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Integrating Rowcovers and Soil Amendments for Organic Cucumber Production: Implications on Crop Growth, Yield, and Microclimate

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Abstract. **The area of organic production has registered a steady increase over past recent years. Transitioning to organic production is not straightforward and often includes a steep learning curve. Organic growers have to develop strategies to best manage nutrients, pests, and crop growth and yield. Additionally, in regions with temperate climate like the Great Lakes region, weather (especially temperature and solar radiation) plays an important role in crop productivity. Growers routinely use compost for nutrient provisioning and rowcovers for insect exclusion and growth enhancement. The objective of this work was to study the combined effect of rowcovers (with different light transmission) and compost organic cucumber (*Cucumis sativus* L.) growth and microclimate. Plots were assigned to three rowcover treatments (60% light transmission, 85% light transmission, and uncovered) and two amendment treatments (compost and no compost) in a split-plot factorial design. Data were collected for ambient air and soil temperature, photosynthetically active radiation (*PAR*), relative humidity, plant growth characteristics, and yield. Rowcovers modified crop microclimate by increasing air and soil temperature and decreasing *PAR*. There was a marked increase in the growing degree-day accumulations under rowcovers when compared with uncovered treatment. The impact of rowcovers on plant growth was significant. Use of rowcovers increased vine length, flower count, leaf area, leaf count, plant biomass, and total marketable yield. Use of compost in conjunction with rowcovers enhanced the rowcover effect. With the use of compost, there were not many significant differences in plant growth characteristics between rowcover materials; however, as expected, rowcover with 60% transmission was able to trap more heat and reduce light transmission when compared with rowcover with 85% transmission. This study clearly shows the importance of organic amendments, especially compost, in organic vegetable production. Applications of compost enhanced crop growth and also led to higher marketable yields. Results of this study suggest additive effects of rowcover and compost application on organic cucumber production.**

For more than a decade, organic agriculture has gained both popularity and attention among consumers and policymakers. Organic agriculture is the fastest growing agricultural sector in the United States with certified organic land present in all 50 states (Dimitri and Greene, 2002). Globally, there has been a constant demand for organically produced food and an increasing tendency to shift toward environmentally sound production practices (Dimitri and Greene, 2002). Growers have shown a keen interest to transition from conventional to organic crop production practices (Giles, 2004). In the United States, organic food sales grew 15.8% in 2008 (OTA, 2009). Croplands under certified organic vegetables have increased from 48,227 acres in 1997 to 98,525 acres in 2007, which is more than a 100% increase (USDA-ERS, 2005). Vegetable production without the use of synthetic fertilizers and pesticides could be challenging and requires implementation of new techniques and production practices. Transitioning to organic production often involves adjustments, technical know-how, and tools to better manage issues pertaining to soil fertility, weed, and pest populations (Dabbert and Madden, 1986). However, once a proper balance is established, organic production minimizes the use of external inputs, improves soil quality, and aims at economic viability with no or minimal impact on the environment.

According to the U.S. National Agricultural Statistics Service, Michigan ranks third in fresh market cucumber (*Cucumis sativus* L.) production after Florida and Georgia (USDA-NASS, 2008). Value of fresh market cucumber has been estimated at $14 and $242 million for Michigan and the United States, respectively (USDA-NASS, 2008). In the recent past, growers have indicated strong interest in transitioning to organic production methods and practices. One of the biggest challenges associated with organic cucumber production is the striped cucumber beetle (*Acalymma vittatum* F.) (Diver and Hinman, 2008; Hoffman, 1998). Cucumber beetle is an important pest of cucurbit crops that not only causes feeding damage on plant leaves, blossoms, and fruits, but also transmits bacterial wilt and can increase the incidence of powdery mildew and fusarium wilt (Diver and Hinman, 2008). Additionally, the variable climate and narrow seasonal window for growing vegetables in regions with a temperate climate, like Michigan, demands innovative crop management tools and efficient insect management strategies (Snapp et al., 2005). Unpredictable climatic conditions in the Great Lakes region such as high rainfall, low temperatures, and humid conditions early in the growing season delay planting and facilitate early and rapid infestation of pest and diseases.

The role of rowcovers as an effective pest management tool has been increasing because they serve as a barrier against various insect pests, including aphids, cucumber beetles, whiteflies, and pathogens these insects transmit (Bextine and Wayadande, 2001; Boisclair and Bernard, 2006; Natwick and Laemmlen, 1993). In addition to insect exclusion, one of the most critical effects of rowcover on plants is the modification of environmental factors such as light, humidity, soil and air temperature, and air movement (Wells and Loy, 1985). All these factors directly impact plant growth and development; however, the most important one is temperature because it is the key component driving the environment's energy status (Lombard and Richardson, 1979). Rowcovers have been reported to significantly alter air temperature, thereby affecting plant growth through changes in leaf characteristics, biomass accumulation, and relative growth rate (Soltani et al., 1995). In regions with cooler temperatures and relatively cloudy days, like the Great Lakes, light transmission of rowcovers could affect crop growth. Few studies have addressed the impact of light transmission on rowcover performance under limiting sunlight conditions. Rowcover materials create a specific microclimate around the plant. Understanding the microclimate and its impact on plant growth and morphology is critical for making good use of rowcover technology. Our study focuses on the use of

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spun-bond polypropylene rowcovers in organic cucumber production and its effects on plant microclimate, growth, and yield. Spun-bond polypropylene rowcovers are being widely used for vegetable production in various regions of the United States (Lamont, 2005), but their performance and efficacy to suit the agroclimatic conditions in the Midwest need to be further investigated. Not many studies have documented the effect of spun-bond polypropylene rowcovers on organic production, especially under a temperate climate. It has been a challenge for organic growers to identify geographically appropriate and crop-specific practices for efficient crop management (Zehnder et al., 2007). Moreover, our study gains further relevance because organic cucumber production, by itself, has not been adequately investigated in our region.

Apart from the use of rowcovers, research is needed in areas like soil fertility and nutrient management to better understand crop management practices for organic cucumber production in the Midwest. For nutrient management, organic production systems rely heavily on inputs like composts and other organic amendments to build soil organic matter and meet crop nutrient demand (Russo and Webber, 2007). These inputs have a direct impact on plant growth, soil fertility, quality, and health. Soil health is critical because it supports microbial communities that perform essential ecosystem services like nutrient cycling, pathogen suppression, and stabilization of soil aggregates (Carrera et al., 2007). Much work has been done on compost for nutrient management under organic systems, but the use of compost in conjunction with rowcovers has not been studied in detail. Possible interactions may exist between soil nutrient status and crop performance under rowcovers. Our objectives, thus, were to 1) evaluate the impact of rowcovers with different light transmission levels on cucumber growth and yield; and 2) test the effect of compost in conjunction with rowcover treatments on vegetative and reproductive yields of cucumber.

Materials and Methods

This study was conducted from 2007 to 2009 at the Horticulture Teaching and Research Center (HTRC) at Michigan State University, Holt, MI. The soil was a Capac loam with 0% to 3% slope. Capac loam is somewhat poorly drained, moderately to moderately slowly permeable soil. The soil at the research plot was under transition (starting in 2006) from a conventional corn/soybean rotation to an organic production system. Table 1 summarizes the mean monthly and long-term air temperature, precipitation, and relative humidity during the cucumber growing season at HTRC. Like most of the organic growers in the region, a cover crop of cereal rye (*Secale cereale* L.) was drilled at a rate of 78 $kg \cdot ha^{-1}$ on 22 Sept. and 26 Sept. in 2007 and 2008, respectively. Dairy compost was applied to the compost treatments at a rate of 25 $t \cdot ha^{-1}$ on 8 May 2007 and 20 May 2008. In 2008, compost application was delayed as a result of excessive rains and persistent water-logged conditions in the field. In both years, after the application of compost, the rye cover crop was mowed and incorporated using a chisel plow. The movement of the plow was closely monitored to minimize compost carryover to no-compost treatment plots.

Nontreated cucumber seeds (*Cucumis sativus* L. 'Dasher-II'; Seedway, Hall, NY) were seeded into an organic medium comprised of peat (Sunshine® Professional Grade; Sun Gro Horticulture Ltd., British Columbia, Canada), dairy compost, and No. 2 vermiculite (Michigan Growers Products, Galesburg, MI) in a ratio 2:1:1 (by volume) on 30 May and 28 May in 2008 and 2009 respectively, and the flats were placed in a heated greenhouse (22 °C). To harden the seedlings before transplanting, they were moved out of the greenhouse and placed inside a lath house for 5 d. Seedlings were transplanted to the field on raised beds covered with black plastic mulch and drip-irrigated on 11 June 2008 and 16 June 2009. Each bed was 7.6 m long, 0.6 m wide, and 0.2 m high with one cucumber row. Transplants were spaced 45 cm inside the rows with beds spaced 167 cm from each other (center to center). The experimental design was a split-plot design with four replications. Main plot treatments were compost or no-compost treatments. Two rowcover treatments and one uncovered control formed the subplots. Rowcover treatments consisted of a 60% light transmission spun-bond rowcover (RC60; Gro-Guard®; Gintec Shade Technologies Inc., Vanessa, Ontario, Canada) and an 85% light transmission spun-bond rowcover (RC85) treatment. Each subplot contained three rows of 14 plants with the data row in the middle and outer two rows serving as guard rows. In addition to guard rows, there were guard plants in each row (one plant on either end of a row). Rowcovers were installed on appropriate treatment rows 7 d after transplanting using galvanized iron hoops and removed after 3 weeks. Rowcover edges and ends were immediately secured with soil after installation. Temperature sensors (WatchDog®; Spectrum Technologies, Plainfiled, IL) and quantum light sensors (PAR Light Sensor; Spectrum Technologies) were installed one per treatment, both inside and outside the rowcovers, to record ambient temperature and photosynthetically active radiation (*PAR*). In 2009, temperature sensors were also placed under the black plastic mulch at a depth of 2.5 cm. Additionally, relative humidity sensors (WatchDog®; Spectrum Technologies) were also installed in 2009.

Rowcovers were removed on 10 July in 2008 and 17 July in 2009 to facilitate pollination. Soon after the removal of rowcovers, data were collected on vine length, flower count, and leaf chlorophyll content (Minolta SPAD-502 Leaf Chlorophyll Meter, Osaka, Japan). Vine length was measured from the base of each plant to the growing point of a main vine. Chlorophyll measurements were made on the recently fully expanded leaf and 10 readings were averaged per experimental unit. Vine length and flower count were recorded for 12 plants and averaged. In addition, in 2009, two plants from each treatment were harvested and used for leaf count, leaf area, and vine dry weight measurements. Leaf area was measured using a LI-3100 Area Meter (LI-COR Inc., Lincoln, NE). Vines and leaves were subsequently dried at 38 °C for 3 d and weighed. Soon after detecting their presence, to control cucumber beetles, Pyganic® (McLaughlin Gormley King Company, Minneapolis, MN) was sprayed to uncovered plants and later to the row-covered plants once every 4 d until harvest. Downy mildew was detected later during the season in 2009. Sonata® (AgraQuest Inc., Davis, CA) was sprayed once a week to control the spread of downy mildew pathogen. Cucumbers were picked seven times in 2008 and six times in 2009 with an interval of 3 d between harvests. Fruits were graded as marketable (U.S. Fancy, U.S. Extra #1, U.S. #1, U.S. #1 Small, and U.S. #1 Large) or nonmarketable (deformed, overgrown, damaged by cuts, scars, sunscald, sunburn, dirt, disease, or insects) grades (U.S. Department of Agriculture, 1958). All data were subjected to analysis of variance (PROC MIXED procedure of Statistical Analysis Systems Institute Inc., Version 9.1; Cary NC).

Results and Discussion

Temperature, relative humidity, and light. In both years, mean air temperature under two rowcovers was higher than the ambient temperature (Fig. 1). In 2008, within the first 2

Table 1. Monthly average air temperature, total precipitation, and relative humidity during the 2008–2009 growing season and the 10-year average at the Horticulture Teaching and Research Center, Michigan State University, Holt, MI.

	Monthly avg air temp (°C)			Total monthly precipitation (mm)			Monthly avg relative humidity (%)		
Month	2008	2009	10-year avg[z]	2008	2009	10-year avg	2008	2009	10-year avg
June	20.0	19.2	19.6	112	126	71	49.6	71.4	72.2
July	21.7	19.3	21.5	96	61	72	72.6	72.7	73.6
August	20.6	20.1	20.6	17	105	67	72.9	77.0	77.2

[z]Ten-year average from 1998 to 2007.

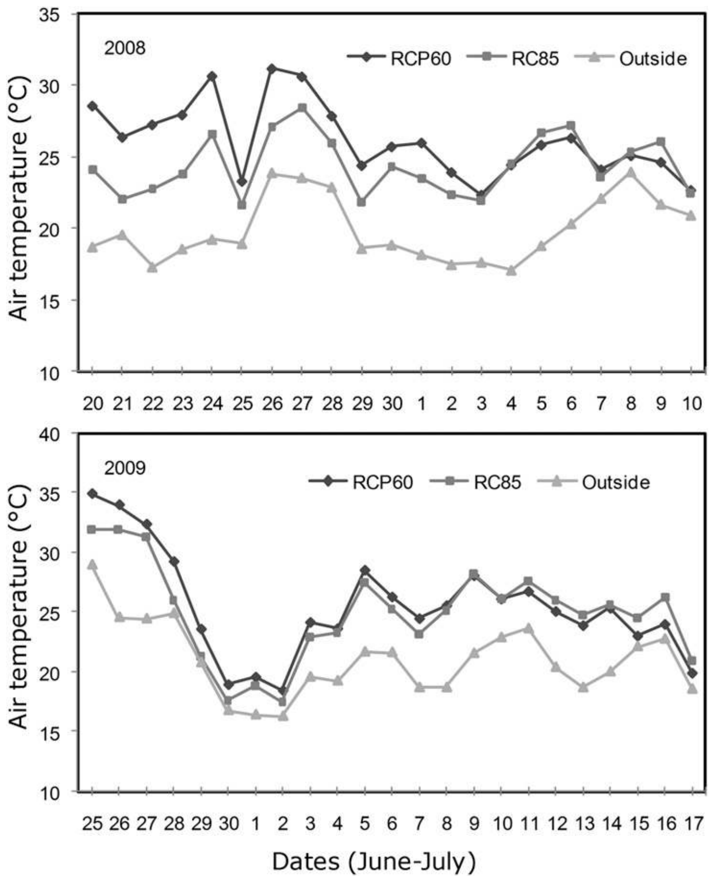

Fig. 1. Ambient air temperature outside and inside spun-bond rowcovers with different light transmission levels. RC6O and RC85 are rowcovers with 60% and 85% light transmission, respectively. Rowcovers were installed 7 d after cucumber transplanting and maintained for 21 and 23 d in 2008 and 2009, respectively. The research was conducted at the Horticulture Teaching and Research Center, Michigan State University, Holt, MI.

weeks of the 3-week rowcover installation, RC60 maintained a slightly higher temperature than RC85, but this temperature difference was not consistent in the last week. Similar results were recorded in 2009. The average difference in air temperature between ambient air and RC60, for the 21-d period in 2008 and the 23-d period in 2009, was 6.2and 4.4 °C, respectively. This temperature difference is largely the result of the heat radiation from the soil, black plastic mulch, and the plants, which are trapped by the spun-bond rowcovers (Ibarra et al., 2001). Rowcovers increase air temperature around the crop and their use has been associated with increased plant growth (Bonanno and Lamont, 1987; Gaye et al., 1992). Many researchers have demonstrated higher air temperatures under rowcovers and attributed it to rowcover permeability and the modified thermal regime inside (Moreno et al., 2002; Motsenbocker and Bonanno, 1989). Although it is desirable to maintain a higher air temperature near the plant canopy, it can also lead to crop injury (Soltani et al., 1995). Higher temperatures under rowcovers have been correlated with yield loss when temperatures exceed 40 °C (Peterson and Taber, 1991). Furthermore, increased temperatures could induce heat stress and affect pollination and fruit set (Gaye et al., 1992; Gerber et al., 1989). None of the rowcovers used in this experiment allowed the temperature to reach excessively high levels. Temperatures were higher under RC60 than RC85 because the material for RC60 is heavier (40 $g \cdot m^{-2}$) than for RC85 (17 $g \cdot m^{-2}$). The average difference in air temperature between RC60 and RC85 (21-d period in 2008 and 23-d period in 2009) was 1.7 and 0.5 °C in 2008 and 2009, respectively. The fact that air temperature was higher inside the rowcover material with low light transmission (heavy weight) suggests that air movement may play an important role in modulating air temperature inside the rowcovers. It is likely that air movement was low under the RC60 and thereby maintained the high temperature compared with RC85. This type of observation would probably not hold true if polyethylene plastic materials are used.

Soil temperatures under the plastic mulch were collected only for 2009. Soil temperatures fluctuated both in uncovered and rowcover treatments. As a result of rains during the last week of June, the soils were well saturated and this led to a decrease in soil temperatures. The heavier rowcover material (RC60) was able to maintain higher soil temperature than under the uncovered treatments (Fig. 2). During the period when rowcovers were installed, soil temperatures under RC60 were generally higher than the uncovered treatment. The average difference in soil temperatures between those two treatments was 2.6 °C. Black plastic mulch has been shown to increase mean soil temperatures (Hemphill and Crabtree, 1988; Hemphill and Mansour, 1986) but the effect is more pronounced when it is used in combination with rowcovers (Soltani et al., 1995). This effect is certainly desirable for growers in temperate regions where soils take longer time to heat up as a result of prolonged winter and wet springs. Higher soil temperature would enhance root growth and accelerate nutrient uptake, plant growth, and overall development. Surprisingly, for most of the dates during the period of rowcover installation in 2009, relative humidity recorded under the rowcovers was lower than the ambient air (Fig. 2). Presumably, relative humidity values tend to be higher under rowcovers as a result of reduced evapotranspiration and condensation of water within the rowcovers under field conditions (Lamont, 1996; Moreno et al., 2002). However, it is also possible that the high temperature under the rowcovers might have reduced relative humidity by increasing vapor pressure deficit.

The amount of *PAR* received by plants under each treatment is shown in Figure 3. As expected, uncovered plants received higher *PAR* when compared with the plants under rowcovers. Table 2 summarizes the amount of light received by plants under covered (RC60 or RC85) and uncovered treatments during the period when rowcovers were installed. In 2008, the total amount of *PAR* received by plants under RC60 and RC85 was 26% and 21% lower, respectively, than the total photon flux received by uncovered plants. Similar pattern was observed in 2009. Rowcovers reduce the amount of sunlight reaching the plants (Healey and Rickert, 1998) and the reduction depended on the rowcover material. In a study conducted by Moreno et al. (2002), instantaneous solar radiation was reduced by 13% by the use of rowcovers. They also reported lower cumulative solar radiation by 17% and 16% under perforated polythene and polypropylene floating rowcovers, respectively. Although there was a reduction in the amount of light received by plants under rowcovers, in our study, plants were more vigorous under the rowcovers. This could primarily be the result of increased air and soil temperature and improved light distribution under the rowcovers (Jenni et al., 1998; Moreno et al., 2002). Partial shading has been shown to promote plant growth (Lamont, 2005).

Plant growth and morphology. At the time of rowcover removal, plants under rowcovers were larger than the uncovered plants (Fig. 4). In the compost treatments, cucumber canopy covered most of the bed area when compared with no-compost treatments. There were significant differences in flower counts within treatments in both years. The interaction between rowcover treatments and the amendment treatment was also statistically significant. In 2008, the rowcover effect was

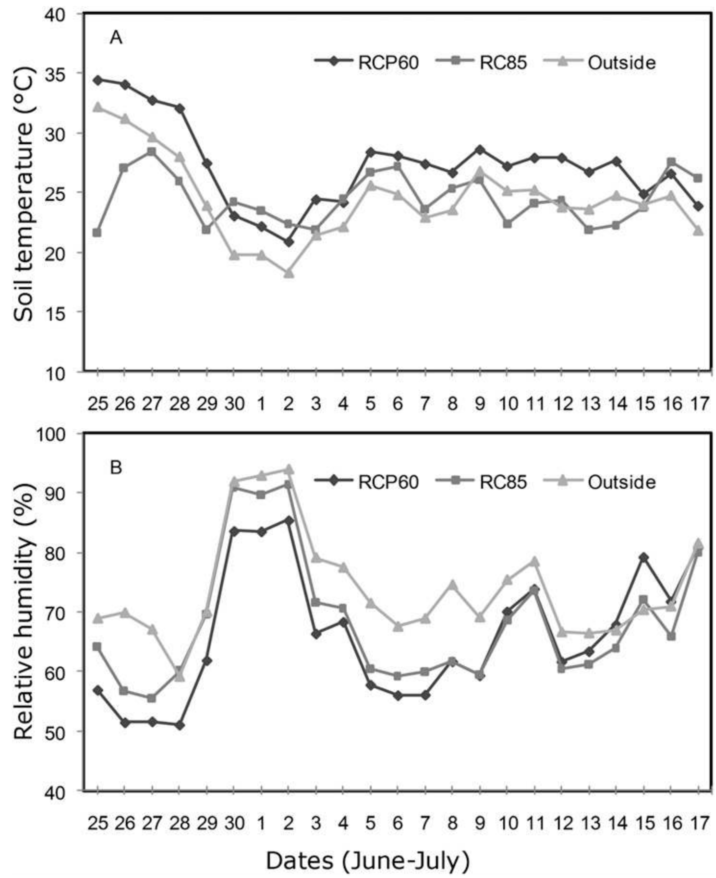

Fig. 2. Soil temperature and relative humidity outside and inside spun-bond rowcovers with different light transmission levels recorded in 2009. RC6O and RC85 are rowcovers with 60% and 85% light transmission, respectively. Rowcovers were installed 7 d after cucumber transplanting and maintained for 23 d. The research was conducted at the Horticulture Teaching and Research Center, Michigan State University, Holt, MI.

significant because the uncovered plants had the lowest flower count under compost and no-compost treatments (Table 3). Wolfe et al. (1989) had also reported lower flower numbers in cucumber plants grown on black plastic mulch alone when compared with black plastic mulch + spun-bond polypropylene rowcover. Differences in flower count between RC60 and RC65 within the amendment treatments were not statistically significant. However, the amendment effect was significant with compost significantly increasing flower counts in rowcover treatments. There was no compost effect on flower count in uncovered treatments. Application of compost adds organic matter and nutrients, improves soil physical properties, and enhances root development and nutrient uptake (Brady and Weil, 2000). As a result, plants have adequate resources for proper vegetative and reproductive development. Similar results were observed in 2009 except that flower counts for row-covered and uncovered plants were statistically not significant for no-compost treatment. Our study clearly shows that installation of rowcovers enhances early flower production in cucumbers, which could potentially contribute toward higher early yields. Higher early yields have been reported by a number of researchers in pepper (Gaye et al., 1992), watermelon (Soltani et al., 1995), and cucumber (Ibarra-Jimenez et al., 2004; Wolfe et al., 1989), and muskmelon (Motsenbocker and Bonanno, 1989) in response to rowcover.

Leaf count and dry weight data were collected only in 2009. There was an interaction effect between cover and amendment treatments for leaf count and leaf dry weights; thus, the main effects were analyzed separately. For the compost treatment, plants under RC60 and RC85 had a higher number of leaves than uncovered plants; however, there was no difference between the two rowcover treatments (Table 4). Under no-compost treatment, leaf counts for plants growing with or without rowcovers were not statistically significant. Effect of compost was highly significant for RC60 and RC85 treatments because the leaf count for compost treatments almost doubled. In the case of uncovered plants, compost had a limited effect on leaf counts. Leaf dry weight was also impacted by rowcovers and compost treatment. Plants under rowcovers not only had more leaves, but accumulated higher leaf biomass. Similar to leaf counts, there were significant differences in leaf dry weights between rowcovered and uncovered plants. Rowcovers significantly increased leaf dry weight when compared with uncovered treatment in both compost and no-compost treatments. Plants under compost treatment accumulated close to two times more leaf biomass (dry weight basis) than those grown without compost. Increased leaf number and dry weights reciprocate into increased photosynthetic capacity of the plant, thereby enhancing plant growth and development. In their experiments with muskmelons, Soltani et al. (1995) positively correlated growing degree-hours (GDH) with leaf number and leaf dry weight (r^2 of 0.92 and 0.90, respectively) under spun-bond polyester fabric rowcover. Thus rowcovers promote accumulation of higher GDH, which in turn increases leaf counts and leaf dry weights.

Unlike other studies, leaf area per plant was similar in all rowcovers in the absence of compost, thereby stressing the importance of soil fertility on plant growth. Although plants under RC60 and RC85 had 20% to 22% higher leaf area than uncovered plants, respectively, the differences were statistically not significant (Table 5). Wolfe et al. (1989) demonstrated higher leaf areas in cucumber plants grown on black/clear plastic mulch with rowcovers (clear plastic/spun-bond) when compared with plants grown on black plastic mulch without rowcovers. Similar results have been reported in muskmelon (Ibarra et al., 2001) and bell peppers (Jolliffe and Gaye, 1995). All these studies were conducted under conventional production systems where nutrient availability is generally not a limiting factor. The effect of rowcovers on leaf area was significant in compost treatment. Uncovered plants in compost treatment had lower leaf area when compared with plants under RC60 and RC85. There was no difference in leaf area between plants grown under RC60 and RC85. An interesting observation was that plants grown under RC60 without compost had leaf area statistically similar to uncovered plants grown with compost. This may be the result of the microclimate changes brought about by RC60, although the importance of compost cannot be undermined because it has far-reaching implications on plant growth and development than leaf area alone. Specific leaf area, which is the ratio of leaf area to leaf dry mass, was unaffected by the presence of rowcover or compost application.

In 2008, cucumber vines were longest for plants under RC60 and RC85 grown with compost (Table 5). Uncovered plants, grown with or without compost, had the shortest vines. Between RC60 and RC85 under no-compost treatment, RC60 produced plants with longer vines. However, this difference was not visible in the compost treatment. In 2009 within the no-compost treatment, there was no effect of rowcovers on vine length because RC60, RC85, and uncovered treatments showed similar values. Vine lengths of plants under compost treatment for uncovered and RC85 were statistically similar. Plants under RC60 had the longest vines. In general, compost treatments exhibited longer vines and this could be attributed to the

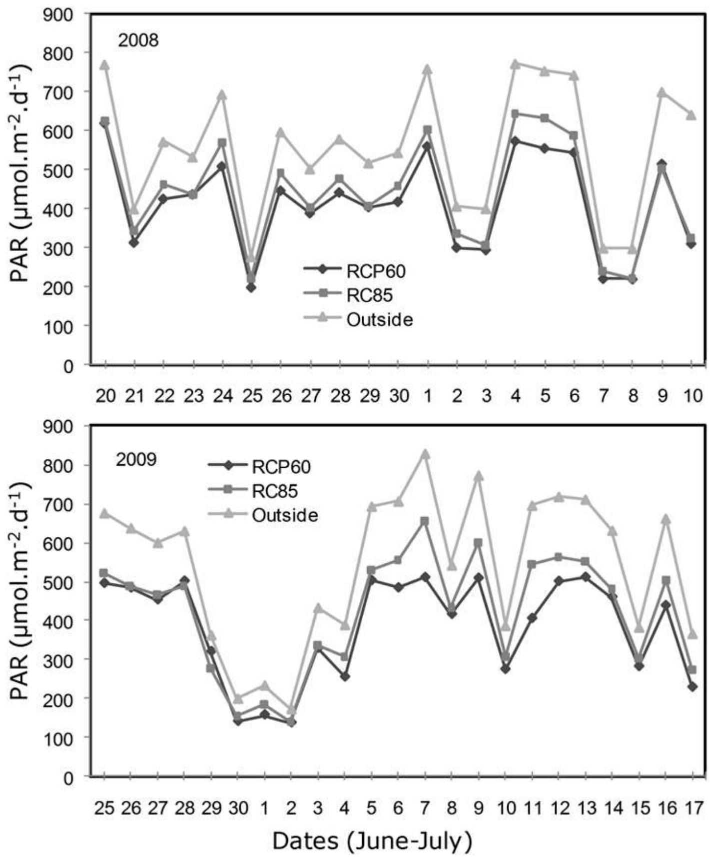

Fig. 3. Amount of photosynthetically active radiation received outside and inside spun-bond rowcovers with different light transmission levels. RC6O and RC85 are rowcovers with 60% and 85% light transmission, respectively. Rowcovers were installed 7 d after cucumber transplanting and maintained for 21 and 23 d in 2008 and 2009, respectively. The research was conducted at the Horticulture Teaching and Research Center, Michigan State University, Holt, MI.

Table 2. Monthly and total photosynthetically active radiation (*PAR*) received by cucumber plants uncovered and under RC60 and RC85 in 2008 and 2009 at the Horticulture Teaching and Research Center, Michigan State University, Holt, MI.

	PAR ($\mu mol \cdot m^{-2} \cdot d^{-1}$)					
	2008[y]			2009		
Treatment[z]	June	July	Total received	June	July	Total received
RC60	4,582.1	4,075.3	8,657.4	2,712.2	6,417.8	9,130.0
RC85	4,895.4	4,400.1	9,295.6	2,808.0	7,303.6	10,111.7
Uncovered	5,970.0	5,760.4	11,730.5	3,600.3	9,321.9	12,922.2

[z]RC60 = rowcover with 60% light transmission; RC85 = rowcover with 85% light transmission.
[y]Rowcovers installed for 21 d in 2008 and 23 d in 2009.

increased nutrients and enhanced microbial activity brought about by the addition of compost. Soil nitrogen in fields under organic production has been positively correlated with soil microbial components (Gunapala and Scow, 1998). Compost treatments in our study produced plants with longer vines and robust growth. Addition of compost did influence vine length, but its effect was insignificant on SPAD readings in 2008 (Table 5). Leaf chlorophyll content was indirectly measured using a SPAD meter. In 2009, all rowcover treatments with or without compost showed similar SPAD readings and were lower than uncovered + compost treatment. This makes sense because plants under RC60 and RC85 received lower *PAR* when compared with uncovered plants. Rowcovers reduce the amount of light reaching the plants, but the effect is compensated by increased air and soil temperature and protection from wind and pests.

Amendment × rowcover interaction was significant for plant biomass. Within compost treatment, plants under RC60 and RC85 had higher plant biomass than uncovered plants (Table 6). Higher biomass accumulation under rowcovers has been previously reported (Ibarra et al., 2001; Wolfe et al., 1989). Higher biomass has been positively correlated to growing degree-day accumulations, which is often used to predict plant biomass and yield (Wolfe et al., 1989). In this study, growing degree-day accumulations (during rowcover presence) under RC60 and RC85 were higher than outside for both years (Table 7). In 2008, RC60 and RC85 accumulated 82.5% and 68.1% more GDD, respectively. when compared with outside. In 2009, rowcovers increased GDD by 50% when compared with outside. Within no-compost treatment, biomass accumulation was lowest for plants growing uncovered. Unlike compost treatment, plants under RC60 did not produce higher biomass when compared with plants uncovered, probably as a result of the shading effect of the rowcover combined with low availability of nutrients in the no-compost treatment. Use of rowcovers in systems where nutrient availability and supply is an issue can adversely affect plant growth and ultimately yield. Nutrient management is often the rate-limiting factor for efficient and profitable organic vegetable production. Regardless of growing with or without rowcovers, plants in the compost treatment produced higher biomass. Robust and high-quality plants can be positively correlated to healthy and nutrient-rich soils. Compost, being a critical component of organic production, supplies nutrients that are released over time and improves soil physical, chemical, and biological quality (Bulluck et al., 2002).

Yield. In our study, the marketable fruit weight did not have any particular trend. In 2008, RC85 + compost treatment produced the highest marketable yield (Table 8). There was no difference in yield between compost and no-compost treatments of RC60 and uncovered plants. Fruit count under compost treatment of rowcovers was higher than uncovered + compost treatment. In 2009, compost treatments clearly stood apart both in marketable fruit weight and count. Compost treatments produced the highest marketable fruit weight and count. Beneficial effects of compost on vegetable growth and yield have earlier been reported (Maynard, 1994). Marketable cucumber yields have been shown to respond positively to compost applications (Roe et al., 1997). Correlation between marketable fruit weight and a number of growth parameters was highly significant. Marketable fruit weight was highly correlated with leaf area followed by plant biomass, leaf number, and vine length (Fig. 5). In our study, use of rowcovers in conjunction with compost improved various plant growth characteristics, indicating a significant contribution made by the vegetative parts toward total marketable yield.

There was no statistical difference in marketable fruit weight or count among plants grown in the compost treatment under RC60, RC85, or without rowcovers. Similar trend was observed within the no-compost treatment. Thus, in 2009, there was no effect of rowcovers on marketable crop yield. A number of studies have reported higher yields under rowcovers, but the yield increases are not consistent (Motsenbocker and Bonanno, 1989; Wolfe et al., 1989). Also, it is important to note that in most cases, higher yields are observed when comparisons are made

Fig. 4. Uncovered and covered plants soon after rowcover removal in 2009. (**A**) Uncovered, (**B**) RC60, (**C**) RC85, (**D**) uncovered + compost, (**E**) RC60 + compost, and (**F**) RC85 + compost. RC6O and RC85 are rowcovers with 60% and 85% light transmission, respectively. Rowcovers were installed 7 d after cucumber transplanting and maintained for 23 d. The research was conducted at the Horticulture Teaching and Research Center, Michigan State University, Holt, MI.

Table 3. Cucumber flower counts recorded at the time of rowcover removal under cover and amendment combinations in 2008 and 2009 at the Horticulture Teaching and Research Center, Michigan State University, Holt, MI.

	Flower count[z]					
	2008			2009		
Amendment	RC60[y]	RC85	Uncovered	RC60	RC85	Uncovered
Compost	4.3 aA[x]	4.5 aA	0.1 bA	10.6 aA	8.9 aA	7.1 bA
No compost	2.7 aB	2.3 aB	0.2 bA	4.9 aB	4.8 aB	4.7 aA

[z]Average number of flowers per plant. Data are the mean of 12 plants per experimental unit.
[y]RC60 = rowcover with 60% light transmission; RC85 = rowcover with 85% light transmission.
[x]Mean separation for an individual year within columns (uppercase letters) and rows (lowercase letters) with Fisher's protected least significant difference (α = 0.05).

Table 4. Cucumber leaf count and leaf dry weight under rowcover and amendment combinations collected at the time of rowcover removal in 2009 at the Horticulture Teaching and Research Center, Michigan State University, Holt, MI.

	Leaf characteristics (2009)					
	Leaf count[z]			Leaf dry wt (g)		
Amendment	RC60[y]	RC85	Uncovered	RC60	RC85	Uncovered
Compost	85 aA[x]	83 aA	57 bA	44.6 aA[w]	44.9 aA	31.4 bA
No compost	45 aB	48 aB	38 aA	22.3 aB	23.5 aB	18.7 aB

[z]Leaves counted from two sample plants harvested at the time of rowcover removal.
[y]RC60 = rowcover with 60% light transmission; RC85 = rowcover with 85% light transmission.
[x]Mean separation for leaf count within columns (uppercase letters) and rows (lowercase letters) with Fisher's protected least significant difference (α = 0.05).
[w]Mean separation for leaf dry weight within columns (uppercase letters) and rows (lowercase letters) with Fisher's protected least significant difference (α = 0.05).

between plants growing on black plastic mulch + rowcover and plants growing on bare soil without rowcovers (Ibarra et al., 2001; Soltani et al., 1995). Similar yields with or without rowcovers in our study in 2009 could be explained by lower pest pressure present. No major outbreak of insect (cucumber beetle) or disease damage occurred in 2009 because of which the additional benefit of using rowcovers because insect barrier was not received. On the other hand, there was moderate insect and disease pressure as a result of cucumber beetles in 2008. Rowcovers may not always impact crop yield, but it can certainly influence crop microclimate, which has a direct impact on plant growth and development (Ibarra et al., 2001; Soltani et al., 1995; Wolfe et al., 1989). The lack of clear yield improvement with the rowcover is probably because the slow growth in the uncovered plant was compensated late in the season. Unless there are limiting factors such as adverse weather conditions, fertility issues, insect and disease pressure, and so on, at the end of the season, we should not expect major differences in total yield among the rowcover treatments.

Interaction between amendment × cover was significant for nonmarketable fruit weight or cull weight in 2008 and 2009, but there was no specific trend. In 2008, within compost treatment, plants under RC85 had higher cull weight than RC60 or uncovered treatment (Table 9). Rowcover treatments had higher cull weight than uncovered plants within no-compost treatment. For individual cover treatments, both uncovered plants and plants under RC85 produced higher cull weight with their respective compost treatment. There was no significant difference in cull weight between compost and no-compost treatments for plants under RC60. In 2009, uncovered plants produced the lowest cull weight in the compost treatment; however, there was no difference in cull weight between rowcovers and uncovered plants in the no-compost treatment. When analyzing the amendment effect, compost treatments of RC60 and RC85 produced higher cull weights, whereas there was no difference in cull weights in the uncovered plants. Higher nonmarketable fruit weight in compost + rowcover treatments was the result of damage attributable to pest and diseases. Second- and third-generation adults of cucumber beetles migrating into the area at midseason fed on fruits resulting in scarring and decreasing its marketability. In 2009, later during the season, the incidence of downy mildew was found to be more pronounced in rowcover treatments. A number of fruits had to be categorized as nonmarketable because they were small in size and misshapen.

Our 2-year study demonstrates a feasible organic cucumber production system. Yields obtained in our study, if not equal, were comparable to conventional production systems. However, it is important to recognize that organic systems are not straightforward. Every individual aspect of the system needs to be thoroughly studied and understood for effective crop management (Russo and Webber, 2007). Our experiment focused on studying the impact of rowcovers on changes in microclimate and plant growth under organic production system. Use of spun-bond rowcovers influenced microclimate and

Table 5. Leaf area, specific leaf area, vine length, and SPAD as affected by amendment and cover combinations in 2009 at the Horticulture Teaching and Research Center, Michigan State University, Holt, MI.

Treatment[z]	Leaf area[y] (cm^2)	SLA NS ($cm^2 \cdot g^{-1}$)	Vine length[x] (cm)		SPAD[w]	
			2008	2009	2008 NS	2009
Uncovered	3519.6 c[v]	190.2	30.8 d	54.9 c	48.2	49.7 ab
Uncovered + compost	6323.4 b	202.8	37.5 cd	75.3 b	46.0	51.0 a
RC60	4389.3 bc	196.8	48.4 b	62.3 c	45.8	44.8 c
RC60 + compost	9089.1 a	202.1	62.3 a	84.3 a	43.5	46.1 bc
RC85	4515.5 bc	192.5	45.0 c	56.7 c	47.5	47.5 abc
RC85 + compost	9223.3 a	203.1	65.8 a	75.9 b	41.6	45.9 bc

[z]RC60 = rowcover with 60% light transmission; RC85 = rowcover with 85% light transmission.
[y]Average of total leaf area from two sample plants.
[x]Length of the longest vine. Data are mean of 12 plants/replication.
[w]Mean of SPAD measurements obtained from the first fully opened leaf near the vine tip. Data are the mean of 12 plants.
[v]Mean separation within columns by Fisher's protected least significant difference ($\alpha = 0.05$).
NS = Nonsignificant.

Table 6. Cucumber plant biomass under rowcover and amendment combinations collected at the time of rowcover removal in 2009 at the Horticulture Teaching and Research Center, Michigan State University, Holt, MI.

Amendment	Plant biomass[z] (g/plant)		
	RC60[y]	RC85	Uncovered
Compost	64.2 aA[x]	62.5 aA	42.3 bA
No compost	30.9 abB	33.0 aB	24.3 bB

[z]Comprises above- and below-ground biomass (dry weights).
[y]RC60 = rowcover with 60% light transmission; RC85 = rowcover with 85% light transmission. The rowcovers were installed 7 d after cucumber transplanting and maintained for 21 and 23 d in 2008 and 2009, respectively.
[x]Mean separation within columns (uppercase letters) and rows (lowercase letters) with Fisher's protected least significant difference ($\alpha = 0.05$).

Table 7. Monthly growing degree-days (GDD) under rowcover treatments during cucumber growing season in 2008 and 2009 at the Horticulture Teaching and Research Center, Michigan State University, Holt, MI.

Treatment[z]	GDD (base temp 10 °C)					
	2008			2009		
	June	July	Total received[y]	June	July	Total received
RC60	219.8	159.9	379.7	122.1	262.5	384.6
RC85	180.7	169.0	349.7	105.7	273.4	379.1
Uncovered	112.3	95.7	208.0	78.7	176.6	255.3

[z]RC60 = rowcover with 60% light transmission; RC85 = rowcover with 85% light transmission.
[y]Data represent cumulative of June and July (data recorded for a 21-day duration in 2008 and 23 d in 2009).

Table 8. Cucumber marketable fruit weight and count under different amendment and rowcover combinations in 2008 and 2009 at the Horticulture Teaching and Research Center, Michigan State University, Holt, MI.

Treatment[z]	Marketable[y] yield			
	2008		2009	
	Fruit wt (kg/12 plants)	Fruit count (number/12 plants)	Fruit wt (kg/12 plants)	Fruit count (number/12 plants)
Uncovered	17.7 bc[x]	49 bc	16.8 b	49 b
Uncovered + compost	15.9 c	45 c	29.6 a	81 a
RC60	16.4 c	46 bc	13.7 b	46 b
RC60 + compost	22.8 bc	65 ab	26.7 a	75 a
RC85	24.1 b	68 a	15.8 b	47 b
RC85 + compost	26.8 a	70 a	29.2 a	81 a

[z]RC60 = rowcover with 60% light transmission; RC85 = rowcover with 85% light transmission.
[y]Comprised fruits of the following USDA grades: U.S. Fancy, U.S. Extra #1, U.S. #1, U.S. #1 Small, and U.S. #1 Large.
[x]Mean separation within columns by Fisher's protected least significant difference ($\alpha = 0.05$).

showed improved plant growth characteristics but not to the extent of a considerable increase in total marketable yield. However, the impact of rowcovers on air and soil temperature; stem, leaf, and flower characteristics; and plant biomass was remarkable. Several environmental factors influence plant growth and development with temperature having one of the strongest effects. By influencing air and soil temperature, a crucial factor, especially in the northern climates, rowcovers can increase heat accumulation units and enhance crop growth and development (Bonanno and Lamont, 1987; Jenni et al., 1998). Rowcovers could also significantly influence plant nutrient status and uptake under field conditions (Moreno et al., 2002). Both rowcovers tested in this study modified crop microclimate favorably. There were fewer significant differences in terms of plant growth parameters between RC60 and RC85.

Most organic systems rely heavily on organic amendments for supply of macro- and micronutrients to meet crop nutrient requirement. Compost is an organic amendment that not only adds nutrient, but also builds soil organic matter, soil structure, increases soil water-holding capacity, and stimulates microbial activity. In our study, compost application positively affected plant growth and marketable yield. Ecological processes determining yields like nitrogen mineralization potential and microbial and parasitoid diversity and abundance are higher in organic systems (Drinkwater et al., 1995). Organic amendments provide advantages beyond benefits of building soil organic matter and enhancing soil microbial activity because nutrients that are seldom applied by growers like zinc, manganese, boron, and sulfur are also supplied. In addition, organic amendments also supplement liming nutrients like calcium and magnesium and safeguard potential yield limitations and losses. Use of compost was synergistic to rowcovers in producing healthy and robust plants. This finding is particularly important for organic production in which nutrients are sometimes limiting factors. Rowcovers not only create a suitable microclimate for plant growth, but also act as an insect barrier and greatly influence the turbulent diffusion of carbon dioxide, sensible heat, and water vapor (Mao and Kurata, 1997). In Michigan, where weather conditions are cooler during early spring, rowcovers can provide protected conditions for early planting of cucumber transplants. There are a number of practices and techniques a grower can adopt and implement under organic cropping systems like cover cropping and use of plastic mulch and rowcovers, but he or she should take into consideration variables like cost of the material, available resources, market, and weather. Weather is by far the most variable and directly affects all ecological processes driving crop growth and development. Use of rowcovers under organic cucumber production systems could provide some leverage against unpredictable weather conditions and possibly increase farm sustainability and yield.

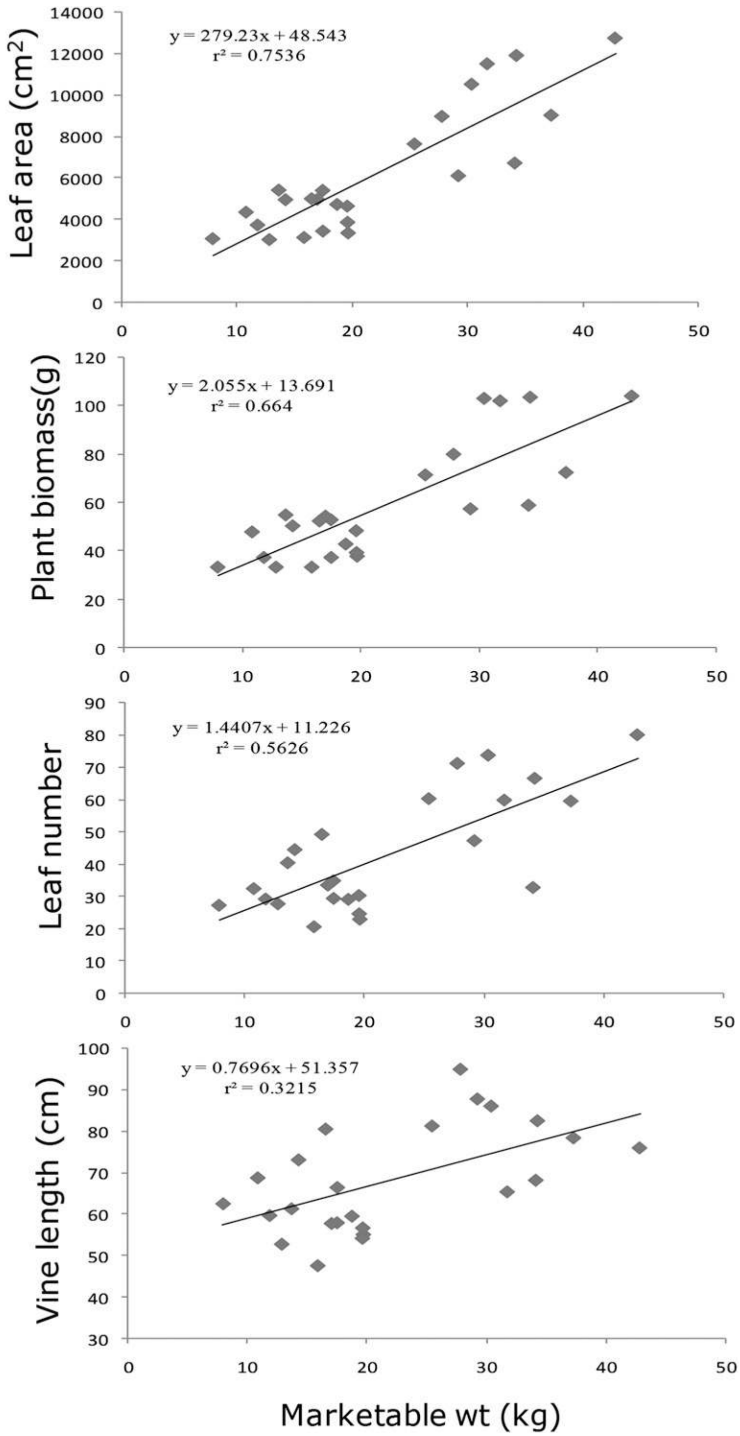

Fig. 5. Correlation between cucumber marketable weight versus leaf area, plant biomass, leaf number, and vine length in 2009. All correlations were highly significant (α < 0.001). Rowcovers were installed 7 d after cucumber transplanting and maintained for 23 d. Data on leaf area, plant biomass, leaf number, and vine length were collected by harvesting two plants from each treatment at the time of rowcover removal. Research was conducted at the Horticulture Teaching and Research Center, Michigan State University, Holt, MI.

Table 9. Nonmarketable cucumber fruit weight under different cover and amendment combinations in 2008 and 2009 at the Horticulture Teaching and Research Center, Michigan State University, Holt, MI.

	Nonmarketable[z] fruit wt (kg)					
	2008			2009		
Amendment	RC60[y]	RC85	Uncovered	RC60	RC85	Uncovered
Compost	4.1 bA[x]	6.1 aA	3.5 bA	7.3 aA	6.8 aA	3.3 bA
No compost	4.1 aA	3.7 aB	2.1 bB	3.1 aB	3.6 aB	2.7 aA

[z]Fruits with defects and diseases were categorized as nonmarketable.
[y]RC60 = rowcover with 60% light transmission; RC85 = rowcover with 85% light transmission.
[x]Mean separation for an individual year within columns (uppercase letters) and rows (lowercase letters) with Fisher's protected least significant difference (α = 0.05).

Literature Cited

Bextine, B. and A. Wayadande. 2001. Effect of insect exclusion on the incidence of yellow vine disease and of the associated bacterium in squash. Plant Dis. 85:875–878.

Boisclair, J. and E. Bernard. 2006. Insect pest management in organic agriculture: Acting in harmony with complexity. Phytoprotection 87: 83–90.

Bonanno, A.R. and W.J. Lamont, Jr. 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.

Brady, N.C. and R.R. Weil. 2000. The nature and properties of soils. Prentice Hall, Upper Saddle River, NJ.

Bulluck L.R., III, M. Brosius, G.K. Evanylo, and J.B. Ristaino. 2002. Organic and synthetic fertility amendments influence soil microbial, physical and chemical properties on organic and conventional farms. Appl. Soil Ecol. 19: 147–160.

Carrera, L.M., J.S. Buyer, B. Vinyard, A.A. Abdul-Baki, L.J. Sikora, and J.R. Teasdale. 2007. Effects of cover crops, compost, and manure amendments on soil microbial community structure in tomato production systems. Appl. Soil Ecol. 37:247–255.

Dabbert, S. and P. Madden. 1986. The transition to organic agriculture: A multi-year simulation model of a Pennsylvania farm. Amer. J. Altern. Agr. 1:99–107.

Dimitri, C. and C. Greene. 2002. Recent growth patterns in the U.S. organic foods market. 6 June 2008. <www.ers.usda.gov/publications/aib777/aib777.pdf>.

Diver, S. and T. Hinman. 2008. Cucumber beetles: Organic and biorational integrated pest management. 28 Mar. 2009. <http://attra.ncat.org/attra-pub/PDF/cucumberbeetle.pdf>.

Drinkwater, L.E., D.K. Letourneau, F. Workneh, H.C. VanBruggen, and C. Shennan. 1995. Fundamental differences between conventional and organic tomato agroecosystems in California. Ecol. Appl. 5:1098–1112.

Gaye, M.M., P.A. Jolliffe, and A.R. Maurer. 1992. Row cover and population density effects on yield of bell peppers in south coastal British Columbia. Can. J. Plant Sci. 72:901–909.

Gerber, J.M., W.E. Splittstoesser, and G. Choi. 1989. A heat system for predicting optimum row tunnel removal time for bell peppers. Scientia Hort. 40:99–104.

Giles, J. 2004. Organic FAQs. Nature 428:796–798.

Gunapala, N. and K.M. Scow. 1998. Dynamics of soil microbial biomass and activity in conventional and organic farming systems. Soil Biol. Biochem. 30:805–816.

Healey, K.D. and K.G. Rickert. 1998. Shading material changes the proportion of diffuse radiation in transmitted radiation. Aust. J. Exp. Agr. 38:95–100.

Hemphill, D.D., Jr. and G.D. Crabtree. 1988. Growth response and weed control in slicing cucumbers under row covers. J. Amer. Soc. Hort. Sci. 113:41–45.

Hemphill, D.D., Jr. and N.S. Mansour. 1986. Response of muskmelon to three floating row covers. J. Amer. Soc. Hort. Sci. 111:513–517.

Hoffman, M. 1998. Developing sustainable management tactics for cucumber beetles in cucurbits. NE-Sustainable Agriculture Research and Education Project Number ANE95-022.

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

Ibarra-Jimenez, L., M.R. Quezeda-Martin, and M. de la Rosa-Ibara. 2004. The effect of plastic mulch and row covers on the growth and physiology of cucumber. Aust. J. Exp. Agr. 44: 91–94.

Jenni, S., K.A. Stewart, D.C. Cloutier, and G. Bourgeosis. 1998. Chilling injury and yield of muskmelon grown with plastic mulches, row covers and thermal water tubes. HortScience 33:215–221.

Jolliffe, P.A. and M.M. Gaye. 1995. Dynamics of growth and yield component responses of bell peppers (*Capsicum annum* L.) to row covers and population density. Scientia Hort. 62:153–164.

Lamont, W.J., Jr. 1996. What are the components of a plasticulture vegetable system? HortTechnology 6:150–154.

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

Lombard, P. and E.A. Richardson. 1979. Physical principles involved in controlling phonological development, p. 429–440. In: Barfield, B.J. and J.F. Gerber (eds.). Modification of the aerial environment of crops. Amer. Soc. Agr. Eng. Monograph No. 2, St. Joseph, MI.

Mao, G. and K. Kurata. 1997. Wind tunnel experiment on turbulent diffusion suppression by row covers. Agr. For. Meteorol. 86:283–290.

Maynard, A.A. 1994. Sustained vegetable production for three years using composted animal manures. Compost Sci. Util. 2:88–96.

Moreno, D.A., G. Víllora, M.T. Soriano, N. Castilla, and L. Romero. 2002. Floating row covers affect the molybdenum and nitrogen status of Chinese cabbage grown under field conditions. Funct. Plant Biol. 29:585–593.

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

Natwick, E.T. and F.F. Laemmlen. 1993. Protection from phytophagous insects and virus vectors in honeydew melons using row covers. Fla. Entomol. 76:120–126.

OTA. 2009. Organic industry survey. 3 Jan. 2010. <http://www.ota.com/pics/documents/01a_OTAExecutiveSummary.pdf>.

Peterson, R.H. and H.G. Taber. 1991. Tomato flowering and early yield response to heat build-up under row covers. J. Amer. Soc. Hort. Sci. 116:206–209.

Roe, N.E., P.J. Stoffella, and D. Graetz. 1997. Composts from various municipal solid waste feedstocks affect vegetable crops. II. Growth, yield and fruit quality. J. Amer. Soc. Hort. Sci. 3:433–437.

Russo, V.M. and C.L. Webber III. 2007. Organic agricultural production in the United States: An old wheel being reinvented. Americas J. Plant Sci. Biotechnol. 1:29–35.

Snapp, S.S., S.M. Swinton, R. Labarta, D. Mutch, J.R. Black, R. Leep, J. Nyiraneza, and K. O'Neil. 2005. Evaluating cover crops for benefits, costs and performance within cropping system niches. Agron. J. 97:322–332.

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

U.S. Department of Agriculture. 1958. United States standards for grades of cucumbers. 14 June 2008. <http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELPRDC5050262>.

USDA-ERS. 2005. Organic production. 14 June 2008. <www.ers.usda.gov/Data/Organic>.

USDA-NASS. 2008. Cucumber. 16 Oct. 2009. <http://www.nass.usda.gov/QuickStats/indexbysubject.jsp?Text1=&site=NASS_MAIN&select=Select+a+State&Pass_name=&Pass_group=Crops+%26+Plants&Pass_subgroup=Vegetables#top >.

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

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.

Zehnder, G., G.M. Gurr, S. Kuhne, M.R. Wade, S.D. Wratten, and E. Wyss. 2007. Arthropod pest management for organic crops. Annu. Rev. Entomol. 52:57–80.