Effects of Compost on Prairie Seedling Establishment and Seed Production

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ABSTRACT Compost is a commonly used soil amendment in horticultural and agricultural practices that is generally known to improve soil conditions and plant growth. We conducted a field experiment to investigate the application of compost to prairie production plots as a method to improve seedling establishment and growth and the seed production of established plants. We evaluated the effect of compost depth and tillage on the survivorship, growth, reproduction and ecophysiology of several prairie plant species commonly used in restoration. Results were mixed; for some species, transplants in compost–amended plots incurred lower survivorship and reduced growth compared to control plots. When compost was used for transplants, improved growth and reproduction were observed more often if compost was tilled into the soil. No benefit from compost was observed for flower and seed production in established prairie species. Compost can be useful in promoting better growth in prairie plots, but its application can produce negative outcomes under certain conditions.

KEY WORDS *Asclepias tuberosa*, *Baptisia bracteata*, compost, growth, seed production, seedling survivorship, *Silphium integrifolium*

The use of compost as a soil amendment, especially in organic agriculture and gardening, is widely accepted. Numerous experimental studies have demonstrated benefits of compost to plant growth and production in agronomic settings (Liebman et al. 2004, Menalled et al. 2005, Bell et al. 2008, Amisi and Doohan 2010). Evidence for the effects of compost includes enhanced nutrient availability and uptake (Liebman et al. 2004, O'Dell and Claassen 2006), enhanced predator control of aphids (Bell et al. 2008), increased competitiveness (Amisi and Doohan 2010), reduced weed emergence (Menalled et al. 2005) and decreased plant–available heavy metals (O'Dell and Claassen 2006). Fennimore and Jackson (2003) indicated that in a vegetable field, organic amendments were correlated with a reduction in weed populations and an increase in soil microbial biomass. They documented that microbial biomass was nearly always higher in the organic amendment plots, while seedling emergence and seedbank densities were lower. Compost is generally advocated by extension services, horticulturalists and others as an efficient way to transform soil characteristics, specifically to increase soil organic matter and water holding capacity, improve soil structure, and increase infiltration and permeability (Alexander 2001, Gould 2012). Giusquiani et al. (1995) demonstrated an increase in porosity in soils treated with compost, and O'Dell and Claassen (2006) reported an increase in cation exchange capacity in serpentine soils amended with compost.

Compared to agronomic settings, there is limited research on the effect of compost on prairie plants, which due to their higher tolerance of low fertility soils, may not have the same response as crop and weed species. O'Dell and Claassen (2006) included field experiments that examined compost effects on serpentine soils (xeric, deficient in essential nutrients, high in phytotoxic heavy metals, erosive) in northern California. They reported that compost resulted in an undesirable increase in the biomass and seed production of two invasive annual grass species in comparison to three native grass species (two perennials and one annual). In general, qualitative and quantitative research on the effects of compost on native plant species is limited.

Chamness Technology is an Iowa company that provides environmentally sound solutions for waste management. One facet of the company is the composting of organic waste, which is done at a facility near Eddyville, IA. Anecdotal testimony from Reiman Gardens at Iowa State University has praised the compost: "In its first year, the Town and Country Garden plantings at Reiman Gardens failed due to extremely poor soil conditions. After hand spading and working in six inches of Chamness Brand Compost the plants installed in the second season thrived. Just three years later, the Town and Country Garden now looks like a mature landscape, which would not have been possible without the improvements that the compost made to the soil structure" (Chamness Technology, Inc. 2013). Likewise, Central College at Pella, Iowa, has utilized the compost and found it very effective: "We found that with the use of Chamness Brand Compost, we were able to take poor clay ground, incorporate four inches of compost into it and then top dress with about an inch to give us a good seed bed. When seeded it produced a decent grass stand on the driving range. Also, just using 0.5 to 3.0 cm as top dressing on some soccer fields helped these fields out tremendously" (Chamness Technology, Inc. 2013).

Our study investigated the use of compost as a soil amendment to improve prairie restoration efforts. Specifically, we evaluated the effects of compost on transplanted prairie seedlings and on older established plants in seed production plots. Compost utilized in the study was decomposed organic matter supplied by Chamness Technology from their Eddyville

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site. Wapello County Conservation manages prairie seed production plots near Eddyville. Due to their close proximity to Chamness Technology's composting plant, Wapello County Conservation cooperated in the research by providing the plant seedlings, location for field experiments, and care for the plants. We hypothesized that the addition of compost would enhance the survival, growth, and fecundity of the transplanted prairie seedlings as well as the fecundity and vigor of established prairie plants. Our research was intended to improve prairie restoration efforts in the long term. Because seeds are an expensive part of prairie restoration efforts, any practice that improves the ability of land managers to grow and produce their own seeds is a benefit to restoration.

STUDY AREA

We established experimental plots at the prairie seed production site for Wapello County Conservation near Eddyville, Iowa, USA. Eddyville is located on the Southern Iowa Drift Plain, a landform characterized by rolling topography underlain by pre-Illinoan glacial till with a mantle of loess that was deposited in the late Wisconsinan glaciation. The soil was chiefly the Clinton series, which was formed in loess, moderately well drained, and occupied summits of interfluves, upper side slopes on uplands, and treads and risers on stream terraces (Natural Resources Conservation Service 2013). Production plots occupied about 0.4 ha of a southwest-facing, 5–9% slope (Web Soil Survey 2013).

Average annual precipitation was 93.7 cm (1981-2010, U.S. Climate Data 2013). May and June were the wettest months, each averaging 11.8 cm. The driest months were January and February with 2.8 cm and 3.1 cm, respectively. Approximately 68% of the annual precipitation occurred during the growing season (April–September). The average annual temperature was 9.4° C (1981-2010, U.S. Climate Data 2013). July was the warmest month with average high and low temperatures of 29.4° C and 17.8° C, respectively. January was the coldest month with average high and low temperatures of −1.7° C and −12.2° C, respectively. The growing season (−1.1° C base) typically ranged between 161 and 200 days, with a median of 181 days (Midwest Regional Climate Center 2013).

METHODS

We applied compost to both new seedling transplants and older established plants. Four prairie species were utilized for investigating the effects of compost on seedling establishment in production plots. These four species were butterfly milkweed (*Asclepias tuberosa*), rosinweed (*Silphium integrifolium*), rough blazing star (*Liatris aspera*), and cream wild indigo (*Baptisia bracteata*). Seedlings were grown by Wapello County Conservation in their greenhouse from seed collected in the county.

We designed the seedling transplant research as a two by two factorial experiment. One factor was the depth of the compost (3 cm versus 6 cm) and the second factor was tillage of the applied compost (tilled into the soil or not tilled). We utilized a fifth treatment as a control that did not receive any compost or tillage. We planted seedling transplants in experimental plots that were assigned to one of the five treatments. We consistently maintained plot size (3 m × 1.8 m) by using a wood frame to apply the compost. We established plots for each species in two parallel rows separated by a buffer zone approximately 50-cm wide (Fig. 1). Except for the control plots, we randomly assigned each plot a compost depth of 3 or 6 cm of compost so that each row contained an equal number of 3-cm and 6-cm depth plots. We randomly selected one of the two rows for tilling so that the tractor could be driven down the entire length of the plots with the tiller engaged. For logistical reasons, we placed control plots at the ends of the two rows. Within each plot, seedlings were planted equally spaced in two rows (Fig. 1) on 3 and 4 June 2010. We established between two and four replicates of each treatment. For example, the planting scheme for butterfly milkweed consisted of twenty plots (10 in each of two parallel rows) each with two rows of eight seedlings, making 16 total seedlings per plot (Fig. 1). We used a similar arrangement for rosinweed. We planted cream wild indigo with 16 seedlings per plot, but with only 14 total plots (three replicates of the four factorial treatments and two replicates of the control). We watered all seedlings after transplanting. We planted rough blazing star seedlings in a similar design to butterfly milkweed. However, unlike the other three species they experienced high mortality (>50%) in the first few weeks and even higher mortality (>75%) by the end of the first growing season. Thus, we excluded rough blazing star from our study by mid-summer 2010.

We selected two established plant species, compass plant (*S. laciniatum*) and sneeze weed (*Helenium autumnale*), to receive compost. Established plants occurred in two double rows that created a planted strip about 2.5-m wide. We divided the strip into equal plots (3.0-m long and 2.5-m wide) with a 0.6-m buffer for separation. We systematically assigned plots to one of three treatments, either 0, 3, or 6 cm of compost, starting at one end and continuing down the strip; three to five replicates were established for each treatment.

We expected that some of the potential compost effects could require more than a year to be recognized, as mineralization of compost occurs slowly over time. Therefore, we designed our research to encompass the 2010 and 2011 growing seasons. We measured variables and categorized them as follows: survival, growth, reproduction and ecophysiological. We used two measures of survival, including survivorship and survival rate. We defined survivorship as the percentage of transplants (individuals) alive at a certain time relative to the initial number transplanted. We measured

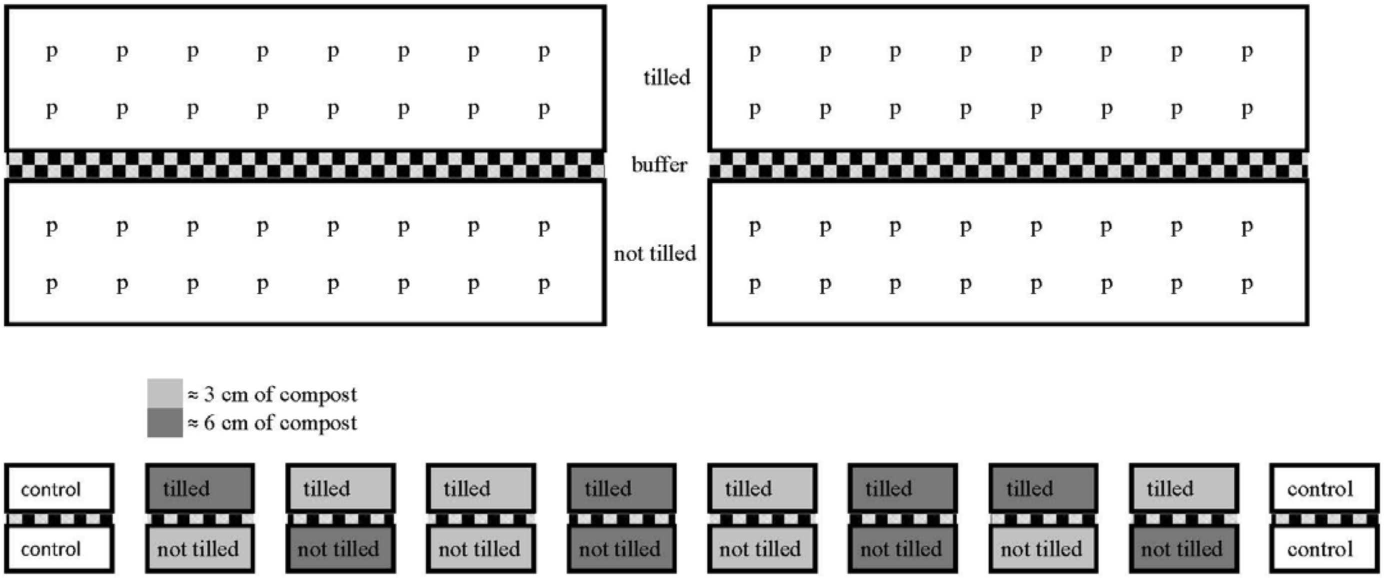

Figure 1. The plot design used for a compost study on transplanted seedlings at Eddyville, Iowa, 2010 to 2011. Plots are the areas encompassed by the solid lines (boxes). The "p" indicates a transplant location. An expanded view of four plots is shown at the top. The bottom series of plots in two rows represents the actual design for butterfly milkweed.

survivorship on the transplanted seedlings at two weeks after transplanting, at the end of the first growing season (September 2010), at the beginning of the second growing season (May 2011), and at the end of the second growing season (September 2011), at which time the study was terminated. We defined survival rate as the number of individuals that survive from one time to another. We measured survival rate for each species over various periods within the study.

The type of growth and reproduction variables that we measured depended on the species. We collected these data by recording measurements of individuals or ramets within each plot, which were averaged to obtain the datum for each plot. For butterfly milkweed, our measurements included the number of ramets per individual, ramet height, the percentage of branchy ramets, and the percentage of reproductive ramets. We used the percentage of branchy ramets as a variable because some of the milkweed ramets were more vigorous than others and exhibited considerable branching. Vigor is best measured by biomass measurements, but because destructive sampling was not possible, we used ramet branchiness as a surrogate for plant biomass. Ramets with four or more branches were labeled branchy and we calculated the percentage of branchy ramets for each individual. We identified reproductive ramets by the presence of flowers, flower buds or fruits.

For cream wild indigo, the variables were the number of ramets per individual and ramet height. Rosinweed initially has an acaulescent growth form with basal leaves. In this case, the variables were the number of basal leaves per individual, the maximum length of the basal leaves for an individual, the percentage of reproductive individuals, and the number of reproductive ramets (flowering stalks) per plant.

For compass plant, we used the stalk index as a measure of vigor. We determined the stalk index by counting the number of full (>1.5-m height) and partial (<1.5-m height) inflorescence stalks; we added these together by counting full stalks as 1 and partial stalks as 0.5. We also measured total seed mass from three randomly selected flowers from the plot. For sneezeweed, the variables were ramet height and the flower mass per ramet.

We measured ecophysiological variables on individuals of butterfly milkweed during fall 2011. We collected these data with an Infrared Gas Analyzer (IRGA, Ciras 1, PP Systems International, Inc., 110 Haverhill Road, Suite 301, Amesbury, MA 01913 USA). We randomly selected two individuals in each plot that had at least one leaf large enough to fill the leaf chamber of the IRGA. We recorded three leaf measurements on each individual over a 10–12 second interval. We averaged these six measurements within each plot to obtain the datum for the plot. We measured and analyzed two variables, including carbon exchange rate (μmol $CO_2/m^2/s$) and stomatal conductance ($mol/m^2/s$). Carbon exchange rate measures the flux of CO_2 for the leaf; positive values indicate more CO_2 entering the plant for photosynthesis than leaving the plant via respiration. Stomatal conductance ($mol/m^2/s$) reflects the flux of water vapor leaving the leaf or the transpiration rate.

In 2010, we collected seeds from sneezeweed ramets by placing a meter stick in each of the two double rows that comprised each plot. We clipped the ramets closest to the 0, 50, and 100-cm mark at the base of the plant, making six ramets collected per plot. We collected flowers and seeds of the ramets and dried them for three weeks at room temperature prior to being weighed. In 2011 we used a more representative method to sample ramets. Plants were initially planted in four rows (two double rows) within the sneezeweed bed. We randomly selected three rows and a random number between 0 and 300 (the length of the plot in cm) for each row and subsequently harvested the ramet closest to that number (e.g., for a total of three ramets per plot).

We sampled three compass plant flowers from the top, middle, and bottom of a stalk that was randomly selected by choosing a number between 0 and 300 (the length of the plot in cm) and locating the closest stalk to the number. We collected all the viable seeds from the flowers and dried them for three weeks at room temperature prior to being weighed.

We used Sigma Stat (Systat Software, Inc**.** 2013) to perform statistical analyses. We used one-way analysis of variance (ANOVA) to analyze the effect of compost depth (0, 3, and 6 cm) on survival, growth, reproduction and ecophysiological variables. For the seedling transplant study, we only utilized the plots that were not tilled (control, 3 cm/no tillage, and 6 cm/no tillage) in our analysis. We used two-way ANOVA to analyze the main effect of tillage and examine the interaction between tillage and compost depth in the seedling transplant study. We considered demonstrable effects either significant ($P \leq 0.05$) or marginal ($0.05 < P \leq 0.10$). In six cases where the data did not pass the normality test for one-way ANOVA, we used a Kruskal–Wallis one-way analysis of variance on ranks and reported median values. We used a Tukey multiple comparison test in the one-way analysis and a Holm-Sidak multiple comparison test in the two-way analysis.

RESULTS

Survivorship

Increases in species survivorship over time are not normally expected because once mortality occurs it is not reversible. Likewise, survival rates should not exceed 100%. However, we observed increases in survivorship for all three species (Table 1) and survival rates greater than 100% for two species (Table 2). These results can only be explained by the inability to reliably detect death in plants (or genets) by observing aboveground growth (or lack of growth). Transplants that appeared to be dead based on the plant's aboveground condition apparently retained viable root tissue that later produced aerial shoots. This was most obvious in butterfly milkweed where the initial survivorship after transplanting was 50%, but by the end of the first year had increased to 81%. Neither of these patterns was observed in the control plots, where mortality was less likely.

Survivorship was affected by both compost depth and tillage (Table 1). Butterfly milkweed exhibited significantly higher survivorship in the control plots than in the 6-cm plots at two weeks after transplanting. However, that effect did not persist through the rest of the study because there were no differences in survivorship by the end of the study. Survivorship in the control plots decreased from 100% in June 2010 to 80% in September 2011. During the same time period in the compost plots, survivorship decreased from 81% to 58% in the 3-cm plots and increased slightly from 50% to 53% in the 6-cm plots. Tillage increased survivorship relative to no tillage during 2010. However, that pattern dissipated in 2011 when survivorship was 55% to 60% for both types of plots. Rosinweed exhibited a similar and more persistent pattern, except that the control and 3-cm plots were equivalent and exhibited higher survivorship than the 6-cm plots (Table 1). This pattern persisted through May 2011, but, by the end of the study, mortality in the control and 3-cm plots resulted in equivalent survivorship among the three treatments. Plants in the tilled plots demonstrated marginally higher survivorship than plants in the untilled plots soon after transplanting, but that effect was gone by the end of 2010 (Table 1). Cream wild indigo did not exhibit any effects of compost on survivorship, other than a marginal interaction between tillage and depth.

Survival Rate

Survival rates in the compost plots tended to be numerically higher than in the control plots (Table 2). However, variation was too large to determine statistical differences; thus there were no effects of compost depth on survival rates for any of the three species and for any of the timeframes examined. Tillage was mostly a non-factor as well, although we observed an effect of tillage on the survival rate of rosinweed from June 2010 to May 2011. Tilling the compost resulted in a 31% reduction in survival rate compared to the no-till plots.

Growth

Butterfly milkweed exhibited several compost/tillage effects (Table 3). By the end of 2010, the control plots exhibited better growth than the 6-cm compost plots. Control plants exhibited greater productivity as indicated by greater branchiness and ramet height. The 3-cm compost plots generally produced either an intermediate effect (ramet height in the 3-cm plots was equal to both the control and the 6-cm plots), or an effect similar to the control (branchiness in the 3-cm plots was greater than the 6 cm plots). Also, tillage of the compost produced better growth than no tillage, as the tillage plants exhibited greater ramet numbers and ramet height (Table 3). Ramet height response was the only one that persisted to September 2011; it was exactly the same as in Sep-

Table 1. Effects of compost depth and tillage on the survivorship (%) of seedling transplants of butterfly milkweed, cream wild indigo, and rosinweed at Eddyville, Iowa, 2010 to 2011. Means/medians with different lowercase letters are statistically different. An (*) indicates a Kruskal-Wallis test and the presentation of medians. An interaction between depth and tillage is indicated by reference to the figure where the interaction is graphically displayed.

	Effect of compost depth				Effect of compost tillage			
Species and time	0 cm	3 cm	6 cm	*P*-value	No tillage	Tillage	*P*-value	Interaction
Butterfly milkweed								
Jun 2010 *	100 [a]	81.3 [ab]	50.0 [b]	< 0.001	63.3 [a]	89.1 [b]	0.002	none
Sep 2010	87.5	73.4	81.3	0.14	66.4 [a]	78.1 [b]	0.10	none
May 2011	84.4	57.8	54.7	0.12	56.2	59.4	0.74	none
Sep 2011	79.7	57.8	53.1	0.16	56.2	55.5	0.92	none
Cream wild indigo								
Jun 2010	100	91.7	97.9	0.38	94.8	88.5	0.40	Fig. 2A
Sep 2010 *	90.6	93.8	93.8	0.56	94.8	94.8	1.00	none
May 2011	78.1	87.5	81.3	0.80	84.4	76.0	0.27	none
Rosinweed								
Jun 2010 *	100 [a]	78.1 [ab]	46.9 [b]	0.001	65.6	79.7 [b]	0.10	none
Sep 2010	93.8 [a]	81.3 [a]	56.3 [b]	0.002	73.4	68.7	0.49	none
May 2011	92.2 [a]	84.4 [a]	62.5 [b]	0.024	73.4	67.2	0.38	none
Sep 2011 *	87.5	81.3	62.5	0.14	70.3	64.8	0.44	none

Table 2. Effects of compost depth and tillage on the survival rates (%) of seedling transplants of butterfly milkweed, cream wild indigo, and rosinweed at Eddyville, Iowa, 2010 to 2011. Means with different lowercase letters are statistically different. There were no interactions between depth and tillage for any of the tests.

	Effect of compost depth				Effect of compost tillage		
Species and time	0 cm	3 cm	6 cm	*P*–value	No tillage	Tillage	*P*–value
Butterfly milkweed							
Sep 2010 to May 2011	83.2	84.7	64.7	0.55	74.7	100.7	0.12
Cream wild indigo							
Sep 2010 to May 2011	85.7	93.2	84.7	0.76	88.9	80.4	0.22
Rosinweed							
Jun 2010 to May 2011	92.2	112.9	126.0	0.32	119.5 [a]	83.2 [b]	0.017
May 2011 to Sep 2011	95.0	91.9	100.0	0.42	95.9	97.3	0.80

tember 2010. A difference in branchiness due to tillage was manifest in September 2011. But unlike in 2010 when tillage produced better growth, the percentage of branchy ramets of butterfly milkweed was higher in the no tillage plots (Table 3). We observed two interactions between tillage and compost depth, one for percentage of branchy ramets in the fall of 2010 and one for ramet height in fall of 2011. There was a minimal effect of compost/tillage observed on the growth of cream wild indigo (Table 4). The only effect measured was greater ramet number on the no tillage plots in fall of 2010.

Effects of compost/tillage on growth of rosinweed were evident soon after transplanting (Table 5). In June 2010, plants on the control plots had more leaves per individual than plants on both the compost plots, and the maximum leaf length on the control plots was greater than those on both compost plots. This detrimental effect of compost persisted to the end of the first growing season, but by then the maximum leaf length of plants on both the control and 3-cm plots was longer than on the plants in the 6 cm plots. There was also an interaction between compost depth and tillage for

Table 3. Effects of compost depth and tillage on butterfly milkweed growth and reproduction at Eddyville, Iowa, 2010 to 2011. Means/medians with different lowercase letters are statistically different. An (*) indicates a Kruskal-Wallis test and the presentation of medians. An interaction between depth and tillage is indicated by reference to the figure where the interaction is graphically displayed.

	Effects of compost depth				Effect of compost tillage			
Time and variable	0 cm	3 cm	6 cm	*P*-value	No tillage	Tillage	*P*-value	Interaction
June 2010								
Ramet ht (cm)	15.8	15.1	16.7	0.14	19.1	18.2	0.48	none
September 2010								
Ramet ht (cm)	84.6 ^{a}	67.2 ^{ab}	56.0 ^{b}	0.01	33.7 ^{a}	43.8 ^{b}	0.003	none
Ramet no.	1.74	1.79	1.67	0.94	1.73 ^{a}	2.13 ^{b}	0.08	none
Branchy ramet (%)	61.3 ^{a}	50.5 ^{a}	17.5 ^{b}	0.003	31.8	34.0	0.79	Fig. 3A
Reproductive ramet (%)	67.9 ^{a}	34.3 ^{b}	27.4 ^{b}	0.001	30.8	38.0	0.37	none
September 2011								
Ramet ht (cm)	69.7 ^{a}	68.3 ^{ab}	60.5 ^{b}	0.061	64.4	64.1	0.92	Fig. 3B
Ramet no.	4.1	4.2	4.4	0.93	4.3	5.2	0.27	none
Branchy ramet (%)	28.7	37.3	47.9	0.37	42.6 ^{a}	24.2 ^{b}	0.025	none
Reproductive ramet (%)	76.6	88.6	74.6	0.43	81.6 ^{a}	67.7 ^{b}	0.027	Fig. 3C
Carbon exchange rate * (μmol CO /m^2/s)	5.03	6.88	8.63	0.80	7.8	9.2	0.49	none
Stomatal conductance * (mol/m^2/s)	120.5	96.8	155.0	0.53	125.9	250.6	0.20	none

Table 4. Effects of compost depth and tillage on cream wild indigo growth at Eddyville, Iowa, 2010 to 2011. Means with different lowercase letters are statistically different. During September 2011, plants senesced before data could be collected.

	Effect of compost depth				Effect of compost tillage			
Time and variable	0 cm	3 cm	6 cm	*P*-value	No tillage	Tillage	*P*-value	Interaction
Jun 2010								
Ramet ht (cm)	10.0	9.6	10.1	0.94	21.9	22.4	0.73	none
Sep 2010								
Ramet ht (cm)	16.1	13.2	12.8	0.25	13.0	15.0	0.11	none
Ramet no.	3.2	3.3	3.4	0.88	3.3 a	2.7 ^{b}	0.022	none

maximum leaf length in September 2010. Tillage initially (in June 2010) affected both leaf number and maximum leaf length, with the plants on tilled plots exhibiting greater numbers of leaves per plant and the plants on no tillage plots exhibiting longer lengths for their largest leaf. These effects were not observed in the fall of 2010. The only growth variable measured on the established plants was mean ramet height per plot for sneezeweed. It was equivalent among all treatments in both 2010 and 2011 (Table 6).

Reproductive Effort

Several effects of compost/tillage on the reproductive variables were observed. The percentage of reproductive ramets in butterfly milkweed at the end of the first season was twice as high on the control plots as the compost plots (Table 3). That effect was not observed in September 2011 when the percentage of reproductive ramets per individual ranged from 74% to 88% for all the plots. However, in September 2011 the no tillage plots exhibited a greater percentage of

Table 5. Effects of compost depth and tillage on rosinweed growth and reproduction at Eddyville, Iowa, 2010 to 2011. Means with different lowercase letters are statistically different. An interaction between depth and tillage is indicated by reference to the figure where the interaction is graphically displayed.

	Effect of compost depth				Effect of compost tillage			
Time and variable	0 cm	3 cm	6 cm	*P*-value	No tillage	Tillage	*P*-value	Interaction
Jun 2010								
No. leaves per genet	4.8 [a]	3.1 [b]	2.4 [b]	0.018	2.7 [a]	3.5 [b]	0.022	none
Max. leaf length (cm)	18.7 [a]	14.9 [b]	12.1 [b]	0.004	16.9 [a]	13.5 [b]	0.008	none
Sep 2010								
No. leaves per genet	44.8	37.6	33.0	0.19	30.0	35.3	0.13	none
Max. leaf length (cm)	40.4 [a]	40.6 [a]	34.1 [b]	0.009	38.2	37.3	0.48	Fig. 2B
Reproductive ind. (%)	11.8	15.61	7.5	0.64	6.5	11.5	0.44	none
Sep 2011								
No. reproductive ramets	13.3 [a]	8.8 [b]	9.8 [b]	0.083	9.3 [a]	12.3 [b]	0.019	none

Table 6. Effect of compost depth and tillage on growth and reproduction of established plots of sneeze weed and compass plant at Eddyville, Iowa, 2010 to 2011. Means with different lowercase letters are statistically different.

	Effect of compost depth			
Species, time and variable	0 cm	3 cm	6 cm	*P*–value
Sneeze weed				
Fall 2010 ramet ht (cm)	90.0	89.8	85.7	0.70
Fall 2011 ramet ht (cm)	69.2	78.1	75.0	0.52
Fall 2010 flower mass/ramet (gm)	3.58	5.12	4.10	0.44
Fall 2011 flower mass/ramet (gm)	3.98	5.53	7.03	0.51
Compass plant				
Fall 2010 stalk index (stalks/plot)	11.4	12.2	14.0	0.69
Fall 2011 stalk index (stalks/plot)	15.3	12.0	6.7	0.14
Fall 2011 seed mass per flower (gm)	2.23	2.02	1.98	0.67

reproductive ramets than the tillage plots, and there was an interaction between tillage and compost depth (Table 3).

Rosinweed exhibited some reproduction during the first season, which was measured by percentage of individuals with flowering stalks. These data indicated no effect of compost/tillage (Table 5). In September 2011, many of the rosinweed plants were in flower. Main effects of compost depth and tillage on the number of reproductive ramets per plant were demonstrated. Control plants exhibited a greater number of reproductive ramets than plants in both the 3 and 6-cm plots, and plants on the tillage plots displayed a greater number of reproductive ramets than the no tillage plots (Table 5). None of the reproductive variables measured on sneezeweed and compass plant demonstrated any effects of compost (Table 6). Compost or tillage had no effect on either carbon exchange rate or stomatal conductance for butterfly milkweed for (Table 3).

Interactions

An interaction between factors is present when the effect of one factor depends on the effect of another factor. Interactions are typically common phenomena in biological systems. They increase the complexity and complicate our ability to fully understand the system. In our study, the use of a 2 × 2 factorial design facilitates the ability to discern interactions between tillage and compost depth. Three types of interaction were represented. One is the outcome where the effect of tillage with 3 cm of compost increased the variable, while the effect of tillage with 6 cm of compost decreased the variable (both relative to no tillage). This interaction was the most common and was observed with cream wild indigo survivorship in June 2010 (Fig. 2A), butterfly milkweed ramet branching in September 2010 (Fig. 3A), and rosinweed maximum leaf length in September 2010 (Fig. 2B).

Another interaction pattern observed was the opposite – the effect of tillage with 3 cm of compost decreased the variable, while the effect of tillage with 6 cm of compost increased the variable (both relative to no tillage). This interaction was observed in butterfly milkweed ramet height in September 2011 (Fig. 3B).

The third interaction pattern was one that resulted in the highest response on 3-cm and no-tillage plots, the next highest on all the 6-cm plots regardless of tillage, and the lowest response on 3-cm tillage plots. This interaction occurred in butterfly milkweed percentage ramet reproduction in September 2011 (Fig. 3C).

DISCUSSION

Overall, our results indicate that benefits of compost were not demonstrated as hypothesized. The application of compost (3 or 6-cm compost depth vs. 0 cm) resulted in less growth and vigor in the transplants. Whenever there was a statistical difference in a variable due to compost depth, the control plots always did better than the 6 cm compost plots (12 examples), and in a few case the controls did better than the 3-cm compost plots (4 examples). Sometimes the 3-cm compost plots did better than the 6-cm compost plots (4 examples). Compost depth effects were much more prevalent in 2010 (9 examples) than in 2011 (3 examples), thus there was a strong tendency for them to dissipate over time. Established plants did not benefit from either 3 or 6 cm of compost.

Tillage results were more balanced. Seven results indicated better performance with tillage, while five results demon-

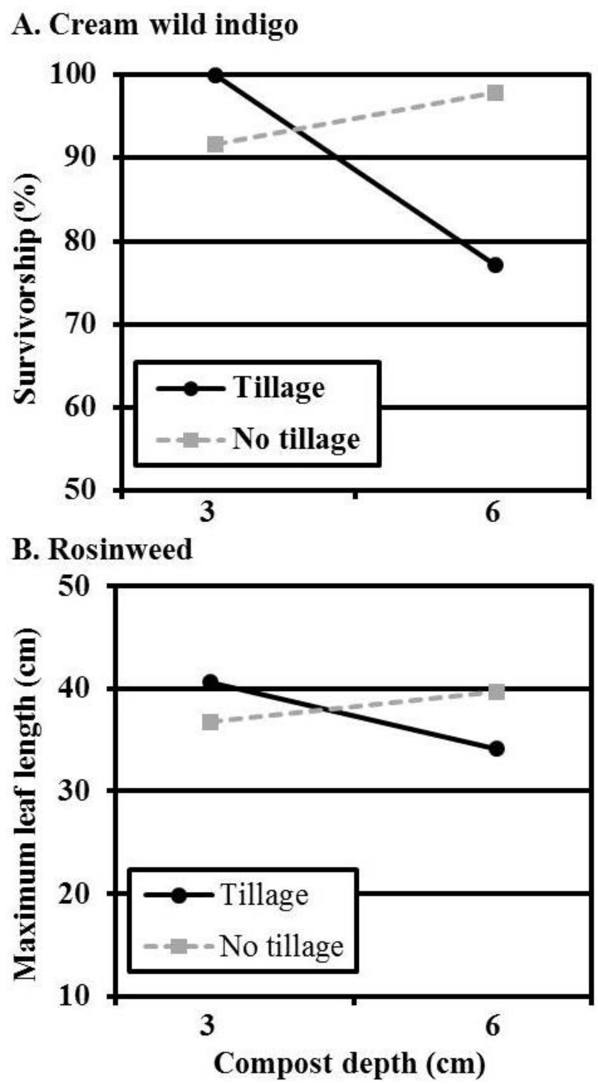

Figure 2. Interactions observed between compost depth and tillage in a study at Eddyville, Iowa, 2010 to 2011. Survivorship for cream wild indigo in June 2010 (A). Maximum leaf length within genets for rosinweed in September 2010 (B).

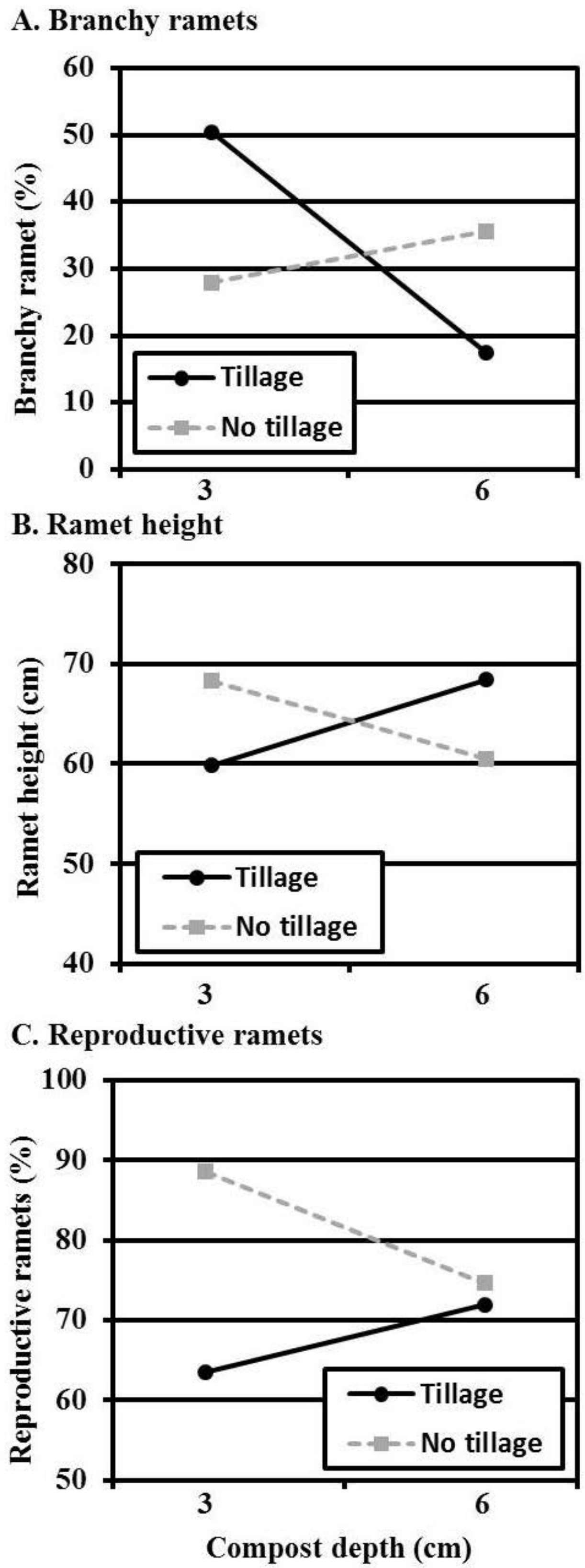

Figure 3. Interactions observed between compost depth and tillage for butterfly milkweed in a study at Eddyville, Iowa, 2010 to 2011. A measure of plant vigor based on the percentage of branchy ramets within genets in September 2010 (A). Ramet height within genets in September 2011 (B). Percentage of ramets within genets that are reproductive in September 2011 (C).

strated that no tillage had better consequences for the plants. Among the seven instances demonstrating a positive effect of tillage, six were manifest in 2010 and one in 2011. The five examples of a positive effect of no tillage were split, two in 2010 and three in 2011.

In a study where tomato seedlings were grown in compost waste soil amendments, Asgharipour and Armin (2010) found that excessive application of municipal compost to agricultural soil might lead to deleterious effects on crops. This was based on the discovery that the highest percentage of germination and dry weight of tomato plants were obtained with the treatment that represented a moderate amount of mixing of compost and soil (1:5 compost to soil ratio compared to ratios of 1:2.5, 1:7.5, and 1:10). The authors speculated that the effect of tillage (or mixing) may have helped initiate fungal and microbial decomposition and lessened heat retention and absorption due to the compost.

Heating affects by the compost could have played a role in our study as well. The significant amount of mortality observed the first weeks after transplanting for butterfly milkweed and rosinweed may have been caused by the dark compost absorbing and retaining heat and causing stress to the young plant roots. Unfortunately, the seedlings were planted on a relatively hot and sunny afternoon, so heat stress was unavoidable. Dark compost in the sun would absorb infrared radiation and increase the soil temperature around the transplant roots thereby creating greater root stress than in the compost free plots. Tillage may have ameliorated survival by mixing the compost with soil and reducing the dark color and hence the amount of heat absorption. It is also possible that these negative effects may have been avoided or diminished if the transplanting had occurred in the evening after the sun was not a factor (or on a cloudy day). That these effects on survivorship were maintained into the second year, at least for rosinweed, verifies that post-transplant survival is crucial in establishing production plots. Mortality did occur in the control plots, but it was low enough in rosinweed that the difference in survivorship between control and compost (the 6-cm plots especially) was consistent into the second year.

Despite the initial negative effects of compost on the survival of transplants (specifically butterfly milkweed and rosinweed), post-transplant survival appears to have favored the plants in the compost plots since there were no differences in survivorship by the end of the study for any of the three species. Although the results for survival rates do not show statistical differences due to compost depth, the majority of the survival rates observed for plants in the compost plots were numerically higher than for plants in the control plots. Compost depth did not have any long term effects on survival.

The stress endured by the plants in the compost plots likely contributed to their poorer growth performance compared to the control. This was most evident for butterfly milkweed and rosinweed during the first season. Perhaps stress on the roots of transplants in the compost plots caused greater allocation of resources to roots than the aboveground growth. By the second growing season the plants were sufficiently established and past the extra transplant shock caused by the compost that, for the most part, they did equally as well as the control. Similar to survivorship, the effect of tillage in decreasing the initial stress of the compost is seen in the higher growth performance of plants in the tillage plots. However, longer term effects of tillage (season 2 in butterfly milkweed) indicate better performance by the plants in the no tillage plots.

It is reasonable to expect the main advantage of tillage was short-term, primarily to mix the compost with topsoil and reduce the darkness (blackness) of the soil in which the transplants were placed. We can only speculate what mechanism might create better long-term performance by the plants in the no tillage plots. It might be that the no tillage plots experienced slower mineralization rates relative to the plots where compost was tilled. Slower (or delayed) mineralization of compost could have resulted in greater nutrient release during the second season (relative to tilled plots). If this nutrient release coincided closely with the nutrient needs of the plants (i.e., it is more likely that transplants will have a higher nutrient demand during the second season relative to the first season due to their greater age and potential for growth), the plants in the tilled plots could be expected to do better than plants in the no till plots. Another possible explanation for a delayed positive effect of no tillage centers on the anecdotal observation made during 2010; compost plots appeared to have less erosion and weed pressure due to the mulching effect of the compost. Perhaps this positive effect lasted longer in the plots that were not tilled (i.e., all the compost was on top of the soil and therefore functioned more as mulch).

It is reasonable to think that because the compost needs time to completely decompose and release nutrients, it is possible that compost benefits would not manifest until after a year or so. However, year two measurements in this study do not generally support this idea. It may be that 6 cm of compost is not a sufficient amount to create higher fertility relative to the fertility inherent in an Iowa prairie soil. The Chamness compost has a C:N ratio of 17.4:1 and contains approximately 0.8% total nitrogen, 0.4% total phosphorus, 0.2% total potassium and 22.1% organic matter (S. Amendt, Chamness Technology, personal communication). A study with sequential additions of municipal solid waste compost over three years on wheat plants showed enhanced growth rates compared to the untreated plots (Ayari et al. 2010). This suggests that repeated additions of compost may be needed.

The interactions we observed indicate that the effects of tillage and compost can be independent, in that each can affect how the other factor will respond. A likely explanation for one of the interactions is that compost could have both negative and positive effects on plants. For example the negative effects of the black color and heating can be minimized by tillage, so that tillage on 3-cm plots results in better plant performance. Compost could also have positive effects by providing weed control via a mulch effect. This effect would be enhanced by deeper compost that is not tilled, thus no tillage on a 6 cm plot could result in better plant performance. This explanation could be applicable to the interactions observed in cream wild indigo survivorship, butterfly milkweed ramet branching (increased vigor), and rosinweed maximum leaf length (Fig. 2, Fig. 3).

In the interaction demonstrated for butterfly milkweed ramet height (Fig. 3B), tillage was better than no tillage with 6 cm of compost, but with 3 cm of compost no tillage was better than tillage. In other words, if 3 cm of compost was used it was better to not till it; if 6 cm of compost was used it was better to till it. A possible explanation for this interaction is that 6 cm may have been a sufficient amount to provide a fertility effect, which was enhanced by tillage since that would help to increase the contact of the compost with decomposers and increase mineralization. Whereas in the 3-cm plots there was not enough compost to produce a fertility effect and instead the compost produced a positive mulching effect that was enhanced by no tillage.

The last interaction (Fig. 3C), which we observed in 2011 for the percentage of reproductive ramets in butterfly milkweed, indicates that tillage had no effect on the 6-cm compost treatment (both tilled and no tillage plots were the same), but with 3 cm the no-tillage plots exhibited higher reproduction than the tilled plots. This suggests the long lasting mulching effect of the compost (which would be enhanced with no tillage) was more beneficial with 3 cm of compost than with 6 cm of compost. Perhaps 6 cm and not tilled was equivalent to 6 cm and tilled (i.e., 6 cm was the same no matter if tilled or not) due to a longer lasting fertility effect that could only be realized with 6 cm of compost.

MANAGEMENT IMPLICATIONS

There were several observations where either tillage or no tillage of compost had some beneficial effects on transplant success, thus the use of compost in production plots to achieve higher plant performance is supported in part. Tillage is helpful for mixing compost with topsoil, and thereby reducing darkness of the compost and decreasing amount of heat absorption and stress to roots. Compost may have dual effects, including fertility enhancement and increased water holding capacity, or mulching effect. The mechanisms of these effects are different and each is affected differently by tillage. Tillage should enhance the fertility effect by providing the microbial community better access to the compost and increase its mineralization rate. For relatively fertile soils, it is possible that more compost than used in this study (6 cm) is needed to achieve fertility enhancement. Compost may also provide beneficial effects in reducing soil erosion by protecting the soil from the impact of rain drops, and decreasing weed density from its mulching (and heating) affect. These benefits are likely enhanced if compost is not tilled into topsoil so that a mulch effect can be maximized.

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