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Cured Dairy Compost Influence on Weed Competition and on 'Snowden' Potato Yield

Alexander J. Lindsey, Karen A. Renner, and Wesley J. Everman*

Potatoes are an important global food crop typically produced in high-input systems in temperate zones. Growers that have access to compost may use it to improve soil health and increase tuber yields, but compost may also increase weed competition by increasing early-season water availability and weed growth. A field study at the Michigan State University Montcalm Research farm in 2010 and 2011 investigated the impact of compost on weed competition in potato. Potatoes were grown in field plots with 0, 4,000, or 8,000 kg carbon (C) ha^{-1} of compost under weed-free conditions, and in competition with common lambsquarters, giant foxtail, and hairy nightshade. Compost did not increase biomass or seed production of any weed species. Giant foxtail and hairy nightshade at 5.3 plants per meter of row reduced potato yield by 20%; common lambsquarters reduced yield by 45%. The yield reduction by giant foxtail and hairy nightshade was due to a decrease in tuber bulking, whereas yield reductions from common lambsquarters were a result of lower tuber set and bulking. Potato yield increased 5 to 15% in compost compared to non-compost treatments; tuber specific gravity decreased by 0.3% in composted treatments. Across weed densities, elevated soil potassium levels in the 8,000 kg C ha^{-1} composted treatment may have increased potato yield and decreased tuber specific gravity.
Nomenclature: Common lambsquarters, *Chenopodium album* L.; giant foxtail, *Setaria faberi* Herrm.; hairy nightshade, *Solanum physalifolium* Rusby; potato, *Solanum tuberosum* L.
Key words: Fertilization, potassium, seed production, tuber quality, weed competition, weed interference.

La papa es un cultivo de importancia a nivel global que es típicamente producido en sistemas con altos insumos en zonas templadas. Los productores que tienen acceso a compost podrían usarlo para mejorar la salud del suelo e incrementar los rendimientos de tubérculos, pero el compost podría también aumentar la competencia de malezas al incrementar la disponibilidad de agua y el crecimiento de las malezas temprano durante la temporada. Un estudio de campo en la Finca de Investigación Montcalm de la Universidad Estatal de Michigan investigó el impacto del compost sobre la competencia de las malezas con la papa. Se sembraron papas en parcelas de campo con 0, 4,000, ó 8,000 kg carbon (C) ha^{-1} de compost bajo condiciones libres de malezas, y en competencia con *Chenopodium album*, *Setaria faberi* y *Solanum physalifolium*. El compost no incrementó la biomasa o producción de semillas de ninguna de las especies de malezas. *S. faberi* y *S. physalifolium* a 5.3 plantas por metro de cultivo redujeron el rendimiento de la papa en 20%. *C. album* redujo el rendimiento en 45%. La reducción del rendimiento causada por *S. faberi* y *S. physalifolium* se debió a la reducción en crecimiento del tubérculo, mientras que las reducciones del rendimiento debido a *C. album* fueron el resultado de una menor producción y crecimiento de tubérculos. El rendimiento de la papa incrementó 5 a 15% en compost al compararse con tratamientos sin compost; la gravedad específica del tubérculo disminuyó en 0.3% en los tratamientos con compost. A través de todas las densidades de malezas, los niveles elevados de potasio en el suelo en el tratamiento con compost con 8,000 kg C ha^{-1} podrían haber incrementado el rendimiento de la papa y disminuido la gravedad específica de los tubérculos.

Potato is a perennial crop grown globally as an important food source. Production in the U.S. is over 36 million tonnes (35 t ha^{-1}) annually with a market value of over three billion dollars (USDA-NASS 2011). In irrigated production systems, growers utilize multiple tillage and irrigation events to maximize yield. However, intensive tillage and limited crop rotation may reduce the sustainability of potato cropping systems. Intensive tillage can decrease soil organic matter, reduce soil structure, and can increase surface erosion (Lal 1993). Applying compost as a soil amendment builds soil carbon (C), increases water and nutrient holding capacity, and enhances soil microbial activity (Gonzales and Cooperband 2002; Magdoff and van Es 2000; Salem et al. 2010). Compost amendments may also suppress soil diseases such as *Verticillium* wilt caused by the fungus *Verticillium dahliae* (Entry et al. 2005) and increase arbuscular mycorrhizal spore populations (Douds et al. 1997). Using compost and manure as nutrient sources can reduce synthetic fertilizer applications (Menalled et al. 2005a), but fresh manure may introduce more viable weed seeds than compost (Wiese et al. 1998) and increase the weed seedbank to a greater degree.

There is limited research on the competitiveness of weeds in chipping potato production systems. Removing weeds by 20-cm potato height can minimize yield loss (Ciuberkis et al. 2007), but a mixed weed population of grass and broadleaf weeds emerging up to 25 d after potato emergence reduced potato yield and tuber size by 15 to 25% (Nelson and Thoreson 1981). In a field experiment by Vangessel and Renner (1990a), natural weed populations emerging in 'Atlantic' and 'Russet Burbank' cultivar potatoes reduced yield, but early hilling of the potatoes in one of two years decreased weed pressure and increased yield. Cultivation and

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* First and second authors: Graduate Assistant and Professor, Department of Crop and Soil Sciences, Michigan State University, East Lansing, MI 48824; third author: Assistant Professor, Department of Crop Science, North Carolina State University, Raleigh, NC 27695. Corresponding author's E-mail: lindse38@msu.edu

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herbicide application at 60% predicted weed emergence (determined using a weed emergence predictive model) resulted in the greatest tuber yield compared with lower levels of weed emergence (Felix et al. 2009). As few as one barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] or redroot pigweed (*Amaranthus retroflexus* L.) plant per m of row decreased marketable tuber yield of Atlantic potatoes in Michigan by 19 and 33%, respectively (Vangessel and Renner 1990b). In field research in Idaho, two hairy nightshade (*Solanum physalifolium* Rusby) plants per m row reduced Russet Burbank marketable yield by 10% while one plant per m row reduced marketable tuber yield of 'Russet Norkotah' by 21% (Hutchinson et al. 2011).

The effect of compost on weed emergence and growth has been documented by numerous researchers. Blackshaw et al. (2005) observed no effect of fall or spring applied beef cattle (*Bos taurus*) compost (30 t ha^{-1}) on biomass accumulation of downy brome (*Bromus tectorum* L.), field pennycress (*Thlaspi arvense* L.), and flixweed [Descurainia sophia (L.) Webb ex Prantl] in wheat (*Triticum aestivum* L.). Similarly, spring application of 45 t ha^{-1} beef manure and 22 t ha^{-1} cull potato compost did not increase the biomass of common lambsquarters in the first three years of application (Gallandt et al. 1998). Common lambsquarters emergence was not influenced by swine (*Sus scrofa*) manure compost (Menalled et al. 2005b). In contrast, swine manure compost at 8000 kg C ha^{-1} increased biomass and seed production of common waterhemp (*Amaranthus rudis* Sauer), but did not increase velvetleaf (*Abutilon theophrasti* Medic.) and giant foxtail biomass (Liebman et al. 2004) or soybean [*Glycine max* (L.) Merr.] yield (Menalled et al. 2004).

Previous research has shown tuber yield increases of 10 to 15% with compost application (Kleinhenz and Cardina 2003; Rigane and Medhioub 2011; Salem et al. 2010). In 'Superior,' a round white potato cultivar, 15 t ha^{-1} spent mushroom compost from horse (*Equus caballus*) manure supplemented with synthetic fertilizer increased the marketable tuber yield compared to equivalent rates of synthetic fertilizer without compost by 38 to 96% (LaMondia et al. 1999), but higher rates (15 Mt ha^{-1}) of the same material alone did not increase yields in fumigated soils (Gent et al. 1998). Superior potato yield increased by 8 to 28%, and specific gravity decreased when amended with 22 t ha^{-1} waste potato compost plus 45 t ha^{-1} beef cattle manure when compared to potato yield and specific gravity from the non-amended treatment (Porter et al. 1999). However, amended plots received equal amounts fertilizer as the non-amended plots and researchers did not adjust fertilizer application rates based on fertility additions from the amendments. Gallandt et al. (1998) observed that four and five consecutive years of 22 t ha^{-1} cull potato compost plus 45 t ha^{-1} beef cattle manure (supplemented with inorganic fertilizer additions each year) addition resulted in equivalent yields to potatoes grown without amendments under weed free conditions. Potato response to N is cultivar specific (Kanzikwera et al. 2001), and none of these studies were performed with the round white cultivar 'Snowden' (a common chipping cultivar in Michigan). There have also been very few published reports of weed competition in potato as influenced by the addition of compost. Therefore, the objectives of this research were to: (1) investigate the impact of cured dairy manure compost on weed competition of three weed species on potato; (2) determine the impact of compost on weed seed production; and (3) evaluate the effect of compost and weed competition on potato growth and yield.

Materials and Methods

A field experiment was established in 2010 and repeated in 2011 at the Michigan State University Montcalm Research Center in Lakeview, MI (43.35°N, 85.18°W; 290 m elevation). This study was conducted in a two-way factorial randomized complete block design with four replications. The first factor was cured dairy manure compost rate at 0, 4,000, or 8,000 kg carbon (C) ha^{-1}, and the second factor was weed species with three species and a weed-free control. The species were common lambsquarters (CHEAL), giant foxtail (SETFA), or hairy nightshade (SOLSA). The soil was a mixture of Montcalm loamy sand and sandy loam (coarse-loamy, mixed, semiactive, frigid Alfic Haplorthods) and McBride loamy sand and sandy loam (coarse-loamy, mixed, semiactive, frigid Alfic Fragiorthods) with 1.1% organic matter content and a pH of 6.9 in 2010 and pH of 6.7 in 2011 at 15-cm depth (Table 1). Each year the field was tilled in the fall with a chisel plow to a 30 cm depth or a disc to a 10 cm depth; spring tillage was a disc and/or a field cultivator to a 15 cm depth.

Compost Application. Composted dairy manure (University Farms, Michigan State University, East Lansing, MI) that had been curing for 2 to 4 months was applied manually to 6.1 by 3.4 m plots and incorporated to a 10 cm depth using a disc on April 29, 2010 and May 4, 2011. Compost rates were 0, 4000, and 8000 kg C ha^{-1}, which was equivalent to a total compost application of 26 and 52 wet t ha^{-1}. A complete soil analysis to 15-cm depth and compost nutrient analysis was conducted in both years prior to compost application (Table 1). Potassium (K) fertilizer was applied to the nonamended plots at 47 kg K ha^{-1} [0N-0P-17.4K, 21S, 10Mg (K-Mag Fertilizer, The Mosaic Company, Plymouth, MN)], and was not applied to composted plots because approximately 90% of the K in the compost was estimated to be released in-season (Rosen and Bierman 2005). Potatoes were planted (cut seed, approximately 42 to 47 g; Snowden cultivar) on May 17, 2010 and May 20, 2011 in 0.86 m rows with 27 cm seed spacing at a 10 cm depth. Nitrogen (N) was balanced based on expected total inorganic N application from the compost and inorganic fertilizer (LaMondia et al. 1999; Nyiraneza and Snapp 2007). A summary of total macronutrient applications in 2010 and 2011 is given in Table 2. Starter fertilizer in the 0 kg C ha^{-1} plots in 2010 was applied at 59 kg N ha^{-1} [24.4–2.9–0 (28% UAN and Liquid Ammonium Phosphate Blend, PotashCorp, Northbrook, IL)] and at 67 kg N ha^{-1} [24.8–2.7–0 (28% UAN and Liquid Ammonium Phosphate Blend, PotashCorp, Northbrook, IL)] in 2011. Starter fertilizer application was reduced in the composted plots in both years based on expected inorganic N release from the amendment. Because N mineralization from composted dairy manure solids has been shown to range between −5 and 20% (Gale et al. 2006; Hartz et al. 2000; Rosen and Bierman 2005), we

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Table 1. Initial soil test and cured dairy manure compost nutrient measurements.[a]

	2010		2011	
Soil property	Soil[b]	Compost[c]	Soil	Compost
pH	6.9	9.3	6.7	8.6
Organic matter (%)	1.1	55.7	1.1	49.5
Carbon content (%)	—	32.3	—	28.7
Water holding capacity (%)	—	—	5.28	14.97
Cation exchange capacity (cmol/kg)	3.6	—	3.0	—
	mg kg^{-1}			
Total Nitrogen (N)	400	22600	450	20000
Inorganic N (Ammonium-N/Nitrate-N)	—	—	3.1/3.1	27/381
Phosphorus	200	5200	224	7200
Potassium	182	19300	142	23100
Magnesium	88	11300	77	16900
Calcium	483	43600	401	57700
Sulfur	12	3200	9	4600
Boron	—	26	0.1	37
Copper	4.3	71	3.0	102
Manganese	13.2	291	10.8	312
Zinc	2.0	137	1.5	212
Iron	31.7	3056	24.8	3195
Sodium	11	2800	5	5300
Aluminum	—	1295	—	794

[a] Soil and compost measurements shown with a dash were not measured.

[b] Soil samples were collected as six homogenized cores to 15-cm depth.

[c] Compost samples were collected from eight random areas within the pile and homogenized. Analysis is reported as concentration on a dry weight basis.

used 10% as the expected N that would mineralize in the first season.

Potatoes received additional applications of N at cultivation [June 15, 2010 and 2011; 66.7 kg N ha^{-1} of 28-0-0 (28% UAN, PotashCorp, Northbrook, IL)] and hilling [June 24, 2010 and June 27, 2011; 41.0 kg N ha^{-1} of 46-0-0 (Urea, Agrium, Inc., Calgary, Alberta, Canada)], and prior to canopy closure (July 7, 2010 and 2011; 41.0 kg N ha^{-1} of 46-0-0). Natural weed populations were controlled after planting (May 19, 2010 and May 20, 2011) using linuron at 0.23 kg ai ha^{-1} (Lorox®, Tessenderlo Kerley, Inc., Phoenix, AZ) + *S*-metolachlor at 0.58 kg ai ha^{-1} (Dual II Magnum®, Syngenta Crop Protection, Inc., Greensboro, NC) applied with a six-nozzle (50 cm spacing) CO_2-pressurized backpack sprayer calibrated to deliver 190 L ha^{-1} at 330 kPa with TeeJet® XR8003 nozzles (TeeJet® Technologies, Springfield, IL) 45 cm above the soil surface. Irrigation (Single-Gun Lateral Irrigator, Reinke Manufacturing Company, Inc., Deshler, NE) was applied as needed to supplement natural rainfall (Table 3). Rainfall and growing degree day accumulation (base 4 C) were recorded using the Michigan State University Enviro-weather station in Entrican, MI (Table 3). Fungicides and insecticides (Table 4) were applied in-furrow or foliarly as needed to alleviate disease and insect pressure using a two-nozzle (86-cm spacing) sprayer at 190 L ha^{-1} and 240 kPa with XR8003 nozzles 45 cm above seed piece or a 16-nozzle (50 cm spacing) sprayer at the same volume and pressure, and with the same nozzle type 75 cm above the plant canopy.

Weed Establishment. Field grown seeds of common lambsquarters (Field collected 2006, East Lansing, MI), giant foxtail (Field collected 2007, East Lansing, MI), and hairy nightshade (Field Collected 2009, Lakeview, MI) were collected and stored at 4 C. Prior to planting, weed seeds were stored at 22 C for 24 h, and hairy nightshade seeds were submersed in gibberellic acid at 2 g L^{-1} for 24 h to stimulate germination (Edmonds 1986; Spicer and Dionne 1961). Four to 10 seeds of each species were planted into 25 by 40 mm media plugs (25mm plugs in Blackmore105/27 Ellepot tray,

Table 2. Macronutrient application total in 2010 and 2011 by compost rate.[a]

	0 kg C ha^{-1}		4,000 kg C ha^{-1}		8,000 kg C ha^{-1}	
Nutrient	2010	2011	2010	2011	2010	2011
	kg ha^{-1}					
Inorganic N	260	270	260	264	258	258
P	9	9	60	76	112	143
K	38	38	231	255	461	511
Ca	0	0	578	710	1160	1420
Mg	11	11	150	208	300	417
S	47	47	43	56	85	114

[a] Abbreviations: C, carbon; N, nitrogen; P, phosphorus; K, potassium; Ca, calcium; Mg, magnesium; S, sulfur.

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Table 3. Growing degree day accumulation (base 4 C), and rainfall and irrigation summary by month.[a]

Month	2010				2011			
	GDD	Rainfall	Irrigation	Total	GDD	Rainfall	Irrigation	Total
		cm				cm		
April	358.0	3.8	0.0	3.8	182.1	8.6	0.0	8.6
May	610.4	9.1	0.0	9.1	566.8	7.9	0.0	7.9
June	800.8	7.9	0.0	7.9	787.0	6.1	0.0	6.1
July	1,013.1	3.6	10.4	14.0	1,033.9	4.3	10.2	14.5
August	978.2	4.9	5.3	10.2	882.4	6.6	2.8	9.4
September	576.7	4.6	0.0	4.6	578.0	6.1	0.0	6.1
Total	4,337.2	33.9	15.7	49.6	4,030.2	39.6	13.0	52.6

[a] Abbreviations: GDD, growing degree days.

Ellepot USA/Blackmore Company, Inc., Belleview, MI) in the greenhouse at Michigan State University in East Lansing, MI (42°43′ N, 84°28′ W; 257 m elevation) 4 wk prior to transplanting at the field site. Plugs were thinned weekly to maintain a density of one plant per plug. Natural light was supplemented with artificial light for 16 h per day at 400 μmol m^{-2} s^{-1} photosynthetic photon flux. Conditions in the greenhouse were maintained at day/night temperatures of 27/24 C.

A single species was transplanted into the second and third row of each plot (with the exception of the weed-free plots) at 70% potato emergence (June 7, 2010 and 2011). Common lambsquarters and hairy nightshade were 2.5 cm tall at the time of transplanting, and giant foxtail was 7.5 cm tall. Weeds were transplanted into the row at a density of 5.3 plants m^{-1} row to simulate weed emergence that would not be affected by cultivation and hilling. Transplants were watered after planting (3.8 L row^{-1}), and experienced a rainfall event of 0.25 to 0.5 cm within 48 h of planting. Weed survival was evaluated one week after transplanting and weeds were thinned as needed to maintain plant density.

In-Season Measurements. Growth of the weeds and potatoes was measured at 14, 28, 42, and 56 d after 70% potato emergence (DAE). Heights of four weed and potato plants per plot were measured, and one weed and one potato plant were

Table 4. Insecticide and fungicide applications used in 2010 and 2011.

Product	2010			2011		
	Rate	Number[a,b]	Method	Rate	Number[c,d,e]	Method
	kg ai ha^{-1}			kg ai ha^{-1}		
Fungicide						
chlorothalonil (Bravo WeatherStik®, Syngenta Crop Protection, Inc., Greensboro, NC)	1.34	1,3,4,7	Foliar	1.34	1,2,3,4,5,6,7,8	Foliar
famoxadone + cymoxanil (Tanos®, E.I. du Pont de Nemours and Company, Wilmington, DE)	0.084 + 0.084; 0.112 + 0.112	—; 2,5	Foliar, Foliar	0.084 + 0.084; 0.112 + 0.112	5,10; 6	Foliar, Foliar
mancozeb (Manzate® Pro-Stick™, E.I. du Pont de Nemours and Company, Wilmington, DE)	1.34; 1.24; 1.17	6,9,10,11,8, 12	Foliar, Foliar, Foliar	1.34	9,10,11	Foliar
	g ai ha^{-1}			g ai ha^{-1}		
Insecticide						
imidacloprid (Admire® Pro™, Bayer CropScience LP, Research Triangle Park, NC)	257	1	In-furrow	257	1	In-furrow
spinetoram (Radiant® SC, Dow AgroSciences LLC, Indianapolis, IN)	55.8	2	Foliar	—	—	—
dimethoate (Dimethoate 4E, Arysta Lifescience North America, LLC, Cary, NC)	83.7	3	Foliar	—	—	—
abamectin (Agri-Mek® 0.15EC, Syngenta Crop Protection, Inc., Greensboro, NC)	—	—	—	12.6	2	Foliar

[a] Application numbers for fungicides in 2010 correspond to the following dates: 1, 6/17; 2, 6/24; 3, 6/30; 4, 7/9; 5, 7/14; 6, 7/21; 7, 7/30; 8, 8/6; 9, 8/13; 10, 8/21; 11, 8/27; 12, 9/5.

[b] Application numbers for insecticides in 2010 correspond to the following dates: 1, 5/17; 2, 6/30; 3, 7/9.

[c] Application numbers for fungicides in 2011 correspond to the following dates: 1, 6/18; 2, 6/25; 3, 6/30; 4, 7/8; 5, 7/14; 6, 7/20; 7, 7/30; 8, 8/6; 9, 8/12; 10, 8/19; 11, 8/26.

[d] Application numbers for insecticides in 2011 correspond to the following dates: 1, 5/20; 2, 7/20.

[e] Applications 5, 6, and 10 contained multiple active ingredients in the same spray mixture.

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destructively harvested from the third row for fresh biomass measurements. Roots were separated and washed for mycorrhizal colonization measurements. Above-ground material was oven-dried for 4 d at 60 C and weighed. Potato vine biomass was calculated by dividing biomass by the number of stems harvested. Additionally in 2011, soil moisture measurements (FieldScout TDR 300 Soil Moisture Meter, Spectrum Technologies, Inc., Plainfield, IL) to 12 cm depth and soil samples (15 cm depth, six per plot) were taken biweekly from the weed-free plots to monitor volumetric water content and inorganic N content. End-of-season measurements of above-ground material occurred at 94 DAE in 2010 and at 91 DAE in 2011. Soil samples were collected to 15 cm depth and analyzed for pH, N, P, K, Ca, Mg, S, and micronutrients. To desiccate remaining weeds after potato senescence, glufosinate at 0.37 kg ai ha^{-1} (Rely 200®, Bayer CropScience LP, Research Triangle Park, NC) was applied using the 16-nozzle compressed air sprayer (190 L ha^{-1}, 240 kPa, TeeJet® XR8003 nozzles) 50 cm above the potato canopy in 2010 and plots were mowed to 15 cm height in 2011.

Weed Seed Production. Weeds were harvested at the end-of-season (Sept. 10, 2010 or Sept. 7, 2011), oven-dried at 60 C for 7 d, and seeds mechanically separated from the plants. A 40-ml subsample of hairy nightshade berries from one plant per plot was separated into diameter classes (DC) and counted, and mature seeds were counted from 10 berries and averaged to obtain number of mature seeds per berry (*spb*) in each DC. In each DC, the berries were weighed to calculate the number of berries per gram (*bpg*), and the weight of each DC in the subsample was divided by the total subsample weight to obtain a percentage. The entire sample from each plant was weighed, multiplied by the DC percentages of the subsample, and the weight of each DC in the total sample was multiplied by *bpg* and *spb* to calculate mature seed production per DC. All seed values from each DC were added together to obtain total mature seeds per plant. Mature seed per plant was divided by the above-ground dry biomass to calculate mature seed production per gram dry biomass.

Common lambsquarters and giant foxtail seeds were sieved and passed through an air-column separator to remove excess chaff and immature seeds. A 0.5-g subsample of common lambsquarters and giant foxtail seed from each plot was counted and weighed; total sample weight was multiplied by seeds per gram to calculate mature seed production per plant, and divided by dry above-ground biomass to calculate mature seed per gram dry biomass.

Potato Tuber Yield and Quality Evaluation. Potatoes were mechanically harvested on Sept. 30, 2010 and Sept. 28, 2011. Tubers were graded by diameter into undersized tubers ($<$ 4.75 cm), marketable tubers (4.75 to 8.25 cm), and oversized tubers ($>$ 8.25 cm); tubers with growth aberrations or cracks were classed as cull tubers. Potatoes in each class were collectively weighed and counted. Marketable and oversized tubers were evaluated for internal defects of vascular discoloration, bacterial canker, and hollow heart. Common scab (*Streptomyces scabies*) severity was not rated because most tubers exhibited similar scab levels. Specific gravity of marketable tubers was measured using the weight in water-weight in air method (Westermann et al. 1994).

Mycorrhizal Analysis. Roots from the plants at 14, 28, 42, 56 DAE, and end-of-season harvest were washed, cut into 1-cm segments, and preserved in 50% ethanol (Grace and Stribley 1991). Roots were cleared in 10% potassium hydroxide and stained with aniline blue following the procedure described by Grace and Stribley (1991). Five root segments of a root sample were wet mounted onto a microscope slide, and two slides were prepared per root sample. Slides were scanned under 200x magnification using a transmitting light microscope and hyphae, arbuscules, and vesicles were counted using the magnified colonization intersections method (McGonigle et al. 1990) to estimate root colonization by arbuscular mycorrhizae.

Statistical Analysis. Data were analyzed using analysis of variance with the MIXED procedure in SAS 9.2 (SAS Institute, Inc., Cary, NC). Year, compost rate, weed species, and their interactions were treated as fixed factors, with replication as a random factor. Normality of the residuals was evaluated by visual examination of normal probability and stem-and-leaf plots. Homogeneity of the variances was evaluated by residual plots, box plots, and Levene's test ($\alpha = 0.1$) and grouped to reduce the AIC value of the model using the GROUP option of the REPEATED statement. When the year by factor interaction was not significant, data were combined across years. When the interaction between compost rate and weed species was found to be significant, comparisons between the combinations at each compost application rate and weed species level were examined by slicing and conducting individual pair-wise comparisons using *t* tests ($\alpha = 0.05$). When factors were found to be significant ($P \leq 0.1$), all-pairwise comparisons were conducted using Fisher's protected LSD.

Results and Discussion

The compost rates used in this study were 4,000 and 8,000 kg C ha^{-1}, equivalent to a total compost application of 26 and 52 wet t ha^{-1}, respectively. These application rates are 10 to 15 times greater than what an average producer would usually utilize in a single season (Otto, personal communication), but were used in this research to emphasize differences in weed growth and competition due to compost application. Compost applied at lower rates (5 or 10 t ha^{-1}) for one year did not raise the soil N, P, K above the nonamended control (Ouedraogo et al. 2001). In contrast, compost applied annually at 3,000 kg C ha^{-1} for three years increased microarthropod abundance, microbial activity, and mineralizable N compared to the non-amended, but did not adversely affect barley crop (*Hordeum vulgare* L.) production (Petersen et al. 2003). Because compost rates at rates below 10 t ha^{-1} may not affect soil properties in a detectable manner in the first year after application, the elevated compost rates were examined in this study.

Effect of Compost on Weeds. Weed height (data not presented) and fresh above-ground biomass (Figure 1) were not affected by compost application 14, 28, 42, or 56 DAE (P

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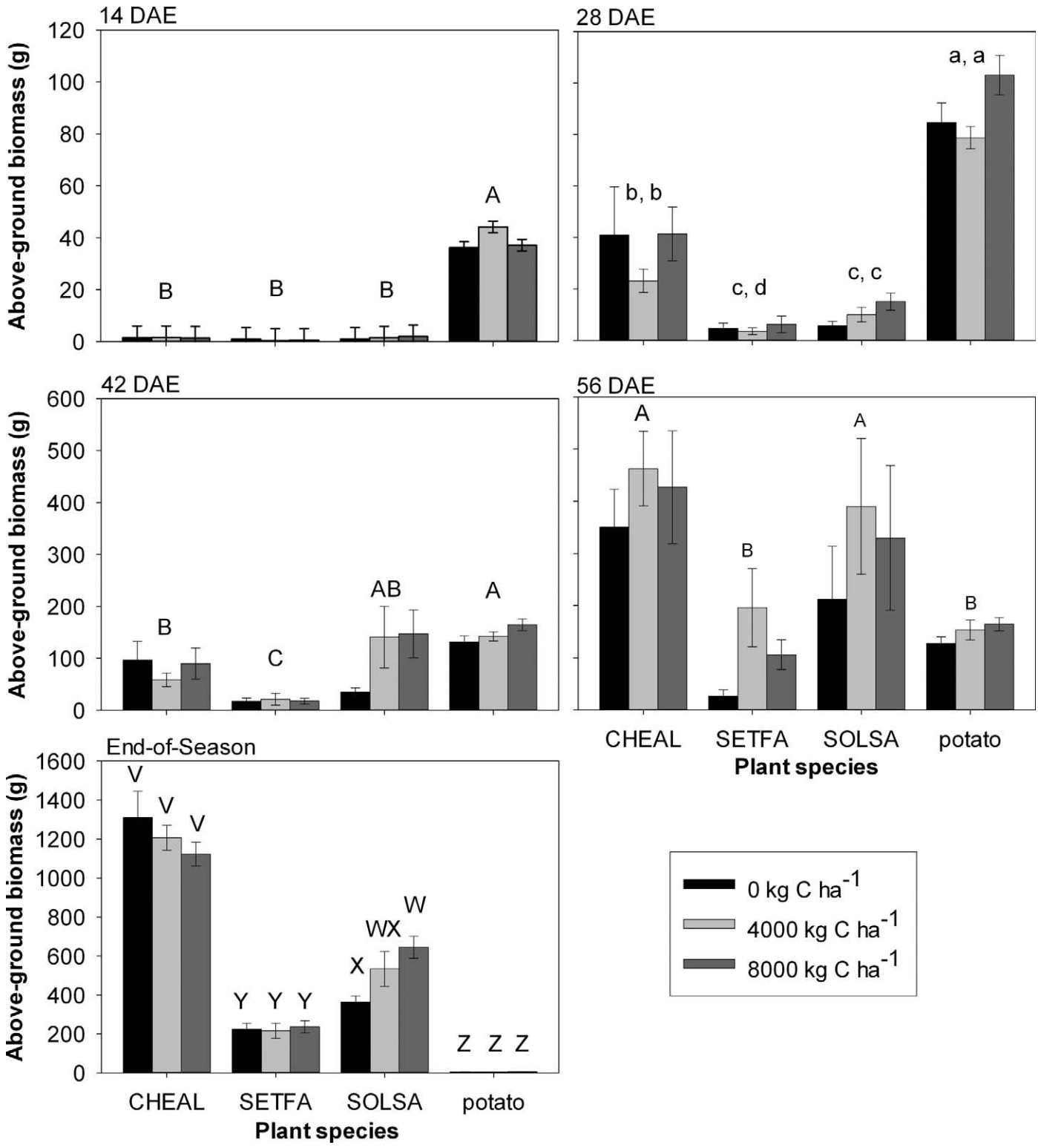


Figure 1. Weed and potato fresh above-ground biomass accumulation at 14, 28, 42, 56 d after potato emergence (DAE) and at the end-of season at each compost rate averaged across years. Biomass is expressed in grams per plant for the three weeds, and grams per stem for potato. Letters of a to d denote differences between the species of common lambsquarters (CHEAL), giant foxtail (SETFA), hairy nightshade (SOLSA), and potato. Letters of v to z denote a significant species by compost rate interaction. Uppercase letters denote differences with analysis combined across years, while lowercase letters denote differences within 2010 or 2011, respectively. There was a year by species interaction 28 DAE because giant foxtail accumulated less biomass in 2011 compared with 2010. Bars on columns are one standard error of the mean.

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Table 5. Weed seed production as influenced by cured dairy manure compost application.[a]

	Mature seeds plant^{-1}				Mature seeds g^{-1} dry biomass			
	Compost rate				Compost rate			
Species	0	4,000	8,000	LSD[b] (0.05)	0	4,000	8,000	LSD (0.05)
	kg C ha^{-1}				kg C ha^{-1}			
CHEAL	111,482	88,788	89,647	ns	247	226	258	ns
SETFA	6,159	6,367	6,100	ns	74	78	63	ns
SOLSA	10,284	13,951	11,696	ns	153	135	118	ns

[a] Abbreviations: C, carbon; LSD, least significant difference; CHEAL, common lambsquarters; SETFA, giant foxtail; SOLSA, hairy nightshade.

[b] Means within a row greater than the LSD value are different from each other, and ns means differences were not significant.

$\leq$ 0.1). Across compost application rates, common lambsquarters produced the greatest above-ground biomass, followed by hairy nightshade, and lastly giant foxtail. Gallandt et al. (1998) observed no effect of spring applied beef cattle manure (45 t ha^{-1}) and cull tuber compost (22 t ha^{-1}) on biomass accumulation of common lambsquarters in the first year, and 8 t C ha^{-1} swine manure compost had no effect on giant foxtail and velvetleaf biomass in soybean (Liebman et al. 2004). Compost rate increased fresh above-ground biomass only within hairy nightshade at the end-of-season timing (Figure 1). Year was significant at the 28 DAE timing because giant foxtail accumulated less biomass in 2011 compared with 2010.

Mycorrhizal colonization was < 3% in potato and the weed species (data not presented). High soil phosphorus (P) levels (> 200 mg kg^{-1} soil) may have limited colonization, as a response to mycorrhizae is unlikely at P levels above 50 to 140 mg kg^{-1} (Amijee et al. 1989; Thingstrup et al. 1998). Furthermore, percent colonization may not accurately predict mycorrhizal effects (Brundrett et al. 1996), and multiple tillage events, such as those utilized in potato production, that destroy mycorrhizal hyphal networks can limit the benefits from potential colonization (Miller 2000; Ryan and Graham 2002).

Compost did not influence weed seed production as measured by seed per plant or seed produced per gram of dry biomass (Table 5). Common lambsquarters produced the most seed per plant, and giant foxtail produced the least seed per plant, averaged across compost treatments. In previous research, dairy manure compost increased redroot pigweed seed production (Amisi and Doohan 2010), but swine manure compost did not increase giant foxtail seed fecundity (Liebman et al. 2004).

Effect of Weeds on Potatoes. Weed competition did not influence potato height, but fresh vine biomass accumulation was typically greater in the weed-free compared to the weedy treatments ($P \leq 0.1$) at 14, 28, and 42 DAE (Figure 2). Weed interference did not affect internal defects, oversized tuber production, cull tuber production (data not presented) or the specific gravity of marketable tubers (Table 6). Marketable tuber yield, marketable number, and total yield were greatest under weed-free conditions (Table 6). Differences in early season biomass may have contributed to tuber yield by allowing more photosynthate production during the early tuber bulking phase or resulting in a longer bulking phase, as the duration of bulking is critical to tuber biomass accumulation (Miller and Hopkins 2008). After the early bulking phase (42 DAE), weed biomass exceeded that of potato and the weeds began to shade the potatoes (Figure 1). The growth of the weeds during the tuber bulking phase may have increased competition for light, and led to a reduction in potato yield. Five giant foxtail plants per m of row reduced marketable tuber yield, marketable number, and total yield by 17, 12, and 13%, respectively. Vangessel and Renner (1990b) observed a 40% decrease in marketable yield of Atlantic potatoes from four barnyardgrass plants m^{-1} planted within

Table 6. Potato tuber yield and specific gravity as influenced by weeds or by compost rate.[a,b]

		Tuber yield			Tuber number		
	SG	Marketable	Undersize	Total	Marketable	Undersize	Total
Competition		t ha^{-1}			x10^3 tubers ha^{-1}		
CHEAL	1.076	14.6c	4.7	19.3c	149c	111b	260b
SETFA	1.076	23.5b	5.5	29.1b	231b	129a	360a
SOLSA	1.075	22.1b	5.7	28.0b	217b	133a	351a
weed-free	1.075	28.4a	5.1	33.6a	262a	119ab	381a
Compost rate							
0 kg C ha^{-1}	1.077A	20.7B	5.3	26.0B	205	124	329
4,000 kg C ha^{-1}	1.075B	22.1AB	5.2	27.3AB	214	121	335
8,000 kg C ha^{-1}	1.074B	23.6A	5.3	29.1A	226	124	350

[a] Abbreviations: SG, specific gravity; CHEAL, common lambsquarters; SETFA, giant foxtail; SOLSA, hairy nightshade; C, carbon.

[b] Lowercase letters denote significance within a column between weed species, and uppercase letters denote significance within a column between compost rates.

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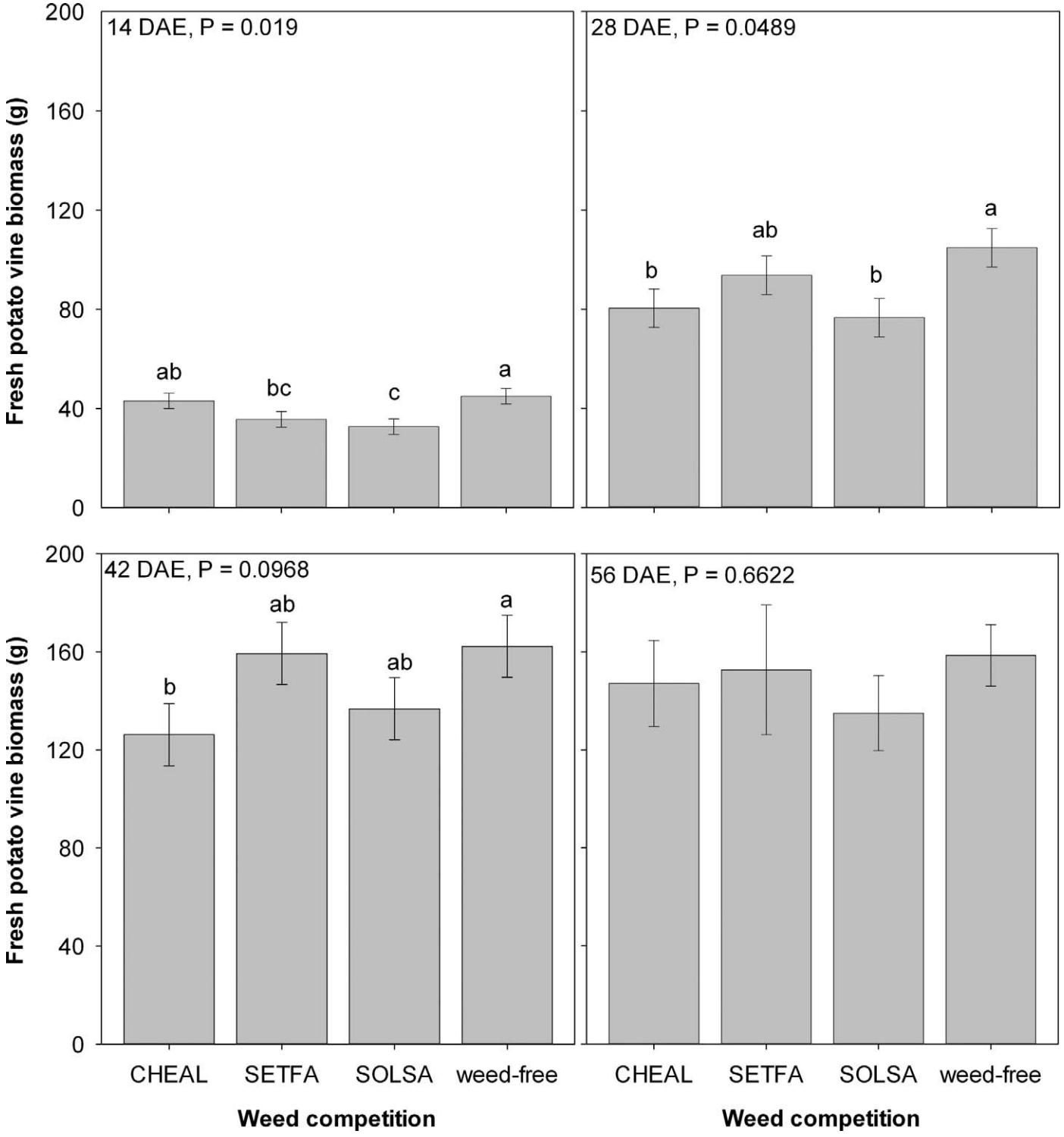


Figure 2. Fresh potato vine biomass per stem as affected by common lambsquarters (CHEAL), giant foxtail (SETFA), or hairy nightshade (SOLSA) competition at 14, 28, 42, and 56 days after potato emergence (DAE). Letters denote differences between species. Bars on columns are one standard error of the mean. P-value is the species effect on potato vine biomass.

the row. Grassy weeds, mainly green foxtail (*Setaria viridis* L.) and yellow foxtail [*Setaria pumila* (Poir.) Roem. & Schult.] at 77 plants m^{-2}, reduced tuber yield by 25% after season-long competition (Nelson and Thoreson 1981).

Five hairy nightshade plants per m of row reduced marketable tuber yield, marketable number, and total yield by 22, 17, and 17%, respectively (Table 6). Hutchinson et al. (2011) observed three hairy nightshade plants m^{-1} decreased

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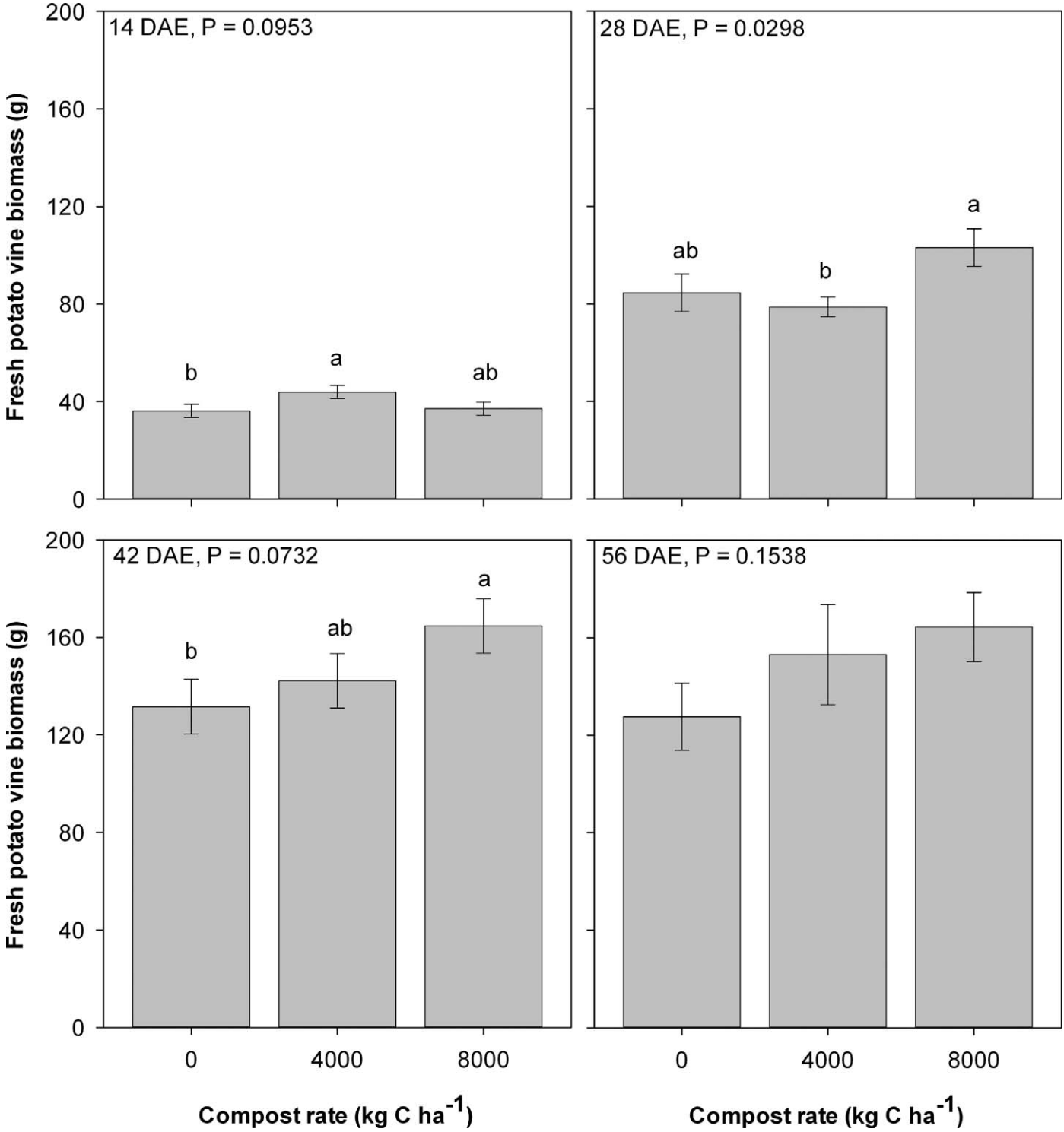


Figure 3. Fresh potato vine biomass per stem as affected by compost application at 14, 28, 42, and 56 days after potato emergence (DAE). Letters denote differences between compost rates. Bars on columns are one standard error of the mean. P-value is the compost rate effect on potato vine biomass.

marketable and total yield of Russet Burbank by 11 and 9%, respectively, while marketable and total yield of Russet Norkotah was reduced by 27 and 25%, respectively. Giant foxtail and hairy nightshade did not significantly reduce total tuber number (< 10%), which indicates the yield reduction was primarily due to reduced tuber bulking. Competition at the time of tuber initiation may not have been great enough to limit tuber set, but competition during tuber bulking may have reduced tuber size.

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Five common lambsquarters plants per m of row reduced marketable tuber yield, marketable number, total yield, and total tuber number by 49, 43, 42, and 31%, respectively (Table 6). The reduction in yield and size indicates tuber initiation of potatoes decreased when growing in competition with common lambsquarters. Potatoes grown with giant foxtail and hairy nightshade experienced a decrease in marketable tubers and an increase in undersized tubers compared to the weed-free potatoes, which resulted in a similar number of total tubers produced. Nelson and Thoreson (1981) also observed yield reductions and similar tuber number when potatoes were grown in competition with weeds. This may indicate a similar number of tubers were initiated, but tuber bulking was less when potatoes were competing with weeds, which is supported by the undersized tuber number (Table 6). Giant foxtail and hairy nightshade competition resulted in undersized tuber number similar to the weed-free plots. Competition with common lambsquarters reduced tuber initiation and bulking; 42% of tubers were undersized in the common lambsquarters plots, averaged over compost treatments. However, potatoes under common lambsquarters competition produced a similar number of undersized tubers to the weed-free plots.

Effect of Compost on Potatoes. Compost did not affect height but influenced fresh vine biomass accumulation ($P \leq 0.1$) at 14, 28, and 42 DAE (Figure 3). Potatoes grown under 8,000 kg C ha^{-1} compost produced the greatest or equivalent to the greatest fresh vine biomass. Potato vine biomass accumulation was negligible by 56 DAE, which coincided with tuber bulking (Figure 1).

Compost did not affect oversized tuber production, cull tuber production, or incidence of hollow heart, vascular discoloration, and bacterial canker (data not presented). Marketable and total yield was lowest when no compost was applied (Table 6), and adding 8000 kg C ha^{-1} increased marketable and total yield over the nonamended by 14 and 12%, respectively. Differences in early season biomass may have increased photosynthate production during the tuber bulking phase, resulting in a yield increase (Miller and Hopkins 2008). During this stage, tubers become the prominent sink for photosynthate, and vine growth slows drastically. Potato fresh vine biomass was very low at the end of the season because the crop had achieved physiological maturity and the vines senesced.

The number of marketable and total tubers did not increase with compost application, indicating the yield difference observed was due to larger tubers being produced in the composted treatments. Specific gravity of marketable tubers decreased where compost was added (Table 6), but was still at an acceptable marketing level for Michigan processors. No differences in soil volumetric water content were observed in the compost vs. noncompost amended treatments ($P > 0.1$) in 2011, suggesting that increased water availability in the composted treatments was not the reason for increased potato yield.

Soil nutrient availability was measured both years in the weed-free compost and noncompost treatments. Soil pH increased because of compost application, and macronutrient availability was still greatest in the pH range of 6.3 to 7.6. Common scab incidence increases at pH above 5.2, and may explain common scab levels observed in the tubers (Pavlista 2008). Sharma and Arora (1987) observed N and K application increased the number and yield of medium and large tubers, but P application increased the yield of small and medium tubers while decreasing larger tuber yield. Because N was balanced across compost treatments we would not expect to see differences in inorganic N by the addition of compost. In 2011 we confirmed that there was no difference in soil inorganic N throughout the growing season due to compost. Potassium application has been shown to increase large and medium tuber yield and decreases small tuber yield (Grewal and Trehan 1993; Kanzikwera et al. 2001; Sharma and Arora 1987; Tawfik 2001). Specific gravity decreased in composted treatments (Table 6), and previous research has shown that excess K will reduce specific gravity by increasing tuber water content (Laboski and Kelling 2007; McDole et al. 1978; Stark and Westermann 2008; Westermann et al. 1994). Sulfur levels in this study were > 15 mg kg^{-1} and should have been sufficient for potato production (Hopkins et al. 2003). Deficiency of Ca can cause internal defects like brown spot (Guenthner and Schotzko 2008), but no differences in internal defects were observed. Soil Ca levels were considered sufficient, soil Mg levels were also above 100 mg kg^{-1}, and micronutrient levels were above levels necessary for adequate supply (Hopkins et al. 2003).

In summary, compost application in irrigated potatoes receiving supplemental N fertilizer did not increase the competitive ability or seed production of summer annual weeds in the first year after application. This suggests potato growers may be able to apply a large amount cured composted dairy manure to production fields in a single application without increasing the competitive ability of summer annual weeds, but lower rates applied annually may have a different effect on the competitive relationship. Common lambsquarters, giant foxtail, and hairy nightshade at five weeds per m of row across compost rates reduced marketable yield by 49, 17, and 22%, respectively, and must be controlled early in the season to minimize yield loss. Snowden potatoes may benefit from compost amendments because of increased K availability and the potential to increase tuber yield, but also risk decreasing specific gravity to an unacceptable level for processing.

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