2015

Strip tillage and rowcovers as a potential alternative to black plastic mulch in cucurbit production

Jennifer Louise Tillman
Iowa State University

Strip tillage and rowcovers as a potential alternative to black plastic mulch in cucurbit production

by

Jennifer Louise Tillman

A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Co-majors: Sustainable Agriculture; Horticulture

Program of Study Committee:
Ajay Nair, Major Professor
Mark Gleason
Thomas Kaspar

Iowa State University

Ames, Iowa

2015

TABLE OF CONTENTS

Page

LIST OF TABLES

ABSTRACT

The use of tillage and plastic mulch are common practices among cucurbit growers to provide warm, moist, weed-free soil around plants. However, there are environmental drawbacks to the use of plastic mulches, such as the material waste given that these products are used for a single season, and the reduced soil health and stability that can come from frequent and intensive tillage. As an alternative strategy, a biological mulch can be formed by rolling and killing a cover crop stand by using a roller crimper. Narrow, tilled strips can be formed within this mulch for the crop to grow in a strip tillage system. This strategy can retain soil moisture and limit weed growth between rows compared to a non-mulched system, but has a tendency to create cooler soils, which can negatively impact growth for warm season crops, for example cucurbits. However, rowcovers could be used to mitigate this issue, as they can warm the air and soil, and provide protection to plants against insects and wind.

In these studies, two production systems were compared (conventional tillage with black plastic mulch and strip tillage into rolled cereal rye) with and without the use of spunbonded rowcovers in conventionally and organically managed summer squash and muskmelon production. Overall, there were many benefits from using the plastic mulch system for both muskmelon and summer squash production. In general, the soil under plastic mulch was warmer than the soil in strip tillage, though it also tended to be lower in soil moisture. Despite this, the use of rowcovers in conjunction with strip tillage had promising results in squash production, in part due to the increased air temperature provided by the rowcovers. We found more positive outcomes from using rowcovers in organically managed crop than in conventionally managed crops. We saw no consistent

effect of production system on soil microbial biomass carbon. A long-term trial would be needed to observe many of the soil health benefits from this conservation tillage system.

CHAPTER 1. GENERAL INTRODUCTION

The use of plastic in horticulture has been increasing since its introduction in the 1950s. Plastic mulches are one of the many plastic products used in horticulture today. In 2004, approximately 140 tons of polyethylene plastic mulch was used in the United States alone (Shogren and Hochmuth, 2004), and in 2006 the global use of plastic mulch was estimated at 700 tons (Espi et al., 2006). Plastic mulches can offer a wide range of benefits to horticultural crops, including warming of the soil, decreasing weed pressure within the row, decreasing the amount of soil moisture lost to evaporation, and ultimately increasing the amount and quality of produce (Kasirajan and Ngouajio, 2012; Lamont, 2005). A plastic mulch system (plasticulture) has consequently become standard practice for growing crops, especially warm season crops like cucurbits.

The benefits of using plastic mulch come at a cost to the environment. Since polyethylene mulches are designed to be used for one season, each year tons of plastic are removed from fields and either hauled to landfills or burned (Kasirajan and Ngouajio, 2012). Due to the amount of soil adhering to the plastic, recycling the material poses serious challenges (Hemphill, 1993). Researchers have designed bio- and photodegradable film mulches to solve the disposal problem; however, these alternative materials vary in their ability to last throughout the season or to completely degrade after being tilled (Kasirajan and Ngouajio, 2012). Although some of these products can produce similar yields compared to typical polyethylene mulch, they are often much more expensive (Cirujeda et al., 2012).

The issue of disposal is not the sole concern when it comes to the growing use of plasticulture. In order to properly install plastic and degradable film mulches alike, intensive tillage is employed. Intensive and deep tillage can reduce soil aggregate stability when compared to less intensive tillage regimes (Karlen et al., 2013; Stenberg et al., 2000). Over time, less aggressive or reduced tillage can improve soil health indicators such as soil microbial biomass carbon and total organic carbon (Karlen et al., 2013). Compounded with the effects of tillage, impervious plastic can accelerate runoff and increase soil erosion if water is channeled off the plastic and into the alleyways during rain events (Wan and El-Swaify, 1999). These facts point to the need for an alternative to plastic mulch that involves reduced tillage.

One technique for mulching in a reduced tillage system is to create a mulch from a rolled and crimped cover crop and till only narrow strips for planting. In this system, a cover crop that produces dense biomass is grown to maturity, at which point a roller crimper is used to push the cover crop over in one direction and kill it by crimping. A common cover crop used for this purpose is cereal rye (*Secale cereal*) because it is readily available and affordable, can be drilled or broadcast seeded, and can provide ground cover over the winter. Herbicides may be used to ensure a complete kill, but rolling can achieve sufficient kill if the planting and termination of cereal rye are timed correctly (Mirsky et al., 2009). The cover crop is left intact and connected to the root system to aid its persistence throughout the season and create uniform coverage over the soil (Teasdale and Mohler, 1993). This strategy also improves ease of planting given the uni-directional orientation of the residue (Creamer and Dabney, 2002). This, or a similar system, can help limit weed growth compared to systems in which the cover crop is chopped into smaller pieces (Creamer et al., 1995; Wayman et al., 2014).

Many crops have been shown to produce similar yields in a rolled cover crop system compared to a bare ground system, including summer squash (Nesmith et al., 1994), peppers (Delate, 2008), pumpkins (Wyenandt et al., 2011), and carrots (Brainard and Noyes, 2012). Canali et al. (2013) found that zucchini planted no-till into rolled barley had the same yield as a conventionally tilled system without cover crops. Leavitt et al. (2011), however, found that tomato, zucchini and pepper planted no-till into rolled rye, hairy vetch, or a rye-vetch mixture had lower yields than a conventionally tilled system without cover crops. Overall, there is a mixed, though generally positive, perception that rolled cover crop systems can be as productive as conventionally tilled systems.

None of these studies, however, compared rolled cover crop systems to plasticulture. Organic residue on the soil can lower soil temperature, and this, compounded with the warming effects of plastic mulch, leads to a large discrepancy in soil warmth between rolled cover crop and plastic mulch systems (Schonbeck and Evanylo, 1998). When growing warm season crops like cucurbits, this could pose a challenge for using a rolled cover crop system. An additional strategy, such as the use of rowcovers, may be needed for a rolled cover crop strip tillage system to be as productive as plasticulture.

A rowcover is a sheet of material that can be laid over one or several rows of crops, often used with a support structure, such as wire hoops, to keep the material from damaging the crop. One main function is microclimate modification; rowcovers create warm air around the plants, and can even warm the soil within the row (Ibarra-Jiménez et al., 2004), though the extent of warming is dependent on the thickness of the rowcover (Nair and Ngouajio, 2010). They can also provide a physical barrier between insects and plants (Weintraub, 2009). For cucurbit crops, the cucumber beetle is a common insect pest. Not only does the cucumber beetle feed on plants, but it can carry a bacterium, *Erwinia tracheiphila*, in its gut. This bacterium, when transferred to cucurbits through insect feeding, causes bacterial wilt. Bacterial wilt has a wide host range, and can cause severe yield loss in many cucurbit crops (McGrath, 2004). Rowcovers can decrease the incidence of bacterial wilt and increase yield in muskmelon, depending on the timing of rowcover removal and the abundance of cucumber beetles in a given season (Caudle et al., 2013; Saalau Rojas et al., 2011). Because cucurbits are insect pollinated, rowcovers must be removed to allow for pollination unless supplemental pollinators are provided under the rowcovers (Saalau Rojas et al., 2011). Spunbonded rowcovers are a common choice for growers who want both microclimate modification and insect exclusion.

Rowcovers have been shown to increase yields in fresh beans (Gogo et al., 2014), muskmelon (Cline et al., 2008), and watermelon (Soltani et al., 1995), among other crops. Rowcovers can also increase early production in muskmelon (Motsenbocker and Bonanno, 1989; Wells and Loy, 1985). However, Ibarra et al. (2001) showed that spunbonded rowcovers in a plasticulture system increased plant biomass but not yield in muskmelon. In cucumbers, spunbonded rowcovers had no effect on plant biomass or yield in plasticulture cucumbers (Ibarra-Jiménez et al., 2004). Nair and Ngouajio (2010) saw a yield increase when rowcovers were used in cucumber on black plastic mulch, but only when compost was added to all treatments. There is potential for rowcovers to aid in plant growth and yield, though previous studies are not conclusive.

My thesis research focused on the field work I performed in 2013 and 2014, in which I compared two production systems (plasticulture and rolled rye strip tillage) with and without rowcovers in conventionally and organically managed summer squash and muskmelon. Chapter 2 will focus on the results from the muskmelon portion of this research, and Chapter 3 will focus on the summer squash. In Chapter 4, I will draw conclusions about the studies, and point to areas where more research is needed.

Literature Cited

Brainard, D.C. and Noyes, D.C. 2012. Strip tillage and compost influence carrot quality, yield, and net returns. HortScience 47:1073-1079.

Canali, S., Campanelli, G., Ciaccia, C., Leteo, F., Testani, E., and Montemurro, F. 2013. Conservation tillage strategy based on the roller crimper technology for weed control in Mediterranean vegetable organic cropping systems. European J. Agron. 50:11-18.

Caudle, J.R., Coolong, T., Williams, M.A., Vincelli, P., and Bessin, R. 2013. Development of an organic muskmelon production system against bacterial wilt disease. II Intl. Organic Fruit Symp. 1001:249-254.

Cirujeda, A., Aibar, J., Anzalone, A., Martin-Closas, L., Meco, R., Moreno, M.M., Pardo, A., Pelacho, A.M., Rojo, F., Royo-Esnal, A., Suso, M.L., and Zaragoza, C. 2012. Biodegradable mulch instead of polyethylene for weed control of processing tomato production. Agron. Sustainable Dev. 32:889-897.

Cline, G.R., Sedlacek, J.D., Hillman, S.L., Parker, S.K., and Silvernail, A.F. 2008. Organic management of cucumber beetles in watermelon and muskmelon production. HortTechnology 18:436-444.

Creamer, N.G. and Dabney, S.M. 2002. Killing cover crops mechanically: Review of recent literature and assessment of new research results. Amer. J. Alternative Agr. 17:32-40.

Creamer, N.G., Plassman, B., Bennett, M.A., Wood, R.K., Stinner, B.R., and Cardina, J. 1995. A method for mechanically killing cover crops to optimize weed suppression. Amer. J. Alternative Agric. 10:157-162.

Delate, K. 2008. Effects of organic fertilization and cover crops on an organic pepper system. HortTechnology 18:215.

Espi, E., Salmeron, A., Fontecha, A., Garcia, Y., and Real, A.I. 2006. Plastic films for agricultural applications. J. Plast. Film Sheeting 22:85-102.

Gogo, E.O., Saidi, M., Ochieng, J.M., Martin, T., Baird, V., and Ngouajio, M. 2014. Microclimate modification and insect pest exclusion using agronet improve pod yield and quality of french bean. HortScience 49:1298-1304.

Hemphill, D.D., Jr. 1993. Agricultural plastics as solid waste: What are the options for disposal? HortTechnology 3:70-73.

Ibarra-Jiménez, L., Quezada-Martin, M.R., and de la Rosa-Ibarra, M. 2004. The effect of plastic mulch and row covers on the growth and physiology of cucumber. Austral. J. Expt. Agr. 44:91-94.

Ibarra, L., Flores, J., and Díaz-Pérez, J.C. 2001. Growth and yield of muskmelon in response to plastic mulch and row covers. Scientia Hort. 87:139-145.

Karlen, D.L., Cambardella, C.A., Kovar, J.L., and Colvin, T.S. 2013. Soil quality response to long-term tillage and crop rotation practices. Soil Tillage Res. 133:54-64.

Kasirajan, S. and Ngouajio, M. 2012. Polyethylene and biodegradable mulches for agricultural applications: A review. Agron. Sustainable Dev. 32:501-529.

Lamont, W.J., Jr. 2005. Plastics: Modifying the microclimate for the production of vegetable crops. HortTechnology 15:477-481.

Leavitt, M.J., Sheaffer, C.C., Wyse, D.L., and Allan, D.L. 2011. Rolled winter rye and hairy vetch cover crops lower weed density but reduce vegetable yields in no-tillage organic production. HortScience 46:387-395.

Licht, M.A. and Al-Kaisi, M. 2005. Strip-tillage effect on seedbed soil temperature and other soil physical properties. Soil Tillage Res. 80:233-249.

McGrath, M.T. 2004. Diseases of cucurbits and their management, p. 455-510, Diseases of Fruits and Vegetables: Diagnosis and Management. Kluwer Academic Publishers, Dordrecht, the Netherlands.

Mirsky, S.B., Curran, W.S., Mortensen, D.A., Ryan, M.R., and Shumway, D.L. 2009. Control of cereal rye with a roller/crimper as influenced by cover crop phenology. Agron. J. 101:1589-1596.

Motsenbocker, C.E. and Bonanno, A.R. 1989. Row cover effects on air and soil temperatures and yield of muskmelon. HortScience 24:601-603.

Nair, A. and Ngouajio, M. 2010. Integrating rowcovers and soil amendments for organic cucumber production: Implications on crop growth, yield, and microclimate. HortScience 45:566-574.

Nesmith, D.S., Hoogenboom, G., and McCracken, D.V. 1994. Summer squash production using conservation tillage. HortScience 29:28-30.

Saalau Rojas, E.S., Gleason, M.L., Batzer, J.C., and Duffy, M. 2011. Feasibility of delaying removal of row covers to suppress bacterial wilt of muskmelon (*Cucumis melo*). Plant Dis. 95:729-734.

Schonbeck, M.W. and Evanylo, G.K. 1998. Effects of mulches on soil properties and tomato production I. Soil temperature, soil moisture and marketable yield. J. Sustainable Agric. 13:55-81.

Shogren, R.L. and Hochmuth, R.C. 2004. Field evaluation of watermelon grown on paper-polymerized vegetable oil mulches. HortScience 39:1588-1591.

Soltani, N., Anderson, J.L., and Hamson, A.R. 1995. Growth analysis of watermelon plants grown with mulches and rowcovers. J. Amer. Soc. Hort. Sci. 120:1001-1009.

Stenberg, M., Stenberg, B., and Rydberg, T. 2000. Effects of reduced tillage and liming on microbial activity and soil properties in a weakly-structured soil. Appl. Soil Ecol. 14:135-145.

Teasdale, J.R. and Mohler, C.L. 1993. Light transmittance, soil-temperature, and soil-moisture under residue of hairy vetch and rye. Agron. J. 85:673-680.

Wan, Y. and El-Swaify, S.A. 1999. Runoff and soil erosion as affected by plastic mulch in a Hawaiian pineapple field. Soil Tillage Res. 52:29-35.

Wayman, S., Cogger, C., Benedict, C., Burke, I., Collins, D., and Bary, A. 2014. The influence of cover crop variety, termination timing and termination method on mulch, weed cover and soil nitrate in reduced-tillage organic systems. Renew. Agric. Food Syst. FirstView:1-11.

Weintraub, P.G. 2009. Physical control: An important tool in pest management programs. Springer, New York.

Wells, O.S. and Loy, J.B. 1985. Intensive vegetable production with row covers. HortScience 20:822-826.

Wyenandt, C.A., Riedel, R.M., Rhodes, L.H., Bennett, M.A., and Nameth, S.G.P. 2011. Fall- and spring-sown cover crop mulches affect yield, fruit cleanliness, and fusarium fruit rot development in pumpkin. HortTechnology 21:343-354.

CHAPTER 2. EVALUATING STRIP TILLAGE AND ROWCOVER USE IN ORGANIC AND CONVENTIONAL MUSKMELON PRODUCTION

Modified from a paper accepted to *HortTechnology*

Jennifer Tillman[1], Ajay Nair[1]*, Mark Gleason[2], and Jean Batzer[2]

Summary

Increasing interest in using cover crops and reduced tillage to build soil health has created a demand for strategies to implement rolled cover crop systems. In northern areas of the U.S., cool soil temperature in rolled cover crop systems can create a challenge when growing warm season vegetable crops. The use of rowcovers could mitigate the issue and facilitate adoption of rolled cover crop systems for both conventional and organic growers. This study investigated muskmelon (*Cucumis melo*) in two production systems [strip tillage into rolled rye (ST) or conventional tillage with black plastic mulch (plasticulture)] with or without the use of spunbonded polypropylene rowcovers. The trial was conducted in two fields, one in organic management and the other in conventional management. In general, ST led to cooler, moister soils than plasticulture, but rowcovers rarely impacted soil temperature. Rowcovers increased mean and maximum daily air temperature and decreased light intensity. Rowcovers sometimes increased fruit size, but rarely affected marketable yield. Overall, ST reduced total and marketable yield compared to plasticulture; however, ST with rowcovers often produced similar vegetative

---

[1]Department of Horticulture, Iowa State University, Ames, IA 50010

[2]Department of Plant Pathology and Microbiology, Iowa State University

*To whom correspondence should be addressed. E-mail nairajay@iastate.edu

growth compared to plasticulture without rowcovers. Given the slow vining growth habit of muskmelon and the late planting inherent in a rolled rye system, achieving high muskmelon yields, especially early yields, may be difficult.

Introduction

Current cucurbit production systems in the U.S. often rely on tillage and plastic film mulches to create favorable growing conditions of warm soils and minimal weed pressure around plants; however, there are environmental concerns about the disposal of plastic mulches (Hemphill, 1993). An alternative would be to use biodegradable film mulches, but they are often prohibitively expensive (Kasirajan and Ngouajio, 2012). Additionally, in order to achieve adequate soil to plastic contact with film mulches, intensive tillage is used, but this practice can harm soil microbes (Jackson et al., 2003), decrease soil carbon (Roper et al., 2010) and decrease earthworm diversity (Pelosi et al., 2014). These factors, and others, are indicators of soil health, as they can be used to measure the soil's ability to sustain and support a viable ecosystem. Interest in preserving soil health and building topsoil is increasing among organic and conventional growers, and a focus on cover crop usage and reduced tillage systems could minimize negative impacts on soil chemical, biological, and physical properties (Balota et al., 2014; Doran, 1987; Roper et al., 2010; Wyland et al., 1996).

Reduced tillage systems can produce similar or greater yields compared to conventional tillage systems in several vegetable crops such as carrot (*Daucus carota*) (Brainard and Noyes, 2012), cabbage (*Brassica oleracea*) (Haramoto and Brainard, 2012), pepper (*Capsicum annuum*) (Delate, 2008), pumpkin (*Cucurbita pepo*) (Rapp et al., 2004), summer squash (*Cucurbita pepo*) (Nesmith et al., 1994), sweet corn (*Zea mays*) (Luna and Staben, 2002), and zucchini (*Cucurbita pepo*) (Canali et al., 2013).

Although reduced tillage systems can increase long-term soil productivity and health, several drawbacks may discourage the adoption of these practices. Growers may confront issues with soil compaction (Salem et al., 2015) and weeds in the years transitioning to reduced tillage (Peigné et al., 2007) and soil temperature can be reduced when some reduced tillage strategies are employed (Canali et al., 2013; Licht and Al-Kaisi, 2005). Depending on the crop, location, and time of year, growers may face reduced yields compared to conventional tillage (Bottenberg et al., 1997; Hoyt et al., 1994).

One method of reduced tillage involves seeding a cover crop in the fall, most commonly cereal rye (*Secale cereale*), and allowing it to reach anthesis in the spring. A roller crimper is then used to kill the cover crop, thus creating an organic mulch for the cash crop. Cash crops could be planted either using a no-tillage approach or by creating a narrow tilled strip into which cash crops are seeded or transplanted. Benefits of strip tillage into rolled cover crops include reduction in weeds between rows (Leavitt et al., 2011; Smith et al., 2011), soil erosion protection (Creamer and Dabney, 2002), and preservation of soil structure. Additionally, strip tillage provides warmer soil in the planting zone compared to no-till (Licht and Al-Kaisi, 2005). However, rolled cover crop mulches can tie up nitrogen in grass based cover crop systems (Delate, 2008) and decrease soil temperature compared to conventional tillage (Leavitt et al., 2011). Crop planting may also be delayed since cereal rye must reach anthesis in order to be effectively terminated by a roller crimper (Mirsky et al., 2009). Nevertheless, rolled cover crops are becoming an increasingly popular strategy in reduced tillage operations.

Rowcovers can increase temperature of both the air and soil (Gogo et al., 2014; Ibarra et al., 2001; Nair and Ngouajio, 2010), and have been shown to increase yields in various vegetable crops such as muskmelon (Cline et al., 2008; Saalau Rojas et al., 2011), french beans (Gogo et al., 2014) and watermelon (Soltani et al., 1995). Rowcovers serve as a physical barrier for the plants, reducing insect damage, disease spread (Saalau Rojas et al., 2011), and movement of pests that lay eggs near plants (Cline et al., 2008). This can be particularly important in regions where cucurbit bacterial wilt (*Erwinia tracheiphila*), spread by spotted and striped cucumber beetles (*Diabrotica undecimpunctata* and *Acalymma vittatum*), is a major factor in yield loss.

The goal of this experiment was to determine if a rolled rye strip tillage system could be as productive for muskmelon in Iowa as a standard system of plasticulture through the added use of rowcovers.

Materials and Methods

Study site

The study was conducted at the Muscatine Island Research and Demonstration Farm in Fruitland, IA (lat. 041°21’15” N, long. 091°08’08” W). Fields used in 2013 and 2014 were adjacent. The 2013 field had been previously in a poor stand of sorghum sudangrass, and the 2014 field had been previously in a corn/soybean rotation under conventional management. Soils are categorized as well-drained, Fruitfield coarse sand (sandy, mixed, mesic Entic Hapludolls).

Experimental design

In each year, a split-plot design with four replications was used in adjacent organically and conventionally managed fields. In both years, the organically managed field was not certified organic. Production system was the main plot factor [strip tillage into rolled rye (ST) or conventional tillage with black plastic mulch (plasticulture)] and rowcover was the subplot factor (rowcover or no rowcover). Experimental units in each replication consisted of 18 plants per 31-ft row. One row of muskmelon separated whole plot treatments and acted as a guard row, as no data was collected from it.

Field implementation

Organically and conventionally managed fields were separated by a 12-ft-wide buffer area. Organic management consisted of using organically certified seeds, fertilizer, and insecticides. Conventional management consisted of using treated seeds and synthetic fertilizer, insecticides, and herbicides.

Field operation timing is summarized in Table 2.1. Cereal rye was drilled in Oct. 2012 at 50 lb/acre. Because of a marginal rye stand in 2013, the rate was increased to 110 lb/acre the following season.

To prepare ST plots, cereal rye was rolled with a roller crimper (I&J Manufacturing, Gap, PA) within 1 week of reaching anthesis to maximize kill and minimize regrowth (Mirsky et al., 2009). This was followed by a single pass of the strip tiller (6000 Strip-Till; Hiniker Co., Mankato, MN). When establishing the strips in 2013, it was challenging to get the strip tiller to run smoothly due to heavy cereal rye residue, so in 2014, an extra pass with the strip tiller was made in April before rye stem elongation. Distance between melon rows was 6 ft center to center. Drip tape (12 inch emitter spacing, 0.45 gal/min/100 ft) was laid on the surface in the strip tilled region.

To prepare the plasticulture plots, cereal rye was mowed and tilled in May. The plots were again tilled in June before using a plastic mulch layer to create 6-ft center to center raised beds and lay drip tape under black plastic mulch (0.9-mil thick, 4-ft wide). A timer was used to irrigate all fields with 0.07 in water per day initially, gradually increasing to 0.27 inch per day by the end of the season.

Granular fertilizer was applied and incorporated after tillage operations, but prior to establishing raised beds. Rate of fertilizer application was based on a preplant soil test. In 2013, ST plots received half of the total fertilizer preplant and the other half at rowcover removal, whereas plasticulture plots received all fertilizer preplant. Total fertility applied was 95 lb/acre of N using urea (46N–0P–0K) for conventional plots and 5N–0.4P–0.8K (Fertrell Co., Bainbridge, PA) for organic plots.

In 2014, a system was designed for the conventionally managed field to fertigate N through drip irrigation. We were unable to find an organic fertilizer compatible with our fertigation system. The conventionally managed field received one third of the total N fertilizer preplant and the rest through fertigation. All K fertility was applied preplant. The organically managed field received all fertilizer preplant. Total fertility applied was 150 $lb \cdot acre^{-1}$ of N and 83 lb/acre of K using urea and KCl (0N–0P–49.8K) preplant and urea ammonium nitrate (32N–0P–0K) through fertigation for the conventional field and 4N–0.9P–3.3K (Fertrell Co.) for the organic field.

Untreated ‘Athena’ muskmelon seeds (Syngenta Seeds, Gilroy, CA) and organic potting mix (Mix #11; Beautiful Land Products, West Branch, IA) were used for the organic field, and insecticide-treated seeds were used for the conventional field. Seeds were planted into 98-cell trays in mid-May of both years. Transplants were planted using a mechanical transplanter (Mulch Planter 1265; Holland Transplanter Co., Holland, MI) in early June of both years with an in-row spacing of 22 inch.

Wire hoops were placed every 4 ft down the row and spunbonded rowcovers (AG-30; Agribon, Polymer Group Inc., Charlotte, NC) were installed the same day of transplanting. Rowcover edges were buried in plasticulture plots and were weighed down with water-filled lay-flat hose in ST plots to avoid disturbing the rolled rye. These methods also prevented tearing the rowcover fabric so it could be used again. Rowcover ends were opened and pinned up when 50% of plants had female flowers. Rowcovers were removed 7 d later.

Plots with no rowcovers received an insecticide treatment at planting. An imidacloprid drench (Admire; Bayer CropScience, Research Triangle Park, NC) was used in the conventionally managed field and spinosad (Entrust SC; Dow AgroSciences, Indianapolis, IN) combined with a feeding stimulant (Cidetrak D; Trécé, Adair, OK) was applied as a band spray in the organically managed field. After rowcovers were removed, plants in the organically managed field were sprayed weekly with kaolin clay (Surround WP; Tessenderlo Kerley, Phoenix, AZ), an insect deterrent. Weekly scouting was used to monitor insects and diseases for further sprays which included permethrin (Pounce; FMC Corporation, Philadelphia, PA), chlorothalonil (Bravo Ultrex Weatherstik; Syngenta Crop Protection, Greensboro, NC), and myclobutanil (Rally; Dow AgroSciences) for the conventional field and spinosad, pyrethrin (Pyganic; McLaughlin Gormley King, Minneapolis, MN), copper, sulfur, and neem oil (Trilogy; Certis USA, Columbia, MD) for the organically managed field. In 2013, one cucumber beetle per plant was the threshold for spraying. In 2014, the cucumber beetle thresholds were 0.5 per plant preflowering, one per plant during fruit pollination, and three per plant at vine touch. In 2013, the entire conventionally managed field was sprayed with a grass herbicide (Poast; BASF Corporation, Research Triangle Park, NC) on 9 July. In both years, plots were hand weeded after rowcover removal.

Data collection

Environmental monitoring. Hobo temperature sensors (Onset Computer Corporation; Bourne, MA) were placed 6 inch below soil surface between two plants within a row in three replications in the conventionally managed field. Temperature was recorded by the sensors every 60 min from date of transplant until last harvest. Hobo temperature/light sensors (Onset Computer Corporation; Bourne, MA) were attached to wooden stakes and installed between two plants within a row in three replications in the conventionally managed field. Sensors were 6 inch above soil surface. Air temperature and light intensity were recorded by the sensors every 30 min from date of transplant until last harvest. Soil moisture sensors (10HS; Decagon Devices, Pullman, WA) were inserted horizontally into an exposed surface of soil 6 inch below the surface between plants within a row in all no rowcover treatments in four replications in the conventionally managed field. Soil moisture was measured only in the no rowcover treatments because we were not interested in the effect of rowcover on soil moisture. The attached data loggers (Em5b loggers, Decagon; Pullman, WA) recorded volumetric water content every 60 min throughout the growing season until last harvest. Environmental monitoring occurred solely in the conventional fields because the differences in management systems (conventional and organic) in our experiment would likely not affect air temperature, soil temperature, or soil moisture.

Plant measurements. Before the first muskmelon harvest, three plants from each plot were excavated for measurement of vine length and plant biomass. All fruit were removed from vines and soil was removed from roots. In plots that had fewer than 10 living plants, only vine length was measured, thus retaining plants so that adequate harvest data could be collected. Vine length was measured from the base to the end of the vine. For plant biomass, plants were placed in paper bags and oven dried at 67 °C for five days before weighing. Muskmelons were harvested at full-slip, two to three times per week. They were categorized as marketable if they weighed at least 2 lb, had adequate netting, and were free of damage caused by insects or pathogens. The number and total weight of marketable and non-marketable (cull) melons were recorded for each plot. There were twelve harvests from 1–30 Aug. 2013 and five from 14–29 Aug. 2014.

Statistical analysis

Data were analyzed using PROC GLIMMIX of SAS (Version 9.3, SAS Institute Inc.; Cary, NC). Replication was treated as a random factor. Mean separation was performed by “lsmeans” and “pdiff” statements using the Satterthwaite method. Unprotected least significant difference (LSD) was used, thereby allowing for comparisons between treatments even without significant main effects or interactions. This was important because the main research question was not about the wholeplot or subplot treatments themselves, but about how they interact.

Results

Weather

Monthly rainfall amounts during the 2013 and 2014 growing seasons were similar to 20-year averages, except for unusually low rainfall amounts in Aug. 2013 (Table 2.2). Average monthly temperatures were similar to the 20-year averages, with slightly cooler than normal weather in July 2014.

Soil temperature

Production system had a more consistent effect on soil temperature than did rowcovers (Table 2.3). Before removal of rowcovers in 2013, plasticulture increased daily mean and maximum soil temperature compared to ST by 1.7 and 2.7 °C, respectively, averaging across rowcover treatments. In 2014 before rowcovers were removed, plasticulture increased minimum and mean soil temperature by 1.7 and 2.0 °C, respectively, and rowcovers increased minimum soil temperature by 1.0 °C.

Once rowcovers were removed in 2013, production system did not affect soil temperature. In 2014, minimum and mean soil temperatures remained 1.2 °C higher in plasticulture compared to ST after rowcovers were removed, and maximum soil temperatures in plasticulture plots were 1.4 °C higher. After rowcover-removal in 2014, the plasticulture plots that previously had rowcovers had cooler soil than the plasticulture plots that had never had rowcovers. There was no interaction between system and rowcover in either year.

Air temperature and light intensity

A strong storm on 17 June 2014 disrupted a number of sensors. Those sensors were repositioned 24 June 2014. Data from 17–24 June 2014 have been discarded.

Rowcovers increased daily mean and maximum air temperature compared to treatments without rowcovers, and increased daily minimum air temperature in 2014 (Table 2.4). While rowcovers increased mean air temperature by 4.2 and 3.0 °C in 2013 and 2014, respectively, maximum temperatures were increased by 11.7 and 6.1 °C. Over both years, rowcovers reduced daily mean light intensity by 33% to 37% and daily maximum light intensity by 32% to 37%.

Soil moisture

Production system had no significant effect on soil moisture in 2013, as seen in Table 2.5; however, daily minimum, mean and maximum soil moisture during the midseason period was marginally ($P \leq 0.1$) higher in ST than in plasticulture. In 2014, ST plots had higher minimum, mean, and maximum daily volumetric water content throughout the entire season.

Plant growth

In 2013, there were interactions between the effect of production system and the effect of rowcover on plant biomass and vine length (Table 2.6); rowcovers more greatly increased melon plant biomass and vine length in plasticulture treatments than they did in ST treatments.

In 2014, rowcovers did not affect plant biomass or vine length (Table 2.6). Plants in plasticulture had more biomass than those in ST in both the organically and conventionally managed fields, whereas plants in plasticulture had longer vines only in the organically managed field.

Yield

Production system had a significant effect on marketable muskmelon yield; plants grown in plasticulture produced more than those grown in ST in both years in the organic and conventional fields (Table 2.7). Rowcovers had a significant effect on the yield only in the 2014 organic field, where ST with rowcover had a higher yield than ST without rowcover. There was no interaction between production system and rowcover in regard to yield. Based on mean separation, the ST with rowcover treatment never produced an equivalent yield to either of the plasticulture treatments. In the conventional field in 2013, however, the ST without rowcover treatment produced the same yield as the plasticulture with rowcover treatment.

The average weight of each fruit was not affected by production system except in the organic field in 2014, when melons from plants grown in plasticulture were 0.5 lbs heavier on average than those from plants grown in ST. Rowcovers increased the average weight of melons in both years and in both organically and conventionally managed fields by 0.6 to 0.9 lbs, except in the conventional field in 2014 when rowcovers had no effect.

For non-marketable (cull) weights in the 2013 organic field, there was an interaction between production system and rowcover, where rowcovers increased cull weights to a greater degree in plasticulture than in ST. In the 2014 organic field, both plasticulture and rowcovers increased cull weights and there was no interaction. In the conventional fields, rowcovers increased cull weights in both years. A large percentage of yield loss caused by insect damage on fruit was due to a sudden influx of cucumber beetles close to harvest for which insecticides were not applied.

Discussion

Soil temperatures were more affected by production system early in the season in 2013 when rowcovers were installed compared to later in the season when rowcovers had been removed. This could be due to the melon plants vining out and covering the surface of the black plastic as the season progressed, thus blocking solar radiation from heating the plastic mulch surface.

In previous studies, spunbonded rowcovers increased mean soil temperature at depths of 2.5 cm (Nair and Ngouajio, 2010), 5 cm (Motsenbocker and Bonanno, 1989), and 10 cm (Ibarra-Jiménez et al., 2004; Soltani et al., 1995). We did not see a strong effect by rowcovers on soil temperature at a depth of 6 in. This is confirmed by Wolfe et al. (1989), as they also did not see significant differences at the similar depth of 15 cm. The soil in this study was a well-drained coarse sand, so one might expect the soil temperature to respond more quickly to temperature fluctuations than it would in a heavier soil; however, this was not observed at a depth of 6 in. Soil temperature has been shown to be a predictor of vegetative growth in muskmelon (Jenni et al., 1996) and may be a better predictor of yield than air temperature (Ibarra et al., 2001).

Rowcovers increased maximum daily air temperature to a point that has been shown to be detrimental to muskmelon plants. Jenni et al. (1996) found that damage to muskmelon may occur when air temperature exceeds 40 °C; this threshold was exceeded by 1.3 to 2.3 °C in no-rowcover treatments, and by 8.4 to 13.0 °C in rowcover treatments, depending on the year. Similarly, Ibarra et al. (2001) found that maximum air temperature under rowcovers reached 51.2 to 52.6 °C as opposed to 37.2 °C in plots with no rowcover; they saw no positive effect of rowcovers on muskmelon yield. This suggests that the weight of rowcovers used in our experiment, 0.9 $oz \cdot yd^{-2}$, perhaps contributed to higher than optimal air temperatures. If high temperatures appear to be damaging plants, we recommend using a rowcover that does not trap as much heat, such as a thinner spunbonded material or a nylon mesh.

Since the melons were grown in the summer and in full sun, the decreased light intensity under the rowcovers likely did not negatively affect their growth. Perring et al. (1989) found that only muskmelon grown under spunbonded rowcovers in the fall, as opposed to the spring, experienced yield loss. However, Nair and Ngouajio (2010) found that cucumbers grown under a thick rowcover (60% light transmission) sometimes produced lower yields than those grown under a light rowcover (85% light transmission). It is hard to differentiate between the effect of temperature and light intensity, as thicker rowcovers trap more heat and block more light.

Strip tillage can increase soil moisture compared to conventional tillage without plastic mulch (Haramoto and Brainard, 2012), in part because organic residue on the ground in strip tillage can decrease evaporation (Johnson and Hoyt, 1999). However, in the current study, it is doubtful that the thin rye mulch prevented more evaporation within the plant row than the film of plastic in plasticulture plots. Because we planted cereal rye in October, as opposed to the preferable September planting date, to accommodate soybean harvest and because of the sandy soil at our site that lacks nutrients and organic matter, the rye stand in both years was not thick enough to completely cover the soil after rolling. This not only allowed weeds to grow between rows, but also allowed for more evaporation and soil warming than would have been observed if the rye residue had been thicker.

Whether in a reduced or conventional tillage system, organic mulches can help maintain greater soil moisture than plots covered in plastic mulch, as organic mulches allow rain to penetrate, while plastic films deflect most rainfall (Schonbeck and Evanylo, 1998). Both production systems in the current study received the same amount of irrigation through drip tape, but most rainfall could not reach the plants in the plasticulture system. If irrigation is limited or non-existent in a certain farm setting, strip tillage could provide a substantial benefit to muskmelon by allowing rain infiltration while minimizing evaporation.

Given that rowcovers, especially when combined with plasticulture, increased plant biomass in 2013, we do not believe the high temperature under the rowcovers negatively affected vegetative growth. This contradicts the assumption that air temperatures over 40 °C would have a negative effect on vine growth as suggested by Jenni et al. (1996). In 2014, however, rowcovers did not increase plant biomass or vine length. This was unexpected, as daily maximum air temperatures in 2013 in rowcover treatments were higher than those in 2014, and both were well over 40 °C (Table 2.4).

The significant interaction between system and rowcover in 2013 may have occurred because plots were not weeded until just after rowcovers were removed so as to not favor the no-rowcover treatment. There were few weeds under the rowcovers in plasticulture plots, but weeds in ST plots did become problematic by that point in the season. Because of this, the rowcovers had a positive effect in plasticulture, but weed competition may have precluded this increase in melon plant biomass in ST. The same weeding protocol was used in 2014, however the interaction was not observed.

Plant biomass and vine length of ST with rowcover was the same in plasticulture without rowcover for both fields in both years with only one exception. This finding shows that ST can produce plants of similar size to those grown in a plasticulture system through the use of rowcovers.

In our study, plasticulture treatments produced higher marketable yields than ST across both years in conventional and organically managed fields. The only instance when rowcovers increased marketable yield compared to no-rowcover treatments was for organic ST plots in 2014 (Table 2.7). This supports the claim that soil temperature may be more important for muskmelon plant growth and yield than air temperature (Ibarra et al., 2001), because plasticulture systems tended to increase 15-cm soil temperature, while rowcovers rarely affected it. Even though rowcovers should provide protection from insects and insect-transmitted diseases (Saalau Rojas et al., 2011), the treatment of ST with rowcovers did not ever produce an equivalent yield compared to plasticulture without rowcovers. The benefit that rowcovers have to offer may change from year to year depending on weather conditions, disease presence, and which, if any, insecticides are used after rowcover removal.

Studies have found that spunbonded rowcovers can increase marketable muskmelon yield (Cline et al., 2008) and increase early muskmelon yield (Motsenbocker and Bonanno, 1989). Given that the system of rolled cereal rye depends on abundant biomass production and, especially in organic systems, the termination of cereal rye at anthesis stage to achieve successful termination, planting muskmelon early enough to capture the early season market would be challenging, even with rowcovers.

Conclusions

The goal of a strip tillage system in rolled cover crops is to generate optimal cover crop biomass to provide weed control and moisture retention throughout the growing season. However, this often leads to delayed melon planting, as growers are supposed to wait until cereal rye reaches anthesis stage for effective termination using a roller crimper. This leads to challenges in early season melon production in a rolled rye system. Because there is potential for building soil health through long-term reduction in tillage, strip tillage remains an important area of research. Rowcovers could be a useful tool in transitioning to reduced tillage systems. In this study rowcovers did not increase marketable muskmelon yield, but did increase fruit weight and plant biomass. Controlling weeds remains a challenge in strip tillage muskmelon production due to the slow vine growth and canopy closure, so achieving a thick rye mulch in strip tillage is important, though it may prevent early planting.

Literature Cited

Balota, E.L., A. Calegari, A.S. Nakatani, and M.S. Coyne. 2014. Benefits of winter cover crops and no-tillage for microbial parameters in a Brazilian oxisol: A long-term study. Agr. Ecosystems Environ. 197:31-40.

Bottenberg, H., J. Masiunas, C. Eastman, and D. Eastburn. 1997. Yield and quality constraints of cabbage planted in rye mulch. Biological Agr. Hort. 14:323-342.

Brainard, D.C. and D.C. Noyes. 2012. Strip tillage and compost influence carrot quality, yield, and net returns. HortScience 47:1073-1079.

Canali, S., G. Campanelli, C. Ciaccia, F. Leteo, E. Testani, and F. Montemurro. 2013. Conservation tillage strategy based on the roller crimper technology for weed control in Mediterranean vegetable organic cropping systems. European J. Agron. 50:11-18.

Cline, G.R., J.D. Sedlacek, S.L. Hillman, S.K. Parker, and A.F. Silvernail. 2008. Organic management of cucumber beetles in watermelon and muskmelon production. HortTechnology 18:436-444.

Creamer, N.G. and S.M. Dabney. 2002. Killing cover crops mechanically: Review of recent literature and assessment of new research results. Amer. J. Alternative Agr. 17:32-40.

Delate, K. 2008. Effects of organic fertilization and cover crops on an organic pepper system. HortTechnology 18:215-226.

Doran, J.W. 1987. Microbial biomass and mineralizable nitrogen distributions in no-tillage and plowed soils. Biol. Fertility Soils 5:68-75.

Gogo, E.O., M. Saidi, J.M. Ochieng, T. Martin, V. Baird, and M. Ngouajio. 2014. Microclimate modification and insect pest exclusion using agronet improve pod yield and quality of French bean. HortScience 49:1298-1304.

Haramoto, E.R. and D.C. Brainard. 2012. Strip tillage and oat cover crops increase soil moisture and influence N mineralization patterns in cabbage. HortScience 47:1596-1602.

Hemphill, Jr., D.D. 1993. Agricultural plastics as solid waste: What are the options for disposal? HortTechnology 3:70-73.

Hoyt, G.D., D.W. Monks, and T.J. Monaco. 1994. Conservation tillage for vegetable production. HortTechnology 4:129-135.

Ibarra, L., J. Flores, and J.C. Díaz-Pérez. 2001. Growth and yield of muskmelon in response to plastic mulch and row covers. Scientia Hort. 87:139-145.

Ibarra-Jiménez, L., M.R. Quezada-Martín, and M. de la Rosa-Ibarra. 2004. The effect of plastic mulch and row covers on the growth and physiology of cucumber. Austral. J. Experimental Agr. 44:91-94.

Jackson, L.E., F.J. Calderon, K.L. Steenwerth, K.M. Scow, and D.E. Rolston. 2003. Responses of soil microbial processes and community structure to tillage events and implications for soil quality. Geoderma 114:305-317.

Jenni, S., D.C. Cloutier, G. Bourgeois, and K.A. Stewart. 1996. A heat unit model to predict growth and development of muskmelon to anthesis of perfect flowers. J. Amer. Soc. Hort. Sci. 121:274-280.

Johnson, A.M. and G.D. Hoyt. 1999. Changes to the soil environment under conservation tillage. HortTechnology 9:380-393.

Kasirajan, S. and M. Ngouajio. 2012. Polyethylene and biodegradable mulches for agricultural applications: A review. Agron. Sustainable Dev. 32:501-529.

Leavitt, M.J., C.C. Sheaffer, D.L. Wyse, and D.L. Allan. 2011. Rolled winter rye and hairy vetch cover crops lower weed density but reduce vegetable yields in no-tillage organic production. HortScience 46:387-395.

Licht, M.A. and M. Al-Kaisi. 2005. Strip-tillage effect on seedbed soil temperature and other soil physical properties. Soil Tillage Res. 80:233-249.

Luna, J.M. and M.L. Staben. 2002. Strip tillage for sweet corn production: Yield and economic return. HortScience 37:1040-1044.

Mirsky, S.B., W.S. Curran, D.A. Mortensen, M.R. Ryan, and D.L. Shumway. 2009. Control of cereal rye with a roller/crimper as influenced by cover crop phenology. Agron. J. 101:1589-1596.

Motsenbocker, C.E. and A.R. Bonanno. 1989. Row cover effects on air and soil temperatures and yield of muskmelon. HortScience 24:601-603.

Nair, A. and M. Ngouajio. 2010. Integrating rowcovers and soil amendments for organic cucumber production: Implications on crop growth, yield, and microclimate. HortScience 45:566-574.

Nesmith, D.S., G. Hoogenboom, and D.V. McCracken. 1994. Summer squash production using conservation tillage. HortScience 29:28-30.

Peigné, J., B.C. Ball, J. Roger-Estrade, and C. David. 2007. Is conservation tillage suitable for organic farming? A review. Soil Use Mgt. 23:129-144.

Pelosi, C., B. Pey, M. Hedde, G. Caro, Y. Capowiez, M. Guernion, J. Peigné, D. Piron, M. Bertrand, and D. Cluzeau. 2014. Reducing tillage in cultivated fields increases earthworm functional diversity. Appl. Soil Ecol. 83:79-87.

Perring, T.M., R.N. Royalty, and C.A. Farrar. 1989. Floating row covers for the exclusion of virus vectors and the effect on disease incidence and yield of cantaloupe. J. Economic Entomol. 82:1709-1715.

Rapp, H.S., R.R. Bellinder, H.C. Wien, and F.M. Vermeylen. 2004. Reduced tillage, rye residues, and herbicides influence weed suppression and yield of pumpkins. Weed Technol. 18:953-961.

Roper, M.M., V.V.S.R. Gupta, and D.V. Murphy. 2010. Tillage practices altered labile soil organic carbon and microbial function without affecting crop yields. Austral. J. Soil Res. 48:274-285.

Saalau Rojas, E.S., M.L. Gleason, J.C. Batzer, and M. Duffy. 2011. Feasibility of delaying removal of row covers to suppress bacterial wilt of muskmelon (*Cucumis melo*). Plant Dis. 95:729-734.

Salem, H.M., C. Valero, M.A. Muñoz, M.G. Rodríguez, and L.L. Silva. 2015. Short-term effects of four tillage practices on soil physical properties, soil water potential, and maize yield. Geoderma 237:60-70.

Schonbeck, M.W. and G.K. Evanylo, 1998. Effects of mulches on soil properties and tomato production I. Soil temperature, soil moisture and marketable yield. J. Sustainable Agr. 13:55-81.

Smith, A.N., C. Reberg-Horton, G.T. Place, A.D. Meijer, C. Arellano, and J.P. Mueller. 2011. Rolled rye mulch for weed suppression in organic no-tillage soybeans. Weed Sci. 59:224-231.

Soltani, N., J.L. Anderson, and A.R. Hamson. 1995. Growth analysis of watermelon plants grown with mulches and rowcovers. J. Amer. Soc. Hort. Sci. 120:1001-1009.

Wolfe, D.W., L.D. Albright, and J. Wyland. 1989. Modeling row cover effects on microclimate and yield: I. Growth response of tomato and cucumber. J. Amer. Soc. Hort. Sci. 114:562-568.

Wyland, L.J., L.E. Jackson, W.E. Chaney, K. Klonsky, S.T. Koike, and B. Kimple. 1996. Winter cover crops in a vegetable cropping system: Impacts on nitrate leaching, soil water, crop yield, pests and management costs. Agr. Ecosystems Environ. 59:1-17.

Table 2.1. Timeline of treatment establishment in muskmelon trials in Muscatine, IA in 2013 and 2014.

Operation	**2013**	**2014**
Drilled cereal rye cover crop, variety unknown	12 Oct. 2012	2 Oct. 2013
Established strip tillage plots	-	8 Apr.
Took soil samples for nutrient recommendation	1 May	23 Apr.
Muskmelon seeded into 98-cell trays	9 May	12 May
Mowed and incorporated rye (plasticulture)	9 May	29 May
Roller-crimped rye at anthesis (strip tillage)	22 May	29 May
(Re)established strips (strip tillage)	3 June	29 May
Tilled and laid plastic (plasticulture)	3 June	5 June
Transplanted muskmelon, installed rowcovers	4 June	10 June
Opened rowcover ends	11 July	10 July
Removed rowcovers	18 July	17 July

Table 2.2. Monthly total precipitation and average daily temperature during the 2013 and 2014 growing seasons and the 20-year average in Muscatine, IA[z].

	Monthly precipitation (mm)			Avg monthly temp (°C)		
Month	**2013**	**2014**	**20-yr avg[y]**	**2013**	**2014**	**20-yr avg**
June	154	125	136	21.7	22.8	22.4
July	75	116	88	23.3	21.7	24.4
Aug.	1	107	104	23.3	22.8	23.4

[z]Monthly data from Iowa Environmental Mesonet at the Muscatine, IA location.

[y]Twenty year averages from 1995–2014.

Table 2.3. Minimum, mean, and maximum daily soil temperature at 15 cm depth in conventionally managed muskmelon before and after rowcover (RC) removal.

		Pre RC removal (°C)[z]			Post RC removal (°C)[y]		
System	**Rowcover[x]**	**Min[w]**	**Mean**	**Max**	**Min**	**Mean**	**Max**
				2013			
Plasticulture	RC	24.3 a[v]	27.6 a	30.7 a	21.6	24.3 b	26.3 a
	NRC	24.1 ab	27.3 a	30.8 a	22.7	25.1 a	27.3 ab
Strip tillage	RC	23.8 ab	26.1 b	28.6 b	22.5	24.4 ab	26.6 ab
	NRC	23.3 b	25.4 b	27.4 b	22.5	24.2 b	25.9 b
		------------------------------*Significance*------------------------------					
System (S)		NS	***	**	NS	NS	NS
Rowcover (R)		*	NS	NS	NS	NS	NS
S × R		NS	NS	NS	NS	NS	NS
				2014			
Plasticulture	RC	24.7 a	28.1 a	31.8 a	23.5 a	25.7 b	28.1 ab
	NRC	23.6 b	27.1 a	31.0 ab	23.9 a	26.4 a	29.0 a
Strip tillage	RC	22.9 c	25.7 b	28.8 b	22.7 b	24.7 c	26.9 c
	NRC	22.0 d	25.5 b	30.1 ab	22.4 b	24.9 c	27.5 bc
		------------------------------*Significance*------------------------------					
System (S)		***	***	NS	***	***	*
Rowcover (R)		***	NS	NS	NS	*	NS
S × R		NS	NS	NS	NS	NS	NS

[z]Pre rowcover removal: 5 June–17 July 2013, 11 June–9 July 2014

[y]Post rowcover removal: 18 July–28 Aug. 2013, 10 July–28 Aug. 2014

Table 2.3 continued

[x]RC = rowcover, NRC = no rowcover

[w]Average daily minimum, mean and maximum temperature.

[v]Mean separation (by year in columns) based on least significant differences at $P \leq 0.05$.

[NS, *, **, ***] Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, based on F-test.

Table 2.4. Air temperature and light intensity in conventionally managed muskmelon in 2013 and 2014 before opening rowcovers, averaged across production system treatments.

	Air temp (°C)			Light intensity (lumens/m^2)	
Rowcover[z]	**Min**[y]	**Mean**	**Max**	**Mean**	**Max**
			2013[x]		
RC	17.4	31.5	53.0	310	1248
NRC	16.9	27.3	41.3	446	1800
	NS	***	***	***	***
			2014[w]		
RC	15.7	29.4	48.4	312	1238
NRC	14.3	26.4	42.3	487	1951
	**	***	***	***	***

[z]RC = rowcover, NRC = no rowcover

[y]Average daily minimum, mean and maximum temperature.

[x]Rowcovers unopened 5 June–10 July 2013.

[w]Rowcovers unopened 11 June–9 July 2014. A storm disrupted row covers and sensors 17 June 2014; data from 17–24 June have been discarded.

[NS, *, **, ***] Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, based on F-test.

Table 2.5. Soil moisture (m^3/m^3) at 15 cm depth in conventionally managed melon with no rowcovers.

	Early season[z]			**Midseason**[y]			**Late season**[x]		
System	**Min**[w]	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**
				2013					
Plasticulture	0.19	0.20	0.21	0.16	0.17	0.19	0.21	0.22	0.24
Strip tillage	0.21	0.22	0.26	0.22	0.24	0.28	0.24	0.26	0.29
	NS	NS	NS	NS	NS	NS	NS	NS	NS
				2014					
Plasticulture	0.14	0.15	0.16	0.11	0.12	0.13	0.15	0.16	0.17
Strip tillage	0.18	0.20	0.22	0.19	0.21	0.23	0.20	0.22	0.24
	**	**	**	***	***	***	***	***	**

[z]Early season: 14 June–2 July 2013, 11 June–6 July 2014

[y]Midseason: 3 July–30 July 2013, 7 July–1 Aug. 2014

[x]Late season: 31 July–28 Aug. 2013, 2 Aug.–28 Aug. 2014

[w]Average daily minimum, mean and maximum soil moisture.

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, based on F-test.

Table 2.6. Plant biomass and vine length of organically and conventionally managed muskmelon in 2013 and 2014.

[z]RC = rowcover, NRC = no rowcover

		2013		2014	
System	**Rowcover[z]**	**Plant biomass (g)**	**Vine length (cm)**	**Plant biomass (g)**	**Vine length (cm)**
Organic					
Plasticulture	RC	139 a[y]	277 a	97 a	183 a
	NRC	70 b	136 bc	80 ab	166 ab
Strip tillage	RC	54 b	161 b	41 b	138 bc
	NRC	37 b	117 c	30 b	115 c
		---------------------------*Significance*---------------------------			
	System (S)	***	***	**	**
	Rowcover (R)	**	***	NS	NS
	S × R	*	**	NS	NS
Conventional					
Plasticulture	RC	148 a	271 a	76 a	163 a
	NRC	78 b	175 b	66 ab	143 ab
Strip tillage	RC	60 b	193 b	43 c	140 b
	NRC	40 c	142 c	47 bc	139 b
		---------------------------*Significance*---------------------------			
	System (S)	**	***	***	NS
	Rowcover (R)	***	***	NS	NS
	S × R	**	**	NS	NS

[y]Mean separation (by year in columns) based on least significant differences at $P \leq 0.05$.

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, based on F-test.

Table 2.7. Marketable yield, marketable fruit weight, and non-marketable (cull) weight (lb) of organically and conventionally managed muskmelon in 2013 and 2014.

		2013			2014		
		Marketable		Cull	Marketable		Cull
System	Rowcover[z]	Yield (lb/plant)	Fruit wt (lb)	lb/plant	Yield (lb/plant)	Fruit wt (lb)	lb/plant
Organic							
Plasticulture	RC	3.6 a[y]	4.4 a	4.2 a	2.8 a	4.1 a	4.5 a
	NRC	3.1 a	3.7 b	1.3 c	2.5 a	3.7 a	2.6 b
Strip tillage	RC	1.6 b	4.7 a	2.2 b	1.5 b	3.7 a	1.6 c
	NRC	1.4 b	3.7 b	0.8 c	0.4 c	3.0 b	0.8 c
		------------------------------------*Significance*------------------------------------					
System (S)		**	NS	***	**	**	***
Row cover (R)		NS	***	***	*	**	**
S x R		NS	NS	*	NS	NS	NS
Conventional							
Plasticulture	RC	4.1 ab	4.7 a	4.0 a	3.1 a	4.1 a	4.5 a
	NRC	5.0 a	3.7 b	0.9 b	3.2 a	4.0 a	2.9 c
Strip tillage	RC	1.6 c	4.0 b	3.0 a	0.7 b	2.3 a	3.9 ab
	NRC	2.4 bc	3.7 b	1.1 b	0.9 b	4.0 a	3.0 bc
		------------------------------------*Significance*------------------------------------					
System (S)		*	NS	NS	***	NS	NS
Row cover (R)		NS	**	***	NS	NS	**
S x R		NS	NS	NS	NS	NS	NS

[z]RC = rowcover, NRC = no rowcover

[y]Mean separation in columns based on least significant differences at $P \leq 0.05$.

[NS, *, **, ***] Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, based on F-test.

CHAPTER 3. ROWCOVERS AND STRIP TILLAGE COULD PROVIDE AN ALTERNATIVE TO PLASTICULTURE SYSTEMS IN SUMMER SQUASH PRODUCTION

Modified from a paper to be submitted to *HortScience*

Jennifer Tillman[1], Ajay Nair[1]*, Mark Gleason[2], and Jean Batzer[2]

Abstract

Plastic mulch is often used in cucurbit production, but it has negative soil health and environmental implications due to use of tillage for installation and generation of plastic waste. This two-year study aimed to find a viable alternative to plastic mulch through the use of strip tillage and rowcovers. A split plot design was used in both conventionally and organically managed summer squash (*Cucurbita pepo*), with production system as the whole plot factor [conventional tillage with black plastic mulch (PL) and rolled cereal rye (S*ecale cereale*) with strip tillage (ST)] and rowcover use as the subplot factor (rowcover until anthesis or no rowcover). Rowcovers increased average air temperature by 1.6 to 4.0 °C and increased maximum air temperature by up to 10.3 °C. Rowcovers decreased average light intensity by 33% to 39%. Though soil temperature in PL tended to be higher than in ST, in one year rowcovers helped bridge the gap. Plant biomass was consistently higher in the PL than ST system. Averaged across rowcover treatments, plants in PL had higher marketable yields than those in ST;

---

[1]Department of Horticulture, Iowa State University, Ames, IA 50010

[2]Department of Plant Pathology and Microbiology, Iowa State University

*To whom correspondence should be addressed. E-mail nairajay@iastate.edu

however, the use of rowcovers often led to comparable yields between production system treatments. Rowcover was a significant factor explaining marketable yield for the organically managed fields both years. There was no consistent effect of production system on soil microbial biomass carbon. Based on our results, strip tillage into rolled rye could be a viable alternative to plasticulture for summer squash production in Iowa, and rowcovers could help increase yields in strip tillage especially in organic management systems.

Introduction

Plastic mulch is commonly used by cucurbit growers, as it increases soil temperature, reduces weed pressure, retains moisture, and increases earliness of harvest for many crops (Lamont, 2005). Black plastic mulch can increase cucurbit yields compared to those grown without mulch for cucumber (Ibarra-Jiménez et al., 2004), muskmelon (Ibarra et al., 2001), and summer squash (Mahadeen, 2014). However, there are concerns about environmental sustainability due to the generation of plastic waste (Hemphill, 1993) and the disturbance to the soil from intensive tillage employed for proper installation of plastic mulch. Bio- and photodegradable film mulches address the issue of waste, but they are more expensive (Cirujeda et al., 2012), vary in their ability to decompose at the proper time (Kasirajan and Ngouajio, 2012), and do not eliminate the need for intensive tillage. Tillage degrades soil structure (Peigné et al., 2007), making it more susceptible to compaction, and can decrease soil microbial biomass (Karlen et al., 2013), soil moisture (Hoyt et al., 1994), and earthworm diversity (Pelosi et al., 2014).

In studying alternatives to the use of plastic mulches as a way to build soil health, it is also important to consider the use of cover crops as a means to reduce soil erosion and add organic matter. Cover crops must be managed so they do not compete with the main crop, however. One common approach is to incorporate the cover crop into the soil through tillage. This adds organic matter to the soil, but again, it leaves the soil vulnerable to erosion (Dickey et al., 1983) among its other potential negative consequences.

One way to terminate cover crops without tillage is to use a roller crimper, which kills a mature cover crop by pushing it over and crimping each stem multiple times. The rolled and crimped residue is then left intact on the soil surface to serve as a biological mulch that can be used as an alternative to plastic mulch. This technique can be adapted to both no-tillage and strip tillage systems. Heavy residue on the soil surface can lower soil temperatures compared to bare soil (Schonbeck and Evanylo, 1998), but reduces weed pressure (Leavitt et al., 2011) and helps maintain high soil moisture (Schonbeck and Evanylo, 1998). Rolled cover crop systems have produced equivalent yields to tilled bare ground systems for pumpkin (Wyenandt et al., 2011), organic bell pepper (Delate, 2008), winter squash (Hoyt, 1999), and tomato (Hoyt, 1999). However, Leavitt et al. (2011) found that tomato, zucchini, and bell pepper in a no-till rolled cover crop system in Minnesota had lower yields than in a conventionally tilled system without cover crops, potentially due to the cooler northern U.S. climate. These mixed results indicate the need for a technique to mitigate the potential yield loss when using a rolled cover crop system as opposed to bare ground.

Given the increased yields in plasticulture systems compared to bare ground, and the mixed results when comparing rolled cover crop systems to bare ground, it is not surprising that little work has been done comparing rolled cover crop systems to plasticulture systems, especially in warm season crops like cucurbits. One way to overcome the possible yield loss in a rolled cover crop system is to use rowcovers. Rowcovers can increase air temperature and soil temperature (Ibarra et al., 2001), and have been shown to increase yield of muskmelon (Cline et al., 2008), cucumber (Nair and Ngouajio, 2010), and watermelon (Soltani et al., 1995). By physically preventing insects from reaching young plants, rowcovers not only prevent damage from insect feeding, but also reduce the spread of insect-transmitted pathogens like *Erwinia tracheiphila* (Saalau Rojas et al., 2011). This pathogen causes cucurbit bacterial wilt, a devastating disease for cucurbit growers.

Our goal was to determine if using rowcovers in a strip tillage system could produce equivalent yield to plasticulture systems in organically and conventionally managed summer squash. We compared two production systems [conventional tillage with black plastic mulch (PL) and rolled rye strip tillage (ST)] with and without the use of rowcovers in organically and conventionally managed fields of summer squash.

Materials and methods

Experimental site

Trials were conducted in Fruitfield coarse sand (sandy, mixed, mesic Entic Hapludolls) at the Muscatine Island Research and Demonstration Farm in Fruitland, IA (lat. 041°21’15” N, long. 091°08’08” W). The 2013 field had previously been in sorghum sudangrass, and the 2014 field had previously been in a corn/soybean rotation under conventional management.

Planting material

For the conventionally managed field, ‘Lioness’ summer squash seeds (Seedway, Hall, NY) treated with thiamethoxam, azoxystrobin, mefenoxam, and fludioxonil were sowed into 72-cell trays with potting mix (Metro Mix 360; Sun Gro Horticulture, Agawam, MA). Untreated summer squash seeds were sowed with organic potting mix (Mix #11; Beautiful Land Products, West Branch, IA) into 72-cell trays for the organically managed field.

Experimental design and treatments

A split-plot complete block design with four replications was used for both organically and conventionally managed fields, which were separated by a 3.7-m buffer. The whole plot factor was production system [(strip tillage into rolled cereal rye (ST) or conventional tillage with black plastic mulch (PL)] and the subplot factor was rowcover use (rowcover or no rowcover). Spacing between rows was 1.8 m. A guard row separated whole plot treatments. Each experimental unit consisted of 18 plants per 9.5-m row.

Land preparation

Timing of field operations is summarized in Table 3.1. Cereal rye was seeded with a drill across all fields in October prior to each field season. In 2012, cereal rye was drilled at a rate of 56 $kg \cdot ha^{-1}$. Due to an insufficient stand of rye in Spring 2013, the October 2013 seeding rate was increased to 123 $kg \cdot ha^{-1}$.

Cereal rye in PL treatments was mowed and tilled in May. Plots were again tilled in June before laying black plastic mulch (0.02 mm thick) on raised beds with drip tape (0.3 emitter spacing, 0.028 $L \cdot s^{-1} \cdot 30.5\ m^{-1}$).

Cereal rye in ST treatments was mechanically killed using a rear-mounted, chevron-patterned roller crimper (I&J Manufacturing, Gap, PA). Rolling was performed when cereal rye was at anthesis stage to maximize kill and minimize regrowth (Mirsky et al., 2009). In 2013, strips were made using a strip tiller (6000 Strip-Till; Hiniker Co., Mankato, MN) after rolling the rye. There were challenges in strip tilling within the mature rye residue in 2013. To mitigate this issue in 2014, an extra pass with the strip tiller was made in early April before rye stem elongation. This approach allowed the strip tiller to work efficiently in the rolled rye residue and form strips that were 20 cm wide in May. Drip tape was laid on the surface of the strip tilled zone.

Fertilizer was applied in a 0.6-m-wide band centered on each row after tillage and then incorporated. Fertilizer application was based on a preplant soil test. In 2013, a total of 72 $kg \cdot ha^{-1}$ of N was added using urea (46N–0P–0K) in the conventionally managed field and an organic fertilizer (5N–0.4P–0.8K) (Fertrell Co., Bainbridge, PA) in the organically managed field. PL treatments received all fertilizer preplant but ST treatments received one-half preplant and the other half was side-dressed when rowcovers were removed.

In 2014, a system was designed for the conventionally managed field to fertigate N through drip irrigation. Based on the preplant soil test, a total of 93 $kg \cdot ha^{-1}$ of K and 112 $kg \cdot ha^{-1}$ of N was applied to the conventionally managed field using KCl (0N–0P–49.8K), granular urea, and liquid urea ammonium nitrate (32N–0P–0K). An organic fertilizer (4N–0.9P–3.3K) (Fertrell Co.) was used in the organically managed field to cover both N and K requirements. All treatments in the conventionally managed field received one-third of the total N requirement preplant with urea, and two-thirds through fertigation with urea ammonium nitrate. Treatments in the organically managed field received all fertilizer preplant because there was not an acceptable organic liquid fertilizer for the fertigation system.

Four-week-old squash seedlings were transplanted in June using a mechanical transplanter (Mulch Planter 1265; Holland Transplanter Co., Holland, MI) with an in-row spacing of 56 cm. The same day as transplanting, wire hoops were installed every 1.2 m down the row in rowcover treatments, and spunbonded rowcovers (AG-30; Agribon, Polymer Group Inc., Charlotte, NC) were placed over the rows. Rowcover edges in the PL treatments were covered with soil. Edges in ST treatments were held in place using water-filled lay-flat hose to minimize disturbance to the rye mulch and prevent tearing of the rowcover fabric. Rowcovers were removed when 50% of squash plants had female flowers.

In the conventionally managed field, treatments without rowcovers received an imidacloprid drench (Admire; Bayer CropScience, Research Triangle Park, NC) at planting. In the organically managed field, treatments without rowcovers initially received a foliar spray of spinosad (Entrust SC; Dow AgroSciences, Indianapolis, IN) combined with an insect feeding stimulant (Cidetrak D; Trécé, Adair, OK). Plants under rowcovers did not receive any insecticide until rowcovers were removed.

Fields were scouted weekly for insects and diseases. A pheromone trap was installed 300 m from the study site to monitor squash vine borer (*Melittia cucurbitae*); the threshold was one adult moth per trap. Thresholds for squash bugs (*Anasa tristis*) and striped cucumber beetles (*Acalymma vittatum*) were one egg mass per plant and one insect per plant, respectively. Pesticide sprays were applied with a backpack sprayer when thresholds were reached; sprays approved by the National Organic Program were used in the organically managed fields. Plots were hand weeded after rowcover removal. In 2013, the entire conventionally managed field was sprayed with a grass herbicide (Poast; BASF Corporation, Research Triangle Park, NC) on 9 July.

Data collection

Environmental monitoring. Hobo pendant temperature/light sensors (Onset Computer Corporation; Bourne, MA) were attached to wooden stakes placed within the row, 15 cm above the soil surface, in three replications in the conventionally managed field. They recorded air temperature and light intensity every 30 min throughout the growing season. Hobo pendant temperature sensors were buried within the row, 15 cm below the soil surface, in three replications in the conventionally managed field. They recorded soil temperature every 60 min throughout the growing season.

Plant measurements. A SPAD meter (SPAD 502 Plus; Konica Minolta Sensing Americas, Ramsey, NJ) was used to measure chlorophyll content on 15 July 2013 and 12 Aug. 2014 at midday on a sunny day. Measurements were taken on eight plants in each subplot. Two readings from the youngest fully expanded leaf were averaged. Fruit were harvested twice per week. Fruit were classified as marketable if they were 15–23 cm long, had minimal scarring, were well-formed, and had no insect damage. The number and total weight of marketable and non-marketable (cull) squash were recorded for each plot. Because the harvest schedule was insufficient to prevent overgrown squash, marketable yield is reported as number of squash instead of weight, and includes oversized squash that were otherwise marketable. There were 14 harvests from 2 July to 16 Aug. in 2013 and 12 harvests from 7 July to 15 Aug. in 2014. At first harvest, on 2 July 2013 and 7 July 2014, three plants from each plot were excavated for measurement of plant biomass. All fruit were removed from the plants and soil was removed from roots. Plants were placed in paper bags and oven dried at 67 °C for five days before weighing.

Soil microbial biomass carbon. Soil samples were taken at the end of each growing season (29 Aug. 2013 and 19 Aug. 2014). Three soil cores (3.8 cm diameter, 15 cm depth) were taken within the row in each plot to make one composite sample per plot. Soil was kept in a sealed bag in a cooler at 4 °C until analysis. Soil samples were sieved using a 2 mm sieve. The sieve size was deemed appropriate instead of a more common 8 mm sieve (Karlen et al., 2013; Vance et al., 1987) because the sandy texture of the soil made it easy to sieve without much disturbance to the soil even with a smaller mesh size. Microbial biomass carbon (MBC) was extracted using a chloroform fumigation extraction method with a procedure modified from Vance et al. (1987). In 2013, extracts were analyzed on a Phoenix 8000 UV-Persulfate Total Organic Carbon (TOC) Analyzer (Teledyne Tekmar, Mason, OH). In 2014, a Torch Combustion TOC/TN Analyzer (Teledyne Tekmar) was used. A conversion factor of 0.33 was used when calculating microbial biomass carbon.

Statistical analysis

Data were analyzed using PROC GLIMMIX and PROC MIXED of SAS (Version 9.3, SAS Institute Inc.; Cary, NC). Years and management systems (organic and conventional) were analyzed separately. Replication was treated as a random factor. Mean separation was performed by “lsmeans” and “pdiff” statements using the Satterthwaite method. Unprotected least significant difference (LSD) was used, thereby allowing for comparisons among treatments even without significant main effects or interactions. This was important because the main research question was not about the wholeplot or subplot treatments themselves, but about how they interacted.

Results

Weather

Monthly rainfall amounts during the 2013 and 2014 growing seasons were similar to 20-year averages, except for unusually low rainfall in August 2013 (Table 3.2). Average monthly growing degree days (GDDs) were similar to 20-year averages, though in both years July had fewer GDDs compared to the 20-year average.

Air temperature and light intensity

In 2013, rowcovers did not affect minimum air temperature, but they increased mean air temperature by 3.1 to 4.0 °C and increased maximum air temperature by 6.2 to 10.3 °C (Table 3.3). In 2014 rowcovers increased minimum air temperature during the early season period by 1.4 °C. Similarly to 2013, rowcovers increased mean air temperature in both season periods by 1.6 to 2.6 °C. Surprisingly, rowcovers increased maximum air temperature in the early season by 5.4 °C but had no effect in the midseason period.

Rowcovers decreased mean light intensity averaged over 24 hr by 33% to 39% and decreased maximum light intensity by 34% to 44%, depending on the year (Table

3.4). The weight of rowcover used in this experiment is expected to have 70% light transmission when new, but the rowcovers used in this experiment had been used in previous seasons as is the typical practice for most growers using rowcovers.

Soil temperature

In 2013, rowcover had no effect on soil temperature in ST or PL systems (Table 3.5). While minimum soil temperature was unaffected by production system in 2013, PL treatments had higher mean and maximum soil temperature both before and after rowcover removal. Before rowcover removal, mean and maximum soil temperatures were 2.1 and 3.5 °C higher in PL, respectively. After rowcover removal, mean and maximum soil temperatures were 1.0 and 2.1 °C higher in PL, respectively.

In contrast, in 2014 rowcovers increased minimum and mean soil temperature by 1.3 and 1.1 °C, respectively, before they were removed. In 2014, when averaging across rowcover treatments, PL treatments always had higher minimum, mean, and maximum soil temperatures than ST treatments, raising the daily minimum soil temperature by 1.7 to 1.8 °C, daily mean soil temperature by 1.7 to 2.0 °C, and daily maximum soil temperature by 2.0 °C. However, before the rowcovers were removed there was no difference in soil temperature between ST with rowcover and PL without rowcover.

Plant biomass and leaf chlorophyll content

Table 3.6 shows that PL treatments had higher plant biomass than ST treatments in organically and conventionally managed fields in both years. Yet, in the conventionally managed field in 2014, biomass in ST with or without rowcovers did not differ from biomass in PL without rowcovers. There was no trend for the effect of production system or rowcovers on SPAD meter readings; in the conventionally managed field in 2013, however, the plants in ST without rowcovers had the highest SPAD meter readings.

Yield

In the organically managed field, production system affected marketable yield in both years (Table 3.7). PL treatments produced 2.6 and 2.1 more marketable squash per plant than ST treatments in 2013 and 2014, respectively. Rowcovers also affected marketable yield in both years in the organically managed field; treatments with rowcovers produced 0.7 and 1.3 more marketable squash per plant than treatments without rowcovers in 2013 and 2014, respectively. In 2014, the yield from plants in ST with rowcovers did not differ from plants in PL without rowcovers. Interaction between production system and rowcover was not statistically significant.

In the conventionally managed field, production system influenced marketable yield in both years, as it did in the organically managed field (Table 3.7). In 2013 and 2014, PL treatments produced 1.6 and 1.5 more marketable squash per plant than ST treatments, respectively. In contrast to the organically managed field, rowcovers had no effect on marketable yield in either year for the conventionally managed summer squash. In 2013, plants in PL with rowcovers produced equivalent yield to ST with or without rowcovers, whereas plants in PL without rowcovers produced more squash than either ST treatment. This outcome could be explained by a windstorm that occurred just before rowcovers were removed from the squash in 2013. The wind pushed the rowcovers down onto the plants, causing many petioles to snap on the large plants in PL. Though the plants recovered, we speculate that this decreased their yield.

In 2013, there were more nonmarketable (cull) summer squash in PL treatments than in ST treatments in both the organically and conventionally managed fields. In contrast, in 2014, there was no effect of production system on number of cull summer squash in either field.

Soil microbial biomass carbon

Production system had no effect on MBC in organically or conventionally managed plots in 2013 or 2014 (Table 3.8). There was, however, marginally (P = 0.056) higher MBC in the PL treatment in the conventionally managed field in 2014 than the ST treatment.

Discussion

Our results indicate that summer squash grown in a rolled rye strip tillage system can be as productive as summer squash grown in plasticulture. The 2013 organically managed field was the only case in which there was no equivalent yield between some of the ST and PL treatments. Walters and Kindhart (2002) found that summer squash grown in no-till and strip tillage systems had equivalent yields compared to those grown in a conventionally tilled system, but their experiment did not involve the use of black plastic mulch. Rowcovers increased squash yield in the ST treatments in the organically managed fields only, though we saw equivalent yields between some ST and PL treatments in the conventionally managed fields as well.

We expected rowcovers to have a stronger positive effect on plant biomass production than observed, as rowcovers have been shown to increase plant biomass (Ibarra et al., 2001) and vine cover (Cline et al., 2008) in muskmelon. Nair and Ngouajio

(2010) found that rowcovers increased cucumber growth when used in a system that incorporated compost. However, it is possible that the rowcovers provided too much additional heat; previous research has found that increasing air temperature above 40 °C can decrease muskmelon plant biomass (Jenni et al., 1996) and yield (Motsenbocker and Bonanno, 1989). In this study, though, even treatments without rowcovers approached or surpassed average daily maximum temperatures of 40 °C, and rowcovers had a neutral or positive effect on plant biomass and marketable yield. There is some evidence that the sensors used to monitor air temperature recorded higher temperatures in the treatments without rowcovers than actually occurred because of their placement in the direct sun. Jenni et al. (1996) placed thermocouples in white plastic tubes to avoid this problem. Our results reiterate the strong effect of plastic mulch on increased squash vegetative growth (Mahadeen, 2014).

Rowcovers had a more pronounced positive effect on squash yield in the organically managed field compared to the conventionally managed field. This could have been due to a difference in the efficacy of the pesticides used. The organic pesticides may not have been as effective as the conventional pesticides, leading to a larger discrepancy in insect damage and disease spread between rowcover and no-rowcover treatments in the organically managed fields compared to the conventionally managed fields.

Though light intensity was reduced under rowcovers, it likely did not impact the growth of plants because rowcovers were in place in June, when there are ample hours of intense sunlight. Even under rowcovers, direct sunlight should have a photon flux density beyond the saturation point for a C3 plant such as summer squash (Wells and Loy, 1985).

When averaged over rowcover treatments, PL had increased yield and biomass compared to ST in our study. Many researchers have measured the effect of mulch treatments on soil temperature at depths of 10 cm or less (Bonanno and Lamont, 1987; Ibarra-Jiménez et al., 2004; Schonbeck and Evanylo, 1998; Soltani et al., 1995) and have found that black plastic mulch increases soil temperature compared to bare ground by 2 to 4 °C. Schonbeck and Evanylo (1998) found that at a depth of 9 cm, a thick layer of hay reduced afternoon soil temperature compared to bare ground by 2.5 to 4.5 °C. Even at a depth of 15 cm, we found the soil under black plastic mulch was on average 1 to 2 °C warmer than that in ST. In our study, the rye mulch likely did not have much of a cooling effect, as our rye mulch did not provide complete coverage of the soil. Rye growth was potentially limited by the sandy nature of the soil and in conjunction with an October planting date which did not allow for as much rye growth in the fall as would occur with an earlier planting date (Mirsky et al., 2009).

We hypothesized that MBC would be higher in ST treatments than in PL treatments due to the different levels of soil disruption, yet our results were inconsistent. We chose to measure MBC specifically because it is known to be more responsive to management practices than other measurements such as soil organic carbon or soil organic matter. However, some researchers have found no differences in MBC even after multiple consecutive years of tillage treatment differences (Awale et al., 2013; Karlen et al., 2014). Karlen et al. (2013) did find that after at least 26 years, MBC was higher in no-till plots than in those that were tilled with a moldboard plow. Additionally, Overstreet and Hoyt (2008) found that after ten years of strip tilling in the same location each year, the MBC between rows, in the undisturbed region, was higher than that within the annually disturbed region. In our study, the warm and organic-residue-rich soil in the PL treatments could have provided a beneficial habitat for microbial growth in the short term. We suspect that tillage treatments would need to be established for more than one growing season to see a benefit of a reduced tillage system on MBC.

The air warming effect of rowcovers often allows growers to plant earlier in the season without risking frost damage. However, in a rolled rye system, early planting is challenging. Cereal rye should be at anthesis stage when using a roller crimper in order to get an effective kill without regrowth, if not using herbicide (Mirsky et al., 2009), though waiting even longer, until early milk stage, can sometimes provide a more effective kill (Wayman et al., 2014). The maximal amount of biomass production is also needed to effectively suppress weeds and retain moisture (Price and Norsworthy, 2013). Given these requirements, planting of squash is delayed and rowcovers in a rolled rye system would likely be covering plants during the heat of the summer. This could be a limitation to the rolled rye strip tillage system.

Even given this challenge, our results show that summer squash grown in a rolled rye strip tillage system can have yields comparable to summer squash grown in plasticulture. Given that long-term reduced tillage can increase various aspects of soil health, the option of using a rolled rye strip tillage system in summer squash production could provide a tool for growers to build soil health. Rowcovers could provide a yield boost in this system, especially when used in an organically managed system.

Literature cited

Awale, R., Chatterjee, A., and Franzen, D. 2013. Tillage and N-fertilizer influences on selected organic carbon fractions in a north dakota silty clay soil. Soil Tillage Res. 134:213-222.

Bonanno, R.A. and Lamont, W.J. 1987. Effect of polyethylene mulches, irrigation method, and row covers on soil and air temperature and yield of muskmelon. J. Amer. Soc. Hort. Sci. 112:735-738.

Cirujeda, A., Aibar, J., Anzalone, A., Martin-Closas, L., Meco, R., Moreno, M.M., Pardo, A., Pelacho, A.M., Rojo, F., Royo-Esnal, A., Suso, M.L., and Zaragoza, C. 2012. Biodegradable mulch instead of polyethylene for weed control of processing tomato production. Agron. Sustainable Dev. 32:889-897.

Cline, G.R., Sedlacek, J.D., Hillman, S.L., Parker, S.K., and Silvernail, A.F. 2008. Organic management of cucumber beetles in watermelon and muskmelon production. HortTechnology 18:436-444.

Delate, K. 2008. Effects of organic fertilization and cover crops on an organic pepper system. HortTechnology 18:215.

Dickey, E.C., Fenster, C.R., Laflen, J.M., and Mickelson, R.H. 1983. Effects of tillage on soil-erosion in a wheat-fallow rotation. Trans. ASAE 26:814-820.

Hemphill, D.D., Jr. 1993. Agricultural plastics as solid waste: What are the options for disposal? HortTechnology 3:70-73.

Hoyt, G.D. 1999. Tillage and cover residue affects on vegetable yields. HortTechnology 9:351-358.

Hoyt, G.D., Monks, D.W., and Monaco, T.J. 1994. Conservation tillage for vegetable production. HortTechnology 4:129-135.

Ibarra-Jiménez, L., Quezada-Martin, M.R., and de la Rosa-Ibarra, M. 2004. The effect of plastic mulch and row covers on the growth and physiology of cucumber. Austral. J. Expt. Agr. 44:91-94.

Ibarra, L., Flores, J., and Díaz-Pérez, J.C. 2001. Growth and yield of muskmelon in response to plastic mulch and row covers. Scientia Hort. 87:139-145.

Jenni, S., Cloutier, D.C., Bourgeois, G., and Stewart, K.A. 1996. A heat unit model to predict growth and development of muskmelon to anthesis of perfect flowers. J. Amer. Soc. Hort. Sci. 121:274-280.

Karlen, D.L., Cambardella, C.A., Kovar, J.L., and Colvin, T.S. 2013. Soil quality response to long-term tillage and crop rotation practices. Soil Tillage Res. 133:54-64.

Karlen, D.L., Stott, D.E., Cambardella, C.A., Kremer, R.J., King, K.W., and McCarty, G.W. 2014. Surface soil quality in five midwestern cropland conservation effects assessment project watersheds. J. Soil Water Conserv. 69:393-401.

Kasirajan, S. and Ngouajio, M. 2012. Polyethylene and biodegradable mulches for agricultural applications: A review. Agron. Sustainable Dev. 32:501-529.

Lamont, W.J., Jr. 2005. Plastics: Modifying the microclimate for the production of vegetable crops. HortTechnology 15:477-481.

Leavitt, M.J., Sheaffer, C.C., Wyse, D.L., and Allan, D.L. 2011. Rolled winter rye and hairy vetch cover crops lower weed density but reduce vegetable yields in no-tillage organic production. HortScience 46:387-395.

Mahadeen, A.Y. 2014. Effect of polyethylene black plastic mulch on growth and yield of two summer vegetable crops under rain-fed conditions under semi-arid region conditions. Amer. J. Agr. Biological Sci. 9:202-207.

Mirsky, S.B., Curran, W.S., Mortensen, D.A., Ryan, M.R., and Shumway, D.L. 2009. Control of cereal rye with a roller/crimper as influenced by cover crop phenology. Agron. J. 101:1589-1596.

Motsenbocker, C.E. and Bonanno, A.R. 1989. Row cover effects on air and soil temperatures and yield of muskmelon. HortScience 24:601-603.

Nair, A. and Ngouajio, M. 2010. Integrating rowcovers and soil amendments for organic cucumber production: Implications on crop growth, yield, and microclimate. HortScience 45:566-574.

Overstreet, L.F. and Hoyt, G.D. 2008. Effects of strip tillage and production inputs on soil biology across a spatial gradient. Soil Sci. Soc. Amer. J. 72:1454-1463.

Peigné, J., Ball, B.C., Roger-Estrade, J., and David, C. 2007. Is conservation tillage suitable for organic farming? A review. Soil Use Mgt. 23:129-144.

Pelosi, C., Pey, B., Hedde, M., Caro, G., Capowiez, Y., Guernion, M., Peigne, J., Piron, D., Bertrand, M., and Cluzeau, D. 2014. Reducing tillage in cultivated fields increases earthworm functional diversity. Appl. Soil Ecol. 83:79-87.

Price, A.J. and Norsworthy, J.K. 2013. Cover crops for weed management in southern reduced-tillage vegetable cropping systems. Weed Technol. 27:212-217.

Saalau Rojas, E.S., Gleason, M.L., Batzer, J.C., and Duffy, M. 2011. Feasibility of delaying removal of row covers to suppress bacterial wilt of muskmelon (cucumis melo). Plant Dis. 95:729-734.

Schonbeck, M.W. and Evanylo, G.K. 1998. Effects of mulches on soil properties and tomato production i. Soil temperature, soil moisture and marketable yield. J. Sustainable Agr. 13:55-81.

Soltani, N., Anderson, J.L., and Hamson, A.R. 1995. Growth analysis of watermelon plants grown with mulches and rowcovers. J. Amer. Soc. Hort. Sci. 120:1001-1009.

Vance, E.D., Brookes, P.C., and Jenkinson, D.S. 1987. An extraction method for measuring soil microbial biomass-c. Soil Biol. Biochem. 19:703-707.

Walters, S.A. and Kindhart, J.D. 2002. Reduced tillage practices for summer squash production in southern illinois. HortTechnology 12:114-117.

Wayman, S., Cogger, C., Benedict, C., Burke, I., Collins, D., and Bary, A. 2014. The influence of cover crop variety, termination timing and termination method on mulch, weed cover and soil nitrate in reduced-tillage organic systems. Renewable Agr. Food Systems FirstView:1-11.

Wells, O.S. and Loy, J.B. 1985. Intensive vegetable production with row covers. HortScience 20:822-826.

Wyenandt, C.A., Riedel, R.M., Rhodes, L.H., Bennett, M.A., and Nameth, S.G.P. 2011. Fall- and spring-sown cover crop mulches affect yield, fruit cleanliness, and fusarium fruit rot development in pumpkin. HortTechnology 21:343-354.

Table 3.1. Field operations for the 2013 and 2014 growing seasons.

Operation	**2013**	**2014**
Cereal rye drilled	12 Oct. 2012	2 Oct. 2013
Rye strip tilled (ST[z])	-	8 Apr.
Squash seeded in 72-cell trays	9 May	14 May
Rye mowed and tilled (PL[y])	9 May	29 May
Rye crimped at anthesis (ST)	22 May	29 May
Rye strip tilled (ST)	3 June	29 May
Soil tilled and plastic laid (PL)	3 June	5 June
Squash transplanted, rowcovers laid	4 June	5 June
Rowcovers removed	26 June	1 July

[z]ST = strip tillage

[y]PL = plasticulture

Table 3.2. Monthly total precipitation and average growing degree days (GDD) during the 2013 and 2014 growing seasons and the 20-year average in Muscatine, IA[z].

	Monthly precipitation (mm)			**Monthly avg GDD[y]**		
Month	**2013**	**2014**	**20-yr avg[x]**	**2013**	**2014**	**20-yr avg**
June	154	125	136	345	375	362
July	75	116	88	391	356	426
Aug.	0.5	107	104	386	398	403

[z]Monthly data from Iowa Environmental Mesonet at the Muscatine, IA location.

[y]Growing degree days with base 10 °C and maximum 30 °C.

[x]Twenty year averages from 1995–2014.

Table 3.3. Air temperature in conventionally managed summer squash in 2013 and 2014 before rowcovers were removed.

	Early season[z]				Midseason[y]		
Treatment	**Min**[x]	**Mean**	**Max**	**°C**	**Min**	**Mean**	**Max**
				2013			
Rowcover	16.3	28.9	49.8		18.6	32.6	52.8
No rowcover	15.7	24.9	39.5		18.0	29.5	46.6
P value[w]	0.208	<.0001	<.0001		0.210	<.0001	<.0001
				2014[v]			
Rowcover	14.9	27.0	46.4		19.8	29.6	46.5
No rowcover	13.5	24.4	41.0		18.8	28.0	44.0
P value	0.007	<.0001	<.0001		0.129	0.022	0.149

[z]Early season: 5 June–15 June 2013, 6 June–16 June 2014

[y]Midseason: 16 June–25 June 2013, 25 June–30 June 2014

[x]Average daily minimum, mean and maximum air temperatures pooled across management systems.

[w]*P* values based on F-test.

[v]A strong storm on 17 June 2014 disrupted a number of sensors. Those sensors were repositioned 24 June 2014. Data from 17–24 June 2014 have been discarded.

Table 3.4. Light intensity in conventionally managed summer squash in 2013 and 2014 before rowcovers were removed[z].

	Light intensity (lumens·m^{-2})	
Treatment	**Mean**[y]	**Maximum**
	2013	
Rowcover	274	1154
No rowcover	407	1742
P value[x]	<.0001	<.0001
	2014[w]	
Rowcover	238	1045
No rowcover	392	1874
P value	<.0001	0.0002

[z]Rowcover were in place 5–25 June 2013 and 6–30 June 2014

[y]Average daily mean and maximum light intensities pooled across production systems.

[x]*P* values based on F-test.

[w]A strong storm on 17 June 2014 disrupted a number of sensors. Those sensors were repositioned 24 June 2014. Data from 17–24 June 2014 have been discarded.

Table 3.5. Soil temperature at 15 cm depth in conventionally managed summer squash in 2013 and 2014.

Production System	Rowcover[y]	Before RC removal (°C)[z] Min[x]	Before RC removal (°C)[z] Mean	Before RC removal (°C)[z] Max	After RC removal (°C) Min	After RC removal (°C) Mean	After RC removal (°C) Max
				2013			
Plasticulture	RC	23.4	26.9 a[w]	30.6 a	22.8	26.4 a	29.7 a
	NRC	21.6	26.3 a	31.0 a	20.9	25.8 ab	29.5 a
Strip tillage	RC	22.8	24.8 b	27.2 b	23.3	25.3 b	27.4 b
	NRC	21.6	24.3 b	27.4 b	22.1	25.0 b	27.6 b
				Significance[v]			
System (S)		0.661	<.0001	0.003	0.420	0.018	0.002
Rowcover (R)		0.066	0.096	0.457	0.152	0.217	0.966
S × R		0.736	0.967	0.802	0.733	0.702	0.705
				2014			
Plasticulture	RC	24.7 a	27.7 a	30.9 a	23.2 a	25.3 a	27.8 a
	NRC	23.5 b	26.4 b	29.6 ab	23.1 a	25.5 a	28.0 a
Strip tillage	RC	22.9 b	25.5 bc	28.2 b	21.6 b	23.8 b	25.9 b
	NRC	21.6 c	24.6 c	28.3 b	21.2 b	23.6 b	25.9 b
				Significance			
System (S)		<.0001	0.0001	0.003	0.002	0.001	0.003
Rowcover (R)		<.0001	0.006	0.273	0.541	0.954	0.870
S × R		0.848	0.471	0.167	0.746	0.641	0.810

[z]Before rowcover removal: 5–25 June 2013, 6–30 June 2014; After rowcover removal: 26 June–31 July 2013, 1 July–1 Aug. 2014

[y]RC = rowcover, NRC = no rowcover

[x]Average daily minimum, mean and maximum soil temperatures.

[w]Mean separation (by year in columns) based on least significant difference at $P \leq 0.05$.

[v]P values based on F-test.

Table 3.6. Plant biomass and SPAD meter readings in conventionally and organically managed summer squash in 2013 and 2014.

Production System	Rowcover[z]	Biomass (g/plant)	SPAD	Biomass (g/plant)	SPAD
Organic		***2013***		***2014***	
Plasticulture	RC	47.7 a[y]	37.8	40.2 a	34.6
	NRC	43.5 a	35.5	37.6 a	33.9
Strip tillage	RC	21.0 b	36.4	26.4 b	36.2
	NRC	13.7 b	35.6	23.0 b	35.7
		----------*Significance*[x]----------			
System (S)		0.001	0.432	0.002	0.166
Rowcover (R)		0.080	0.086	0.409	0.630
S × R		0.595	0.369	0.912	0.944
Conventional		***2013***		***2014***	
Plasticulture	RC	44.9 a	36.7 b	32.1 a	35.1
	NRC	45.6 a	36.8 b	23.3 b	39.5
Strip tillage	RC	25.5 b	39.2 b	17.7 b	36.3
	NRC	19.7 b	41.2 a	16.6 b	35.8
		----------*Significance*----------			
System (S)		0.0001	0.038	0.0004	0.614
Rowcover (R)		0.323	0.121	0.081	0.426
S ×R		0.208	0.164	0.168	0.326

[z]RC = rowcover, NRC = no rowcover

[y]Mean separation (by year in columns) based on least significant difference at $P \leq 0.05$.

[x]P values based on F-test.

Table 3.7. Marketable and nonmarketable yield of organically and conventionally managed summer squash in 2013 and 2014.

Production System	Rowcover[z]	Marketable Yield (no./plant)	Cull Yield (no./plant)	Marketable Yield (no./plant)	Cull Yield (no./plant)
Organic		***2013***		***2014***	
Plasticulture	RC	7.2 a[y]	1.4 a	7.7 a	0.9
	NRC	6.9 a	1.3 a	6.7 b	1.0
Strip tillage	RC	4.9 b	0.8 b	5.9 b	0.8
	NRC	4.0 c	0.5 b	4.2 c	0.9
		----------------------------*Significance*[x]---------------------------			
System (S)		0.006	0.020	<.0001	0.500
Rowcover (R)		0.038	0.126	0.001	0.429
S × R		0.257	0.312	0.285	0.992
Conventional		***2013***		***2014***	
Plasticulture	RC	7.1 ab	1.5 ab	9.2 a	1.1
	NRC	8.3 a	1.6 a	8.5 ab	1.0
Strip tillage	RC	6.1 b	1.0 b	7.4 b	0.9
	NRC	6.0 b	0.9 b	7.2 b	0.8
		----------------------------*Significance*----------------------------			
System (S)		0.016	0.011	0.007	0.373
Rowcover (R)		0.178	0.843	0.334	0.296
S ×R		0.123	0.589	0.545	0.797

[z]RC = rowcover, NRC = no rowcover

[y]Mean separation (by year in columns) based on least significant difference at $P \leq 0.05$.

[x]*P* values based on F-test.

Table 3.8. Soil microbial biomass carbon (SMBC) (mg/kg) in conventionally and organically managed summer squash in 2013 and 2014.

Production System	SMBC (mg/kg)	
Organic	***2013***	***2014***
Plasticulture	75.8	151.0
Strip tillage	62.1	118.0
P value[z]	0.417	0.138
Conventional		
Plasticulture	85.1	125.3
Strip tillage	69.8	114.6
P value	0.331	0.056

[z]*P* values based on F-test.

CHAPTER 4. CONCLUSIONS

There were many similarities between how summer squash and muskmelon were affected by the production system and rowcover treatments. For both crops, plasticulture gave a general advantage over strip tillage in plant growth and yield. This was likely caused by the increase in soil temperature along with the decrease in weed pressure, both recognized benefits of using plastic mulch. Though we did not adequately measure weed biomass throughout the season, we spent noticeably more time weeding strip tillage plots than plasticulture plots, and were often not able to weed as frequently as desirable. The higher weed pressure in strip tillage could have negatively affected crop growth.

Additionally, rowcovers had a more positive and consistent effect in the organically managed plots compared to the conventionally managed plots for both crops. This discrepancy could have been due to the organic pesticides being less effective than the conventional pesticides. Perhaps this led to the rowcovers being a more distinct advantage for the organically managed plants, whereas the conventional insecticides provided a similar efficacy compared to the rowcovers.

Though there were similarities in how the two crops responded to the production system treatments, summer squash seemed to be a better fit than muskmelon for the rolled rye strip tillage system. In muskmelon, plants in plasticulture always produced more fruit than plants in strip tillage, whereas there was some overlap in yield between the production systems in summer squash. This appeared to be primarily an issue of growth habit. Summer squash quickly forms a more complete canopy, allowing it to more effectively compete with weeds compared to muskmelon. The vining, slower-growing muskmelon did not outcompete weeds early in the season. By the time the rowcovers were removed and we weeded all plots, the muskmelon plants in strip tillage treatments were more overwhelmed with weeds than the summer squash. In fact, we did not weed the summer squash plots at all in 2014, yet spent many hours weeding the muskmelon plots. Additionally, there could be a difference in range of ideal soil temperatures for summer squash and muskmelon. Muskmelon may require warmer soil than summer squash for maximum yield.

In many horticultural crops, early-season yields are desired due to their higher market value than produce later in the season. Plasticulture can increase early yields in muskmelon (Ibarra-Jiménez et al., 2004; Ibarra et al., 2001), which is in part why plasticulture in muskmelons is popular. In this study, it was not feasible to attain an early yield in strip tillage because planting could only occur after rye reached maturity. We therefore planted the transplants in early June both years. Due to the fact that we planted both production system treatments on the same day to minimize confounding effects, we started harvesting summer squash in early July and muskmelon in August, likely later than the somewhat ambiguous “early market” time period.

Rowcovers did not have as pronounced of an effect on yield as we anticipated. One explanation for this is that, because of our June planting, we may have missed the first wave of cucumber beetles. By the time the next wave of cucumber beetles arrived, the rowcovers had already been removed. In addition, due to the later planting date, the warming effect that the rowcovers provided may not have been as advantageous to the plants as it would have been earlier in the season when the air temperature was lower.

After two years of field trials, I am left with some unanswered questions regarding the possibility of finding a more sustainable approach to growing cucurbit crops. Below are some directions for future research in this area that could help find a viable alternative to plastic mulches.

1. Perform these trials on different soil conditions and plant rye earlier in an effort to establish a thicker stand of rye.

2. Manage all treatments for weeds as a grower would. Plots without rowcovers would be weeded before rowcovers are removed from other plots. Periodic weeding of strip tillage plots under the rowcovers may be needed.

3. Maintain the same placement of strips from year to year. No-till drill the cover crop seeds in strip tillage plots so that the between-row areas are left undisturbed for multiple consecutive years. Ideally rotate crops from year to year to manage disease issues, similar to work done by Dr. Daniel Brainard at Michigan State University.

4. Breed for earlier maturing rye or other cereal crops so rolling and planting can occur earlier in the season and potentially produce earlier yields.

5. Test for different soil health indicators, such as soil respiration, soil microbial biomass at shallower depths, etc.

6. Perform an economic analysis of strip tillage and plasticulture

Literature Cited

Ibarra-Jiménez, L., Quezada-Martin, M.R., and de la Rosa-Ibarra, M. 2004. The effect of plastic mulch and row covers on the growth and physiology of cucumber. Austral. J. Expt. Agr. 44:91-94.

Ibarra, L., Flores, J., and Díaz-Pérez, J.C. 2001. Growth and yield of muskmelon in response to plastic mulch and row covers. Scientia Hort. 87:139-145.