First Field Evaluation of a Polylactic Acid-based Weed Barrier with Compost for Carrot Production

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ABSTRACT. Hand weeding is a common but expensive weed management practice in organic carrot (*Daucus carota*) production. To improve weed suppression and reduce hand weeding in these systems, we developed and tested different biobased polylactic acid (PLA) mulch and compost combinations for carrot production. Carrot was direct-seeded onto PLA mulches and top-dressed with a layer of compost to facilitate carrot germination and rooting through the semipermeable mulch surface. This PLA mulch reduced total weed emergence by 90% relative to bare soil. Yields were not significantly different among mulch types and bare soil controls, partly because weeds were removed weekly after counting. The PLA mulch reduced plant available soil nitrate by 47% relative to bare soil controls. The results suggest that PLA mulch paired with compost is an effective alternative to hand weeding in carrot production. Future research should seek to address the observed nitrogen immobilization.

Weeds compete for resources such as light, moisture, and nutrients, and cropping systems with a higher weed density typically have lower yields (Knezevic et al. 1994; Swinton et al. 1994). Some specialty crops are especially prone to yield reduction when subject to increased weed pressure. Carrot (*Daucus carota*), for example, tends to emerge slowly, and the critical period of weed control is ∼3 to 6 weeks after crop emergence, depending on the location and planting date (Swanton et al. 2010; Van Heemst 1985). The slow growth habit of carrot makes selective intrarow weed management difficult, particularly in organic carrot production, where conventional postemergent herbicides are prohibited (Bell et al. 2000). Intrarow mechanical weed control is generally not selective, but techniques like brush weeding have been shown to reduce weed pressure by 20% to 80%, depending on the growth stage (Fogelberg 1999). Mechanical options for intrarow weed management are typically less effective than herbicides, may damage the crop, and can be inconsistent under field conditions (Fogelberg 1999; Fogelberg and Kritz 1999).

Preventative weed control measures can help reduce weed densities in carrot before planting. Stale and false seedbed techniques require delayed crop planting to kill an initial wave of weed growth while minimally disturbing the bed top to prevent additional weed germination. One study found the combination of stale seedbedding and flaming was effective for decreasing weed densities (Caldwell and Mohler 2001). Soil solarization is another preventative tactic that uses a polyethylene tarp to trap solar energy, thus creating fatal conditions for soilborne pathogens, weed seeds, and weed seedlings. Although soil solarization can be successful in warmer regions, the effectiveness of the method varies depending on the climate and maximum temperature potential (Birthisel and Gallandt 2019; Frillman 2019). Notably, intrarow weeds are not fully controlled by these preventative tactics, and supplemental in-season hand weeding is often still required.

Agricultural mulches are popular physical weed control options in specialty crop production that provide intrarow weed suppression (Melander et al. 2005; Tofanelli and Wortman 2020). The potential benefits of agricultural mulches include soil warming, moisture conservation, and weed suppression that often contribute to increased crop yield (Kasirajan and Ngouajio 2012; Tofanelli and Wortman 2020). Polyethylene mulch film is considered the most common and affordable mulch; however, it can be a significant contributor to environmental pollution (Parida et al. 2023; Serrano-Ruiz et al. 2021). In contrast, biodegradable agricultural mulches are made of materials that can be readily decomposed by microbes in soil or compost (Madrid et al. 2022). However, the increased price and variability in weed suppression among biodegradable mulch products can be obstacles to grower adoption (Parida et al. 2023; Tofanelli and Wortman 2020).

Despite the variety of intrarow weed control available to growers, the majority are not effective or compatible for use in organic crops, especially crops that are grown at high population densities like carrot. The nonselective nature of most intrarow mechanical control methods restricts their use to the preemergence stage in densely planted crops (Fennimore and Doohan 2008). Weed-suppressive benefits of a typical agricultural mulch would be negligible for crops grown at high-density populations given the number of individual plants and planting holes required in the mulch (Miles et al. 2012; Tofanelli et al. 2021). As a result, many growers still rely on hand weeding as a primary form of weed control, especially in small-scale and organic agriculture, for which most herbicides are restricted. Although hand weeding is highly selective, it is difficult to source, labor-intensive, and among the most expensive forms of weed control (Baker and Mohler 2015; Fennimore and Doohan 2008; Sosnoskie and Culpepper 2014). Organic sweet corn (*Zea mays*) and eggplant (*Solanum melongena*) production in the United States has been found to require between 515 and 1162 person-hours of hand weeding

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per hectare (Chen et al. 2017). For crops planted at high-density populations like carrot, the costs of hand weeding can range between \$2208 and \$4830/ha (Bell et al. 2000).

Tofanelli et al. (2021) first demonstrated the potential for crop roots to penetrate and grow through a semipermeable polylactic acid (PLA) mulch barrier in greenhouse experiments during which carrot and lettuce (*Lactuca sativa*) seeds were planted directly onto the mulch surface with a soilless medium to facilitate seedling establishment and root penetration through the PLA mulch (Tofanelli et al. 2021). In doing so, the need for traditional planting holes is eliminated and the weed-suppressive capacity of the mulch is retained for crops grown at high-density populations. Although it is possible for a weed seed to land on and grow through the mulch (in the same way that a crop seed can), this is uncommon when used with annual crops because most nearby weedy plants will produce seed after the critical weed-free periods of the crop. Total yields were similar to or greater than those of no mulch controls for lettuce and carrot crops tested in the greenhouse study, suggesting that root growth through the mulch membrane did not negatively affect crop physiological development (Tofanelli et al. 2021). Although Tofanelli et al. (2021) demonstrated the potential for this technology in carrot and lettuce plantings, the agronomic performance and weed-suppressive capacity of this system have not yet been tested under field conditions.

The goal of this study was to adapt the biobased mulch production method demonstrated by Tofanelli et al. (2021) to be used in the field as an alternative to bare soil production of a densely planted carrot crop. The objective of this study was to measure the effects of different PLA mulch and compost combinations on weed suppression, soil nutrient availability, crop establishment, and yield in a carrot production system in which seeds are planted directly on the mulch surface.

Methods

Experimental location and design. We conducted a field experiment at the University of Nebraska–Lincoln East Campus Research Farm (University of Nebraska–Lincoln, Lincoln, NE, USA) (lat. 40°50′12″N, long. 96°39′48″W) in 2021. Soil type at the field location was Zook silty clay loam (Reid et al. 2022). Pigweed (*Amaranthus* sp.) and crabgrass (*Digitaria sanguinalis*) were the dominant broadleaf and grass weed species in the field. The experimental design was a randomized complete block design consisting of four blocks. Experimental plots measuring 15 ft (bed length) × 4 ft (bed width) were separated by an in-row gap of 3-ft and arranged lengthwise from east to west within blocks. Each block was one bed-row, and rows were spaced 12 ft apart, center to center.

The experimental treatments consisted of different biobased mulch types and compost topdressing combinations that were compared with bare soil controls (Table 1). Compost types used were locally sourced and manufactured from either yard waste or a mix of food waste, yard waste, and animal manure (Table 1). The biobased mulch types tested included 80 $g \cdot m^{-2}$ or 120 $g \cdot m^{-2}$ PLA biofabric mulches consisting of a black meltblown PLA layer (50 or 90 $g \cdot m^{-2}$, depending on treatment) and a white spunbond PLA layer (30 $g \cdot m^{-2}$) (3M Co., Saint Paul, MN, USA) (Table 1). Mulch-only controls were not included because preliminary trials demonstrated that consistent seedling establishment was not possible in the absence of a compost topdressing that holds moisture and prevents seed losses to wind, rain, or predation (unpublished data).

Production system management. Field conditions were in a weedy fallow state and rototilled before bed formation. Organic soybean meal fertilizer was applied at a rate of 75 lb/acre nitrogen (N) before shaping beds (RB-448; Nolt's Produce Supplies, Leola, PA, USA). The PLA mulches were laid onto experimental plots, followed by a topdressing of compost (Fig. 1A and B). Compost topdressings were applied using a compost dropper to a thickness of ∼0.5 inch (BCS Spreader; BCS America, Oregon City, OR, USA). On 24 May, 'Napoli' carrot seed (Johnny's Selected Seeds, Waterville, ME, USA) was planted onto bed tops in six rows spaced 5 inches apart such that bed tops received ∼48 seeds per linear foot using a three-row push seeder (Jang JP-3; Jang Automation Co., Seoul, South Korea) (Fig. 1C). Three lines of drip irrigation tape (0.55 gal/min/100 ft of drip tape; Irritec, Fresno, CA, USA) were installed on the bed tops, and the plots were irrigated for 2 h of every 6 h during the first 5 weeks to ensure successful crop establishment (Fig. 1D). Thereafter, irrigation was reduced to 3 h/day (or less, depending on precipitation). Season-long weed management between beds included a combination of rototillage, flail mowing, and line trimming.

Data collection. Carrot stand counts were measured 2 weeks after planting by counting the number of carrot plants that had emerged within a random selection of one of the six established rows. Broadleaf and grass weed densities were recorded on a weekly basis using a 1 × 1 ft^2 quadrat placed at two random locations within each plot to assess weekly weed emergence. Immediately after the weed density counts, all weeds were pulled from the entire plot to mitigate weed-induced yield loss and ensure an accurate estimation of weed emergence the following week. Weed densities were measured for 5 weeks after carrot planting until the crop canopy closed.

Carrots were harvested from experimental plots on 5 Aug using a broadfork, and individual carrots were processed by removing the foliage. Residual soil and PLA mulch fragments were also removed from carrot roots at the time of processing before collecting yield measurements. After processing the carrots, the total fresh weight yield per plot was recorded. From the harvest, 25 carrots per plot from two separate blocks were randomly sampled to assess carrot quality by recording the individual carrot root diameter and length.

Pairs of cation and anion resin probes [Plant Root Simulator (PRS) Probes; Western Ag Innovations, Saskatoon, SK, Canada] were used to measure changes in total plant available soil nitrate-nitrogen (NO_3-N), potassium (K), and phosphorus (P) concentrations over time. After the carrots were planted, three pairs of probes were buried in experimental plots ∼7 ft apart from the next pair. Small slits were made in PLA mulches to facilitate probe burial and retrieval. After a 2-week soil incubation period, probe pairs were removed from each plot and replaced with new pairs to prevent ion saturation. Immediately after collection, probe pairs were rinsed

Table 1. **Polylactic acid (PLA) mulch and compost treatment combinations used for carrot production.**

Treatment[i]	Mulch[ii]	Compost type[iii]
B	None	None
MB	None	Mixed feedstock
YB	None	Yard waste feedstock
M8	$80\text{-g}\cdot\text{m}^{-2}$ PLA	Mixed feedstock
Y8	$80\text{-g}\cdot\text{m}^{-2}$ PLA	Yard waste feedstock
M12	$120\text{-g}\cdot\text{m}^{-2}$ PLA	Mixed feedstock
Y12	$120\text{-g}\cdot\text{m}^{-2}$ PLA	Yard waste feedstock

[i] Treatments: B = bare soil control, no compost, no mulch; MB = mixed feedstock compost, no mulch; YB = yard waste feedstock compost, no mulch; M8 = mixed feedstock compost, $80\text{-g}\cdot\text{m}^{-2}$ PLA mulch; Y8 = yard waste feedstock compost, $80\text{-g}\cdot\text{m}^{-2}$ PLA mulch; M12 = mixed feedstock compost, $120\text{-g}\cdot\text{m}^{-2}$ PLA mulch; Y12 = yard waste feedstock compost, $120\text{-g}\cdot\text{m}^{-2}$ PLA mulch.

[ii] $1\ \text{g}\cdot\text{m}^{-2} = 0.0033\ \text{oz/ft}^2$.

[iii] Mixed feedstock compost contains food wastes, yard wastes, and animal manure materials.

with deionized water and stored at 4.4 °C. This procedure was repeated every 2 weeks for 6 weeks. After week 6, samples were shipped to the laboratory (Western Ag Innovations) for soil NO_3, K, and P extraction and analysis.

Soil temperature data were logged every 4 h using a waterproof temperature sensor and data logger (HOBO 64K pendant; Onset, Bourne, MA, USA) buried to a depth of 2 inches near the center of each plot. The volumetric water content to a depth of 3 inches was measured weekly after the carrots were planted using a soil moisture meter (FieldScout TDR 300; Spectrum Technologies Inc., Aurora, IL, USA) by taking the average of three readings per plot.

Statistical analysis. Data were analyzed using an analysis of variance in the GLIMMIX procedure (SAS 9.4; SAS Institute Inc., Cary, NC, USA). The model included the block as a random effect, and compost, mulch, and their interaction as fixed effects. Time and all possible interactions with it were included as additional fixed effects in the model that evaluated changes in nutrient concentrations. Tukey's honestly significant difference test or the Šídák test (comparisons involving time) were used for multiple comparisons and orthogonal contrasts of mean effects at a significance level of $\alpha = 0.05$.

Results

Weed suppression. The PLA mulches topped with compost reduced broadleaf weed emergence by 90% and 96% compared with compost-only and bare soil controls, respectively ($P < 0.001$) (Fig. 2). Similarly, PLA mulches topped with compost reduced grass weed emergence by 91% and 95% compared with compost-only and bare soil controls, respectively ($P = 0.034$) (Fig. 2). There were no differences in weed suppression between PLA mulch thicknesses (Fig. 2). Broadleaf weed emergence was also reduced in compost-only controls by 57% compared with bare soil controls ($P = 0.022$) (Table 2); however, grass weed emergence was unaffected by compost ($P = 0.183$) (Table 2).

Soil parameters. Season-long volumetric soil moisture was affected by mulch presence regardless of the compost type ($P = 0.020$). Soil moisture was greater in 80 g/m^2 PLA (16.7% ± 0.9%; mean ± 1 *SE*) compared with compost-only controls (14.9% ± 0.9%), but it was not different from that of bare soil controls (15.9% ± 1.3%). Season-long soil temperature was not different among the compost or mulch types tested ($P > 0.05$; data not shown).

Soil NO_3 availability, as measured with PRS probes, was influenced by mulch presence ($P < 0.001$) (Fig. 3). Plots containing PLA mulch reduced soil NO_3 availability by 88% compared with control treatments without mulch (Fig. 3). However, soil NO_3 availability did not differ between PLA mulch types or between compost types (Fig. 3).

The interacting effects of mulch and compost influenced soil K availability as measured by PRS probes ($P = 0.030$) (Fig. 4). Yard waste compost increased K availability in soil, even in the presence of the thicker PLA mulch (Fig. 4). When averaged across PRS probe incubations, soil K availability was 25% greater in yard waste compost compared with the mixed feedstock compost. There were no differences in soil P availability among treatments ($P > 0.05$; data not shown).

Carrot establishment, yield, and quality. Carrot stand establishment was influenced by mulch presence ($P < 0.001$) (Fig. 5). Plots containing

Fig. 1. Establishment of the biobased mulch production system for carrot. (A) Polylactic acid (PLA) mulches are first laid over raised bed tops and the edges of the mulches are buried. (B) A compost dropper then deposits a 0.5-inch (1.27 cm) layer of compost on top of the raised bed surfaces. (C) After the compost application, six rows of carrot seed are planted with 5-inch spacing between rows. (D) Three lines of drip tape [0.55/gal/min/100 ft of drip tape ($6.831\ \text{L}\cdot\text{min}^{-1}$ per 100 m)] are laid onto bed surfaces after carrot planting. (E) Carrot seed germinates and roots penetrate the PLA mulch surface under the protection of the compost to establish a dense crop stand. (F) Carrots are harvested from plots using a broadfork and are washed to remove any residual soil or PLA mulch.

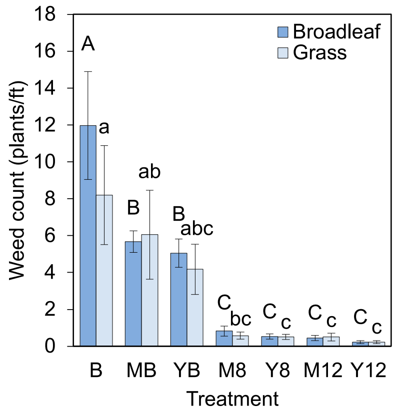

Fig. 2. Effects of polylactic acid (PLA) mulch and compost type on the average broadleaf and grass weed density across weekly weeding events. Weed density counts were collected until the carrot canopy closed. Error bars represent ± 1 *SE* of treatment means. Different letters above bars indicate significant differences at α < 0.05. Treatments were as follows: B = bare soil control, no compost, no mulch; MB = mixed feedstock compost, no mulch; YB = yard waste feedstock compost, no mulch; M8 = mixed feedstock compost, 80-g·m^{-2} PLA mulch; Y8 = yard waste feedstock compost, 80-g·m^{-2} PLA mulch; M12 = mixed feedstock compost, 120-g·m^{-2} PLA mulch; Y12 = yard waste feedstock compost, 120-g·m^{-2} PLA mulch. 1 weed/ft^2 = 10.7639 weeds/m^2. 1 g·m^{-2} = 0.0033 oz/ft^2.

PLA mulches, regardless of type, had 88% greater carrot stand density than compost-only and bare soil controls (Fig. 5). Mean total carrot yield across all treatments, including the bare soil control, was 22.9 lb/plot (~16,629 lb/acre assuming row spacing of 4 ft). There were no differences in carrot yield among compost types or mulch types (Fig. 6). Similarly, neither carrot diameter nor length were different among mulch or compost types (P > 0.05) (Table 3).

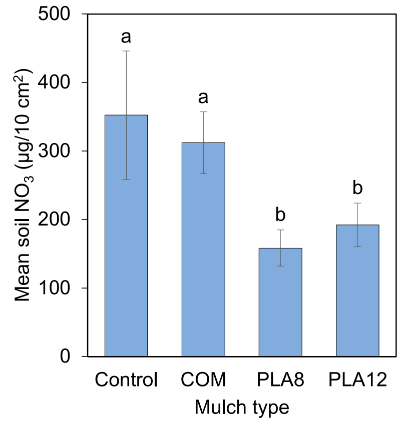

Fig. 3. Effect of polylactic acid (PLA) mulch type on mean soil nitrate (NO_3) availability during the 6 weeks following planting. Error bars represent ± 1 *SE* of treatment means. Different letters above bars indicate significant differences at α < 0.05. Treatments were as follows: control = no compost, bare ground controls; COM = bare ground treatments with a compost topdressing; PLA8 = 80-g·m^{-2} PLA mulch treatments containing a compost topdressing; PLA12 = 120-g·m^{-2} PLA mulch treatments containing a compost topdressing. 1 µg/10 cm^2 (1.6 in^2) = 0.1417 oz/acre. 1 g·m^{-2} = 0.0033 oz/ft^2.

Discussion

Our results suggest that PLA biofabric mulch combined with compost topdressings can successfully be used for direct-seeded carrot production and provide measurable weed suppression without compromising yield potential. Weed density reduction was greater than 90%, which is an important threshold because a 90% reduction in weed biomass has been defined as a commercially acceptable level of weed control for the determination of critical weed control periods (Swanton et al. 2010). Weed density and biomass are typically positively correlated to an upper density limit (Wilson et al. 1995). Given the weekly removal of weeds between weed counts, weed competition was nearly nonexistent across treatments, and no yield differences were detected between mulch treatments and controls (Fig. 6). Although it is unlikely that organic growers will remove weeds weekly for up to 5 weeks as we did for this study, this was necessary for our evaluation of yield effects from the mulch itself or changes in soil nutrient availability (which would not have been possible if weeds were left to grow in the plots without PLA mulch). We also observed that PLA mulches reduced soil NO_3 availability compared with bare soil plots, which could potentially limit yields if soils are not supplemented with additional N fertilizer (Fig. 3).

In a similar study, weed biomass was reduced in carrot plantings containing hydromulch and compost blankets compared with no mulch control

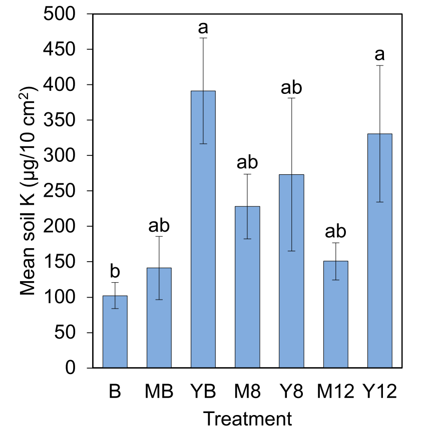

Fig. 4. Effect of polylactic acid (PLA) mulch and compost type on mean soil potassium (K) availability during the 6 weeks following planting. Error bars represent ± 1 *SE* of treatment means. Different letters above bars indicate significant differences at α < 0.05. Treatments were as follows: B = bare soil control, no compost, no mulch; MB = mixed feedstock compost, no mulch; YB = yard waste feedstock compost, no mulch; M8 = mixed feedstock compost, 80-g·m^{-2} PLA mulch; Y8 = yard waste feedstock compost, 80-g·m^{-2} PLA mulch; M12 = mixed feedstock compost, 120-g·m^{-2} PLA mulch; Y12 = yard waste feedstock compost, 120-g·m^{-2} PLA mulch. 1 µg/10 cm^2 (1.6 in^2) = 0.1417 oz/acre. 1 g·m^{-2} = 0.0033 oz/ft^2.

Table 2. Pooled contrast estimates for broadleaf and grass weed density between compost only and bare soil control treatments in carrot.

Label	Estimate	*SE*	df	*t* value	$P > \|t\|$[iii]
Broadleaf weed density B vs. MB+YB[i]	6.6125	2.5039	12	2.64	0.022
Grass weed density B vs. MB+YB[ii]	−0.1750	1.7831	12	−0.10	0.183

[i] Contrast compares broadleaf weed density between the bare plot control without compost (B) and bare plot treatments with pooled compost (MB+YB). Treatments: B = bare soil control, no compost, no mulch; MB = mixed feedstock compost, no mulch; YB = yard waste feedstock compost, no mulch.
[ii] Contrast compares grass weed density significance between the bare plot control without compost ("B") and bare plot treatments with pooled compost (MB+YB).
[iii] Šídák adjustment for multiplicity used for contrast estimates.
df = degrees of freedom.

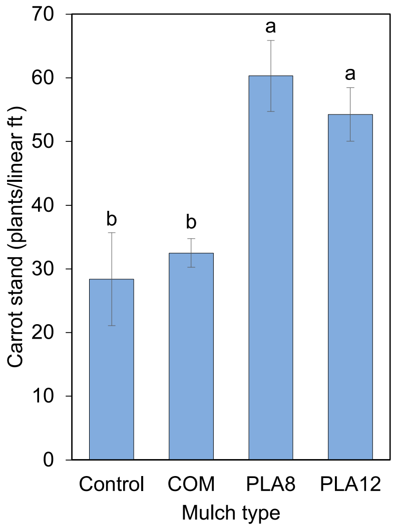

Fig. 5. Effects of polylactic acid (PLA) mulch type on carrot stand establishment 2 weeks after planting. Error bars represent ± 1 *SE* of treatment means. Different letters above bars indicate significant differences at $\alpha < 0.05$. Treatments were as follows: control = no compost, bare ground controls; COM = bare ground treatments with a compost topdressing; PLA8 = 80-g·m^{-2} PLA mulch treatments with a compost topdressing; PLA12 = 120-g·m^{-2} PLA mulch treatments with a compost topdressing. 1 plant/ft = 3.2808 plants/m. 1 g·m^{-2} = 0.0033 oz/ft^2.

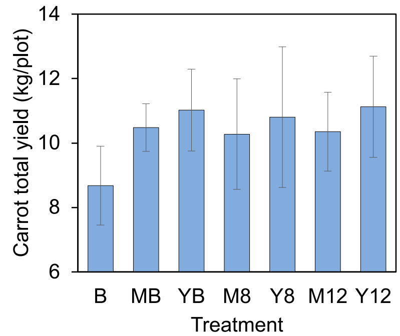

Fig. 6. Mean carrot yield among polylactic acid (PLA) mulch and compost treatment combinations (no significant differences). Error bars represent ± 1 *SE* of treatment means. 1 kg per plot [15 ft × 4 ft (4.6 m × 1.2 m)] = 1794.0 kg·ha^{-1} = 1600.6 lb/acre assuming row spacing of 4 ft. Treatments were as follows: B = bare soil control, no compost, no mulch; MB = mixed feedstock compost, no mulch; YB = yard waste feedstock compost, no mulch; M8 = mixed feedstock compost, 80-g·m^{-2} PLA mulch; Y8 = yard waste feedstock compost, 80-g·m^{-2} PLA mulch; M12 = mixed feedstock compost, 120-g·m^{-2} PLA mulch; Y12 = yard waste feedstock compost, 120-g·m^{-2} PLA mulch. 1 g·m^{-2} = 0.0033 oz/ft^2.

plantings (Puka-Beals and Gramig 2021). This strategy is effective because the mulch and compost block light and physically obstruct weed emergence (Teasdale and Mohler 2000). In our experiment, broadleaf and grass weed densities were reduced by more than 90% in PLA mulch plots compared with bare soil controls. Compost alone suppressed broadleaf weeds by 57% relative to the bare soil control, but not grass weeds (Fig. 2, Table 2). Similar results were reported by Puka-Beals and Gramig (2021), who found that a compost blanket application achieved similar reductions in weed biomass compared with the hydromulch application. However, weed suppression offered by compost alone in our study might have been limited by the thickness of compost applied, ~0.5 inches, compared with the 5-inch depth used by Puka-Beals and Gramig (2021). Weed germination rates typically decline in response to decreasing light transmittance through mulch surfaces (Teasdale and Mohler 2000).

Total carrot yield was unaffected by PLA mulch, which is consistent with the results of the first greenhouse trials using this new planting approach (Tofanelli et al. 2021). Previous studies of growing fruiting crops in a similar PLA mulch construction also reported no difference in yield compared with bare soil controls, which suggested that weed suppression (not soil warming or moisture conservation) was the primary benefit of the mulch (Wortman et al. 2015, 2016). If weeds were left to grow within test plots throughout the season (and not removed after counting), then we would expect that bare soil control treatments without compost would yield significantly less than plots with compost and PLA mulch because of intense weed competition (Knezevic et al. 1994). In addition to the similarities in yield, carrot quality was similar among compost and mulch treatments. During their greenhouse study, Tofanelli et al. (2021) noted that visible root constriction on carrot shoulders induced by PLA mulches could reduce carrot fresh weight marketability (Tofanelli et al. 2021); however, our results suggest that PLA mulches did not influence quality or marketability under field conditions (Table 3). Although not formally measured, it has been our observation that PLA mulch does not interfere with normal harvest operations using a manual broadfork or tractor-powered bedlifter/undercutter. In addition to normal weathering and deterioration, the high population and large circumference of carrot roots seem to have a shredding effect on the PLA mulch. Carrots were easily removed from the PLA mulch, and most residues adhering to the carrot (often embedded with soil) were removed during normal washing operations. Occasionally, less deteriorated PLA mulch residues had to be removed by hand.

Soil temperature results of this study were similar to those of previous studies in which PLA mulch did not warm the soil surface relative to bare soil (Wortman et al. 2015, 2016). However, these same studies did demonstrate increased soil moisture beneath PLA mulch compared with bare soil (Wortman et al. 2015, 2016), similar to the results of this study, which found that 80-g·m^{-2} PLA increased moisture slightly compared with compost-only controls. Similarities in soil temperature and minor differences in moisture, combined with the lack of intense weed competition caused by regular weeding, may have contributed to the lack of

Table 3. Mean individual carrot root diameter and length (±1 *SE*) as observed among polylactic acid (PLA) mulches and compost treatment combinations.

Treatment[i]	Carrot diam (cm)[ii]	Carrot length (cm)[ii]
	(Mean ± *SE*)	
B	2.7 ± 1.9	11.9 ± 8.4
MB	2.6 ± 1.8	11.0 ± 7.8
YB	2.4 ± 1.7	11.0 ± 7.8
M8	2.5 ± 1.8	11.2 ± 7.9
Y8	2.5 ± 1.8	11.4 ± 8.1
M12	2.5 ± 1.8	10.4 ± 7.4
Y12	2.7 ± 1.9	12.8 ± 9.1

[i] Treatments: B = bare soil control, no compost, no mulch; MB = mixed feedstock compost, no mulch; YB = yard waste feedstock compost, no mulch; M8 = mixed feedstock compost, 80-g·m^{-2} PLA mulch; Y8 = yard waste feedstock compost, 80-g·m^{-2} PLA mulch; M12 = mixed feedstock compost, 120-g·m^{-2} PLA mulch; Y12 = yard waste feedstock compost, 120-g·m^{-2} PLA mulch. 1 g·m^{-2} = 0.0033 oz/ft^2.

[ii] No significant differences in carrot diameter or carrot length were observed among treatments ($P > 0.05$). 1 cm = 0.3937 inches.

observed differences in total carrot yield and quality among treatments.

Differences in carrot stands between experimental and control groups could have resulted from hand weeding because carrot stands were reduced in bare soil plots in which hand weeding was more frequent (Fig. 5). Previous studies have identified hand weeding as a possible source of damage to germinating carrot seedlings (Fennimore et al. 2014; Swanton et al. 2010). Given the high volume of germinating weeds in bare soil treatments, it is plausible that early-season hand weeding could have uprooted carrot seedlings and reduced stand counts.

Reductions in soil NO_3 availability between mulched and nonmulched treatments were likely caused by N immobilization induced by the high carbon content of the PLA mulches. Similar studies that used PLA mulches embedded with wood particles have noted N immobilization in low-fertility soils, although the authors largely attributed this immobilization to the embedded wood particles (Reid et al. 2022; Samuelson et al. 2022). Mulch presence did contribute to lower soil N availability compared with bare soil during this study (Fig. 3), but that did not seem to negatively impact carrot yield (Fig. 6). Nonetheless, starter fertilizer should be explored as a potential remedy for N deficiency when using high-carbon PLA mulches. Starter fertilizer could be added directly to the PLA mulch as a convenient strategy for reducing the mulch C:N and potential for soil N immobilization, but potential weed suppression tradeoffs should be studied (Wehrbein and Wortman 2023).

Plots containing compost had increased season-long K levels compared with bare soil controls without compost, which is typical for compost-amended soils (Miernicki et al. 2018). However, increased soil K availability from compost applied on top of PLA mulch was somewhat unexpected and suggests that the K was leached through the mulch membrane with irrigation and rainwater. In soil, K is mobile and susceptible to leaching (Alfaro et al. 2004); this result suggests the potential for nutrients like K to move through the semi-permeable PLA mulch membrane. However, less mobile nutrients like P did not appear to move through the membrane; instead, they likely remained in the compost or the membrane (Azevedo et al. 2018).

Conclusions

Biobased PLA mulches combined with compost topdressings provided effective weed suppression in carrot production without adverse impacts on harvest operations, yield, or crop quality. The reduced hand-weeding frequency in this new PLA mulch system has the potential to reduce labor needs and improve farmer profitability and overall quality of life. Ongoing research aims to explore the potential for direct-seeding or propagating different vegetable, small fruit, and cut flower crops in this PLA mulch system; furthermore, it aims to determine the potential benefits and tradeoffs of including starter fertilizer in the mulch membrane.

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