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Duration of Composting of Yard Wastes Affects Both Physical and Chemical Characteristics of Compost and Plant Growth

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Abstract. **Windrows of municipal yard and landscape waste at three commercial composting sites in California were sampled at ≈3-week intervals through 12 to 15 weeks of composting to observe changes in physiochemical and biological characteristics of importance to horticulture. Initial C, N, P, and K content averaged 30%, 1.3%, 0.20%, and 0.9%, respectively. Carbon concentration declined rapidly through the first 6 to 9 weeks, while N, P, and K remained relatively stable throughout the sampling period. Few viable weed seeds were found in any compost. A high level of phytotoxicity, as measured by a tomato (*Lycopersicon esculentum* Mill.) seed bioassay, was observed at only one site; overall, the degree of phytotoxicity declined with compost age. Short-term net N immobilization (in a 2-week aerobic incubation) was observed in nearly all samples, with an overall trend toward decreased immobilization with increased compost age. In a 16-week pot study in which fescue (*Festuca arundinacea* Shreb.) was grown in compost-amended soil, net N mineralization averaged only 2% to 3% of compost total N content. Neither composting site nor duration of composting significantly affected either N mineralization rate or fescue growth. Growth of vinca (*Catharanthus roseus* Don.) in a blend of 1 compost : 1 perlite increased with increasing compost age. Overall, at least 9 to 12 weeks of composting were required to minimize the undesirable characteristics of immature compost.**

The recycling of urban solid waste has increased in recent years as cities strive to reduce their utilization of limited landfill space. In California, where yard and landscape green wastes represent ≈25% of the solid waste stream, composting green waste has become commonplace. Given the volume of material available for composting (>5.4 million tons annually), commercial agriculture will be the end user for most of the compost.

The physiochemical and biological characteristics of composted yard waste (CYW) determine the most appropriate horticultural use (as a mulch, incorporated soil amendment, constituent of potting medium, etc.). Previous studies (Hartz et al., 1996; Hegberg et al., 1991; Rosen et al., 1993) showed that considerable variability existed among CYW from various sources, and among batches within sources. Hartz et al. (1996) also documented differences in biological properties, such as phytotoxicity and N mineralization behavior.

The degree of compost maturity strongly influences compost quality. Unfortunately, the measurement of compost maturity is a complex issue, and there is no consensus regarding what analytical procedures best characterize maturity (Mathur et al., 1993). Furthermore, some of the more promising procedures, such as the C/N ratio of water-soluble extracts (Garcia et al., 1992), enzyme activity (Herrmann and Shann, 1993), or microbial activity (Iannotti et al., 1994), require specialized equipment and/or expertise, making them unlikely to be routinely used by compost producers. There are also economic incentives for composters to minimize windrow management and limit the composting period. The typical CYW now produced in California has been composted for 4 months or less, with little or no curing time. By comparison, the production of mature, biologically stable CYW may require 9 months or more (Johnson et al., 1993; Rynk, 1992). The objective of this study was to document the change in horticulturally important physiochemical and biological characteristics of CYW through the initial 3 to 4 months of composting.

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Materials and Methods

Two windrows of composting municipal yard and landscape wastes were sampled at each of three commercial composting facilities in central and southern California. Windrow management differed among composting facilities, and one element of management was also manipulated between windrows within sites to maximize the range of CYW characteristics studied. At site 1, yard waste was composted within 3-m-diameter, 60-m-long polyethylene bags originally developed for silage fermentation (Ag-Bag Compost Technology, Warrenton, Ore.). Windrow moisture was controlled by adding water during bag filling and temperature was controlled by forced ventilation through perforated pipes at the bottom of the bag. Windrow A was maintained at lower temperatures than B by increased ventilation. Sites 2 and 3 used conventional, open windrows. Windrow A was turned more frequently than B (every 2 weeks vs. 4 weeks) at site 2, while windrow A was watered more heavily than B at site 3.

Temperature was monitored by two continuously recording thermistors placed 60 cm deep in each windrow. Representative CYW samples were collected at ≈2- to 3-week intervals through 12 to 15 weeks of composting. Each sample was a composite of four to five subsamples collected from 0.4- to 0.8-m depths at various locations in the windrow. Upon collection, 2 N KCl extracts were prepared and analyzed for NH_4-N and NO_3-N by the method of Carlson (1978). All remaining samples were screened to pass through 12-mm mesh and air-dried before further analysis or utilization in the various bioassays. Once dried, electrical conductivity (EC) and pH of saturated paste extracts were determined. Total N and C were determined using a combustion gas analyzer (Carlo Erba 1500; Fisons Instruments, Beverly, Mass.). Total P was determined by inductively coupled plasma atomic emission spectrometry following microwave acid digestion (Sah and Miller, 1992), and K by atomic emission spectrometry following extraction in 2% acetic acid. NH_4-N and NO_3-N were again measured, as previously described.

The presence of phytotoxic compounds was determined using a tomato seed bioassay. Twenty grams of CYW and 100 mL deionized water were mixed and shaken for 2 h, filtered, and the extract diluted 2:1 with deionized water. The diluted extract was used to wet filter paper in petri dishes. Ten seeds (cv. Halley) were placed in each dish, which was then incubated at 22 ± 1 °C for 3 d. There were three replicate dishes per CYW sample. A germination index (GI) was calculated by the method of Zucconi and deBertoldi (1987).

Weed seed survival in CYW was determined by a 6-week assay. The CYW (2 L/sample) was placed 2.5 cm deep in trays in a greenhouse at 25 ± 5 °C. The samples were kept moist throughout the period; germinating seedlings were counted and identified as to species.

Nitrogen mineralization/immobilization behavior was measured by controlled-environment aerobic incubation. Blends of 10% CYW/90% soil mix (50% silt loam/50% coarse sand) were moisture-equilibrated under 25 kPa pressure, then incubated at constant moisture for 14 d at 30 °C. The change in mineral N concentration (as measured in 2 N KCl extracts) over the incubation period represented net mineralization/immobilization. There were three replicate samples per CYW sample. An N mineralization index was calcu-

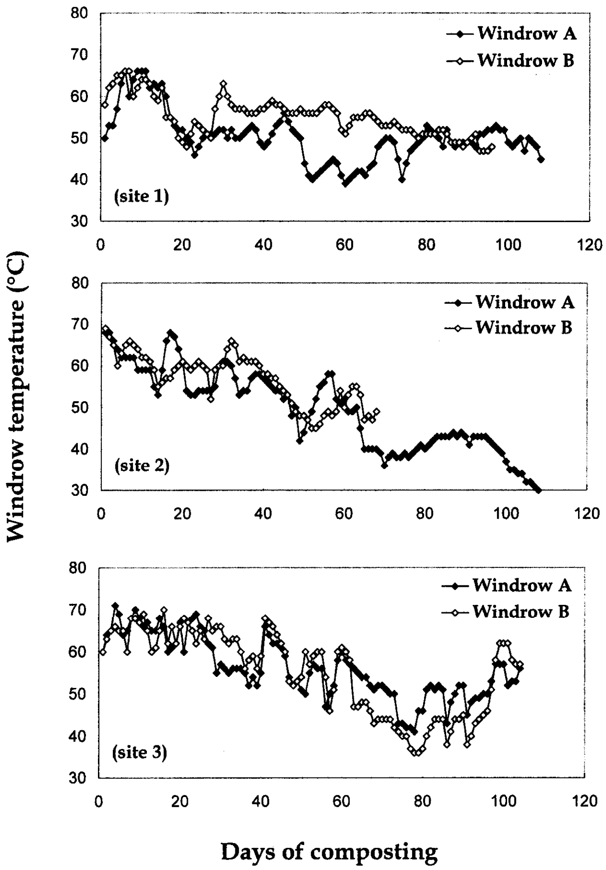

Fig. 1. Mean daily temperature (°C) of yard waste compost windrows.

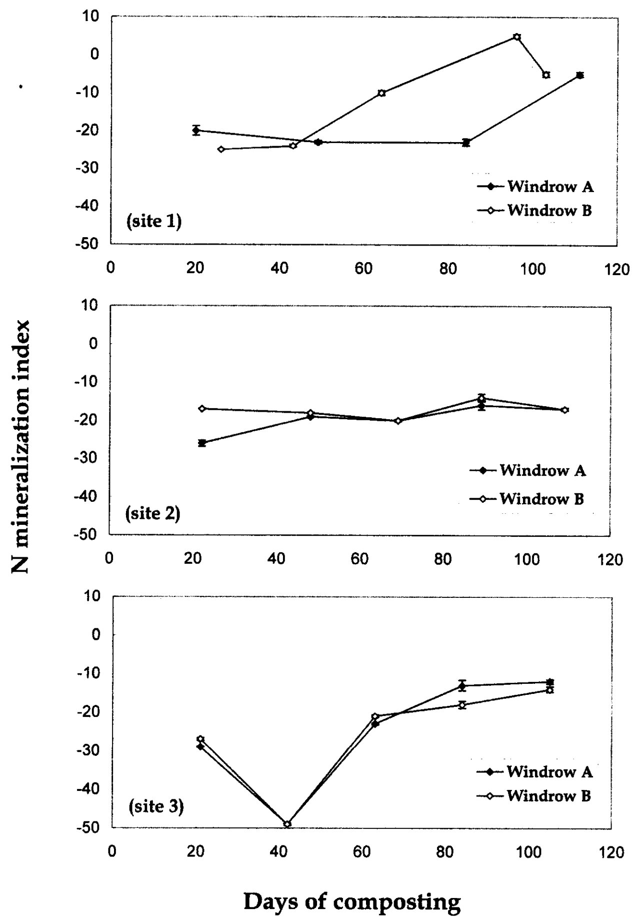

Fig. 2. Effect of duration of composting on nitrogen mineralization index of yard waste compost. The index compared the relative change (mg·kg^{-1}) in mineral N of a compost/soil blend over a 2-week incubation period with that of unamended soil. Mean of three replicate measurements; bars indicate SE.

lated [(Δ mineral N concentration of CYW amended soil mix, in mg·L^{-1}, over the incubation period) – (Δ mineral N of unamended soil mix)]. A negative index represented net N immobilization.

Longer-term N mineralization from CYW was determined in a lath house study conducted at the Univ. of California, Davis, from 8 May to 4 Sept. 1996. The CYW from windrows 1A (49 and 111 d of composting), 2A (48 and 109 d), and 3A (42 and 105 d) was blended with the soil mix previously described at 2% by dry mass. Pots (4-L volume) were filled with this blend and seeded with 'Bonzai' fescue. Fescue was chosen because it roots vigorously and tolerates repeated clipping. Pots (four per CYW sample) were watered but not fertilized. On 19 June and 26 July, the fescue was clipped and dried; on 4 Sept., total fescue biomass (tops and roots) was harvested and dried. Fescue N content was determined by the method of Sweeney (1989), and leachate from the pots was captured and analyzed for mineral N content by the method of Carlson (1978). The net N mineralization of CYW was calculated as total fescue N plus mineral N in leachate, minus those quantities from pots of the unamended soil mix.

The suitability of CYW as a constituent of a container medium was evaluated in a greenhouse experiment. Germinated plugs of vinca (cv. 'Pink Cooler') were planted in 5-cm-diameter pots filled with a blend of 1 CYW : 1 perlite (by volume). There were 12 pots per CYW sample arranged in a randomized complete-block design. The plants were fertilized once per week with a 100 mg·L^{-1} N solution (as 20N–8.6P–16.6K plus minor elements). After 6 weeks of growth at 23 ± 5 °C the plants were harvested and oven-dried, and total top dry mass was recorded. To help determine whether differences in plant growth were related to physical properties of the blend, air-filled porosity, bulk density, and water-holding capacity were measured on triplicate samples by the method of Bragg and Chalmers (1988).

Results

Windrow temperature pattern varied among sites (Fig. 1). Neither turning frequency (site 2) nor moisture management (site 3) consistently affected temperature, but the degree of ventilation within the composting bags (site 1) did. Temperatures >60 °C were limited to the first 20 d of composting in windrow A while windrow B continued to experience temperature >60 °C until day 70 at site 1. At site 3 both windrows were maintained above the 65% (by mass) moisture content limit suggested by Rynk (1992).

Macronutrient content of the original feedstocks was low at all sites (Table 1). Total N concentration ranged from 1.1% to 1.5% and increased slightly over time. Rapid mineralization of C in the initial 6 to 9 weeks of composting resulted in rapidly decreasing C/N ratio over that period, the ratio stabilizing thereafter. Final C/N ratios varied from 12 to 16. Initial P and K concentrations varied from 0.16% to 0.27% and 0.5% to 1.2%, respectively. The content of K remained stable over time, while that of P increased marginally. Electrical conductivity varied widely among sites, reflecting differences in windrow management and evaporative potential at each site. The pH of all windrows was at or below pH 7.0 initially, then rose steadily until it reached or exceeded 7.5.

Mineral N concentration was highly variable, but an overall pattern was evident (Table 1). Extracts of fresh compost contained high NH_4-N and very low NO_3-N concentrations during the early stages of composting. As composting proceeded, NH_4-N levels generally declined, with NO_3-N increasing substantially in a few late samples. Air-drying samples

Table 1. Changes in chemical characteristics of CYW throughout the composting period at three commercial composting facilities in central and southern California.

Site	Windrow	Days of composting	C (%)	N (%)	C/N	P (%)	K (%)	Ash (%)	EC[z] (ds/m)	pH	NH_4-N (mg·kg^{-1}) Fresh	NH_4-N (mg·kg^{-1}) Dry	NO_3-N (mg·kg^{-1}) Fresh	NO_3-N (mg·kg^{-1}) Dry
1	A	0	30	1.1	28	0.16	0.8	37	6.9	6.5				
		20	25	1.6	16	0.20	0.9	51	7.2	7.3	110	6	5	12
		49	22	1.5	14	0.22	0.8	56	6.3	7.4	13	14	4	2
		84	24	1.6	15	0.24	0.8	51	5.5	7.6	107	20	16	35
		111	22	1.6	14	0.25	0.7	56	4.5	7.5	67	18	42	77
	B	0	33	1.3	26	0.16	0.9	33	7.0	6.6				
		26	27	1.5	18	0.22	1.0	49	7.4	7.1	328	48	4	12
		43	26	1.7	15	0.24	1.0	46	6.6	7.4	181	37	3	40
		64	22	1.6	14	0.22	0.9	54	6.3	7.4	72	13	164	38
		96	24	1.9	13	0.25	0.9	55	6.5	7.3	74	14	162	209
		103	24	1.7	15	0.24	0.7	59	4.1	7.6	18	11	21	12
2	A	0	26	1.1	24	0.18	0.5	53	5.4	6.6				
		22	24	1.3	19	0.19	0.6	52	5.0	6.9	441	121	8	1
		48	24	1.2	20	0.18	0.6	53	5.0	7.1	126	12	2	42
		69	22	1.3	17	0.22	0.5	57	4.0	7.5	34	13	2	61
		89	20	1.2	17	0.19	0.5	61	3.6	7.7	158	10	9	18
		109	22	1.4	16	0.20	0.5	56	3.6	7.8	96	11	4	13
	B	0	26	1.1	24	0.18	0.5	53	5.4	6.6				
		22	24	1.1	21	0.18	0.5	49	4.4	7.0	226	18	2	1
		48	25	1.3	22	0.17	0.6	47	4.3	7.0	100	11	4	93
		69	19	1.1	18	0.21	0.6	59	4.2	7.4	47	14	4	18
		89	19	1.3	15	0.20	0.6	57	4.9	7.7	153	9	7	35
		109	20	1.3	16	0.20	0.6	61	4.9	7.8	108	8	4	55
3	A	0	29	1.5	20	0.27	1.2	41	11.0	6.9				
		21	27	1.4	18	0.24	1.1	47	12.9	7.0	245	49	5	20
		42	24	1.5	16	0.28	1.2	53	14.7	7.3	265	147	4	1
		63	18	1.4	13	0.26	0.9	66	14.5	7.7	102	32	2	7
		84	19	1.6	12	0.29	1.0	62	14.7	8.0	117	10	14	19
		105	20	1.6	13	0.28	1.1	62	16.0	7.9	602	15	7	89
	B	0	32	1.5	22	0.24	1.2	37	11.0	7.0				
		21	31	1.7	18	0.29	1.3	39	13.1	7.3	170	48	7	28
		42	26	1.5	18	0.26	1.0	48	12.3	6.8	511	377	15	1
		63	18	1.5	12	0.28	0.9	63	14.0	8.0	76	13	6	21
		84	18	1.4	13	0.29	1.0	61	15.4	8.0	278	14	9	25
		105	16	1.3	12	0.28	1.1	64	16.9	8.0	182	11	55	121

[z]Electrical conductivity.

before extraction yielded quite different values, with NH_4-N decreasing dramatically and NO_3-N generally increasing.

The N mineralization index also showed a clear trend (Fig. 2). A high level of N immobilization was observed in samples from all sources collected in the first 50 d of composting. The degree of immobilization generally decreased with duration of composting, but nearly all samples continued to show some level of immobilization, even after >100 d of composting. There was little net N mineralization in the 16-week fescue assay. All CYW samples showed similar net N mineralization, averaging only 3%, 2%, and 2% of compost total N content in samples from sites 1, 2, and 3, respectively. Duration of composting did not significantly influence N mineralization. Effects of CYW on fescue growth were similarly modest, with pots amended with CYW showing only a 17% increase in fescue biomass over pots of the N-limited soil : sand blend. Neither site nor duration of composting affected fescue growth.

An average of one weed seedling per 2-L sample was found in the original yard waste feedstock. Samples of CYW averaged only 0.5 seedling per 2 L after 3 weeks of composting. Of the seven species identified, California burclover (*Medicago hispida* Gaertn.) accounted for >50% of the total; burclover seedlings were found in several CYW samples that had been composted >80 d. Hartz et al. (1996) also reported burclover to be the most common weed species to survive in CYW.

A high level of CYW phytotoxicity, as measured by the tomato seed germination index, was found only in CYW extracts from site 3 (Fig. 3). Despite the relatively dilute extract used in this assay, high compost EC at site 3 may have suppressed the germination index. Prolonged high temperature and higher than optimum moisture may also have resulted in the accumulation of organic acids or other phytotoxic compounds (Rynk, 1992).

The growth of vinca in the CYW : perlite potting mix showed a similar trend, with growth increasing with increased duration of composting (Fig. 4). Vinca dry mass was correlated with the physical properties of the mix (r^2 = 0.32 and 0.64 for air-filled porosity and bulk density, respectively, $P < 0.05$). The significance of those correlations was questionable, since the air-filled porosity of nearly all CYW : perlite samples was in the 10% to 15% range recommended by Bragg and Chambers (1988), and bulk density varied in a narrow range (190 to 260 g·L^{-1}). There was a quadratic relationship between dry mass of vinca and days of composting ($y = .19 + .023x - .000007x^2$, r^2 = 0.65, $P < .05$). The CYW did not influence N nutrition; tissue N concentration, which ranged from 4.3% to 4.7%, was not correlated with growth of vinca.

Discussion

Despite the different composting techniques employed, CYW from all sites showed similar trends over time in both physiochemical and biological characteristics. Relatively rapid changes were evident through the first 6 to 9 weeks of composting, with more subtle changes continuing throughout the period studied. At the end of the sampling period none of the CYW samples could be considered mature (as evidenced by continued high temperature, high NH_4-N concentration, and N immobilization), but they were representative of CYW being utilized throughout California, where few commercial green waste composters use composting periods >4 months. Undoubtedly, important characteristics of CYW would continue to change with a longer duration of composting, but any additional cost input for prolonged composting would need to be weighed against demonstrable benefits.

The practical significance of the degree of CYW maturity varies with the intended end use. Compost applied as a nonincorporated surface mulch for orchard, vineyard, or landscape use is intended primarily to suppress weeds and conserve soil moisture. For those uses, the primary requirement is that the material has gone through a thermophilic phase sufficient for control of weed seeds and pathogenic fungi. In this study, few viable weed

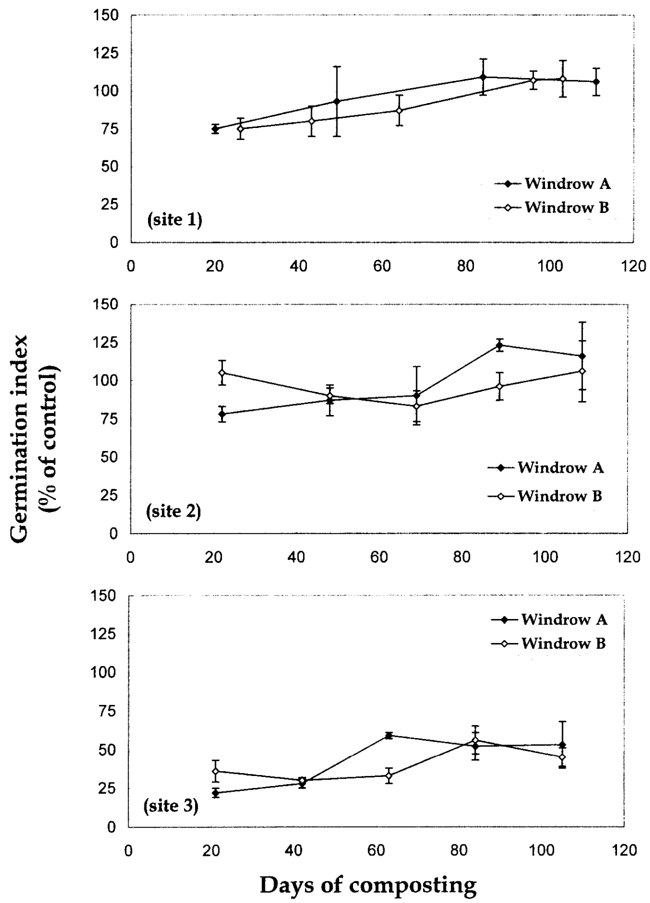

Fig. 3. Effect of duration of composting on the tomato seed germination index of yard waste compost extracts. The index compared the germination rate and seedling vigor of tomato seed imbibed in compost extracts with those imbibed in deionized water. Mean of three replicate measurements; bars indicate SE.

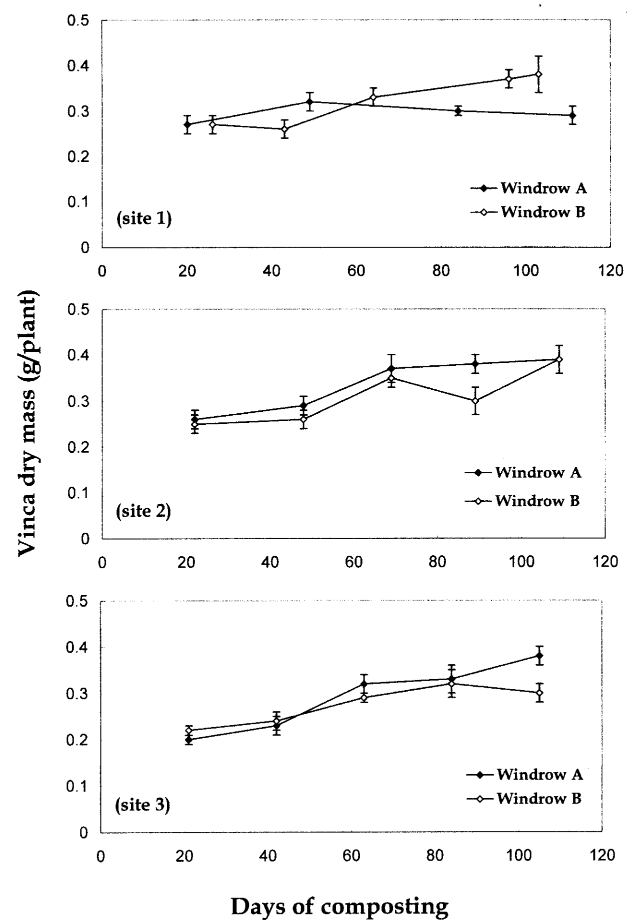

Fig. 4. Effect of duration of composting on the growth of vinca in pots of yard waste compost/perlite media. Mean of 12 pots; bars indicate SE.

seed were found, even in the fresh feedstock. The degree of heating encountered in the first 3 weeks of composting (>400 h of >50 °C in all windrows) would have been sufficient to kill most weed seeds, based on extensive study of soil solarization (Katan and DeVay, 1991). Control of common plant pathogens would also be expected with that degree of heating (Bollen, 1993). At the high rate of application commonly used for effective mulching (typically >100 $Mg \cdot ha^{-1}$), economic considerations usually dictate that minimally composted material be used.

Compost may serve as an amendment of field soil for vegetable or row crop production to enhance soil fertility, improve soil physical properties, and to stimulate microbial activity for enhanced plant health and disease suppression. This study and previous work (Hartz et al., 1996) clearly showed that CYW tends to immobilize N in the short term, and provide N slowly in the longer term. The fescue assay indicated that net N release over 16 weeks (roughly equivalent to a field growing season) was <0.5 $kg \cdot Mg^{-1}$, an inconsequential amount at typical application rates (<15 $Mg \cdot ha^{-1}$); the degree of short-term N immobilization observed was also modest (<0.25 $kg \cdot Mg^{-1}$ in most samples). Substantial impact on N fertility would require either very high rates of CYW application, or a long-term program of repeated applications. Improved soil structure and reduced surface crusting with the application of organic amendments could be expected with a program of CYW application, regardless of compost maturity stage. The economic value of these changes in soil environment would vary greatly, depending on original soil conditions and the value of crops produced.

Plant pathogen suppression in nursery media by the inclusion of compost has been clearly demonstrated (Hoitink et al., 1993), but significant disease suppression in field soils at typical compost application rates has not been widely documented. In nursery media, significant disease suppression may require >20% (by volume) content of compost (Hoitink et al., 1991), but annual field application of compost seldom exceeds 3% (by volume) in the top 15 cm.

The use of CYW as a constituent of container media is by far the highest value use, with the most exacting requirements. Physical, chemical, and biological properties of compost can all affect plant growth in compost-amended potting mix (Burger et al., 1997; Hartz et al., 1996; Rosen et al., 1993; Siminis and Manios, 1990). The increase in plant growth with increased duration of composting in the vinca assay suggested that the degree of compost maturity was important. The degree of pathogen suppressiveness has also been linked to compost maturity (Grebus et al., 1994; Hoitink et al., 1993). This study indicated that 3 months of composting was sufficient to substantially improve the performance of CYW as a media amendment but not necessarily to maximize it. In addition to requiring a minimum length of composting, a nursery operator could further minimize the variability in performance of CYW by stockpiling the material to ensure a degree of curing at moderate temperature before use, and by limiting the volume of CYW in the mix to <25% (Burger et al., 1997; Siminis and Manios, 1990).

Large-scale composting of yard wastes is relatively new in California, as it is in most of the United States. Additional research is needed to identify yard waste composting practices that optimize compost characteristics for specific horticultural uses, and that clearly document the economic and environmental value of compost use. In urbanized states, such as California, CYW supply far exceeds the requirements of traditional compost users, mostly organic growers. Until the value of CYW can be consistently demonstrated in conventional horticultural production systems, its utilization by conventional growers will lag.

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