Integrating Rowcovers and Strip Tillage for Pest Management in Summer Squash and Muskmelon Production

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ADDITIONAL INDEX WORDS. *Acalymma vittatum*, black plastic mulch, cucumber beetle, *Cucumis melo*, *Cucurbita pepo*, *Diabrotica undecimpunctata howardi*, integrated pest management

SUMMARY. Pest management in cucurbit (Cucurbitaceae) cropping systems is challenging. As a result, pesticides are heavily used for managing insect pests and diseases. This work focused on the application of integrated pest management (IPM) techniques to control pests and reduce reliance on insecticide sprays while maintaining the quality and quantity of marketable yields in two commonly grown cucurbit crops: muskmelon (*Cucumis melo*) and summer squash (*Cucurbita pepo*). Plasticulture (raised beds covered in black plastic mulch) and strip tillage, two soil management systems commonly used for cucurbit IPM production, were compared to determine their impact on yield and pest numbers during the 2013–14 growing seasons. Additionally, the use of early season rowcovers and their impact on yield and pest pressure were investigated. Plasticulture use increased marketable yields compared with strip tillage for both summer squash and muskmelon, but strip tillage resulted in fewer total pests for both crops. Rowcover use did not have a consistent effect on insect pest numbers and showed a negative impact on the yield of both summer squash and muskmelon. No significant impacts on yield were observed when the interaction between rowcovers and the tillage system was investigated. The use of rowcovers impacted pest numbers, but these impacts were not consistent between insect pest species. Insecticide use was reduced in covered treatments, but only by one application. We concluded that these management techniques have the potential to be used in an IPM system, but the reduced marketable yield of strip tillage systems may reduce the adoption of this IPM technique for these crops.

vittatum) and spotted cucumber beetle (*Diabrotica undecimpunctata howardi*). Squash bug is known to harbor and transmit cucurbit yellow vine disease (*Serratia marcescens*), which can cause up to 100% yield loss (Bruton et al., 2003; Pair et al., 2004). Cucumber beetle species can cause severe feeding damage and spread cucurbit bacterial wilt (*Erwinia tracheiphila*) (Ellers-Kirk and Fleischer, 2006; Rojas et al., 2015), thereby costing U.S. producers more than \$100 million per year in crop losses and control measures (Schroder et al., 2001). Diseases often spread quickly throughout a field and can substantially decrease the marketable yield and crop value (Blancard et al., 1994).

Insecticide use alone does not ensure control of pest arthropods and can have a negative impact on beneficial arthropods, such as pollinators and predators (Criswell, 1987; Desneux et al., 2007; Dively and Kamel, 2012). Alternative control measures should be considered (Lewis et al., 1997) to reduce reliance on insecticides. Growers have been encouraged to adopt various integrated pest management (IPM) techniques for cucurbit cropping systems. These techniques are designed to reduce sole reliance on chemical insecticide, boost ecosystem functioning, and increase yield (Kogan, 1998; Waterfield and Zilberman, 2012).

Research of cucurbit IPM for insect pests and the pathogens they vector has focused on physical control [i.e., rowcover barriers, cultivation practices, and mulching (Orozco-Santos et al., 1995; Rojas et al., 2011; Zehnder et al., 2007)] and cultural control [i.e., crop rotation, the use of trap crops, adjustment of planting dates, and soil amendments (Cavanagh et al., 2009; Dogramaci et al., 2004; Keinath, 1996; Zehnder et al., 2007)]. Growers can also

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Muskmelon (*Cucumis melo*), squash (*Cucurbita* sp.), cucumber (*Cucumis sativa*), pumpkin (*Cucurbita pepo*), and other cucurbit crops are valued at more than \$1.6 billion per year in the United States (U.S. Department of Agriculture, 2017). Historically, pest management has been challenging in these crops. Arthropods cause damage by feeding and vectoring many cucurbit diseases (Cranshaw, 2004; Zitter et al., 1996). The two most important disease vectors in cucurbit systems in Kentucky are squash bug (*Anasa tristis*) and cucumber beetles [striped cucumber beetle (*Acalymma*

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.3048	ft	m	3.2808
0.0929	ft ²	m ²	10.7639
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	kg·ha ⁻¹	0.8922
2.2417	ton(s)/acre	Mg·ha ⁻¹	0.4461

incorporate the use of monitoring techniques to more accurately and judiciously use insecticides (Tollefson, 1986).

The use of rowcovers and production management practices, such as soil management, are two of the most easily manipulated and often used IPM techniques in cucurbit cropping systems. Rowcover use has been broadly studied and recommended as an IPM technique, and it is commonly used in both conventional and organic production to reduce insecticide use (Skidmore et al., 2017), nontarget effects (Jensen and Malter, 1995), disease (Perring et al., 1989; Webb and Linda, 1992), harvest time (Arancibia and Motsenbocker, 2008), and pest numbers (Webb and Linda, 1992). Rowcovers are also used to increase marketable yields (Arancibia and Motsenbocker, 2008; Ibarra et al., 2001; Loy and Wells, 1975; Perring et al., 1989; Skidmore et al., 2017) and plant vigor (Soltani et al., 1995) and to optimize the microclimate (Condrón et al., 2000; Loy and Wells, 1975; Nair and Ngouajio, 2010; Orozco-Santos et al., 1995). Soil management in cucurbit production can impact arthropod populations and improve crop yields (Aziz et al., 2013; Batey, 2009; Sheibani and Ahangar, 2013; Wolters, 2000; Yao et al., 2006). Strip tillage is a form of conservation tillage that reduces the disruption of the soil and increases microbial biomass by only disrupting narrow strips with tillage for planting and leaving the remaining area untilled (Aziz et al., 2013; Hoyt et al., 1994; Kladvik, 2001; Lupwayi et al., 1998; Stinner and House, 1990). This can result in yields equivalent to those of conventional tillage systems for summer squash (NeSmith et al., 1994; Tillman et al., 2015a), but it can be challenging for muskmelon production (Skidmore et al., 2017; Tillman et al., 2015b) because fruit in direct contact with soil is more susceptible to damage and disease. Plasticulture is a management system that uses conventional tillage with plastic-covered raised beds. It is often used for cucurbit production because it decreases disease and arthropod pests and increases soil temperatures and yields (Baker and Reddy, 2001; Mahadeen, 2014; Necibi et al., 1992; Tarara, 2000; Tillman et al., 2015a,

2015b). One major challenge to this system is the removal of the plastic, which results in waste that is difficult to recycle and often nonbiodegradable (Haapala et al., 2014; Kyrikou and Briassoulis, 2007).

The influences of rowcover use and tillage system on yield and pest pressure in cucurbit cropping systems should be investigated to improve our understanding of the impact that these management practices have on ecosystem functioning and production economics. We focused on the use of rowcovers and soil management to increase cucurbit yields and reduce environmental impacts in conventionally managed production systems using two model cucurbit crops: summer squash and muskmelon. The authors have previously published the results of similar studies of an organic management system (Skidmore et al., 2017). Skidmore et al. (2017) determined that strip tillage systems decreased pest numbers, but the overall marketable yields of summer squash and muskmelon were significantly greater in plasticulture systems. Rowcover use increased yields in both systems, but the plasticulture system with rowcovers produced the greatest yields. Many of the IPM techniques developed for cucurbit crops can be used in both organic and conventional systems. This work aimed to determine if rowcover use and different soil management practices would result in comparable yields and pest control in conventionally managed agriculture systems.

Materials and methods

EXPERIMENT LOCATION AND DESIGN. Field sites were located at the University of Kentucky Horticulture Research Farm in Lexington (lat. 37°58'25.92"N, long. 84°32'5.85"W). Each 0.3-acre field was separated by a 10-ft-wide grass buffer from any other experiments conducted in surrounding fields.

Summer squash and muskmelon studies were conducted in 2013 and 2014. Each year, and for each crop, a randomized complete block design with a split-plot treatment arrangement was used to create a total of four replicate blocks. Each block was divided into two main plots (each was 27 × 50 ft) that were randomly assigned to strip tillage or plasticulture

production systems. This resulted in a field plot containing four strip tillage and four plasticulture main plots. Main plots consisted of four 40-ft-long rows on 6-ft centers. The two outer rows were buffer rows, and two center rows were designated as treatment rows. Grade 20 spun-bonded polypropylene rowcover (Berry Plastics, Evansville, IN) was randomly assigned to one treatment row, and the other treatment row was left uncovered. At the time of planting, rowcovers were stretched over metal hoops (height, 2 ft) and held in place with soil. Rowcovers were removed at the time of appearance of pistillate flowers to allow for pollination.

FIELD PREPARATION. Field preparation was similar for summer squash and muskmelon studies in 2013 and 2014 (Table 1). The plasticulture subplots were moldboard-plowed and disked, and a plastic layer (Rain-Flo Irrigation, East Earl, PA) was used to form 3-ft-wide × 4-inch-high raised beds covered in black plastic. Tillage in strip tillage rows was 8 inches wide and ≈6 inches deep, with the remaining ground left undisturbed. In 2013, a walk-behind tractor with a tillage implement (710; BCS America, Portland, OR) was used to form the strip till rows; however, in 2014, a strip tiller (6000 Strip Till Components; Hiniker Co., Mankato, MN) was used. Paraquat dichloride herbicide (Gramoxone Inteon; Syngenta, Basel, Switzerland) applied at the recommended rate (Saha et al., 2015) was used between rows and around plot edges in both soil management systems to help with weed management. Drip irrigation lines (FlowControl; The Toro Co., Bloomington, MN) were placed in the center of each row, either under the plastic-covered raised beds or centered on the surface of the strip-tilled area and secured in place by sod staples (31206; Agri Supply, Garner, NC).

'Multipik' summer squash and 'Athena' muskmelon transplants were started from seeds (Johnny's Selected Seeds, Winslow, ME), grown in a greenhouse, and acclimated to outside conditions before transplanting. When planted, seedlings were 5 weeks old in 2013 and 3 weeks old in 2014. This difference was due to waterlogged soils in 2013, which delayed

Table 1. Order of field operation in 2013 and 2014 at the University of Kentucky Horticulture Research Farm, Lexington, KY, for muskmelon and summer squash production.

Field operation	2013		2014	
	Muskmelon	Summer squash	Muskmelon	Summer squash
Planting of cover crop ^z		Fall 2012		Fall 2013
Summer squash and muskmelon seeded		15 Apr.		1 May
Preparation of strip tillage plots		20 May		20 May
Preparation of plasticulture plots		20 May		21 May
Transplanting date; implementation of rowcover		21 May		27 May
Removal of rowcover		18 June	20 June	16 June
Start of harvest	23 July	21 June	21 July	16 June
Final harvest	12 Aug.	23 July	8 Aug.	18 July

^zCover crop mix of 148.5 lb/acre cereal rye (Johnny's Selected Seeds, Winslow, ME), 37 lb/acre tillage radish (Johnny's Selected Seeds), and 123.5 lb/acre austrian winter pea (SeedBarn, Odessa, FL). 1 lb/acre = 1.1209 kg·ha⁻¹.

planting. A mechanical planter (1600 Series; Rain-Flo Irrigation) was used to transplant 20 plants per row with 2-ft spacing.

Fungicides were applied with a weekly schedule when cucurbit powdery mildew (*Podosphaera xanthii* and *Erysiphe cichoracearum*) was detected in neighboring cucurbit fields. Insecticide was sprayed when pest density was more than one cucumber beetle per plant when surveyed (Brust and Foster, 1999; Brust et al., 1996; Burkness and Hutchison, 1998). Although squash bug does not have a set economic injury level, we used the same threshold of one per plant. Insecticides and fungicides were rotated throughout the season based on the mode of action and applied according to label specifications (Table 2). Imidacloprid use increased in 2014 due to changes in farm management practices to mitigate pest infestations across the farm; this was beyond the control of the researchers. Muskmelon were harvested twice weekly and summer squash were harvested three times per week for 4 weeks in both 2013 and 2014. Fruit in both studies were graded based on the University of Kentucky Vegetable Production Guide for Commercial Growers (Saha et al., 2015).

PEST MONITORING. To analyze the impact of soil management systems and rowcover on pest management, key pests [striped cucumber beetle (STCB), spotted cucumber beetle (SPCB), and squash bug (SB)] were recorded throughout the season in the summer squash and muskmelon plots using visual surveys. These visual pest surveys were conducted on a weekly basis (muskmelon 2013, 3 June–5 Aug.; muskmelon 2014, 10 June–28 July; summer squash 2013, 5 June–1 July; summer squash 2014, 9 June–4 July) during both years. Visual surveys

were begun for uncovered treatments at the time of planting. Three 60-s observations were made in each treatment row using a 3-ft × 3-ft quadrat randomly placed in the plant row area. The area within the quadrat was thoroughly searched (including foliage, flowers, and ground), and the total numbers of adult STCB, adult SPCB, and adult and nymph SB were recorded. In the covered treatments, “zeros” were reported before rowcover removal because the rowcovers effectively blocked pests from entering the system, and removal of covers to search plants would have exposed treatments to pests. Throughout the study, all observations were made between 7:00 and 11:00 AM, after dawn, and before the heat of the day.

DATA ANALYSIS. An analysis of variance using a Proc GLM (SAS version 9.4; SAS Institute, Cary, NC) was conducted to compare yield and pest data. Yield data and pest data were log-transformed for analysis, and normality was assessed for the residuals of all models using the Shapiro-Wilk test, for which α values >0.05 were considered normally distributed. Marketable yield (those that could be sold) and nonmarketable yield (those that must be discarded) were compared across soil management systems and rowcover treatments in each study. The total pest numbers observed were also compared across soil management systems and rowcover treatments for both studies. Summer squash and muskmelon systems were analyzed individually.

Results

MUSKMELON STUDY. Yield data showed significant differences between soil management systems (Table 3). Plasticulture increased marketable yield

in both 2013 and 2014, with significantly greater marketable yields when analyzed by both weight [2013: $F = 81.24$ (numerator, denominator $df = 1,6$), $P < 0.001$; 2014: $F = 109.66$ ($df = 1,6$), $P < 0.001$] and fruit number [2013: $F = 95.45$ ($df = 1,6$), $P < 0.001$; 2014: $F = 55.69$ ($df = 1,6$), $P < 0.001$]. In 2013, there was no significant difference in nonmarketable yield; however, in 2014, plasticulture had an increase in nonmarketable weight and fruit number as compared with strip tillage. The marketable yield of uncovered treatments was not significantly greater than that of covered treatments in either 2013 or 2014. This was also reflected in the nonmarketable yield data for both 2013 and 2014. No significant interactions between the soil management system and rowcover use were observed in either year of the study.

STCB and SPCB were found in sufficient numbers to compare statistically (Fig. 1A and B). SB was observed in the field but did not reach our predetermined economic injury level of one per plant. In 2013, there were no statistical differences between soil management system for STCB or SPCB, but total pests were reduced in the strip till system. Rowcover treatments showed no difference with regard to SPCB, but rowcover use decreased STCB and total pests. In 2014, tillage treatment did not significantly impact STCB, but it was nearly significant when the total pest numbers were combined. Rowcover significantly reduced the number of STCB and total number of pests, but it had no significant effects on SPCB. In both years of the study, SPCB had no significant treatment interaction.

Table 2. Insecticide and fungicide applications used for muskmelon and summer squash studies in 2013 and 2014 at the University of Kentucky Horticulture Research Farm, Lexington, KY.

Date	Muskmelon	Summer squash	Chemical application ^z	Rate (lb/acre) ^y
2013				
21 May	✓	✓	Imidacloprid	0.71
19 June	✓	✓	Clethodim	0.75
17 July	✓	✓	Ethalfuralin	9.15
			Paraquat dichloride	5.09
24 July	✓		Azoxystrobin	0.77
30 July	✓		Penthiopyrad	3.70
2 Aug.	✓		Ethalfuralin	9.15
			Paraquat dichloride	5.09
6 Aug.	✓		Azoxystrobin	0.77
2014				
27 May	✓	✓	Imidacloprid	0.71
27 June	✓	✓	Penthiopyrad	3.70
			Bifenthrin	1.26
1 July	✓	✓	Zeta-cypermethrin	0.49
			Pyraclostrobin + boscalid	2.73
16 July	✓	✓	Zeta-cypermethrin	0.49
			Penthiopyrad	3.70
22 July	✓	✓	Acetamiprid	0.46
			Bifenazate	2.89
			Quinoxifen	1.90
25 July	✓		Myclobutanil	0.68
			Propamocarb hydrochloride	18.28
6 Aug.	✓		Acetamiprid	0.46
			Myclobutanil	0.68
			Cuprous oxide	5.71
13 Aug.	✓		Spiromesifen	2.69
			Penthiopyrad	3.70
			Quinoxifen	1.90
			Acetamiprid	0.46

^zInsecticides: acetamiprid (Assail 30 SG; United Phosphorus, King of Prussia, PA); bifenthrin (Brigade 2EC; FMC Corp., Philadelphia, PA); imidacloprid (Admire 4.6F; Bayer, Triangle Park, NC); spiromesifen (Oberon 2SC; Bayer); and zeta-cypermethrin (Mustang Maxx; FMC Corp.). Fungicides: azoxystrobin (Quadris; Syngenta, Basel, Switzerland); chlorothalonil (Equus 720 SST; Makhteshim Agan of North America, Raleigh, NC); cuprous oxide (Nordox 75 WG; Nordox, Oslo, Norway); myclobutanil (Rally 40WSP; Dow AgroScience, Indianapolis, IN); penthiopyrad (Fontelis; DuPont, Wilmington, DE); propamocarb hydrochloride (Previcur, Bayer); pyraclostrobin + boscalid (Pristine; BASF Corp., Florham Park, NJ); quinoxifen (Quintec; Dow AgroScience); and zinc ion + manganese ethylenebisdithiocarbamate (Manzate Pro-Stick; United Phosphorus). Herbicides: clethodim (SelectMax; Valent, Walnut Creek, CA); ethalfuralin (Curbit EC; Loveland Products, Loveland, CO); and paraquat dichloride (Gramoxone Inteon, Syngenta).

^y1 lb/acre = 1.1209 kg·ha⁻¹.

The interaction between rowcover use and soil management system was significant for STCB, with uncovered plastic treatments having greater pest pressure in 2013; however, in 2014, uncovered strip till treatments had greater pest pressure. The interaction between treatments and total pests was significant in both years, with uncovered plastic treatments having more pests in both 2013 and 2014.

SUMMER SQUASH STUDY. Marketable yields were greater than nonmarketable yields in both years of the study (Table 3). Plasticulture resulted in significantly higher marketable yields than strip tillage in 2013 and 2014, both in weight [2013: $F = 20.43$ ($df = 1,6$), $P < 0.004$; 2014: $F = 59.87$ ($df = 1,6$), $P < 0.001$] and fruit number [2013: $F = 10.52$ ($df = 1,6$), $P = 0.018$; 2014: $F =$

55.58 ($df = 1,6$), $P < 0.001$]. Strip tillage had lower nonmarketable yields than plasticulture in 2013 and 2014, in both weight and fruit number. Rowcover use significantly increased marketable yield weight in 2013, but it did not significantly impact the marketable yield number or marketable yield weight in 2014. Rowcover use did not result in significant differences between nonmarketable yield in either year of the study for weight or number. The interaction between the soil management system and rowcover was not significant for marketable yield weight or total fruit number in either year.

In 2013, no significant differences were observed between tillage systems for any pest species (SB, STCB, SPCB) or total pests. In 2014, there were fewer SB, STCB,

and total pests with strip tillage, but SPCB were increased. Rowcover use did not significantly influence pest numbers in 2013. In 2014, rowcover use decreased the number of SB, STCB, SPCB, and total pests. There was no interaction between rowcover use and soil management system for any pest species or total pests. There was a significant interaction between tillage and rowcover use in 2014, when rowcover use and plasticulture increased STCB, but there was no significant interaction for the other pest species SB, SPCB, or total pests. These results are shown in Fig. 2A and B.

Discussion

Because of the environmental benefits of reduced tillage (Aziz et al.,

Table 3. Mean marketable and nonmarketable yield (scaled to reflect the yield per acre) of the 2013 and 2014 muskmelon and summer squash studies at the University of Kentucky Horticulture Research Farm, Lexington, KY.

		2013				2014			
		Marketable		Nonmarketable		Marketable		Nonmarketable	
		(tons/ acre) ^z	(fruit/ acre) ^z	(tons/ acre)	(fruit/ acre)	(tons/ acre)	(fruit/ acre)	(tons/ acre)	(fruit/ acre)
Muskmelon									
Treatment ^y									
	PR	10.91	4,401	15.47	6,942	27.34	8,470	12.09	4,598
	PN	15.15	5,853	15.68	8,258	29.21	10,285	10.69	3,872
	SR	0.95	8,170	13.52	7,532	8.63	2,844	3.61	1,513
	SN	1.56	1,361	14.47	7,215	8.50	3,328	4.82	1,997
		<i>P</i>							
	R ^x	0.096	0.087	0.639	0.306	0.400	0.098	0.599	0.825
	T	0.001	0.001	0.360	0.876	0.001	0.001	0.001	0.003
	R × T	0.363	0.639	0.663	0.258	0.669	0.918	0.282	0.288
Summer squash									
Treatment									
	PR	17.77	41,745	3.34	9,892	20.09	82,462	4.01	16,940
	PN	16.66	41,881	3.61	11,525	23.73	96,558	4.38	18,271
	SR	14.31	33,169	2.28	8,803	11.44	46,827	2.18	9,317
	SN	10.66	29,721	2.45	8,440	12.84	54,087	2.72	11,193
		<i>P</i>							
	R	0.047	0.535	0.324	0.563	0.117	0.984	0.290	0.194
	T	0.004	0.018	0.001	0.032	0.001	0.001	0.010	0.001
	R × T	0.137	0.501	0.758	0.294	0.748	0.918	0.818	0.688

^z1 ton/acre = 2.2417 Mg·ha⁻¹, 1 fruit/acre = 2.4711 fruit/ha.

^yPR = plasticulture with rowcover; PN = plasticulture with no rowcover; SR = strip tillage with rowcover; SN = strip tillage with no rowcover.

^xR = rowcover; T = tillage.

Significance (*P* values) are based on total yields from the entire season. Total marketable yield + total nonmarketable yield = total yield.

2013; Hole et al., 2005; Lewis et al., 2016; Lupwayi et al., 1998; Mäder et al., 2002; Sheibani and Ahangar, 2013; Stinner and House, 1990; Verhulst et al., 2010), one of our objectives was to determine if strip tillage could be an acceptable alternative to plasticulture in cucurbit production. Strip tillage underperformed in both years of the study compared with plasticulture, and it resulted in significantly reduced summer squash and muskmelon yields. Although conservation systems have the potential for yields comparable to those of conventional tillage (Hoyt, 1999; NeSmith et al., 1994; Tillman et al., 2015a), this was not observed in our study.

SOIL MANAGEMENT SYSTEM. The soil management system impacted both yield and pest management. Marketable yields and pest numbers were generally greatest in the plasticulture systems for both the summer squash and muskmelon studies in 2013 and 2014. Previous studies also showed increased yields in plasticulture systems compared with other tillage practices (Lilley and Sánchez, 2016; Mahadeen, 2014; Parmar

et al., 2013; Tillman et al., 2015a, 2015b), and pest pressure is often greater in conventionally tilled crops than in reduced tillage systems (Cheshire and All, 1979; Dieterich-Mabin, 2017; Stinner and House, 1990).

Plasticulture contributes to increased yields by increasing soil temperatures, resulting in increased plant biomass and yield in cucurbit systems (Baker and Reddy, 2001; Jenni et al., 1996; Tillman et al., 2015a). Strip tillage has been shown to decrease soil temperatures and increase soil moisture, which can impede vine growth and yield in cucurbit crops (Hoyt et al., 1994; Johnson and Hoyt, 1999; Tillman et al., 2015a, 2015b; Verhulst et al., 2010). Plasticulture resulted in greater marketable yields of both the summer squash and muskmelon. Because of the considerably greater yields with plasticulture, it was not surprising that these treatments had greater nonmarketable yields than the strip tillage systems.

In the muskmelon study, plasticulture resulted in an increased total

number of total pests. Individual species (STCB, SPCB) showed no significant response to soil management. Quinn et al. (2016) observed that foliar insect pest populations do not always respond to production system changes and can be equally prevalent in strip tillage and conventional tillage systems.

Soil management systems influenced STCB, SPCB, and SB numbers in the summer squash study. During both years, there was higher total pest pressure with plasticulture. Rowcover use and the tillage system influenced STCB in 2014, with uncovered plasticulture treatments having a higher number of beetles. Individual species were also influenced by growing practices; SB numbers were higher with the plasticulture system (2013) and SPCB numbers were higher with strip tillage (2014). Pest populations fluctuate across multiple seasons, but basic biological differences may explain these differences. Larger plants, resulting from the benefits of plasticulture, may have proved more attractive to STCB and SB, and these plants provided a larger habitat area

Fig. 1. Mean number of insect pests collected per week from row-covered and nonrow-covered strip tillage and plasticulture production systems in the muskmelon study during the 2013 (A) and 2014 (B) growing seasons at the University of Kentucky Horticulture Research Farm in Lexington. Total insect pest numbers were compared (total pests), and insects were further subdivided into significant insect pests [striped cucumber beetle (STCB) and spotted cucumber beetle (SPCB)]. R = rowcover, T = tillage, 1 insect/m² = 0.0929 insect/ft².

for SB to use for reproduction (Metcalf and Flint, 1962; York, 1992). STCB and SPCB lay their eggs in soil (Metcalf and Flint, 1962; York, 1992) at the base of plants, so they may have been more attracted to the available open ground provided by strip tillage.

A grower might be willing to accept reduced yield if input costs are reduced and if there are increases in beneficial insects, microbial biomass, and soil stability (Holland, 2004; Verhulst et al., 2010). In our study, these potential benefits (such as reduced pest pressure) were overshadowed by the reduction of yield observed for both the summer squash and muskmelon. As noted by similar strip tillage studies (Lilley and

Sánchez, 2016; Tillman et al., 2015b), the reduced yield observed in the muskmelon study would not be acceptable to a grower.

One potential change that could improve our system is better cover crop management. In the strip tillage system, the cover crop [cereal rye (*Secale cereal*), austrian winter pea (*Pisum arvense*), and tillage radish (*Raphanus sativus* var. *niger*) mix] was extremely thick and difficult to incorporate in the soil with the minimal tillage we used and resulted in poor soil tilth. This created clumping; in combination with the poor soil, this resulted in compaction that affected plant growth in the strip tillage system

throughout both growing seasons. Cover crops can provide many benefits to agriculture production (Dabney et al., 2001; Hartwig and Ammon, 2002), but cucurbit crops are not always impacted by these benefits (Galloway and Weston, 1996; Walters and Young, 2010). We suspect that the decreased soil temperatures (Hoyt, 1999), increased moisture and drainage, and compaction problems (Stivers-Young and Tucker, 1999) in the strip tillage system resulted in reduced yields. Mowing the cover crop earlier in the season to reduce biomass (Snapp and Borden, 2005; Snapp et al., 2005; Stivers-Young and Tucker, 1999) could be an alternative option to help mitigate this problem in the future.

IMPACT OF ROWCOVER USE. Rowcover use did not consistently impact marketable yields in our study. Pest numbers tended to be reduced with treatments involving rowcovers, although there was an increased number of SB with rowcover treatments in the 2013 summer squash study.

Several challenges commonly faced by growers may have influenced our results, including unsuitable environmental temperatures, pollination concerns, and cost-benefit considerations. The temperatures observed under spun-bonded rowcovers are often substantially higher than outside temperatures, which can have a detrimental effect on cucurbit crops (Ibarra et al., 2001; Jenni et al., 1996). Alternative materials, such as high-density polyethylene mesh (ProtekNet; Dubois Agrinovation, Saint-Rémi, QC, Canada) (Brown, 2014; Hanna et al., 2015), may be lighter alternatives that retain less heat, thereby decreasing the temperature stress created by cloth-type spun-bonded materials in cucurbit production. The timing of rowcover removal is key for proper plant pollination and growth (Lilley and Sánchez, 2016; Soltani et al., 1995; Tillman et al., 2015b; Walters, 2003); therefore, our management decision to remove the rowcover at the time of pistillate flower appearance may have influenced yield. Additionally, rowcovers add costs to production and are often usable for only one season, depending on the material weight and handling technique. With the relative

Fig. 2. Mean number of insect pests collected per week from row-covered and nonrow-covered strip tillage and plasticulture production systems for summer squash during the 2013 (A) and 2014 (B) growing seasons at the University of Kentucky Horticulture Research Farm in Lexington. Total insect pest numbers were compared (total pests), and insects were further subdivided into significant insect pests [striped cucumber beetle (STCB), spotted cucumber beetle (SPCB), and squash bug (SB)]. R = rowcover, T = tillage, 1 insect/m² = 0.0929 insect/ft².

efficiency of conventional insecticides and fungicides, the benefits of rowcover for pest management might be negated by their cost and yield reduction of these crops.

Rowcovers did not significantly decrease the amount of insecticide used for either the summer squash or the muskmelon systems. The treatments were different because at the time of planting, uncovered treatments received a soil application of imidacloprid. This product was effective for controlling pest numbers for the same period of time as the rowcovers when they were in place. When a grower uses a less effective chemical control, or when the climate

supports higher disease occurrence, additional sprays would be needed. In these systems, rowcovers would reduce the need for chemical applications until their removal for pollination.

Although rowcovers did not increase yields in our study, Tillman et al. (2015b) observed that rowcovers can increase plant biomass and fruit weight and may be a useful tool for growers using reduced tillage systems in Iowa.

IMPACT OF EXTERNAL FACTORS. Although the results were not compared between 2013 and 2014, it was suspected that external factors had a major role in the differences observed between the 2 years. Crop

yields are impacted by changes in climate, weather patterns, and temperatures (Hatfield et al., 2011). Although we could control the amount of irrigation during drought periods, excessive rain events during our study (Kentucky Mesonet, 2017; National Centers for Environmental Information, 2017) resulted in field flooding that could have had a negative impact on yield (Şimşek et al., 2005). These field conditions created a poor environment for plant growth and development. In 2013, nonmarketable yield was greater than marketable yield of muskmelon, and pest numbers were greater in both the muskmelon and summer squash studies. Losses observed in the muskmelon study were credited to saturated soils that resulted in compaction and plant stunting early in the growing season and waterlogged soils late in the season that increased disease pressure and fruit rot. The plastic mulch provided a more favorable microclimate around the plants, thus increasing plant mass and reducing losses (Parmar et al., 2013). Weather changes can influence arthropod populations (Beleznaï et al., 2017) and disease pressure. In our study, insect pest pressure was lower in 2014, possibly because of the lower spring temperatures and heavy rains throughout the season. Although our study was not designed to examine these external factors, our results showed that soil management systems and rowcover use can impact pest numbers.

IMPLICATIONS OF RESULTS. Reduced tillage and rowcover use can be beneficial in many agricultural settings; however, as shown in this study, these techniques do not always improve plant production or provide equivalent yields. Dogramaci et al. (2004) reported that trap crops reduced SB numbers and damage but negatively impacted the yield of watermelon (*Citrullus lanatus*). Similar studies that have investigated the impact of strip tillage on summer squash and muskmelon production found reduced yields compared with conventional tillage soil management systems (Lilley and Sánchez, 2016; Skidmore et al., 2017; Tillman et al., 2015b). In our study, we showed that although strip tillage may reduce pest numbers, its direct effect on yield would preclude its use for these crops. Producers should consider these

results when choosing to grow summer squash and muskmelon. The results of this study have further increased the understanding of how these IPM strategies can be used in summer squash and muskmelon production systems.

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