter by 40 days after application. In that study, NO_3^--N remained high in unleached soil after 40 days after application. In the current experiment, NO_3^--N may have leached from the soil when pots were watered. Thus, N availability probably was low by 12 WAP which likely accounted for the low leaf N (<1%) and lack of difference between the CPL- and FPL-treated strawberry plants at that time. Early availability of N as NH_4^+ from FPL may have been critical for strawberry plant growth.

Source of litter generally had little effect on strawberry plant growth and leaf mineral content in CPL and FPL treatments. This consistency suggests that significantly different composting methods from different locations can still provide a predictable source of minerals.

Soil affected growth and dry weight. Leaf mineral concentrations were affected by soil and significant soil-by-fertilizer interactions were found. However, trends were not observed as high leaf mineral content was not associated with one soil type. Clay had greatest runner and total dry weight but lowest root dry weight. Soil characteristics, such as bulk density, may have reduced root growth and altered partitioning of biomass from roots to runners. Reduced root growth in clay may also have affected N uptake so that no differences in leaf N were found whether treated with CPL, FPL, or synthetic fertilizer.

It is interesting that leaf P in CPL-amended soils was greater than in FPL-amended soils that had poultry litter from West Virginia. Numerically greater leaf P was also found in soil amended with CPL from Maryland. This is the reverse effect that compost treatment had on leaf N at 6 WAP. In a previous experiment, Mehlich one-extractable P (plant available P) from poultry litter was not reduced by composting (Preusch et al., 2002). Thus, applying CPL at rates to provide higher N, even though high leaf N was not achieved in this study, still resulted in higher leaf P in strawberry plants grown in CPL from West Virginia. These findings coincide with the prediction that applying compost at N-based rates could lead to excess P of which may buildup in the soil, be lost to run-off or leaching, or absorbed by plants (Roberts et al., 1999; Kraus and Warren, 2000; Preusch et al., 2002; Preusch and Tworkoski, 2003). Overabundant P may be problematic in field conditions where short-term soil N deficiencies require large CPL applications to meet plant N needs (Hartz et al., 2000).

Poultry litter can be an economically attractive source of N for growing strawberry plants in a greenhouse (Hamdar and Rubeiz, 2000). Compost-amended soils reduced the amount of fertilizer needed for optimum strawberry plant growth (Wang and Lin, 2001). Compost increased fruit concentrations of N and K but decreased Mn, Fe, Mo, and Ni without affecting Zn and Cd. In the current study, leaf concentrations of K, Ca, Mg, Mn, Zn, Cu, and Fe were generally the same or lower in CPL and FPL-amended soils than soils treated with synthetic fertilizer. Due to low N mineralization rates, large applications of composted manure may be necessary to provide the N needed by crops (Hartz et al., 2000). Excess P in a previous mineralization experiment (Preusch et al., 2002) and higher leaf P seen in this study indicate that overabundant P can result when CPL is applied on an N-use basis. Reducing the rate of CPL application to avoid excess P will likely result in significant deficits of N and possibly of other nutrients. Kraus and Warren (2000) found composted turkey litter could provide necessary P for container-grown *Rudbeckia fulgida* and *Cotoneaster dammeri*. However, supplemental N was probably needed for *C. dammeri*. In general, CPL may have value in organic strawberry systems that improve soil while providing an economically competitive, high quality crop (Hamdar and Rubeiz, 2000). The results from the current experiment indicate that CPL will not provide sufficient nutrients for strawberry production and that additional nutrient inputs may be necessary.

5. Conclusion

Strawberry plants can be grown in soil amended with fresh or composted poultry litter as a fertilizer but application rates and availability of all minerals should be considered. Leaf N at 6 WAP was always greater in strawberry plants treated with FPL than CPL. Leaf P at 12 WAP was greater in strawberry plants treated with CPL than FPL from West Virginia.

Similar, but non-significant, results were obtained with CPL and FPL from Maryland. These results support the hypothesis that applying CPL on the N-based rate requirements may lead to over application of P.

Acknowledgements

We would like to acknowledge and thank Trish Steinhilber at the University of Maryland Nutrient Management Program for the plant tissue analysis at the University of MD Agricultural Analytical Services Laboratory, College Park, MD. We also thank Brent Black and Mark Brown for reviews of an earlier version of this manuscript.

References

Adler, P.R., Wilcox, G.E., 1985. Rapid perchloric acid digest methods for analysis of major elements in plant tissue. Commun. Soil Sci. Plant Anal. 16, 1153–1163.

Anonymous, 1999. Compost utilization on the farm. In: Mark, D. (Ed.), Field Guide to On-Farm Composting. Publication No. 114, Natural Resource, Agriculture and Engineering Service (NRAES), pp. 85–97.

Ben-Dor, F., Banin, A., 1989. Determination of organic matter content in arid-zone soils using a simple "loss-on-ignition" method. Commun. Soil Sci. Plant Anal. 20, 1675–1695.

Chang, C., Janzen, H.H., 1996. Long-term fate of nitrogen from annual feedlot manure applications. J. Environ. Qual. 25, 785–790.

Davies, B.E., 1974. Loss-on-ignition as an estimate of soil organic matter. Soil Sci. Soc. Am. Proc. 38, 150–151.

Hamdar, B.C., Rubeiz, I.G., 2000. Organic farming: economic efficiency approach of applying layer litter rates to greenhouse grown strawberries and lettuce. Small Fruits Rev. 1, 3–14.

Hartz, T.K., Mitchell, J.P., Giannini, C., 2000. Nitrogen and carbon mineralization dynamics of manures and composts. HortScience 35, 209–212.

Kraus, H.T., Warren, S.L., 2000. Performance of turkey litter compost as a slow-release fertilizer in containerized plant production. HortScience 35, 19–21.

Lipton, E., 1997. Poultry Poses Growing Potomac Hazard. Washington Post,1 June, 1997, p. A01.

Millner, P.D., Sikora, L.J., Kaufman, D.D., Simpson, M.E., 1998. Agricultural uses of biosolids and other recyclable municipal residues. In: Wright, R.J., Kemper, W.D., Millner, P.D., Power, J.F., Korcak, R.F. (Eds.), Agricultural Uses of Municipal, Animal and Industrial Byproducts. USDA Agric. Res. Serv. Conserv. Res. Rep. No. 44, pp. 9–44.

Munson, R.D., Nelson, W.L., 1990. Principles and practices in plant analysis. In: Westerman, R.L. (Ed.), Soil Testing and Plant Analysis. Soil Science Society of America, Madison, WI, Book Series 3, pp. 359–387.

Murphy, J., Riley, J.P., 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta 27, 31–36.

Paul, E.A., Clark, F.E., 1996. Soil Microbiology and Biochemistry. Academic Press, San Diego, pp. 182–197.

Preusch, P.L., Adler, P.R., Sikora, L.J., Tworkoski, T.J., 2002. Nitrogen and phosphorus availability in composted and uncomposted poultry litter. J. Environ. Qual. 31, 2051–2057.

Preusch, P.L., Tworkoski, T.J., 2003. Nitrogen and phosphorus availability and weed suppression from composted poultry applied as mulch in a peach orchard. Hortscience.

Roberts, W., Duthie, J., Edelson, J., Shrefler, J., 1999. Limitations to the use of poultry litter as a fertilizer for vegetables. HortScience 34, 456 (abstract 136).

SAS/STAT, 1991. SAS Users Guide Statistics, 4th ed. SAS Institution., Cary, NC.

Sims, J.T., 2000. Advances in animal waste management for water quality protection: case study of the Delmarva Peninsula. In: Proceedings of the Managing Nutrients and Pathogens for Animal Agriculture, Natural Resource, Agriculture, and Engineering Service (NRAES) Conference, NRAES-130, Camp Hill, PA, 28–30 March, pp. 44–59.

Stephenson, A.H., McCaskey, T.A., Ruffin, B.G., 1990. A survey of broiler litter composition and potential value as a nutrient resource. Biol. Wastes 34, 1–9.
Ulrich, A., Mostafa, M.A.E., Allen, W.W., 1992. Strawberry deficiency symptoms: a visual and plant analysis guide to fertilization. Agricultural Experiment Station Bulletin. University of California, Oakland, CA, 1917, pp. 43–52.
Wang, S.Y., Lin, S., 2001. Effect of compost application on strawberry plant growth and fruit quality. HortScience 36, 475 (abstract 478).