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Effect of buckwheat and silage tarps on sweetpotato between-row weed control

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Abstract

Field studies were conducted on certified organic land in Lafayette and Vincennes, IN, in 2023 to determine the impact of different between-row weed control methods on weed suppression and sweetpotato yield. Between-row treatments consisted of organic buckwheat (108 kg ha^{-1}) broadcast seeded immediately after sweetpotato transplanting followed by silage tarping from 3 wk after transplanting (WATr) through harvest, organic buckwheat (108 kg ha^{-1}) broadcast seeded 3 WATr and terminated 7 WATr, and cultivation as a grower standard. Weed density at 6 WATr was 0, 184, and 162 plants m^{-2} for the silage tarping, living mulch buckwheat, and cultivation treatments, respectively. Total yield was 11,048 kg ha^{-1} for the living mulch buckwheat, 19,792 kg ha^{-1} for the cultivation, and 17,814 kg ha^{-1} for the tarping treatments. Tarping effectively suppressed weeds and produced sweetpotato yields comparable to cultivation, indicating the potential for use by organic growers. When buckwheat was grown between rows 3 to 7 WATr, sweetpotato yield was lower than it was with tarping and cultivation. These results suggest that researchers should be evaluating tarps for small-acreage farmers as a weed management strategy.

Introduction

In the United States, sweetpotato holds significant importance as a vegetable crop (Woodard et al. 2024), with the most production in NC, MS, and CA (USDA-NASS 2020). In recent years, there has been a notable increase in organic sweetpotato production across the country (Ponisio et al. 2015; USDA-NASS 2017). According to USDA-NASS (2020), organic sweetpotato ranks as the fourth highest commodity in sales among all organic vegetables grown in open fields. In 2019, a total of 401 organic sweetpotato farms harvested 3,695 ha, yielding approximately 85 million kg of sweetpotato valued at US$77 million (USDA-NASS 2020).

Despite advancements in organic sweetpotato production, concerns persist regarding the crop's productivity, particularly due to the limited options for weed control. Sweetpotato is typically grown on raised beds formed from bare, tilled soil. Nonrooted stem tip cuttings are transplanted directly into these raised beds. Weed management in sweetpotato production traditionally relies on herbicides, preplant tillage, in-season between-row cultivation, and hand weeding (Lewthwaite and Triggs 2000; Nwosisi et al. 2019). Sweetpotato growers typically cultivate three to four times per season before the vines fully cover the area between middles. For some, the frequency of cultivation is determined by the level of weed pressure present in the field. Others cultivate more routinely based on the number of days between cultivations. Escaped weeds are typically hand removed once or twice per season, which is both time consuming and expensive (Chaudhari et al. 2020).

Cultivation practices in sweetpotato farming can pose several disadvantages, including adverse effects on soil structure, increased soil erosion and evapotranspiration, and a reduction in organic matter content (Shrestha et al. 2006). In response to these challenges, conservation tillage systems offer a promising alternative to conventional cultivation methods. Cover cropping, one of many conservation tillage practices, has demonstrated numerous benefits for agroecosystems (Creamer et al. 1997; Kaluwasha et al. 2019). Beyond weed suppression, cover crops can prevent erosion, reduce nutrient leaching, increase organic matter content, and enhance microbial activity (De Laune et al. 2019; Fernandes et al. 2018; Treadwell et al. 2008). According to Mohler et al. (2021), maintaining optimal soil properties through cover cropping facilitates easier weed management. Additionally, cover crop residue left on the soil surface can act as mulch, inducing alterations in the soil microenvironment that inhibit the germination of weed seeds.

In sweetpotato systems that employ conservation tillage, the common practice is to sow winter annual cover crops during the fall and terminate them in the early spring, prior to transplanting slips into the cover crop residue (Smith et al. 2022). Others plow or disk cover crop in the spring before making beds for sweetpotato, mainly to help nutrient cycling, decrease erosion in the fall to early spring period, and improve soil tilth (Treadwell et al. 2007). Termination of cover crops in these systems is achieved through applying herbicides, mowing, roller-crimping, or tilling. However, in organic systems, termination methods are restricted to mowing, roller-crimping, and tilling (Kaluwasha et al. 2019; Werle et al. 2023a).

Werle et al. (2023b) observed a 1-fold reduction in weed biomass in sweetpotato plots utilizing cover crops compared to those with bare soil. In their study, the cover crop was terminated in the spring using a flail mower, which allowed the residue to remain on the soil surface. On the other hand, Treadwell et al. (2007) compared three nonchemical weed control strategies in organic sweetpotato production systems, no cover crop with tillage, mixed species of cover crop and tillage, and mixed species of cover crop without tillage, against a conventional system with tillage and chemical controls. Their research suggested that the suppression of predominantly monocot weeds was similar across the cover crop treatments and the conventional system. Tilling cover crops enriches soil nutrient content by integrating organic materials but limits the cover crop's mulching ability, which is vital for weed suppression during early crop growth.

Buckwheat, a type of broadleaf grain, is often utilized as a summer cover crop and is widely recognized for its ability to suppress weeds, improve air and water infiltration into the soil, increase organic matter, and offer nectar for pollinators. As a short-season cover crop, buckwheat establishes rapidly, maturing within a span of 70 to 90 d (Clark 2007). In a comparative study of winter and summer cover crops, Werle et al. (2023a) observed that plots with buckwheat exhibited a significantly lower weed density relative to all fallow treatments. These empirical data highlight the potential effectiveness of buckwheat as a summer cover crop in weed control strategies. Buckwheat seedlings emerge within 3 to 5 d and can form a thick canopy in as little as 2 wk (Marshall and Pomeranz 1982). Gibson et al. (2011) found that planting buckwheat between tomato (*Solanum lycopersicum* L.) rows after the critical weed-free period (CWFP) did not affect tomato yield but led to a 59% decrease in viable weed seed production compared to a control treatment where weeds were allowed to emerge after the CWFP. Buckwheat's abilities to shade and compete are key characteristics that contribute to its primary role in weed suppression.

Tarping, an alternative to traditional tillage or cultivation, has also been demonstrated as an effective physical weed control technique on small-scale organic farms (Birthisel and Gallandt 2019; Rylander et al. 2020a). This method entails the use of opaque plastic to cover the soil surface for prolonged periods, essentially resulting in a stale seedbed and eliminating emerged vegetation by occultation (Lounsbury et al. 2022). Silage tarps, typically 5 to 6 mm thick and black on one side and white on the other, can be repurposed and reused for approximately six or more growing seasons (Kubalek et al. 2022). When these tarps are laid on the soil surface, the black side faces upward, warming the soil and promoting weed seed germination. However, owing to the absence of sunlight, germinated weed seedlings will die while the tarp remains in place (Chandran et al. 2018). Rylander et al. (2020b) assessed the effects of tarps on weed suppression and beet (*Beta vulgaris* L. 'Boro') yield and reported a decrease in weed biomass and an increase in yield when a tarp was used for 3 wk or longer. They concluded that a tarping duration of 3 wk could enhance the feasibility of conservation tillage methods for organic vegetable production. Although tarping is efficient, it is important to note that weeds differ in their control susceptibility, and perennial weeds may only be impacted by extended tarping periods (Mohler et al. 2021).

After a thorough search, we found no published research that investigates the effect of using tarps for in-season between-row weed control in organic sweetpotato production. Furthermore, research on cover crops for between-row weed control in sweetpotato production is very limited. These two conservation tillage techniques could aid organic sweetpotato farmers in devising a more effective weed management strategy, which could additionally confer benefits to soil characteristics by reducing reliance on repeated cultivations. The objective of this study was to compare the use of buckwheat and silage tarps to the traditional cultivation approach for controlling weeds between raised beds in an organic sweetpotato production system.

Materials and Methods

Locations and Field Preparation

Field experiments were conducted at a single location each in certified organic fields at the Samuel G. Meigs Horticulture Research Farm, Lafayette, IN (40.28°N, 86.88°W), and at the Southwest Purdue Agricultural Center, Vincennes, IN (38.74°N, 87.48°W), in 2023. At Lafayette, the soil type was a mixture of Starks (fine-silty, mixed, superactive, mesic Aeric Endoaqualfs) and Fincastle (fine-silty, mixed, superactive, mesic Aeric Epiaqualfs) silt loam with 1.6% organic matter and pH 6.4. At Vincennes, the soil was a Bloomfield loamy fine sand (sandy, mixed, mesic Lamellic Hapludalfs) with 1.0% organic matter and pH 6.1.

At Lafayette, the field was mowed using a rotary mower (Bush Hog 2212, Bush Hog, Selma, AL, USA) to remove a preceding fall-planted cereal rye (*Secale cereale* L.) cover crop, then subjected to three passes of a field cultivator (Farmall 200, International Harvester, Chicago, IL, USA) attached to a John Deere 6410 tractor (John Deere, Moline, IL, USA). Fertilizer (1,345 kg ha^{-1} of 5-4-5 [Revita Pro™, Ohio Earth Food, Hartville, OH, USA] and 224 kg ha^{-1} of 0-0-50 (sulfate of potash, Ohio Earth Food]) was broadcast and then incorporated into the soil prior to bed formation. At Vincennes, site preparation consisted of two passes of a disk (White 271 disk, White Machine and Manufacturing Company, Zanesville, OH, USA) attached to a Ford 8360 tractor (Ford–New Holland, Dearborn, MI, USA) to incorporate a fall-planted mixture of hairy vetch (*Vicia villosa* Roth) and red clover (*Trifolium pratense* L.), followed by a single pass of a rotary tiller (Land Pride RTR2570, Great Plains Manufacturing, Salinas, KS, USA) attached to a John Deere 2510 tractor, and lastly a single pass of the same White 271 disk. The same amount of fertilizer as in the Lafayette location was used. However, owing to the sandy soil texture and the likelihood of nutrient loss from infiltration, fertilizer application at Vincennes was split, with 50% of the total applied before bed formation and the remainder applied 8 wk after transplanting (WATr). Raised beds were formed using a Buckeye 1512-ND bedder (Buckeye Tractor Company, Columbus Grove, OH, USA) attached to a New Holland 1510 tractor (New Holland Agriculture, New Holland, PA, USA) on June 8, 2023, at Vincennes and a Rain-Flo 2550 (Rain-Flo Irrigation, East Earl, PA, USA) attached to a John Deere 6410 tractor on June 7, 2023, at Lafayette.

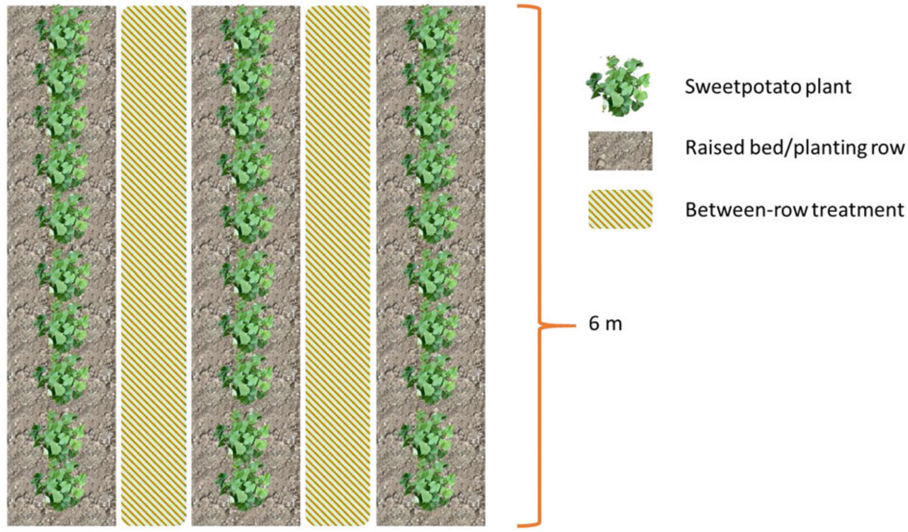

Figure 1. Experimental units consisting of three raised-bed rows with only the middle one harvested. Between-row treatments were placed on each side of the middle row.

Treatments and Experimental Design

Plots consisted of three raised-bed rows (~0.1 m in height), each 6 m long and 0.8 m wide, and their corresponding between-row areas, each 1.5 m wide (Figure 1). Nonrooted, organic 'Covington' sweetpotato stem tip cuttings (slips) 25 to 30 cm long (Jones Family Farms, Bailey, NC, USA) were hand transplanted 30 cm apart on June 7, 2023, at Lafayette and June 8, 2023, at Vincennes. Between-row treatments consisted of (1) organic buckwheat seed (108 kg ha^{-1}; Byron Seeds, Rockville, IN, USA) broadcast seeded immediately after sweetpotato transplanting, followed by silage tarping 3 WATr; (2) organic buckwheat seed (108 kg ha^{-1}) broadcast seeded 3 WATr and terminated 7 WATr; and (3) cultivation as a grower standard (Table 1). Between-row areas of all plots were rototilled at 3 WATr prior to tarping using a BCS 749 two-wheel tractor with a rototiller (BCS America, Oregon City, OR, USA) to terminate buckwheat planted in the silage tarping treatment and to create a weed-free seedbed for the living mulch buckwheat planted 3 WATr. In addition to the 3 WATr rototilling, between-row areas in the cultivation treatment were cultivated 5 and 7 WATr using a Farmall 200 cultivator (International Harvester) at Lafayette and a BCS 749 with a rototiller at Vincennes. The living mulch buckwheat treatment planted 3 WATr was terminated 7 WATr using a BCS 749 two-wheel tractor with a flail mower at a blade height adjusted to 6 cm. Silage tarps (5 mil, low-density polyethylene, Farmers Friend, Centerville, TN, USA) placed 3 WATr were anchored using small sandbags and remained in place for the duration of the trial. Overhead irrigation was used to supplement rainfall at the early stage of buckwheat establishment at both locations. Weeds were removed from the tops of the beds by hoe weeding and hand removal until sweetpotato vines completely covered the beds. At both locations, the experiment was a randomized complete-block design with four replicates.

Data Collection and Analysis

Weed density and height and buckwheat canopy were recorded using a 0.09 m^2 quadrat placed randomly at two locations within the two between-row areas of each plot at 5, 6, and 7 WATr. Weed height data were collected from two random weeds within the quadrat, regardless of species. A visual estimate of sweetpotato canopy cover between rows was recorded at 5, 6, 7, and 8 WATr by estimating the total ground surface area occupied by sweetpotato vines using a scale of 0% (no cover) to 100% (complete cover). At 111 d after transplanting (DATr), aboveground biomass in all plots was rotary mowed using a Bush Hog 2212 attached to a John Deere 6410 tractor at Lafayette and a Bush Hog 287 attached to a Ford 7600 at Vincennes to remove foliage and facilitate smooth operation of equipment for harvest. Sweetpotato roots were harvested from the entirety of each center row in each plot at 112 DATr with a single-row chain digger (Willsie Equipment Sales, Thedford, ON, Canada). Storage roots were graded and weighed as jumbo (>8.9 cm diameter), U.S. No. 1 (>4.4 to 8.9 cm diameter), and canner (>2.5 to 4.4 cm diameter and misshapen roots of any size) (USDA-AMS 2005). The summation of jumbo, U.S. No. 1, and canner grades is presented as total yield.

Data were subjected to statistical analysis using R software (RStudio®, PBC, Boston, MA, USA). Canopy cover data were arcsine square root transformed for normality and skewness to meet assumptions of analysis of variance (ANOVA). Data for both locations were subjected to ANOVA using the general linear mixed model (GLMM) to test the fixed effects of weed management methods and random effects of replicates nested within location. Mean comparisons among weed management methods were generated using Tukey's honestly significant difference test at the 5% probability level for Type I errors.

Results and Discussion

Weed Density and Height

The composition and density of weed species varied between the two locations. In Lafayette, approximately 80% of the observed weeds were summer annual grasses (barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.], large crabgrass [*Digitaria sanguinalis* (L.) Scop.], and giant foxtail [*Setaria faberi* Hermm.]), with the remaining 20% being broadleafs (common purslane [*Portulaca oleracea* L.] and redroot pigweed [*Amaranthus retroflexus* L.]). At Vincennes, the observed weeds comprised approximately 65% summer annual grasses (goosegrass [*Eleusine indica* (L.) Gaertn.] and large crabgrass) and 35% broadleafs (*Amaranthus* spp., carpetweed [*Mollugo verticillata* L.], and common ragweed

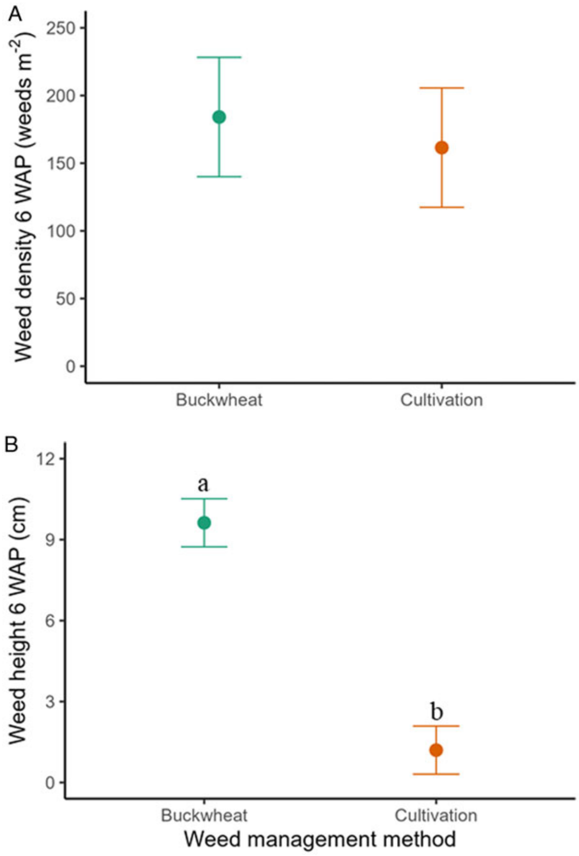

Figure 2. Effect of weed management method on weed density (A) and weed height (B) 6 wk after transplanting (WATr) in 2023. Points and bars represent observed mean and standard error, respectively. Letters represent treatment differences with Tukey's HSD ($P < 0.05$). Between-row spaces in the buckwheat treatment contained buckwheat planted 3 WATr and terminated 7 WATr. Between-row spaces in the cultivation treatment were cultivated 3, 5, and 7 WATr.

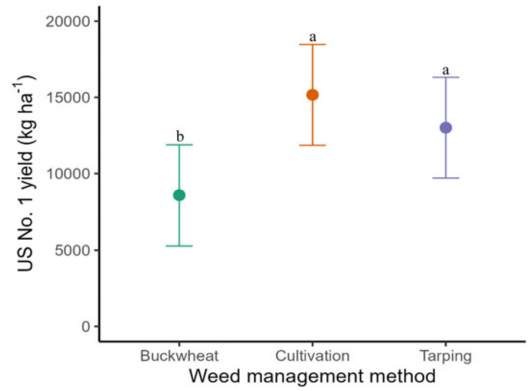

Figure 3. Effect of between-row weed management method on U.S. No. 1 sweetpotato yield in 2023. Points and bars represent the observed mean and standard error, respectively. Letters represent differences among treatments with Tukey's HSD ($P < 0.05$). Between-row spaces in the buckwheat treatment contained buckwheat planted 3 WATr and terminated 7 WATr. Between-row spaces in the cultivation treatment were cultivated 3, 5, and 7 WATr. Between-row spaces of the tarping treatment contained buckwheat from sweetpotato transplanting through 3 WATr followed by tarping until crop harvest.

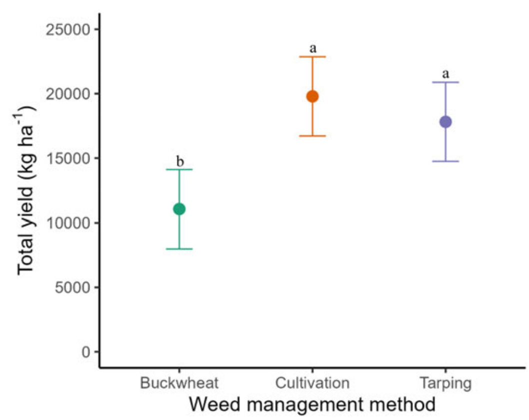

Figure 4. Effect of between-row weed management method on total sweetpotato yield in 2023. Points and bars represent observed mean and standard error, respectively. Letters represent treatment differences with Tukey's HSD ($P < 0.05$). Between-row spaces in the buckwheat treatment contained buckwheat planted 3 WATr and terminated 7 WATr. Between-row spaces in the cultivation treatment were cultivated 3, 5, and 7 WATr. Between-row spaces of the tarping treatment contained buckwheat from sweetpotato transplanting through 3 WATr followed by tarping until crop harvest.

[*Ambrosia artemisiifolia* L.]). Despite the differences in weed species and densities, the distribution of weed species was consistent within each field.

At 6 WATr, no weeds were present in row middles covered with a silage tarp. Weed density for the living mulch buckwheat and cultivation treatments was 184 and 162 weeds m^{-2}, respectively, at 6 WATr (Figure 2 A). Despite the similar weed densities observed for both the living mulch buckwheat and the cultivation treatments, there was a significant ($P \leq 0.00001$) difference in weed height between the two treatments. At 6 WATr, weed height was 10 cm for the living mulch buckwheat treatment and 1.2 cm for the cultivation treatment (Figure 2 B). The reduced weed height in the cultivation treatment can be attributed to the cultivation carried out at 5 WATr, which eradicated established weeds. Notably, weeds emerging in the cultivation treatment plots at 6 WATr were predominantly in the seedling stage.

Buckwheat Growth

At 1 WATr the living mulch buckwheat treatment (4 WATr sweetpotato), the average buckwheat density was 362 plants m^{-2}. The buckwheat canopy covered 62% and 72% of the between-row areas at 6 and 7 WATr sweetpotato, respectively. Concurrently, the average height of buckwheat plants measured 35 cm and 49 cm at 6 and 7 WATr, respectively. Clark (2007) noted that buckwheat can establish a relatively dense, shading canopy within 2 WATr due to its wide leaves, which can reach up to 7.6 cm. Consistent with this observation, our treatments involving living mulch buckwheat demonstrated a dense canopy presence at 6 and 7 WATr sweetpotato, corresponding to 3 and 4 WATr buckwheat, respectively. Buckwheat was terminated at 7 WATr because it started to flower, and there was no regrowth. Following termination, buckwheat residue decomposed quickly on the soil surface and was not sufficiently effective in suppressing summer annual grasses.

Sweetpotato Yield

U.S. No. 1 yield differed among treatments, with the living mulch buckwheat treatment yielding less (8,580 kg ha^{-1}) than the tarping (13,010 kg ha^{-1}) and cultivation (15,160 kg ha^{-1}) treatments (Figure 3). Similarly, total yield in the living mulch buckwheat treatment was less (11,050 kg ha^{-1}) than the cultivation (19,790 kg ha^{-1}) and tarping treatments (17,810 kg ha^{-1}) (Figure 4). Jumbo

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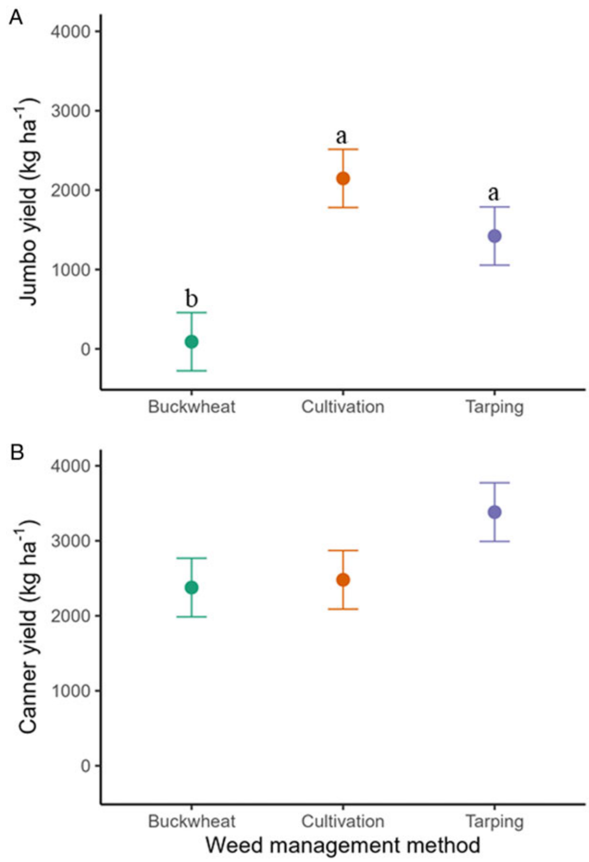

Figure 5. Effect of between-row weed management method on jumbo (A) and canner (B) sweetpotato yields in 2023. Points and bars represent observed mean and standard error, respectively. Letters represent treatment differences with Tukey's HSD ($P < 0.05$). Between-row spaces in the buckwheat treatment contained buckwheat planted 3 WATr and terminated 7 WATr. Between-row spaces in the cultivation treatment were cultivated 3, 5, and 7 WATr. Between-row spaces in the tarping treatment contained buckwheat from sweetpotato transplanting through 3 WATr followed by tarping until crop harvest.

yield of the tarping (1,420 kg ha^{-1}) and cultivation (2,150 kg ha^{-1}) treatments was greater than for the living mulch buckwheat treatment (90 kg ha^{-1}) as well (Figure 5 A). Canner yield did not differ among the living mulch buckwheat (2,380 kg ha^{-1}), tarping (3,380 kg ha^{-1}), and cultivation (2,480 kg ha^{-1}) treatments (Figure 5 B).

The observed reduction in sweetpotato yield from the living mulch buckwheat treatment is likely the result of interspecific competition. However, given that weeds were routinely removed from the planted row, the source of competition was vegetation from between rows. The majority of the between-row area was occupied by buckwheat, which had an average height 3 times greater than the weeds present at 6 WATr. Buckwheat's quick growth rate contributes to its success as a weed-suppressing cover crop. However, the presence of buckwheat between sweetpotato rows 3 to 7 WATr overlapped with the reported CWFP for sweetpotato, 2 to 6 WATr (Seem et al. 2003). Conversely, silage tarped plots that contained buckwheat in their corresponding row middles from the date of sweetpotato transplanting through 3 WATr did not experience a reduction in yield relative to the cultivation treatment.

In 2023, the mean wholesale price of No. 1, No. 2, and jumbo fresh market sweetpotatoes pooled across California, Louisiana, Mississippi, and North Carolina was US$1.19, US$0.77, and US $0.77 kg^{-1}, respectively (Rentzel 2024). Sweetpotatoes graded commercially as No. 2 are roughly equivalent to the canner grade used in the present study. This equates to a gross income of US $31,631 ha^{-1} for the cultivation treatment, US$28,103 ha^{-1} for the tarping treatment, and US$18,647 ha^{-1} for the buckwheat treatment (Table 1). The cost for the new silage tarps used in the study including shipping was US$0.86 m^{-2}. Given that the between-row area in the present study occupied 65% of the field, approximately 6,500 m^{-2} of silage tarps would be required to cover 1 ha of production at an initial cost of US$5,590 ha^{-1}. Divided by the 4- to 6-yr useful life of the tarp (Kubalek et al. 2022), this suggests that the tarping method could be a cost-effective alternative for weed management in small-scale, organic production systems.

Table 1. Gross income from sweetpotatoes harvested from living mulch buckwheat, cultivation, and sileage tarping row middles treatments pooled across Lafayette and Vincennes, IN, in 2023.[a]

	Grade			
Treatment	No. 1	Jumbo	Canner	Total
	US$ ha^{-1}			
Buckwheat[b]	10,210	6,607	1,830	18,647
Cultivation	18,045	11,676	1,910	31,631
Tarping[c]	15,481	10,017	2,605	28,103

[a]Mean wholesale fresh market value in 2023: No. 1, US$1.19 kg^{-1}; jumbo, US$0.77 kg^{-1}; canner = US$0.77 kg^{-1}.
[b]Between-row spaces contained buckwheat planted 3 wk after sweetpotato transplanting (WATr) and terminated 7 WATr.
[c]Between-row spaces contained buckwheat from sweetpotato transplanting to 3 WATr followed by a sileage tarp from 3 WATr through a sweetpotato harvest.

Practical Implications

In this study, we found that tarping was as effective as traditional cultivation in terms of sweetpotato yield, but with the added benefit of a single application and greater weed suppression. This suggests that tarping could be an alternative method for between-row weed control in small-scale organic sweetpotato production. The living mulch buckwheat treatment resulted in decreased sweetpotato yield and likely acted as a weed in the 2- to 6-wk CWFP for sweetpotato. Although buckwheat may still be an option, our research suggests that 3 to 7 WATr is not optimal for sweetpotato yield. Owing to the low-growing nature of most sweetpotato cultivars and the fact that their vines utilize the between-row spaces, cover cropping in between rows during the growing season does not appear to be a viable option.

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Competing interests. The authors declare no conflicts of interest.

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