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Cover crops for weed suppression in organic vegetable systems in semiarid subtropical Texas

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Abstract Economic losses due to weeds are exceptionally high in organic agriculture particularly in tropical and subtropical growing regions where weeds are persistent year-round. For organic vegetable growers, weed control accounts for the largest portion of labor effort to produce crops. The use of cover crops during fallow period has gained popularity among organic growers who cannot use synthetic herbicides on their farms for weed management. We conducted a 2-year study in a certified organic vegetable farm in the semiarid subtropical region of south Texas. We compared cover crop canopy closure, cover crop and weed biomass, and subsequent weed emergence in cash crops after cover crop termination for four different cover crop treatments: sudangrass (*Sorghum* × *drummondii*), sunn hemp (*Crotalaria juncea*), cowpea (*Vigna unguiculata*), and a mix of the three species. Sudangrass produced the highest biomass followed by the three-species mix in 2017, while cowpea treatments had the lowest total cover crop biomass in both years. Weed biomass was the highest untreated fallow (control) and there was no significant difference among the four cover crop treatments. When followed by subsequent cash crops, the weedy fallow plots had significantly higher weed biomass in both years, and in 2018, sunn hemp plots had the lowest weed biomass. Overall, our results indicate that cover crops, especially those with the ability to grow quickly and develop a closed canopy or known to have allelopathic properties, have the potential to control weeds in organic vegetable farms in semiarid subtropical Texas.

Keywords *Sorghum* × *drummondii* · *Crotalaria juncea* · *Vigna unguiculata* · Organic farming · Weed biomass · Canopy closure · Weed management

Introduction

Weeds in agricultural soils worldwide cause a significant reduction in the cash crop yield and quality by competing for resources such as light, nutrients, and water (McErlich and Boydston 2014) as well as through allelopathic effects (Kadioglu et al. 2005; Tanveer et al. 2012). In addition, weeds also harbor pests (nematodes, insects, and pathogens) causing the reduction in the potential yields and quality of crops (Norris and Kogan 2000; Capinera 2005). Farmers rank weeds as the major barrier to production (Walz 1999), and for organic farmers and those willing to transition to certified organic practice, weed management is the number one constraint (Sumption et al. 2004; Turner et al. 2007; Walz 1999; Bàrberi 2002; Lee and Thierfelder 2017).

Mechanical weed management techniques such as hoeing, tillage, or cultivation are expensive and time consuming and cause a significant impact on soil health

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(Govaerts et al. 2008; Van der Weide et al. 2008). With the increasing cost of fossil fuels, these methods bring additional cost to growers (Sainju and Singh 2008). For conventional growers, development of herbicide resistance attributed to the extensive use of synthetic herbicides, is concerning (Heap 2014; Owen et al. 2014; Kniss 2018). Additionally, due to growing concerns about the negative impacts of these options on both human health and soil health, a non-chemical-based weed control method has gained a significant interest among both growers and researchers.

The importance of weed management using alternatives to chemical control is not new. Beginning in the 1920s (Harker and O'Donovan 2013), cover crops have been widely used as a soil health and weed management technique, especially in organic farming systems (Hill et al. 2016; Soti et al. 2016; Baraibar et al. 2018; Langeroodi et al. 2018). Cover crops have been proven to successfully suppress weeds through various mechanisms including by modifying seed environments, changing light availability, soil temperature, and moisture, and through allelopathy (Creamer et al. 1996; Weston and Duke 2003; Reberg-Horton et al. 2012). As such, these techniques are often associated with reduced weed pressure in subsequent crop seasons (Teasdale and Daughtry 1993; Teasdale 1996; Teasdale et al. 2002; Brennan and Smith, 2005, b; Kruidhof et al. 2008; Kumar et al. 2008; O'Reilly et al. 2011) and improved yield, especially in organic systems (Ngouajio et al. 2003; Isik et al. 2009; Wortman et al. 2013). However, despite the growing popularity of cover crops across organic farms worldwide along with the strong encouragement from the National Organic Program (Bellows 2005), this management option has not been adopted by growers in the semiarid region of south Texas, likely due to the fact that there is a dearth of research cover crops in these arid regions and as such those practicing organic agriculture are left with very little information to help guide cover crop selection and management that helps with weed suppression.

The objective of this study was to evaluate the potential of various cover crop species to suppress weeds in organic vegetable farms in subtropical United States (USDA Plant Hardiness Zones 9–11). We analyzed the potential of three different cover crop species, sunn hemp (*Crotalaria juncea*), sudangrass (*Sorghum drummondii*), and cowpea (*Vigna unguiculata*), to suppress weed pressure in during warm summer fallow in organic vegetable farms in south Texas. We compared the cover crop biomass accumulation of these species in monoculture and as a three-species mix and their effects on weed biomass during the fallow period and in the subsequent cash crops.

Materials and methods

Research site and experimental design

This study was conducted during summer (June–August) of 2017 and 2018 at a certified organic vegetable farm in Edinburg, TX (26° 15′ 58.2588″ N, 98° 5′ 48.948″ W). In this region, the peak vegetable growing season spans from September through May each year. After the spring vegetable growing season, a two-acre field was disked and divided into 20 plots 35 m × 7 m with a 1-m buffer space between each treatment block. The experimental design was randomized a complete block with five cover crop treatments and four replicates in both year 1 and year 2. The soil in this site was Brennan fine sandy loam with pH 8.0, with very low organic matter (0.6%). The site received no rainfall during the 2017 study period while it received 50-mm total rainfall during the 2018 study period. The average maximum temperature was 35.5 °C and the average minimum temperature was 24.5 °C (weather.gov).

Cover crops and cash crop

The selected cover crops were planted on June 20 in 2017 and June 25 in 2018 using a handheld seed spreader (Scotts™ Handy Green, Maryville, OH), at producer recommended rates (Table 1). The legume cover crops were inoculated by *Bradyrhizobium* sp. as recommended by the seed vendor. Treatment plots were lightly disked using a tractor to cover the seeds. The field was flood-irrigated immediately after planting and at 4 weeks (July 20 and July 27 in 2017 and 2018 respectively) when the plants started showing signs of water stress (wilting). The control plots were also treated with disking and irrigation, but otherwise left as weedy fallow. Edges were cultivated once before irrigation at 4 weeks, but no weeds were pulled out of the cover crop plots. Cover crops and weeds in each treatment block were terminated about 60 days after planting (DAP), August 19 and August 24 in 2017 and 2018 respectively with a flail mower. In early September, 2 weeks after cover crop termination, all fields were disked to

Table 1 Cover crop treatments, species, crop types, and seeding rate used in the study

Cover crop treatment	Cover crop species	Crop type	Seeding rate (kg/ha)
Sudangrass (SG)	*Sorghum drummondii*	Grass	45
Cowpea (CP)	*Vigna unguiculata*	Legume	28
Sunn hemp (SH)	*Crotalaria juncea*	Legume	45
Sudangrass + cowpea + sunn hemp (mix)	-	-	16 + 10 + 16
Control (C)	-	-	-

incorporate the cover crop biomass and bedded into rows to prepare for fall planting. In both years, the cover crops suffered a damage by granivore ants (red harvester ants, *Pogonomyrmex barbatus*) feeding on the seeds and the Texas leaf cutting ants (*Atta texana*) foraging on the sudangrass. Foraging of sudangrass by the leaf cutting ants was slightly lower in 2018 (personal observation).

Each cover crop plot was divided into two equal plots for the two cash crops: zucchini (*Cucurbita pepo*) and bush beans (*Phaseolus vulgaris*). Seeds of organic zucchini and bush beans were planted in rows as traditionally done by growers (row hills 1.2 m apart and about 0.5 m between plants). The cash crop plants were drip-irrigated and the edges around the treatment plots were hand-weeded as necessary.

Cover crop growth

A location was randomly selected in each treatment plot and was flagged, and light readings, measuring the photosynthetic photon flux density (PPFD), were collected every week starting the third week after planting. A LI-COR Quantum Line Sensor (LI-COR, Inc., Lincoln, NE, USA) and data logger (LI-1400, LI-COR, Lincoln, NE, USA) were used to measure PPFD at the soil surface below the cover crop canopy and at the top of the cover crop canopy at clear conditions between 1200 and 1300 h. Reduction in the amount of light reaching the soil surface was recorded to assess canopy closure.

Cover crop and weed biomass measurements

At week 8, just before termination, 1-m^2 grid was randomly selected in each treatment plot. The aboveground plant material was collected from these grids and was separated into cover crops, and “other” (weeds). Weed and cover crop samples were dried to constant weight in paper bags in an oven at 75 °C for at least 72 h. Dried samples were weighed to determine cover crop and weed biomass in each treatment. Weed estimation within subsequent crops was conducted during the first week of October, when the weeds were about 10 cm tall. A 1-m^2 grid was randomly selected in each treatment plot, and the total number of weeds growing in each of the grids was counted. Entire plants were pulled to estimate total above and below ground biomass. Roots of weeds were washed and dried in an oven at 75 °C for 74 h, and the dry weight of weeds in each treatment plots was recorded.

Statistical analysis

All data were subjected to normality test. When data (weed biomass in cover crops) was not normalized with transformation, non-parametric test (Friedman’s two-way non-parametric test) was conducted. Repeated measures analysis of variance (ANOVA) was used to compare the reduction in PPFD over the 8-week period among the different treatments. Multiple regression was used to analyze the reduction of PPFD over the 8-week period, with control and week 8 as reference groups. Analysis of variance was performed on the cover crop and weed biomass variables. Initially, cover crop biomass and weed biomass in both cover crops and cash crops were subjected to 2-way ANOVA (year × cover crop treatments). As there was no significant difference in year by cover crop treatment for weed biomass, cover crop data was averaged for both years and analyzed. Also, since there was no significant difference in the weed biomass in the two cash crops, weed biomass data in both the cash crop treatments were averaged for analysis. Mean separation was done using Fisher’s least significant difference test at $P < 0.05$ level of significance. All analyses were done using SAS statistical software version 9.4 (SAS Institute Inc., Cary, NC, USA).

Results and discussion

Cover crops are widely known to control weeds and benefit the subsequent crops. Results from this study are consistent with other studies that suggest that cover crops can potentially control weed density and biomass and provide some preliminary evidence of this potential in arid subtropical systems and organic farms.

Cover crop canopy cover varied between the 2 years and among the different cover crops (Fig. 1 and Table 2). Results from repeated measures ANOVA indicate that there was a significant difference in PPFD reduction among the different cover crop treatments over the period of 8 weeks for both years studied ($F_{1,4} = 17.85$, $P < 0.0001$, 2017; $F_{1,4} = 4.82$, $P < 0.0001$, 2018). By the third week, cover crops had on average 46% and 68% (in 2017 and 2018 respectively) reduction in PPFD reaching the soil surface. However, in the control plots, there was a reduction of only about 5% in both years. In both years, sudangrass had the fastest emergence and subsequent canopy cover among the different cover crop species with a significant reduction in light reaching the ground. Results from simple regression indicate that, on average, PPFD at the soil surface of sudangrass plot was reduced by 37% and 43% in 2017 and 18 respectively compared with the weedy control followed by the three-species mix in 2017 and sunn hemp in 2018. At 8 weeks (reference group in regression), PPFD at the soil surface is reduced by 57% in 2017 and 32% in 2018 compared with week 3. Quick canopy cover is an important factor for suppressing weeds by cover crops. The potential cover crop to suppress weed is highly proportional to the cover crop canopy (Liebman and Davis 2000); a dense cover crop canopy reduces the weed germination, growth, and establishment with the reduction of light penetrating through the canopy to the surface.

Total aboveground biomass of the different cover crop species produced in 60 DAP was slightly higher in 2018. This difference was likely due to the additional rainfall but was not found to be statistically significant. However, there was a significant difference in biomass production among the different cover crop treatments (Fig. 2).

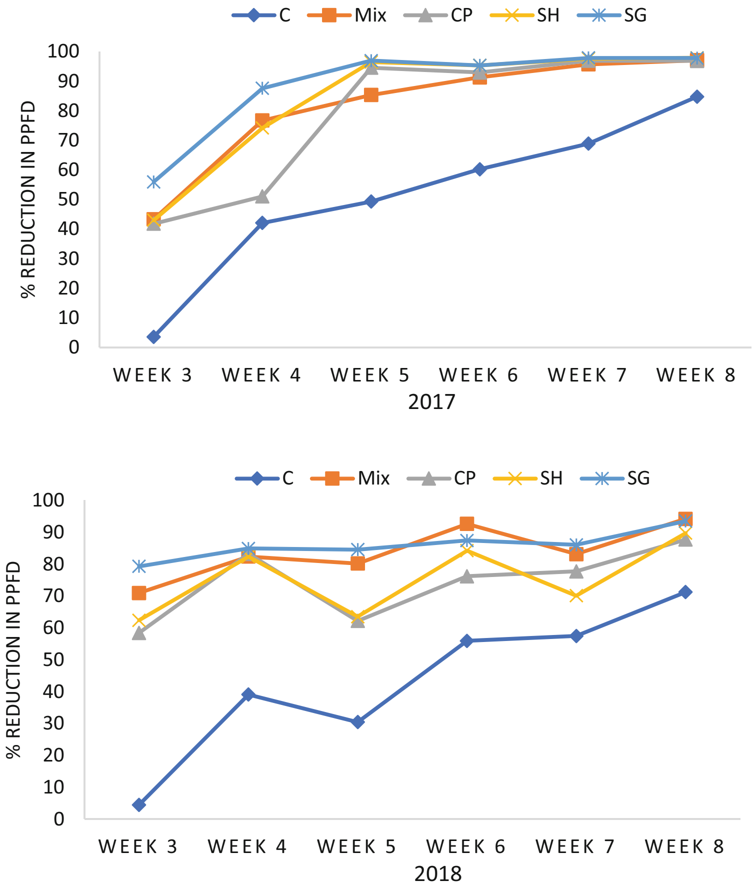

Fig. 1 Percentage reduction in the photosynthetic photon flux density (PPFD) in the different treatment plots in 2017 and 2018

Table 2 Summary of simple regression analysis for the reduction in PPFD for the different cover crop treatments during the study period

	2017			2018		
Variables	Coefficient	Standard error	tStat	Coefficient	Standard error	tStat
Sudangrass	37.11	2.54	14.63	42.88	3.99	10.75
Mix	30.10	2.54	11.87	40.84	3.99	10.24
Cowpea	27.55	2.54	10.86	31.16	3.99	7.81
Sunn hemp	32.62	2.54	12.86	32.3	3.99	8.1
Week 3	− 57.34	2.78	− 20.64	− 32.18	4.37	− 7.36
Week 4	− 28.57	2.78	− 10.28	− 12.88	4.37	− 2.95
Week 5	− 10.36	2.78	− 3.73	− 23.11	4.37	− 5.29
Week 6	− 7.86	2.78	− 2.83	− 8	4.37	− 1.83
Week 7	− 3.50	2.78	− 1.26	− 12.38	4.37	− 2.83
R^2	0.89			0.66		
F	97.57			24.1		

Overall, sudangrass produced significantly the higher biomass in both years, 2846.5 kg h^{-1} and 2963.7 kg h^{-1} in 2017 and 2018 respectively, while cowpea had the lowest biomass across both years of the study, 887.6 kg h^{-1} (2017) and 977.5 kg h^{-1} (2018). The amount of biomass produced by cover crops in this study is lower than that reported in previous studies (Creamer and Baldwin 2000; Perin et al. 2006; Wang et al. 2008); this reduction in the cover crop biomass could be caused by the granivore ants feeding on the cover crop seeds and leaf cutting ants foraging on the cover crop plants, and other factors such as soil fertility, water availability, and planting methods. While the potential of cover crops to manage insect pests has received much attention (Bugg and Waddington 1994; Zehnder et al. 2007; Danne et al. 2010; Paredes et al. 2013), influence of insect pests on cover crops is limited and warrants further research to determine the pest cover crop relationships to gain maximum benefits of cover crops.

Major weeds in the experimental plots growing alongside cover crops were common sunflower (*Helianthus annuus*) and Palmer amaranth (*Amaranthus palmeri*). Our results show that all the cover crops used in the study significantly suppressed the weed growth in both 2017 ($F_{4,15} = 19.88$, $P = 0.000$) and 2018 ($F_{4,15} = 64.87$, $P = 0.000$), thus reducing the weed seed pool in the soil and resulting in the low weed emergence in the cover crop treatment plots (Table 3 and Fig. 3c). While the year × cover crop interaction did not have a significant effect on the weed biomass in cover crops ($F_{4,30} = 2.05$, $P = 0.112$), the interaction did have a significant impact on the weed biomass in the cash crops ($F_{4,30} = 205.64$, $P = 0.000$). For weeds in cash crops, in 2017, there was no significant difference in weed emergence in cash crops among the different cover crop treatments; however, in 2018, cash crops in sunn hemp plots had the lowest weed emergence compared with other cover crop treatments and control. There was a significant

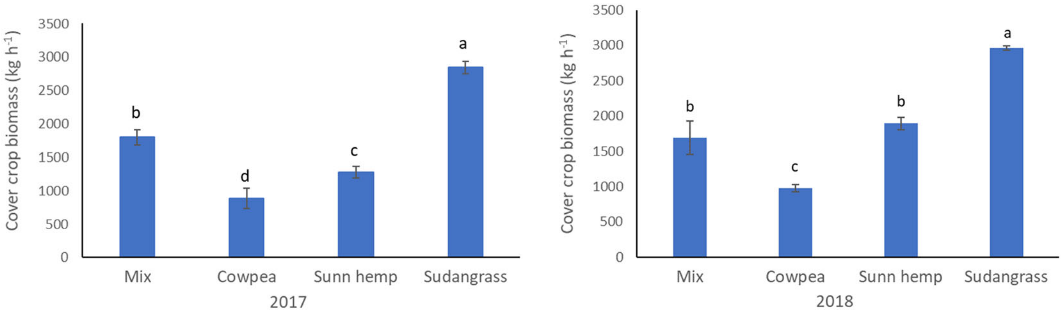

Fig. 2 Cover crop biomass production during 2017 and 2018. Bars sharing a common letter do not differ significantly at $P \leq 0.05$

Table 3 Weed biomass (g m^{-2}) in the different cover crop treatments and weed biomass in the cash crops after cover crop termination in 2017 and 2018

Cover crop treatment	Weed biomass in cover crops (g m^{-2})		Weed biomass in cash crops (g m^{-2})	
	2017	2018	2017	2018
Control	834.4a	691a	11.94a	7.65a
Mix	86b	13.75b	4.398b	5.55b
Cowpea	7.38b	11.50b	4.29b	4.77b
Sunn hemp	4.37b	11.25b	3.34b	2.75c
Sudangrass	3.20b	4.50b	2.68b	4.27bc

Means in columns followed by the same letter are not significantly different according to Fisher's protected least significant difference test ($P < 0.05$). Since there was no significant difference in the two cash crop subplots, the data presented here is the average of both

reduction in Palmer amaranth biomass, the only weed growing with the cash crops, in both years. The common sunflower, a summer annual, was not present in any of the cash crop treatment plots indicating Palmer amaranth to be the major agricultural weed in fall vegetable production systems at this site. Cover crops (especially grasses) with faster growth rates and total biomass accumulation rates can control weeds by competition for resources such as light, water, and nutrients (Teasdale 1996; Akemo et al. 2000; Creamer and Baldwin 2000; Teasdale et al. 2007). Other cover crops with allelopathic properties (Scott and Weston 1992; Czarnota et al. 2003; Cheema et al. 2007) can also out compete weeds.

In organic farms where chemical termination is limited, cover crops need to be terminated before the plants reach full height for easy mechanical management. Generally, the benefits of cover crops accrue over a long time period, and a short-term study does not represent the benefits of cover crops over time. Data from this study is consistent with other researches which suggest that incorporating cover crops into the cropping cycle (instead of weedy fallow) provides a significant reduction on weed growth during the subsequent cash crop cycle (Ngouajio et al. 2003; Mischler et al. 2010; Altieri et al. 2011; Amossé et al. 2013; Björkman et al. 2015), and thus may save on labor-intensive weed management costs.

When selecting cover crop species for weed management, time to establishment and canopy cover are important considerations. All three cover crops that used in this study—sunn hemp, sudangrass, and cowpea—

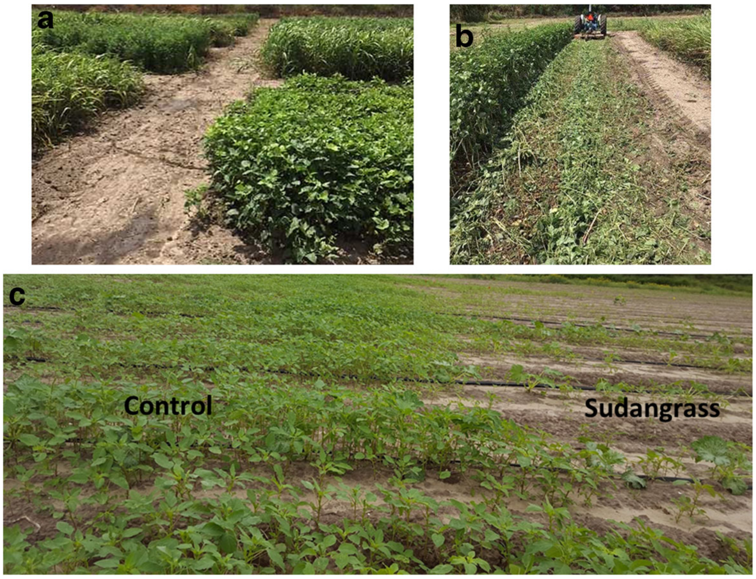

Fig. 3 Cover crop treatment plots (**a**), cover crop termination with a flail mower (**b**), and Palmer amaranth emergence in cash crop, *Cucurbita pepo* (**c**)

successfully established during warm arid conditions, revealing their weed suppression potential as warm season cover crops. All three species have high tolerance to heat and drought and grow quickly to allow for rapid canopy cover. Although the risk of irrigation water carrying the seeds of Palmer amaranth into the field remains, this research demonstrates that cover crops (sunn hemp and sudangrass in particular) have strong potential to significantly reduce weed pressure in these subtropical systems. Both treatments were associated with a reduction in the emergence of Palmer amaranth in subsequent fall vegetable planting, and thus should be included as an effective tool for weed management tools in organic vegetable systems.

Future research is needed to better understand the mechanism of weed suppression for proper cover crop species selection and management. Additionally, more practical research including on timing and effective termination is needed in these subtropical conditions, especially where there is no potential for winter kill or chemical termination. Additional research is required to better understand the cost-effectiveness of these technologies, including cost-benefit analyses that account for seed costs and other opportunity costs versus doing nothing (fallow). This information could then be included in recommendations for a vegetable cropping system that utilizes cover crops in rotation with cash crops to ensure the greatest amount of weed suppression throughout the year.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

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