Integrated Weed Management in Cucurbit Production Using Spring-seeded Grass Cover Crops

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ABSTRACT. Achieving commercially acceptable weed control in plasticulture vegetable production systems can be challenging because many herbicides do no provide season-long control. Additionally, several weed species have recently evolved resistance to labeled herbicides. Consequently, multiple cultivations or frequent hand-weeding are needed to control emerged weeds. Cover crops have recently gained attention as a tool for helping to manage weeds. Field studies were conducted in Maryland and New Jersey to assess the efficacy of combining spring-seeded grass cover crops and herbicide treatments for weed control in cucumber and watermelon production. Three spring cover crop treatments consisting of cereal rye, spring oats, or cereal rye and spring oats were hand-broadcasted after laying plastic in Apr 2021 and 2022. Postplant treatments were applied to cover crops and emerged weeds 78 days later, ~3 weeks after planting each crop. Postplant treatments included shielded herbicide applications (paraquat or clethodim) or crimping without an herbicide. Residual herbicide (fomesafen + *S*-metolachlor) was included or not with each postplant treatment. Cover crops decreased broadleaf weed density before and 2 weeks after postplant treatment (WAT) by 73% and 68%, respectively, and weed biomass 6 WAT by 84% compared with no cover. Terminating an oat cover crop with paraquat totally suppressed smooth pigweed 2 WAT compared with clethodim or crimping treatments. Overall, cover crop treatments showed 50% greater weed control compared with no cover. Weed control in the interrow area ranged from 90% to 95% when paraquat was applied to a cover crop compared with less than 75% following crimping a cover crop. Cucumber and watermelon commercial yield decreased 63% and 52%, respectively, when cover crops were not used. These results show that spring-seeded cereal cover crops can be successfully integrated with an herbicide strategy to provide effective weed control in cucurbit production.

Cucumber (*Cucumis sativus* L.) and watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai] were produced on more than 74,000 ha and valued at more than $1077 million in the United States, respectively representing 54% and 56% of the total acreage and value of cucurbit (Cucurbitaceae) crops in 2023 [US Department of Agriculture (USDA) 2024a]. In 2022, 14,800 ha of cucurbits were planted in the Mid-Atlantic region (Delaware, Maryland, New Jersey, New York, and Pennsylvania) including 1180 ha of cucumber in New Jersey and 960 ha of watermelon in Maryland (USDA, National Agriculture Statistics Service 2024b). In the Mid-Atlantic region, cucumber and watermelon are mostly cultivated using plasticulture production systems. Plasticulture involves forming raised beds that are then covered with plastic mulch. Cucumber seeds and watermelon transplants are placed in holes punched in the mulch and are irrigated and fertigated using drip irrigation. This system helps increase yield, improves water and fertilizer use efficiency, and reduces weed pressure (Bonanno 1996; Monks et al. 1997). However, plasticulture vegetable systems are often planted using wide row spacing (1.8 to 2.4 m), leaving large bare-ground areas of the field early in the crop cycle. Weeds germinating between mulched rows can compete with crops, interfere with harvest, serve as hosts for pathogens and other plant pests, impede spray deposition, produce seeds that impact subsequent crops, and interfere with mulch removal (Bedford et al. 1998; French-Monar et al. 2006; Gilreath and Santos 2004; Rich et al. 2009). Weeds are often mechanically managed in these systems through frequent cultivation, mowing, and/or hand-weeding. However, these tactics often need to be repeated to control weeds, such as Palmer amaranth (*Amaranthus palmeri* S. Watson), that germinate throughout the growing season, thus increasing labor costs (Chahal et al. 2021; Jha and Norsworthy 2009; Keeley et al. 1987). The utility of mechanical cultivation for weed control is limited by the vining nature of cucurbit crops (Gilreath and Everett 1983). Hand weeding, although effective, is costly and dependent on the availability of labor (Taylor et al. 2012). Repeated cultivation can rip the plastic mulch, as well as damage the soil, leading to the degradation of soil organic matter, increase soil erosion, reduce soil water content, and interfere with residual herbicide activity (Bonanno 1996; Reddy et al. 2003). This, along with repeated mowing or hand-labor, can be a costly endeavor. Herbicides can provide good weed control; however, chemical weed control in vegetables can be challenging because there are fewer registered herbicides (Sharpe and Boyd 2019). The limited number of herbicides is due to the high value of most vegetable crops, smaller acreage on which vegetables are grown, and product registrants limiting potential liability and crop injury (Boyd et al. 2022; Fennimore and Doohan 2008). In addition, the problem has been exacerbated by the onset of herbicide-resistance, subsequently reducing the number of effective herbicides (Boyd et al. 2022). Moreover, multiple herbicide applications may be required for full season weed control. Currently, the area between crop rows receives herbicides when beds are formed, after transplanting (often with hooded or shielded sprayers), and before removing the plastic mulch. Consequently, current weed management practices can be costly and have long-term detrimental impacts on plasticulture cropping systems. Therefore, alternative management practices are needed.

Cover crops have been evaluated as an alternative weed management tool with positive results in row crops. Cover crops can compete with weeds for resources required for growth and development such as sunlight, water, and nutrients (Cornelius and Bradley 2017; Teasdale et al. 2007; Vollmer et al. 2020a). Comparatively limited research has been conducted with cover crops in vegetable production (Price et al. 2018). Cereal rye is often fall planted to serve as a windbreak in plasticulture production (Hodges and Brandle 1996) but is usually not planted throughout an entire field. In addition, plasticulture vegetable production is often not compatible with fall-planted cover crops in the Northeastern United States because tillage is required for bed formation, making it difficult to incorporate an existing cover. Spring-seeding cover crops between rows after laying plastic has been shown to be an effective method establishing a cover and controlling weeds (Vollmer et al. 2020b). However, three major challenges exist in using cover crops between mulched rows of plastic: getting the cover crop established before weeds can dominate, competition between the cover crop and cash crop (Bruce et al. 2022; Chase and Mbuya 2008), and controlling emerged weeds within the cover crop (Tarrant et al. 2020; Vollmer et al. 2020b). The first challenge may be addressed by choosing faster growing cover crop species. Cornelius and Bradley (2017) attributed higher winter annual weed suppression with grass species such as cereal rye (*Secale cereale* L.), wheat (*Triticum aestivum* L.), and annual ryegrass (*Lolium multiflorum* ssp. *multiflorum*) compared with broadleaf species such as winter pea (*Pisum sativum* ssp. *arvense*), hairy vetch (*Vicia villosa* Roth), and crimson clover (*Trifolium incarnatum* L.) due to faster emergence and growth and greater percent groundcover. The second and third challenges may be addressed by incorporating an effective postemergence (POST) herbicide to control weeds within the cover crop and manage the cover crop to prevent it from competing with the cash crop. A grass cover crop, such as spring oats [*Avena sativa* L. var. *orientalis* (Shreb.)], can be selectively terminated with an acetyl-CoA carboxylase (ACCase)-inhibiting herbicide [Weed Science Society of America (WSSA) group 1] in several vegetable crops including cucumbers, peppers, tomatoes, and watermelon; however, these herbicides will not control broadleaf weeds. Paraquat (WSSA group 22 photosystem I electron diverter) is a nonselective herbicide that can be used to terminate and control grass cover crops and broadleaf weeds (Syngenta 2019). However, paraquat is labeled for row-middle applications only in many crops and must be applied using specialized equipment, such as a shielded sprayer to avoid crop injury. ACCase-inhibiting herbicides such as clethodim and sethoxydim can be broadcasted over the top of a broadleaf crop without causing injury. Furthermore, paraquat has a higher acute toxicity for humans compared with clethodim or sethoxydim. As a result, the ability to use herbicides with lower toxicity and fewer restrictions would be more desirable for growers. The objectives of this study were to 1) assess the effectiveness of the presence of spring-seeded cereal cover crops for weed suppression, 2) assess which cover crop species or mixture provides more effective weed suppression, and 3) assess different methods for weed control at cover crop termination.

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Materials and methods

Design and treatments. Trials were conducted in 2021 and 2022 at the University of Maryland Wye Research and Education Center near Queenstown, MD, USA (lat. 38.9°N, long. 76.2°W), and at the Rutgers Agricultural Research and Extension Center in Bridgeton, NJ, USA (lat. 39.5°N, long. 75.2°W). Soil type at the Maryland location was a Nassawango silt loam (fine-silty, mixed, semiactive, mesic Typic Hapludults), 44.6% sand, 40.2% silt, and 15.2% clay, with pH values of 5.8 to 6.3, and organic matter of 2.0% to 2.1%. Soil type at the New Jersey location was a Chillum silt loam (fine-silty, mixed, semiactive, mesic Typic Hapludults), 15% sand, 68% silt, and 17% clay, with pH value of 5.5 and organic matter of 1.7%.

The study was conducted as a split-split plot experiment with postplant treatment (main plots), cover crop species (subplots), and residual herbicide (sub-subplots) factors arranged in a randomized complete block design with four replications. Individual plots were four rows of plastic mulch 7.6 m long and 6.9 m wide in 2021 and 4.6 m long and 6.9 m wide in 2022. Dates of the various field operations for the trials conducted at both locations in 2021 and 2022 are listed in Table 1.

Cover crop species consisted of ‘Aroostook’ cereal rye (rye) seeded at 268 $kg \cdot ha^{-1}$, ‘Everleaf 126’ spring oats (oats) seeded at 310 $kg \cdot ha^{-1}$, and a mix of cereal rye and spring oats (mix) seeded at 134 $kg \cdot ha^{-1}$ and 155 $kg \cdot ha^{-1}$, respectively, as well as a no cover treatment. Cover crops were hand-broadcasted between the rows and raked in to homogenize the distribution of the seeds and facilitate their germination.

Cash crops were planted ~1.5 to 2 months after cover crop seeding. ‘Fascination’ and ‘Captivation’ watermelon cultivars were transplanted at the Maryland site in 2021 and 2022, respectively at a density of 14,346 plants/ha. ‘SP-6’ pollenizers were also transplanted within the plot rows at the site both years. ‘Python’ cucumber cultivar was seeded at the New Jersey location in 2021 and 2022 at a density of 14,300 plants/ha. Drip irrigation under plastic was used at all sites, and fertilizers, fungicides, and insecticides were applied according to local recommendations (Wyenandt et al. 2024).

Postplant treatments were implemented 3 to 4 weeks after planting the cash crops to terminate the cover crop and eliminate emerged weeds. Herbicides were applied to row middles using

Table 1. Dates for field operations conducted in cover crop trials at Queenstown, MD, USA, and at Bridgeton, NJ, USA, in 2021 and 2022.

Location	Year	Bed formation	Cover crop		Crop	
			Seeding	Postplant treatment	Planting	Harvest
Queenstown	2021	20 Apr	27 Apr	14 Jul	24 Jun	8 Sep to 21 Sep
	2022	14 Apr	25 Apr	12 Jul	16 Jun	7 Aug
Bridgeton	2021	6 Apr	7 Apr	24 Jun	2 Jun	14 Jul to 3 Aug
	2022	13 Apr	20 Apr	6 Jul	7 Jun	26 Jul to 9 Aug

a tractor-mounted Redball hooded sprayer (Willmar Fabrication, LLC, Benson, MN, USA) fitted with drift guard 95015 even spray nozzles (TeeJet, Glendale Heights, IL, USA) and calibrated to deliver a spray volume of 347 $L \cdot ha^{-1}$ and 281 $L \cdot ha^{-1}$ in Maryland and New Jersey, respectively. Treatments included 140 g a.i./ha clethodim (Select Max®; Valent USA Corp., Walnut Creek, CA, USA) plus 0.25% v/v nonionic surfactant (Scanner®; Loveland Products Inc., Greeley, CO, USA), 336 g a.i./ha paraquat (Gramoxone® SL 2.0; Syngenta Crop Protection, Greensboro, NC, USA) plus 0.25% v/v nonionic surfactant (Scanner®) or crimped (no herbicide). Crimped treatments consisted of using only the tractor, without applying an herbicide. The tractor used at the Maryland location was a John Deere 3150 (John Deere, Moline, IL, USA) weighing ~5338 kg, and the tractor used at the New Jersey location was a John Deere 5075M weighing ~3538 kg.

Residual herbicides were applied to row middles within 24 h of postplant treatments at both locations using a shielded CO_2 backpack sprayer with a spray volume of 187 $L \cdot ha^{-1}$ at 137 kPa and 8004 even spray nozzles (TeeJet, Glendale Heights, IL, USA). Treatments consisted of 421 $g \cdot ha^{-1}$ fomesafen (Reflex®; Syngenta Crop Protection, Greensboro, NC) plus 1783 $g \cdot ha^{-1}$ *S*-metolachlor (Dual Magnum®; Syngenta Crop Protection, Greensboro, NC) plus 0.25% v/v nonionic surfactant (Scanner®) or no residual herbicide treatment.

Sampling methods. Aboveground cover crop biomass was collected before postplant treatments by cutting plants at the soil level from two 0.25 m^2 quadrats randomly selected within each plot. Weed density and aboveground biomass were assessed from two permanent 0.25-m^2 quadrats established between the two middle rows of each plot at a minimal distance of 1 m from the beginning of the plot. To ensure species consistency across site-years, 500 seeds of smooth pigweed were seeded in the first quadrat. Naturally occurring populations of carpetweed (*Mollugo verticillata* L.), common lambsquarters (*Chenopodium album* L.), hairy galinsoga (*Galinsoga quadriradiata* Cav.), henbit (*Lamium amplexicaule* L.), ivyleaf morningglory (*Ipomoea hederacea* Jacq.) spurred anoda [*Anoda cristata* (L.) Schltdl.], smooth pigweed (*Amaranthus hybridus* L.), redroot pigweed (*Amaranthus retroflexus* L.), yellow woodsorrel (*Oxalis stricta* L.), and Persian speedwell (*Veronica persica* Poir.) were present at both locations. Because of the variability in sites, these species were grouped together and henceforth referred to as other annual broadleaves (OAB) and were evaluated in the second quadrat. Weed density in both the smooth pigweed and OAB quadrats was recorded before postplant treatment both years and for both sites. A second evaluation was conducted 2 weeks after postplant treatment (WAT) both years in Maryland and in 2022 in New Jersey. Smooth pigweed and OAB biomass was collected on average 6 WAT in 2022 by cutting plants at the soil level. Weed and cover crop biomass samples were benched dried in a greenhouse for 14 d at 35 °C in Maryland and were or oven-dried at 60 °C for 7 d in New Jersey before weighing. Finally, overall weed control (relative to the no cover, crimped, no herbicide treatment) 3 WAT was visually evaluated both years in Maryland and in 2021 in New Jersey using a 0 to 100 scale, with 0 = no plant response and 100 = complete plant death. Vollmer et al. (2020b) reported that cover crops do not grow well adjacent to the plastic. Therefore, weed control evaluations were separately conducted at the center of the row middle and within 20 cm of the edge of the plastic row.

Watermelons and cucumbers were harvested from the two center rows within each plot at both locations. Watermelon fruits weighing at least 4 kg were considered marketable (Johnson and Ernest 2018). Cucumbers were graded according to USDA grades and standards instruction (USDA 2018). Yield data for both crops consisted of count and weight of total and marketable fruits as well as the individual weight of marketable fruits. Watermelons were harvested over three and one picks in 2021 and 2022, respectively, whereas cucumbers were harvested over three picks in both years.

Data analysis. Data were subjected to analysis of variance (ANOVA) using the generalized linear mixed model (GLIMMIX) procedure in SAS software (version 9.4; SAS Institute, Cary, NC, USA). Cover crops, postplant treatments, and inclusion of a residual herbicide as well as all interactions between these three factors were considered fixed effects. Locations, runs, and replication nested within runs were designated as random factors in the model. Because of unequal variance, percentage or numerical data were converted using the arcsine square root or the square root transformation, respectively, before ANOVA and back-transformed for presentation purposes (Grafen and Hails 2002). When main effect interactions were not significant, data were combined over fixed effects. Mean comparisons for the fixed effects were performed using Tukey's honestly significance test when *F* values were statistically significant ($P \leq 0.05$).

Results and discussion

Cover crop biomass. Spring-seeded cover crops were allowed to grow for ~78 d before termination each year. Before postplant treatments and across crops and runs, oats accumulated significantly greater aboveground biomass (576 $g \cdot m^{-2}$) than rye (405 g·m^{-2}) or the rye-oat mix (448 g·m^{-2}) (data not presented). These results are likely due to genetic differences and differences associated with common planting dates between the two cover crops. Cereal rye is best established in the late summer and fall, whereas spring oats are best established in fall, winter, or spring (Sustainable Agriculture Research and Education 2016). As a result, late planting or early termination can result in reduced cover crop growth and biomass production (Mirsky et al. 2011). In this particular study, rye never progressed past the tillering stage (Feekes 4.0) and oats were at the heading stage (Feekes 10.5) before postplant treatment.

Smooth pigweed. The main effect of cover crop was significant for smooth pigweed density at the time of postplant treatment ($P < 0.0001$). All cover crops treatments reduced smooth pigweed density ≥77% compared with the no cover treatment (108 plants/m^2). Smooth pigweed density was reduced 50% on average with the rye-oat mix (15 plants/m^2) as compared with the rye (31 plants/m^2) or oat (28 plants/m^2) monocultures (data not shown).

There was a significant postplant treatment by cover crop interaction for smooth pigweed density collected 2 WAT. Cover crop treatments reduced weed density 64% when terminating with clethodim or by crimping compared with the no cover treatment. However, no differences in smooth pigweed density were observed among cover crop treatments terminated with paraquat (Table 2).

The postplant treatment of paraquat on oats eliminated smooth pigweed unlike the use of clethodim or crimping. In the no cover crop treatment, paraquat was also more effective with 88% lower smooth pigweed than observed with other postplant treatments. Across clethodim and crimping treatments, cover crops reduced smooth pigweed density 82% on average compared with the absence of cover crops. However, the efficacy of paraquat at controlling broadleaf weeds, smooth pigweed density 2 WAT did not exceed 8 plants/m^2 with oats providing better suppression than rye or the absence of cover crop under this postplant treatment.

There was also a significant cover crop-by-residual herbicide application for smooth pigweed density collected 2 WAT. Including a residual herbicide immediately after postplant treatment significantly reduced smooth pigweed density ≥88% for all cover crops and 46% for the no cover crop treatment (Table 2). When a residual herbicide was included, smooth pigweed density was 95% lower on average when a cover crop was seeded, and the oats plus rye mix provided greater suppression than the rye alone. In the absence of residual herbicide, smooth pigweed averaged 39 plants/m^2 for the rye and no cover crop treatments but decreased ≥74% when oats were seeded.

Table 2. Interaction effect of cover crops with postplant treatment and inclusion of residual herbicide on smooth pigweed density 2 weeks after postplant treatment and dry biomass 6 weeks after postplant treatment. Density data combined from cucumber trials conducted in 2022 at Bridgeton, NJ, USA, and watermelon trials conducted in 2021 and 2022 at Queenstown, MD, USA. Biomass data combined from cucumber and watermelon trials in 2022.

	Density								Dry biomass[i]
	Rye		Oat		Mix		No cover		
Treatments	plants/m^2								g·m^{-2}
Postplant treatment									
Clethodim	16 a[ii]	*y*	6 a	*y*	8 a	*y*	56 a	*x*	7 a
Paraquat	8 a	*x*	0 b	*y*	2 a	*xy*	7 b	*xy*	3 b
Crimped	17 a	*y*	8 a	*y*	6 a	*y*	58 a	*x*	4 ab
P value					0.0131				<0.0001
Residual									
Yes	3 b	*y*	1 b	*yz*	0 b	*z*	25 b	*x*	3 b
No	31 a	*xy*	8 a	*z*	17 a	*yz*	46 a	*x*	7 a
P value					0.0237				0.0042

[i] 1 g·m^{-2} = 8.92 lb/acre.

[ii] Data were pooled across runs and means followed by the same letter in a column (a and b) or row (*x* and *y*) are not significantly different based on based on Tukey's honestly significant difference (α = 0.05).

The main effects of postplant treatment and residual herbicide application were significant for smooth pigweed aboveground dry biomass collected 6 WAT but not for cover crop or for interactions between the main effects (Table 2). Paraquat treatments resulted in lower smooth pigweed biomass (3 g·m^{-2}) compared with clethodim treatments (7 g·m^{-2}), but no differences were observed for crimped treatments (4 g·m^{-2}). Including a residual herbicide with a postplant treatment reduced smooth pigweed biomass 57% compared with no residual treatment.

Other annual broadleaf weeds. The main effect of cover crop was significant for OAB density at postplant treatment ($P < 0.0001$). At postplant treatment, cover crop treatments reduced OAB density 68% compared with the no cover crop treatment (98 plants/m^2), and there were no differences among cover crop species with OAB density ranging from 25 to 36 plants/m^2 (data not presented).

The main effects of postplant treatment cover crop and residual herbicide were significant for OAB weed density 2 WAT with no significant interactions between main effects. Cover crop treatments reduced OAB density 85% compared with the no cover crop treatment (36 plants/m^2), and there were no differences among cover crop species with an average of 5 plants/m^2 (Table 3). Residual herbicides reduced OAB density 71% compared with no residual herbicide, and terminating with paraquat reduced OAB density 94% compared to termination with clethodim or by crimping.

The main effect of cover crop was significant. Cover crop treatments reduced OAB biomass 84%, regardless of cover crop species, compared with the no cover treatment (Table 3). There was also a significant postplant treatment by residual herbicide interaction for OAB biomass 6 WAT. In the absence of a residual herbicide application, terminating with paraquat reduced OAB dry biomass 80% compared with clethodim, but no significant differences were observed with crimped treatments. When a residual herbicide was applied, no significant differences were observed between postplant treatments with OAB biomass averaging 16 g·m^{-2}.

Table 3. Effect of cover crops, postplant treatment, and inclusion of residual herbicide on density 2 weeks after postplant treatment and dry biomass 6 weeks after postplant treatment of other annual broadleaf weed species. Density data combined from cucumber trials conducted in 2022 at Bridgeton, NJ, USA and watermelon trials conducted in 2021 and 2022 at Queenstown, MD, USA. Biomass data combined from cucumber and watermelon trials conducted in 2022.

Treatments	Density plants/m^2	Dry biomass[i] g·m^{-2}			
Cover crop					
Rye	5 b[ii]	31 b			
Oat	7 b	12 b			
Mix	4 b	10 b			
No cover	36 a	112 a			
P value	<0.0001	<0.0001			
Residual herbicide		Yes		No	
Yes	5 b	—		—	
No	17 a	—		—	
P value	<0.0001				
Postplant treatment					
Clethodim	21 a	17 a	*y*	88 a	*x*
Paraquat	1 b	8 a	*x*	18 b	*x*
Crimped	15 a	22 a	*y*	55 ab	*x*
P value	<0.0001	0.0175			

[i] 1 g·m^{-2} = 8.92 lb/acre.
[ii] Data were pooled across runs and means followed by the same letter in a column (a and b) or row within cultivars (*x* and *y*) are not significantly different based on based on Tukey's honestly significant difference (α = 0.05).

Weed control. Significant interactions of cover crop by postplant treatment and cover crop by residual herbicide were noted for weed control 4 WAT in the center of the row of each plot. The presence of a cover crop controlled weeds an average of 87% compared with no cover treatments (22%) (Table 4). Terminating the cover crop with paraquat controlled weeds ≥90% in the rye or mix cover crops compared with ≤81% for the crimping treatments. No weed control differences were detected between postplant treatments for the oat cover crop.

Averaged over postplant treatment, the inclusion of a residual herbicide significantly improved weed control 4 WAT in the oat cover crop compared with the lack of residual herbicide (Table 4). However, the benefit of including a residual herbicide was not observed for the rye and mix cover crop treatments.

There was a similar interaction of cover crop-by-postplant treatment and cover crop for weed control along the edge of the plastic 4 WAT. Cover crop treatments provided better edge weed control (≥62%) compared with the no cover treatments (≤48%), albeit at observably lower values than the center of the rows (Table 4). Postplant treatment did not affect weed control in plots where cover crops were present, but applying paraquat in the no cover treatment controlled weeds 48% compared with clethodim (3%) and crimped (1%). Regardless of residual herbicide, most cover crop treatments provided better edge weed control (≥61%) compared with no cover treatments (≤12%).

Watermelon yield. Cover crop treatments had a significant effect on all components of the total and marketable yield. When averaged over postplant treatment and residual herbicide treatment, marketable yield was 65% lower and total yield was 52% lower in no cover treatments compared with cover crop treatments (Table 5). Similarly, no cover crop treatments produced 39% fewer marketable fruit and 48% fewer total fruit compared with cover crop treatments. Marketable fruit weight from the no cover treatments was 22% lower compared with the rye and mix treatments. Total fruit from cover crop treatments was larger than the no cover treatment, but rye treatments were 17% larger than oat treatments.

The main effect of residual herbicide treatment also had a significant effect on total yield (P = 0.0439), total fruit number (P = 0.0167), but there were no interactions. When averaged over postplant treatment and cover crop, total watermelon yield was

Table 4. Interaction effect of cover crops with postplant treatment and inclusion of residual herbicide on weed control 3 weeks after postplant treatment in the center and at the edge of the interrow. Data combined from cucumber trials conducted in 2021 at Bridgeton, NJ, USA, and watermelon trials conducted in 2021 and 2022 at Queenstown, MD, USA.

Treatments	Center of the interrow								Edge of the interrow							
	Rye[i]		Oat		Mix		No cover		Rye		Oat		Mix		No cover	
	%															
Postplant treatment																
Clethodim	81 ab	*x*	90 a	*x*	88 ab	*x*	6 b	*y*	62 a	*x*	82 a	*x*	69 a	*x*	3 b	*y*
Paraquat	90 a	*x*	95 a	*x*	91 a	*x*	59 a	*y*	73 a	*x*	83 a	*x*	83 a	*x*	48 a	*y*
Crimped	75 b	*x*	85 a	*x*	81 b	*x*	1 b	*y*	66 a	*x*	68 a	*x*	77 a	*x*	1 b	*y*
P value	<0.0001								0.0017							
Residual herbicide																
Yes	84 a	*x*	93 a	*x*	89 a	*x*	8 a	*y*	70 a	*x*	82 a	*x*	78 a	*x*	12 a	*y*
No	81 a	*x*	88 b	*x*	85 a	*x*	23 b	*y*	61 a	*x*	74 a	*x*	74 a	*x*	10 a	*y*
P value	0.0300								0.8342							

[i] Data were pooled across runs and means followed by the same letter in a column (a and b) or row within cultivars (*x* and *y*) are not significantly different based on based on Tukey's honestly significant difference (α = 0.05).

Table 5. Main effect of cover crop on cumulated watermelon yield, fruit number, and fruit weight at harvest. Data combined over runs for trials conducted in Queenstown, MD, USA, in 2021 and 2022.

Cover crop	Yield[i]		Fruit no.		Fruit wt	
	Marketable	Total	Marketable	Total	Marketable	Total
	kg·ha^{-1}		fruit/ha		kg/fruit	
Rye	2,985 a[ii]	22,888 a	2,465 a	29,465 a	4.51 a	4.66 a
Oat	1,905 ab	20,388 a	1,951 a	27,123 a	4.43 ab	3.98 b
Mix	2,973 a	24,175 a	2,422 a	30,763 a	4.85 a	4.54 ab
No cover	907 b	10,839 b	1,396 b	15,031 b	3.67 b	3.31 c
P value	<0.0001	<0.0001	<0.0001	<0.0001	0.0019	<0.0001

[i] 1 kg·ha^{-1} = 0.892 lb/acre.
[ii] Data were pooled across runs and means followed by the same letter in a column are not significantly different based on based on Tukey's honestly significant difference (α = 0.05).

5% lower, and total fruit number was 8% lower when a residual herbicide was not included (data not presented).

Cucumber yield. The main effect of cover crop had a significant effect on all total and marketable yield parameters tested. When averaged over postplant treatment and residual herbicide treatment, marketable yield was 66% lower and total yield was 63% lower without cover crop compared with a cover crop (Table 6). Similarly, no cover treatments produced 65% fewer marketable fruit and 62% fewer total fruit compared with cover treatments. Marketable fruit was 21% lower with no cover treatments compared with the rye and mix treatments. Total fruit was 17% lower with no cover treatments compared with cover crop treatments.

The main effect of postplant treatment also had a significant effect on total and marketable yield and fruit number, but there were no interactions. When averaged over cover crop and residual herbicide treatment, marketable yield was 31% lower and total yield was 38% lower with clethodim treatments compared with paraquat treatments (Table 6). Similarly, clethodim treatments produced 33% fewer total fruits compared with paraquat treatments, but paraquat treatments produced 44% more marketable fruits than clethodim or crimped treatments.

Our results agree with previous results from Vollmer et al. (2020b) showing that spring-seeded grass cover crops can reduce weed density and weed biomass. Overall, including a cover crop often resulted in fewer weeds and improved weed control compared with no cover crop.

Although cover crops reduced weed density and biomass, an effective herbicide often improved weed control. Similarly, Tarrant et al. (2020) reported that cover crops such as cereal rye, barley, and wheat showed a decrease in weed biomass, but weeds remained a major component of total biomass in cover crop treatments. Terminating the cover crop with paraquat was often more effective compared to terminating with clethodim or by crimping. Paraquat is a nonselective that controls a broader range of weeds, including broadleaf and grass species, whereas clethodim is a selective herbicide used exclusively for grass control.

Furthermore, our results showed that incorporating a cover crop with paraquat can result in greater weed control compared with either alone. An oat cover crop terminated with paraquat resulted in a greater reduction in smooth pigweed density compared with an oat cover crop terminated with clethodim or by crimping. Similarly, greater weed control in the center of the interrow was achieved when the rye or the mix cover crops were terminated with paraquat compared with crimping. Although cover crops can suppress weeds, they cannot control weed escapes. If factors such as reduced stands affect a cover crop's ability to compete with weeds, then an effective postemergence herbicide will be needed to achieve acceptable control.

Our research also demonstrates improved control when a residual herbicide was included with a cover crops. Smooth pigweed density was lower when a residual herbicide was included in a cover crop treatment, as was overall interrow weed control when a residual herbicide was included with an oat cover crop.

In general, cover crop treatments yielded higher than no cover crop treatments. Cover crop treatments consistently increased total yields, provided more fruit per plot, and had more sizeable watermelons and cucumbers compared with no cover crop treatments. In addition, cover crops can improve soil structure leading to a better growing environment for cucurbit crops. However, there were no differences between oat and no cover treatments for marketable watermelon yield and marketable watermelon fruit weight as well as marketable cucumber fruit weight. This may be attributed to cover crop/cash crop competition and/or interference. Bertucci et al.

Table 6. Main effect of cover crop and postplant treatment on cumulated cucumber yield, fruit number, and fruit weight at harvest. Data combined over runs for trials conducted in Bridgeton, NJ, USA, in 2021 and 2022.

Treatments	Yield[i]		Fruit no.		Fruit wt	
	Marketable	Total	Marketable	Total	Marketable	Total
	kg·ha^{-1}		ha^{-1}		kg/fruit	
Cover crop						
Rye	8,927 a[ii]	10,676 a	31,713 a	35,752 a	0.28 a	0.30 a
Oat	9,512 a	11,274 a	34,137 a	38,335 a	0.27 ab	0.29 a
Mix	10,217 a	11,716 a	34,515 a	38,742 a	0.30 a	0.31 a
No cover	3,208 b	4,170 b	11,476 b	14,370 b	0.23 b	0.25 b
P value	<0.0001	<0.0001	<0.0001	<0.0001	0.0019	0.0029
Postplant treatment						
Clethodim	6,516 b	6,918 b	22,443 b	25,471 b	0.28	0.29
Paraquat	9,392 a	11,230 a	34,096 a	38,187 a	0.27	0.29
Crimped	6,640 ab	8,595 ab	24,754 b	29,298 ab	0.28	0.28
P value	0.0227	0.0109	0.0068	0.0085	0.9409	0.8644

[i] 1 kg·ha^{-1} = 0.892 lb/acre.
[ii] Data were pooled across runs and means followed by the same letter in a column are not significantly different based on based on Tukey's honestly significant difference (α = 0.05).

(2019) reported a critical weed free period of ∼2.5 weeks. Because postplant treatments occurred at ∼3 after cucurbit crop planting, the more advanced growth stage of oats compared with rye may have caused these observed reductions. At the heading stage, oats had an erect growth habit and greater biomass, which could have interfered with vine development. Comparably, rye was still at the tillering stage at termination, and vines were not growing into the standing cover. However, because a true weed-free comparison was not included in this study, additional research is needed to verify this claim. Further research is also needed to determine the optimal timing to terminate a spring-seeded grass cover crop as well as evaluate other herbicides that may be used as an alternative to paraquat.

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