Wildflower Establishment in Seedbeds Created from an Industrial Co-product and Co-composted Municipal Waste[1]

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Abstract

Ten cm (4 in) deep synthetic seedbeds created from co-composted municipal waste (CCMW), an industrial co-product (Iron-Rich material, IRM), CCMW:IRM (1:1, by vol), and surface tilled (2.5 cm; 1 in) soil were compared for establishment and growth of seven wildflower species. The IRM seedbed resulted in increased seedling emergence compared to other seedbeds. Percentage and rate of seedling emergence were similar in soil and CCMW:IRM seedbeds, but seedling shoot dry weight was greater in CCMW:IRM. By 400 days after planting, both IRM and CCMW:IRM seedbeds supported similar wildflower populations (200% and 490% greater than soil and CCMW seedbeds, respectively), but the population density of the wildflower species was more uniform in CCMW:IRM. Shoot dry weights per meter^2 (10.8 ft^2) at 400 days after planting were similar in all seedbeds.

Index words: seedling emergence, synthetic topsoil, waste utilization.

Species used in this study: Common yarrow (*Achillea millefolium* L.), Bachelor's button (*Centaurea cyanus* L.), Ox-eye daisy (*Chrysanthemum leucanthemum* L.), Queen Anne's lace (*Daucus carota* L. var. *sativa* DC), Purple coneflower (*Echinacea purpurea* Moench), Black-eyed susan (*Rudbeckia hirta* L.), Sweet william catchfly (*Silene armeria* L.).

Significance to the Nursery Industry

Results of this study have shown that an effective seedbed for wildflower establishment can be created from equal volumes of an industrial co-product and co-composted municipal waste. The synthetic seedbed, with the appearance of high quality 'topsoil', provides the nursery industry with a growth medium of reasonably predictable quality and lessens the volume of the components that must be stock-piled or land-filled. Extending our findings to other industrial co-products/byproducts or municipal solid wastes should be approached with caution owing to the different properties of these materials.

Introduction

Traditional waste disposal methods, landfilling, incineration and ocean dumping, are being replaced by recycling, which includes composting of organic materials. However, the quantity of waste generated, particularly in the urban northeastern U.S., continues to increase. Since disposal into landfills is four to seven times more expensive than it was 10 years ago (8), composting becomes an alternative. Currently, 16 municipal solid waste (MSW) composting facilities operate in the U.S. Of these, 10 listed horticulture/landscaping as the primary end-use for the compost (14). Sewage sludge can be composted with MSW to form a co-composted municipal waste (CCMW).

Several containerized greenhouse and nursery crops were satisfactorily grown in wood chips and sludge compost at 20 to 60% volumetric incorporation in media (4, 16). In addition to being an inexpensive bulk ingredient in growth media, the compost provided all the essential elements except nitrogen to support marigold growth (1). The turf and landscape industry also can benefit from using sludge compost for establishing turf in the absence of 'topsoil' and as a backfill component when transplanting trees and shrubs (16).

The Delaware Solid Waste Authority (Wilmington, DE) produces 36,000 metric tonnes (39,700 tons) annually of CCMW (17) by composting municipal solid waste (following removal of metals and glass) and anaerobically digested sewage sludge (20% solids) in a 1:1 wet weight ratio. This material was an effective soil amendment for agronomic crops (17, 19), provided N immobilization due to the high C:N (52:1) ratio of CCMW was corrected with supplemental N fertilization. Purman and Gouin (12) demonstrated satisfactory growth of bedding plants and flowering plants in media containing 25 to 50 percent volume of CCMW from the Delaware Solid Waste Authority in peat plus perlite.

Disposal of industrial byproducts and co-products is an increasing problem confronting industrialized nations. Tens of thousands of tonnes (tons) of iron-rich material (IRM) are produced annually in the Mid-Atlantic region of the USA. The IRM used in this study, a co-product from an industrial process that generates a TiO_2 pigment, was an effective component in synthetic topsoil or containerized growth media (7).

The objective of this research was to compare seedling establishment and growth of seven wildflower species in seedbeds created from IRM, CCMW, IRM:CCMW (1:1, by vol) or soil.

Materials and Methods

Seedling emergence plots. Seedbeds (1 × 1 m; 39 × 39 in) were established on Matapeake silt loam (fine-silty, mixed mesic, Typic Hapladult). Existing turfgrass, primarily Kentucky bluegrass (*Poa pratensis* L.), was killed by treatment with glyphosate [(N-(phosphonomethyl) glycine), Monsanto, St. Louis, MO]. The soil of all seedbeds was tilled to 2.5 cm (1 in) depth. Such tillage permitted good seed to soil contact

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and yet avoided movement of weed seeds to near the soil surface in soil plots (11). CCMW, acquired from the Delaware Solid Waste Authority in 1991, had been stored in turned windrows for at least 18 months. IRM of sandy loam texture (15) and of red-brown color was acquired from E.I. DuPont de Nemours and Company, Inc., Wilmington, DE. Chemical properties and organic matter concentration of CCMW and IRM are shown in Table 1.

The plots were not covered (soil) or were covered with 10 cm (4 in) depth of the CCMW, IRM, or CCMW:IRM (1:1, by vol) equivalent to 30, 1050, or 790 dry metric tonnes/ha (13, 470, 350 tons/A), respectively. The seedbeds were overhead-irrigated with 1 cm (0.4 in) daily for one week to permit settling. Final seedbed depth was adjusted to 10 cm (4 in) by adding or removing IRM, CCMW or IRM:CCMW. The four seedbeds were replicated three times in randomized block design. Composite samples of each seedbed at the time of seed sowing, were analyzed by the University of Delaware Soil Testing Laboratory (18) for: organic matter (Walkley-Black wet oxidation), total nitrogen (Kjeldahl), electrical conductivity (media:distilled water, 2:1, by vol), pH (media:distilled water, 1:1, by vol), and available nutrients (0.05N HCl and 0.025N H_2SO_4 extraction then argon plasma spectroscopy) (Table 2).

Seedbed bulk density was calculated as the oven dry weight divided by the bulk volume using 10 replications of 0.5 liter (16.5 fl oz) plastic cups filled with 330 cm^3 of each air-dried seedbed media that were wetted and settled (7). Brass rings (5 cm diameter × 2.5 cm high) were driven into the surface of the seedbed media within the cups until buried. Available moisture of the seedbed materials in the rings was calculated as the difference in moisture content at –0.01 and –0.3 MPa (–0.1 and –3.0 Atm) matric potentials created within a pressure plate apparatus (10).

Seeds of seven wildflower species included the annuals [*Centaurea cyanus* L. (Bachelors-button) and *Silene armeria* L. (Sweet william catchfly)], a biennial [*Daucus carota* L. var. *sativa* DC. (Queen-Anne's-lace)], and the perennials [*Achillea millefolium* L. (Common yarrow), *Chrysanthemum leucanthemum* L. (Ox-eye daisy), *Echinacea purpurea* Moench (Purple coneflower), *Rudbeckia hirta* L. (Black-eyed susan)]. One-hundred seeds of each species were sown (21 June 1991) in 1 cm (0.4 in) deep, 60 cm (24 in) long furrows in the surface of each seedbed. The furrows were 10 cm (4 in) apart and furrow ends were 20 cm (8 in) from the seedbed edge. Seeds were covered with 0.5–1 cm (0.2–0.4 in) depth of the seedbed material. Plots were overhead-irrigated daily to keep the seedbed surface moist.

Table 1. Chemical properties and organic matter concentration of co-composted municipal waste (CCMW) and Iron-rich material (IRM).

Property	CCMW	IRM
pH	6.8[z]	7.8
Electrical conductivity (dS/m)	4.9	2.6
Organic matter (%, wt/wt)	>15.0	0.6
Total N (%, wt/wt)	1.3	0.1
Available elements (mg/kg)[y]		
P	152	ND[x]
K	1752	32
Mg	992	518
Ca	5220	5020
Mn	74	53
Zn	167.5	1.1
Cu	3.1	0.2
B	42.6	0.2
Fe	5.8	0.6
Total elements (mg/kg)[w]		
Cd	12	6
Cr	209	414
Ni	97	59
Pb	480	108
Hg	5.4	0.1
Fe	367	140275

[z] Mean values for 5 composited samples.

[y] Extraction with 0.05N HCl and 0.025N H_2SO_4.

[x] ND = not detectable.

[w] Extraction with nitric and perchloric acids.

Seedlings (hypocotyls visible) were counted daily for 14 days to calculate final percent emergence (FE) and days to 50% of FE (E_{50}). At 20 days after planting (DAP), seedling shoots were pruned at the seedbed surface and dried at 65°C (149°F) for 10 days for determining growth.

Long-term plots. Larger plots (3 × 3 m; 10 × 10 ft) of each seedbed were prepared in the same fashion and at the same time as the seedling emergence plots. The plots were broadcast sown with a seed mixture of the species (% by seed weight; % by seed number): *A. millefolium* (5; 17), *C. cyanus* (25; 3), *C. leucanthemum* (25; 13), *D. carota* var.

Table 2. Dry bulk density, available water and selected chemical properties of seedbeds: soil (control); co-composted municipal waste (CCMW); Iron-rich material (IRM); and CCMW:IRM (1:1, by vol) at time of seeding.

	Dry bulk density	Available water[z]	Organic matter	Total N	Electrical conductivity		Available elements						
							P	K	Mg	Ca	Mn	Zn	Fe
Seedbed	(g/cm^3)	(%,wt/wt)	(g/dm^3)	(%,wt/wt)	(dS/m)	pH	mg/kg						
Soil	1.19	4.8	2.6	0.25	0.30	6.9	34.1	168	189	1458	35	9	7.4
CCMW	0.36	14.7	14.0	1.02	0.37	6.9	50.7	566	471	4216	28	100	7.0
IRM	1.14	9.1	0.7	0.29	0.33	6.0	0.9	38	297	3425	17	1	0.1
CCMW:IRM (1:1, by vol)	0.82	24.0	3.7	0.27	0.22	6.8	1.0	223	346	3502	20	6	0.4
LSD 0.05	0.17	5.7	0.9	0.20	0.09	1.3	23.6	117	39	426	11	11	0.9
F-test significance[y]	***	***	***	***	*	NS	**	***	***	***	*	***	***

[z] Water retained between –0.01 and –0.30 MPA matric potentials.

[y] ***, **, *, NS Significant at 0.001, 0.01, 0.05, or not significant, respectively.

sativa (12; 1), *E. purpurea* (13; 2), *R. hirta* (13; 27), and *S. armeria* (7; 37). Plots were arranged in randomized complete blocks with four replications. The seeds for each plot were mixed in vermiculite No. 5 (W.R. Grace, Cambridge, MA) at 19 g seeds/dm^3 (1.1 lbs/ft^3) and evenly broadcasted over each plot. The plots were raked lightly to incorporate the seeds and compressed with a 61 × 46 cm diameter (24 × 18 in) roller half-filled with water. The plots were mulched with straw (95 g/m^2; 20 lb/1000 ft^2) to maintain moisture. Seedbeds were overhead-irrigated daily for one hour for one month following seeding. Shoots of all plants from a 1 × 1 m (39 × 39 in) area selected from the central area of each plot were pruned at the media surface at 120 DAP. The shoots were separated into respective species (including weeds) and their dry weights determined. Fragmentation of the shoots prevented determination of the plant number for each species.

These plots were mowed to 20 cm (8 in) height in November 1991 after shoot death, and clippings removed. Plots received no further maintenance until July, 1992, when all plants were pulled from a 1 × 1 m (39 × 39 in) area within each of the plots. The number of plants of each species was counted, the root systems removed, and the shoots dried (65°C; 149°F) to measure growth. All data were subjected to ANOVA.

Results and Discussion

Seedling emergence plots. Final emergence of all species in IRM alone (52%) was 14 to 23 percentage points greater than in the other seedbeds which had similar FE (Table 3). Species and seedbeds did not interact to influence FE. FE varied from 13% (*C. leucanthemum*) to 61% (*C. cyanus*). CCMW resulted in lower emergence rate (higher E_{50}) than IRM or CCMW:IRM, but the 1.8-day E_{50} range due to seedbeds was small (Table 3). *A. millefolium* and *C. cyanus* had the fastest emergence (E_{50} averaging 3.3 days) and *C. leucanthemum* the slowest emergence (E_{50} of 9.6 days). Shoot dry weights 20 DAP were greater in CCMW and CCMW:IRM than in the soil seedbed; the IRM seedbed giving similar shoot dry weights to both soil and CCMW:IRM seedbeds. Thus, seedlings in the CCMW:IRM seedbed compared to the soil seedbed had similar FE and E_{50} but 74% greater seedling shoot dry weights.

The higher FE and emergence rate of seedlings in IRM than in CCMW were not related to osmotic effects since solution electrical conductivities of these seedbeds were similar at time of seeding (Table 2) despite the fact that the initial electrical conductivity of CCMW was double that of IRM (Table 1). Irrigation between planting and seedling emergence may have leached salts from the seedbed. However, MSW composts can increase soluble salt concentration of growth media and inhibit vegetable seed germination (13). Compost made from sludge and wood chips decreased populations of hardwood forestry seedlings (6) or softwood forestry seedlings (3) when applied to loamy sand at >112 or >56 t/ha (50 or 25 ton/A), respectively. Although chloride in IRM is high (ca 130 g/dry kg; 2 oz/dry lb), it can be removed readily by leaching (15).

Lower FE and higher E_{50} in CCMW than in IRM may have resulted from non-osmotic, phytopathic effects. However, the influence of aliphatic hydrocarbons, fatty acids, and phthalate esters found in composted municipal refuse (2) on seed germination and seedling emergence have not been examined. The higher FE and emergence rate of seedlings in IRM than in CCMW may have resulted from greater seedbed drying between irrigations. Although CCMW had greater available water than IRM on a weight basis (Table 2), the three-fold difference in dry bulk density of these seedbed materials (Table 2) caused double the available water in IRM (10.3%) than in CCMW (5.3%) on a volume basis. However, seedbed water relations can not explain the lower FE in CCMW:IRM than in IRM, since FE and available water were related inversely in these seedbeds.

Table 3. Final emergence (FE), days to 50% of FE (E_{50}), and shoot dry weight at 20 days after planting (DAP) seeds of seven wildflower species in different seedbeds.

Treatment	Final emergence (%)	E_{50} (days)	Shoot dry wt. at 20 DAP (mg/shoot)
Seedbed			
Soil	37.3 b[z]	6.4 ab	19 c
Co-composted municipal waste (CCMW)	29.3 b	7.3 a	41 a
Iron-rich material (IRM)	52.2 a	5.5 b	25 bc
CCMW:IRM (1:1, by vol)	38.3 b	6.1 b	33 ab
Species			
Achillea millefolium	51.1 abc	3.7 c	12 b
Centaurea cyanus	60.8 a	2.9 c	126 a
Chrysanthemum leucanthemum	12.9 d	9.6 a	10 b
Daucus carota var. *sativa*	39.3 c	6.5 b	17 b
Echinacea purpurea	53.3 ab	7.2 b	18 b
Rudbeckia hirta	41.3 bc	6.6 b	11 b
Silene armeria	16.4 d	7.7 b	9 b
Significance[y]			
Seedbed	***	**	**
Species	***	***	***
Seedbed × Species	NS	NS	NS

[z] Mean separation within columns for seedbed or species by LSD, $P = 0.05$. Arcsine transformations for FE percentage data prior to analysis.

[y] ***, **, NS Significant at 0.001, 0.01, or not significant, respectively.

Long-term plots. By 120 DAP, total shoot dry weight per m^2 (10.8 ft^2) was greatest in CCMW, least in soil, and intermediate in IRM and CCMW:IRM (Table 4). Greater shoot growth in the synthetic seedbeds may be attributed to improved tilth of these recently formed seedbeds compared to the more compacted soil seedbed which had received only surface tillage. Even though wildflower roots by 120 DAP had undoubtedly penetrated the underlying soil, the positive early (20 DAP) effect of the CCMW or CCMW:IRM seedbeds (Table 3) on shoot growth was retained by 120 DAP (Table 4). The greater shoot growth in CCMW at both 20 and 120 DAP than in IRM or soil seedbeds may be attributed to higher initial N concentration (Table 2) and subsequent elevated N release although the latter was not monitored. The slow-release nutrient supplying benefits of CCMW have been noted (1, 5). Lower shoot dry weight in IRM than in CCMW at 20 or 120 DAP may be associated with lower P availability in IRM (Tables 1 and 2). In CCMW:IRM, the P from CCMW presumably reacted with soluble Fe and Fe (hydr)oxides of IRM thereby 'fixing' P in a manner similar to that found in oxisols (Y. Salingar, personal communication). While total Fe in IRM was 140275 mg/kg (Table 1),

Table 4. **Wildflower shoot dry weights at 120 days after planting (DAP) and population densities of weeds and seven wildflower species at 400 DAP grown in seedbeds of soil (control), co-composted municipal waste (CCMW), Iron-rich material (IRM), and CCMW:IRM (1:1, by vol).**

	Wildflower shoot dry weight at 120 DAP	Wildflower population density at 400 DAP	Weed population density at 400 DAP
	(g/m^2; g/10.8 ft^2)	(no./m^2; no./10.8 ft^2)	(no./m^2; no./10.8 ft^2)
Species mean			
Achillea millefolium	3.5 bc[z]	11.7 bcd	
Centaurea cyanus	59.3 a	4.1 cd	
Chrysanthemum leucanthemum	2.2 c	20.3 b	
Daucus carota var. *sativa*	18.4 b	16.5 bc	
Echinacea purpurea	1.3 c	1.4 d	
Rudbeckia hirta	15.4 bc	62.8 a	
Silene armeria	5.6 bc	4.9 cd	
Seedbed total			
Soil	24.8 c	64.4 b	9.2 b
CCMW	206.8 a	32.9 b	86.9 ab
IRM	111.4 b	195.3 a	110.4 a
CCMW:IRM (1:1, by vol)	113.3 b	193.9 a	100.1 a
F-test significance[y]			
Seedbed	*	*	***
Species	***	***	NA
Seedbed × Species	NS	NS	NA

[z] Mean separation within columns for seedbed or species by LSD, $P = 0.05$.

[y] ***, *, NS Significant at 0.001, 0.05, or not significant, respectively. NA = not applicable.

available Fe at time of seed sowing was only 0.1 mg/dm^3 (Table 2).

Weed shoot dry weight as a percentage of the total weed plus wildflower shoot dry weight at 120 DAP was 92% in soil, 58% in CCMW, 57% in IRM, and 70% in CCMW:IRM. Weed seedling emergence from seeds in the underlying soil may have been reduced by the 10-cm covering of seedbed materials. The lower wildflower shoot dry weights in soil than in other seedbeds at 120 DAP (Table 4) could be attributed, in part therefore, to greater competition from weeds. While the synthetic seedbeds reduced the proportion of weed biomass, weed competition with wildflowers was strong in all seedbeds.

By 400 DAP, IRM and CCMW:IRM seedbeds had three-fold more wildflower plants per meter^2 (10.8 ft^2) than the soil seedbed and six-fold more than the CCMW seedbed (Table 4). However, the CCMW:IRM seedbed supported a more even population density of the wildfower species than the IRM seedbed. Seedbed generally had no effect on shoot dry weights per m^2 (10.8 ft^2) at 400 DAP, except for greater shoot dry weights of *D. carota* var. *sativa* in CCMW and *R. hirta* in soil (Table 5). Shoot dry weights per plant at 400

Table 5. **Shoot dry weights at 400 days after planting (DAP) of seven wildflower species and of weeds grown in seedbeds of soil (control), co-composted municipal waste (CCMW), Iron-rich material (IRM), and CCMW:IRM (1:1, by vol).**

	Seedbed				
				CCMW:IRM	
	Soil	CCMW	IRM	(1:1, by vol.)	Species mean
	Shoot dry weight at 400 DAP (g/m^2; g/10.8ft^2)[z]				
Achillea millefolium	28.7	30.1	41.2	10.7	27.7 b
Centaurea cyanus	2.1	125.4	21.1	113.8	65.6 b
Chrysanthemum leucanthemum	5.6	3.9	42.7	92.6	36.2 b
Daucus carota var. *sativa*	11.9	423.3	62.4	148.5	161.5 a
Echinacea purpurea	0	0.5	0	1.8	0.6 b
Rudbeckia hirta	492.9	21.7	254.9	114.0	220.9 a
Silene armeria	0.3	0.9	0.3	3.4	1.2 b
	---------- LSD$_{0.05}$ (interaction): 144.9 ----------				
Seedbed wildflower total	541.8	606.2	422.8	485.1	
Seedbed weed total[y]	107.9 d	311.0 b	190.9 c	391.6 a	

[z] F-test significances: Seedbed (not significant), species ($P \leq 0.001$, means separated by LSD, $P = 0.05$), and seedbed × species ($P \leq 0.001$).

[y] Weed shoot dry weight ANOVA conducted separately, seedbed ($P \leq 0.01$). Means separated by LSD, $P = 0.05$.

DAP were lower in seedbeds containing IRM than in other seedbeds. Average shoot dry weights (g/shoot) were: soil (8.4), CCMW (18.4), IRM (2.2), and CCMW:IRM (2.5). Thus, IRM-containing seedbeds produced a higher population of wildflowers than soil or CCMW, but individual plants grew less vigorously presumably in response to increased plant competition.

Weed population density at 400 DAP was highest in the IRM-containing seedbeds, lowest in soil, and intermediate in CCMW (Table 4). Weeds as a percentage of total (weed plus wildflower) plant population densities averaged 35% in IRM-containing media, 11% in soil, and 73% in CCMW. Weed shoot dry weights (Table 5) as percentages of total (weed plus wildflower) shoot dry weights in soil, CCMW, IRM, and CCMW:IRM were 17, 34, 31 and 45, respectively.

Thus, while the combined CCMW:IRM seedbed compared to soil resulted in a greater population density and more even population distribution of wildfower species, both weeds and wildflowers in the combined seedbed grew less vigorously in response to greater interplant competition. Average dry weights per shoot of wildflowers and weeds in CCMW:IRM were 2.5 g and 3.9 g, respectively. In the soil seedbed, respective dry weights per shoot were 8.4 g and 11.9 g.

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