HORTSCIENCE 43(6):1770–1774. 2008.

Integration of Cover Crop, Conservation Tillage, and Low Herbicide Rate for Machine-harvested Pickling Cucumbers

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Additional index words. cereal rye, no tillage, oat, strip tillage, weeds

***Abstract*. The effects of two cover crops [cereal rye (*Secale cereale* L.) and oat (*Avena sativa* L.)], four tillage systems [no tillage (NT), strip tillage (ST), conventional tillage with cover crops incorporated (CTC), and conventional tillage without cover crop (CTN)], and three pre-emergence herbicide rates (full rate, half rate, and no herbicide) on pickling cucumber (*Cucumis sativus* L.) growth and production, weed populations, and the incidence of pythium fruit rot were studied. Weed infestations, cucumber establishment, and cucumber leaf chlorophyll content were similar between the rye and oat treatments. However, the oat treatment had higher cucumber fruit number and weight and a lower percentage of cucumber fruit infected with *Pythium* spp. compared with the rye treatment. The NT and CTC systems reduced cucumber stand and leaf chlorophyll content, but had equivalent cucumber fruit number and weight compared with CTN. The NT and ST had lower weed biomass and weed density than CTN and CTC. The NT also reduced the percentage of cucumber fruit affected with pythium compared with CTN and CTC. Reducing the pre-emergence herbicide rate by half did not affect weed control or cucumber fruit yield compared with the full rate. However, weeds escaping herbicide application were larger in the half-rate treatment. The experiments indicate that with the integration of cover crops and conservation tillage, it is possible to maintain cucumber yield while reducing both herbicide inputs (by 50%) and the incidence of fruit rot caused by *Pythium* spp. (by 32% to 60%).**

In the United States, pickling cucumber (*Cucumis sativus* L.) production was a $148 million industry in 2005 with over 47,000 ha planted [U.S. Department of Agriculture (USDA), 2005]. Michigan, the largest pickling cucumber producer in the United States, supplied ≈30% of the total national production. In Michigan, cucumbers represent the second most important group of vegetables after potatoes (*Solanum tuberosum* L.) and provide an important contribution to the State economy (USDA, 2005). However, as a result of short-term crop rotations and humid summers, disease incidence and weed infestations have increased, whereas soil fertility has decreased over the years (Ando and Grumet, 2006).

Cucumber fruit rot, caused by soilborne diseases such as *Phytophthora capsici* and *Pythium* spp., is a serious limiting factor for cucumber production in Michigan and other states (Ando and Grumet, 2006; Hausbeck and Lamour, 2004). Screening of cucumber accessions has so far failed to identify significant resistance to these diseases (Gevens et al., 2006). Integrated management strategies based on biology and ecology of the diseases have been suggested to reduce crop losses (Ristaino and Johnston, 1999). Direct contact of the soil by fruit is the major cause of losses in pickling cucumber. Therefore, strategies that limit fruit–soil contact could help manage soilborne diseases. This can be achieved by choosing a well-drained field, by keeping fruit off the ground, or by reducing splash dispersal (Hausbeck and Lamour, 2004; Ristaino and Johnston, 1999). Cover cropping, combined with conservation tillage, can leave enough residue on the soil surface to minimize contact of the soil by fruit. Ristaino et al. (1997) showed that no-till wheat (*Triticum aestivum* L.) cover significantly reduced incidence of *Phytophthora capsici* on bell pepper (*Capsicum annuum* L.) because the residue provides an effective barrier to inoculum dispersal.

Winter annual cover crops, like cereal rye (*Secale cereale* L.) and wheat, are widely used in pickling cucumber cropping systems in Michigan. The organic matter from the cover crops increases the size and diversity of soil microbial populations, which can reduce nematodes and soilborne diseases (Merwin and Stiles, 1989; Roberts et al., 2005; Sumner et al., 1995). Cover crops have been used to enhance production systems in many crops and locations (Lal et al., 1991). Cover crops are essential components of most conservation tillage systems. Lonsbary et al. (2004) studied various conservation tillage systems, including no tillage, zone tillage, and disking, and found that pickling cucumber yield in those systems was similar to yield in the conventional system. Benefits of conservation tillage include reductions in production cost, water pollution, soil erosion and degradation, and nutrient leaching (Corak et al., 1991; Hall et al., 1984; Lonsbary et al., 2004).

Weed management in pickling cucumber production relies on two key herbicide a.i.: ethalfluralin [N-ethyl-N-(2-methyl-2-propenyl)-2,6-dinitro-4-(trifluoro-methyl) benzenamine] and clomazone {2-[(chlorophenyl)methyl]-4,4-dimethyl-3-isoxazolidinone} (Zandstra, 2002). Therefore, alternative weed management practices such as cover cropping are needed to help minimize risks like herbicide resistance and environmental contamination.

Machine-harvest pickling cucumber has an average growing cycle of 40 to 55 d. Its canopy closes ≈3 to 4 weeks after emergence. Because weeds that emerge early in the growing season cause more losses than late-emerging weeds, a cropping system that delays weed seed germination would favor crop establishment. The combination of cover crops and conservation tillage may reduce early weed competition by delaying germination and can help reduce herbicide inputs (Burgos and Talbert, 1996; Hoffman et al., 1993; Teasdale, 1996). Weston (1990) showed that winter cover crops were effective in suppressing weed growth up to 45 d after kill without affecting cucumber establishment. Therefore, the rapid growth of cucumber and the weed suppression from integration of cover crops and conservation tillage provide the rationale for reduced herbicide rates in cucumber production systems.

Studies on cucumber production systems have been limited to exploring effects of cover crops, conservation tillage, or herbicide rates. The integration of the three components into a unique cropping system has not been investigated. Thus, the objective of this work was to study cucumber yield, weed population dynamics, and disease incidence in a system that integrates cover crops, conservation tillage, and reduced herbicide rates.

Materials and Methods

Experimental site and design. Experiments were conducted in 2005 and 2006 at the Michigan State University Horticulture

Received for publication 2 Apr. 2008. Accepted for publication 7 June 2008.
This research was funded in part by Project GREEEN (Generating Research and Extension to meet Environmental and Economic Needs) No. GR04-023 and No. GR05-007, PPRC MSU (Pickle and Pepper Research Committee for Michigan State University), PPI (Pickle Packers International Inc.), and the Michigan Vegetable Council. Pickling cucumber seeds were provided by Seminis Inc. We acknowledge technical support from William Chase and Gary Winchell from the Horticulture Teaching and Research Center at Michigan State University.
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Teaching and Research Center at East Lansing (lat. 42.7°N, long. 84.5°W; 264 m above sea level) on a Marlette fine sandy loam soil with pH 6.1 and 2.0% organic matter. Mean daily temperature during the summer growing season varied from 17.9 to 28.3 °C. Weekly average temperature and cumulative rainfall during cucumber growth in 2005 and 2006 are shown in Figure 1. The cucumber crop was irrigated (with a traveling irrigation gun) as needed so that plants were free of drought stress.

The experiment was a split-split plot design with four replications. The main plots were cereal rye and oat. The subplots were four tillage systems: strip tillage (ST), no tillage (NT), conventional tillage with cover crops incorporated (CTC), and conventional tillage without cover crops (CTN). The subsubplots were herbicide rate: no, half rate, or full rate of pre-emergence herbicides. Each subsubsubplot was 8.23 m long with three rows of cucumber set 0.61 m apart. The middle row was used for data collection. Rye cultivar VNS (Michigan State Seed Solutions, Grand Ledge, MI) was sown at 110 $kg \cdot ha^{-1}$ and oat cultivar Ida (Michigan Crop Improvement Association, Lansing, MI) was sown at 130 $kg \cdot ha^{-1}$ both years in 15-cm rows. In 2005, rye and oat were sown on 19 Apr. and killed with 1.4 $kg \cdot ha^{-1}$ a.e. of glyphosate (Roundup; Monsanto Company, St. Louis, MO) on 8 June. For the 2006 growing season, rye was sown on 12 Sept. 2005 and oat on 18 Apr. 2006. Glyphosate was sprayed on rye on 22 May and oat on 14 June as a result of differences in growth of the two cover crops. The cover crops were incorporated to a depth of 15 cm in the soil on 20 June 2005 and 15 June 2006 using a rototiller (CTC and CTN treatments) or a strip tiller (ST treatments). For the ST treatment, a band of 20 to 25 cm used as the seed line was tilled with a Craftsman 4-cycle Cultivator (Sears, Roebuck and Co., Hoffman Estates, IL) to a depth of 3 to 5 cm. Cucumber cultivar Journey (Seminis, St. Louis, MO) was sown on 20 June 2005 and 16 June 2006 with 7-cm spacing within the row for a final planting density of 230,000 seeds/ha. With the assumption of 25% lack of germination and seedling death, this corresponded to a target density of 170,000 plants/ha.

The herbicide treatments were applied within 3 d after cucumber sowing and before seedling emergence. The full rate treatment received 840 $g \cdot ha^{-1}$ a.i. of ethalfluralin (United Agri Products, Greeley, CO) plus 270 $g \cdot ha^{-1}$ a.i. of clomazone (FMC Corp., Philadelphia, PA). The half-rate treatment received 420 $g \cdot ha^{-1}$ a.i. of ethalfluralin plus 135 $g \cdot ha^{-1}$ a.i. of clomazone, and there was no herbicide applied in the control. There was no postemergence herbicide used in any treatments. Fertilizers were applied at the rate of 448 $kg \cdot ha^{-1}$ (19N–19P_2O_5–19K_2O) the day of herbicide application and the field was irrigated immediately to incorporate the fertilizer and to activate the herbicides. Diseases and insects were controlled using standard production practices for Michigan.

Data collection and analysis. Rye and oat height and dry biomass were measured before glyphosate application. Cucumber leaf chlorophyll content was measured three times each year in all tillage systems that received the full herbicide rate using a SPAD 502 Chlorophyll Meter (Konica Minolta Sensing, Osaka, Japan). Leaves at similar positions (second most recent fully expanded leaf) on the cucumber plants were used and 20 measurements were taken per plot.

Weed populations were assessed 28 and 24 d after cucumber sowing in 2005 and 2006, respectively. Weed density was determined using two 50 × 50-cm quadrats and total dry biomass was measured. Cover crop residue was assessed visually weekly based on percent soil cover. Cucumbers were harvested on 1 Aug. 2005 and 31 July 2006 when ≈10% fruit was oversize as recommended by Schultheis et al. (1998). Plants in the middle row of each bed were destructively harvested by hand to simulate machine-harvest. The number of cucumber plants was recorded and cucumber fruit was separated from the vines using a prototype machine developed by Michigan State University. Cucumber vines were weighed and fruit was sorted into grade 1, 2, 3, and oversize (OS) according to market standards (USDA, 1997). Grades 1, 2, 3, and OS consisted of fruit with diameters of 0 to 27, 28 to 39, 39 to 51 mm, and greater than 51 mm, respectively. Cucumber fruit and weight by grade were determined. Only grades 1, 2, and 3 were considered marketable. The fruit was left in a cool room at 4 °C for 1 week after harvest. At the end of the week, the number of rotted fruit was determined and the percentage calculated. The percentage data were Ln (percentage + 1) transformed to meet the normality of F test (Osborne, 2002). Untransformed data are shown for clarity of the presentation.

Analysis of variance was used to detect year and treatment effects. The 2-year data on specific variables were combined when no significant year × treatment interaction was observed. The GLM procedure in SAS was used to compare the treatments. All means were separated by protected least significant difference at a probability level of 0.05.

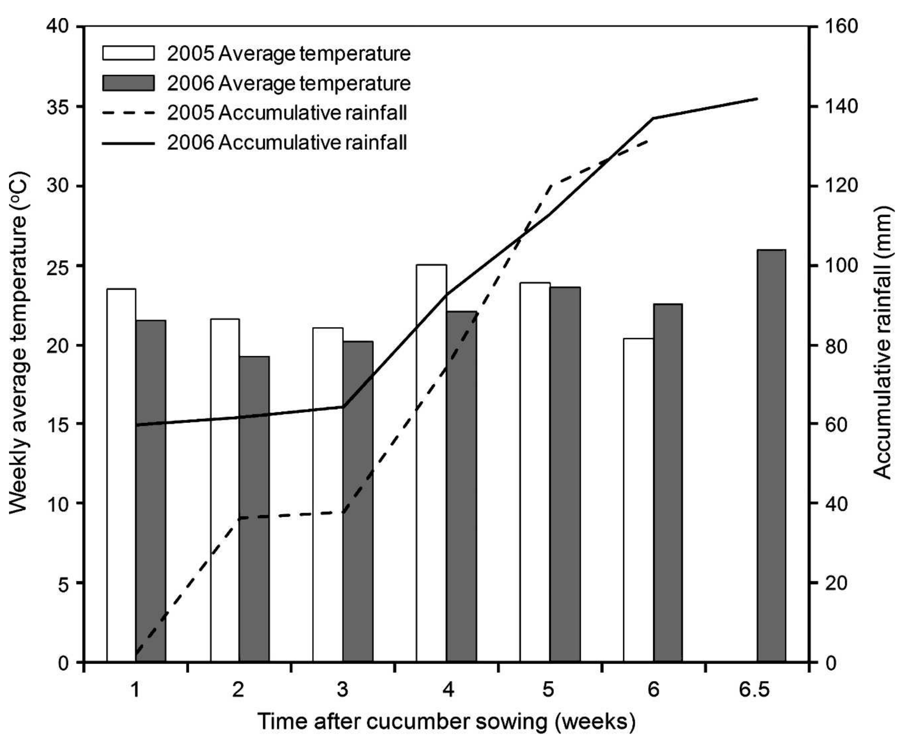

Fig. 1. Weekly average temperature and cumulative rainfall during machine-harvested pickling cucumber-growing seasons in 2005 and 2006 in East Lansing, MI.

Results

Cover crop biomass. Oat plants were 50 to 70 cm tall and produced 4.5 and 7.0 $t \cdot ha^{-1}$ biomass in 2005 and 2006, respectively. Rye sown in April 2005 grew 15 cm tall and produced 3.0 $t \cdot ha^{-1}$ biomass. In 2006, rye sown the previous fall season grew 150 cm tall and produced 11.4 $t \cdot ha^{-1}$ dry biomass before being killed. There was no significant difference between the biomass of oat and rye in 2005. However, rye residue decomposed completely 1 month after glyphosate application. In 2005, oat residue was detectable 2 weeks longer than rye in ST, NT, and CTC treatments. When rye was sown the preceding fall, it produced more biomass than oat (2006), and a large amount of residue of both cover crops was still in the field at cucumber harvest.

Cucumber leaf chlorophyll content. There was no interaction between cover crop type and herbicide rate. Therefore, data were pooled for these factors during analysis.

Cucumber leaf chlorophyll content was analyzed by year because of a treatment × year interaction. There was no difference between rye and oat for the six measurements of leaf chlorophyll in either 2005 or 2006 (data not shown). Tillage treatment had a limited effect on cucumber leaf chlorophyll content in 2005 (Table 1). In 2006, however, CTN had higher leaf chlorophyll content than the other three tillage systems.

Weed density and biomass. There were no differences between oat and rye for weed density, biomass, or size (Table 2). Tillage system affected weed populations. The NT treatment had the smallest weed density and biomass but the largest weed size (Table 3). Weed density of CTN was 10 times higher than NT but had smallest weed size as a result of the high density. The application of pre-emergence herbicide significantly reduced weed density and biomass (Table 4). Half and full rate of herbicide resulted in lower weed density and lower weed biomass than no herbicide. The half rate of herbicide gave similar weed control as the full rate in terms of weed density and weed biomass. However, the half rate of herbicide resulted in larger weed size, probably because of lower weed density compared with no herbicide treatment. There was also earlier weed emergence in the half-rate treatment compared with the full rate of the herbicide.

Cucumber stand and yield. Stands were equivalent in oat and rye (Table 2). However, oat increased number of marketable fruit in all grades and increased fresh weight of grades 2 and 3 compared with rye (Fig. 2).

Tillage treatment had significant effects on cucumber production (Table 3). The NT and CTC reduced cucumber stand by 13.7% compared with CTN. Although ST had the highest cucumber marketable fruit number and fruit weight, CTC had the lowest cucumber production among the tillage treatments with both lower fruit number and weight (Table 3).

Herbicide treatments did not affect cucumber stand but significantly impacted fruit yield (Table 4). Applying half rate or full rate of the pre-emergence herbicides increased cucumber fruit number by 38.5% and 33.0%, respectively, compared with no herbicide treatment. The half rate of the pre-emergence herbicide had equivalent cucumber vine fresh weight, fruit number, and fruit weight in comparison with the full rate of the herbicide. Herbicide application increased the number and weight of all marketable grades of cucumbers (Fig. 2).

Cucumber fruit rot. After 1 week of storage, the major disease observed was fruit rot caused by *Pythium* spp. The percentage of cucumber fruit infected by the disease was significantly affected by cover crop, tillage system, and herbicide treatments. Cucumbers from rye plots (4.36%) were significantly more affected by pythium fruit rot than those from oat plots (2.64%) (Table 2). The NT significantly reduced the percentage of fruit affected by pythium compared with CTC and CTN (Table 3). There was less soil splashing on cucumber plant and fruit in NT and ST plot than CTN and CTC after rain in field observations. The half rate of herbicide resulted in significantly lower percentage of rotted fruit than plots receiving no herbicide (Table 4).

Discussion

Oat produced more biomass in 2006 than in 2005. In 2006, oat was killed ≈1 week later

Table 1. Leaf chlorophyll content (SPAD units) of machine-harvested pickling cucumber grown under various tillage systems in East Lansing, MI, in the 2005 and 2006 growing seasons[z].

	2005			2006		
Treatment[y]	July 11	July 18	July 25	July 13	July 20	July 26
NT	52.40	44.23	44.16 b[x]	39.17 ab	37.00 b	37.58 b
ST	52.36	44.04	44.66 ab	38.76 b	36.04 b	38.20 b
CTC	51.14	44.78	44.98 ab	37.88 b	36.25 b	36.61 b
CTN	52.03	45.35	46.25 a	40.89 a	39.53 a	40.84 a

[z]Cucumber leaf chlorophyll content was measured with a SPAD 502 Chlorophyll Meter (Konica Minolta Sensing) in plots that were treated with a full rate of herbicides (840 g·ha^{-1} a.i. ethalfluralin and 270 g·ha^{-1} a.i. of clomazone). Leaves in similar position on cucumber plants were used. A total of 20 measurements were taken in each plot and the average was used for analysis.

[y]The tillage systems were NT (no-till with cereal rye or oat cover crops), ST (strip tillage with a 20- to 25-cm band tilled in cereal rye or oat residue), CTC (conventional tillage with cover crop incorporated into the soil), and CTN (conventional tillage without cover crop).

[x]Means within a column followed by the same letter do not differ significantly according to Fisher's least significant difference ($P \leq 0.05$).

Table 2. The effects of cover crops on machine-harvested pickling cucumber stand, vine fresh weight, fruit number and weight, pythium fruit rot, and weed populations in East Lansing, MI, in the 2005 and 2006 growing seasons[z].

	Cucumber					Weed		
Cover crop	Stand (× 10^3 plant/ha)	Vine fresh wt (t·ha^{-1})	Marketable fruit number (× 10^3 fruit/ha)	Marketable fruit wt (t·ha^{-1})	Pythium fruit rot (%)	Density (plant/m^2)	Biomass (g·m^{-2})	Size (g/plant)
Oat	142.54	22.37	181.17 a[y]	13.21 a	2.64 b	155.76	64.76	0.42
Cereal rye	138.75	20.90	151.83 b	10.17 b	4.36 a	123.24	45.68	0.37

[z]Cucumber cultivar Journey (Seminis, Inc., St. Louis, MO) was sown on 20 June 2005 and 16 June 2006 and weed populations were assessed on 18 July 2005 and 20 July 2006 in two areas of 0.25 m^2 each per plot during cucumber growth. Cucumbers were harvested when ≈10% fruit was oversized. Marketable cucumber fruit includes grades 1, 2, and 3 with diameters of 0 to 27, 28 to 39, and 39 to 51 mm, respectively. Cucumbers from each grade were counted and fresh weight was measured.

[y]Means within a column followed by the same letter do not differ significantly according to Fisher's least significant difference ($P \leq 0.05$).

Table 3. The effects of tillage systems on machine-harvested pickling cucumber stand, vine fresh weight, fruit number and weight, pythium fruit rot, and weed populations in East Lansing, MI, in the 2005 and 2006 growing seasons[z].

	Cucumber					Weed		
Tillage system[y]	Stand (× 10^3 plant/ha)	Vine fresh wt (t·ha^{-1})	Marketable fruit number (× 10^3·fruit/ha)	Marketable fruit wt (t·ha^{-1})	Pythium fruit rot (%)	Density (plant/m^2)	Biomass (g·m^{-2})	Size (g/plant)
NT	131.75 c[x]	21.79	169.10 a	11.70 ab	2.19 b	29.32 c	25.16 b	0.86 a
ST	143.36 ab	22.35	176.18 a	12.97 a	2.74 ab	47.16 c	27.40 b	0.58 ab
CTC	134.86 bc	20.14	144.56 b	10.57 b	3.68 a	304.24 a	77.80 a	0.26 c
CTN	152.62 a	22.29	176.15 a	11.53 ab	5.42 a	177.24 b	90.52 a	0.51 bc

[z]Cucumber cultivar Journey (Seminis, St. Louis, MO) was sown on 20 June 2005 and 16 June 2006 and weed populations were assessed on 18 July 2005 and 20 July 2006 in two areas of 0.25 m^2 each per plot during cucumber growth. Cucumbers were harvested when ≈10% fruit was oversized. Marketable cucumber fruit includes grades 1, 2, and 3 with diameters of 0 to 27, 28 to 39, and 39 to 51 mm, respectively. Cucumbers from each grade were counted and fresh weight was measured.

[y]The tillage systems were NT (no-till with cereal rye or oat cover crops), ST (strip tillage with a 20- to 25-cm band tilled in cereal rye or oat residue), CTC (conventional tillage with cover crop incorporated into the soil), and CTN (conventional tillage without cover crop).

[x]Means within a column followed by the same letter do not differ significantly according to Fisher's least significant difference ($P \leq 0.05$).

Table 4. The effects of herbicide rates on machine-harvested pickling cucumber stand, vine fresh weight, fruit number and weight, pythium fruit rot, and weed populations in East Lansing, MI, in the 2005 and 2006 growing seasons[z].

	Cucumber					Weed		
Herbicide[y]	Stand ($\times 10^3$ plant/ha)	Vine fresh wt ($t \cdot ha^{-1}$)	Marketable fruit number ($\times 10^3 \cdot$fruit/ha)	Marketable fruit wt ($t \cdot ha^{-1}$)	Pythium fruit rot (%)	Density ($plant/m^2$)	Biomass ($g \cdot m^{-2}$)	Size (g/plant)
None	138.34	18.67 b[x]	134.44 b	9.03 b	4.31 a	329.12 a	121.64 a	0.37 b
Half rate	143.45	23.45 a	186.26 a	13.47 a	3.40 b	58.24 b	32.12 b	0.55 a
Full rate	140.14	22.80 a	178.79 a	12.58 a	3.81 ab	31.12 b	11.84 b	0.38 b

[z]Cucumber cultivar Journey (Seminis, St. Louis, MO) was sown on 20 June 2005 and 16 June 2006 and weed populations were assessed on 18 July 2005 and 20 July 2006 in two areas of 0.25 m^2 each per plot during cucumber growth. Cucumbers were harvested when ≈10% fruit was oversized. Marketable cucumber fruit includes grades 1, 2, and 3 with diameters of 0 to 27, 28 to 39, and 39 to 51 mm, respectively. Cucumbers from each grade were counted and fresh weight was measured.

[y]The full rate of herbicide received 840 $g \cdot ha^{-1}$ a.i. of ethalfluralin plus 270 $g \cdot ha^{-1}$ a.i. of clomazone. The half-rate treatment received 420 $g \cdot ha^{-1}$ a.i. of ethalfluralin plus 135 $g \cdot ha^{-1}$ a.i. of clomazone, and there was no herbicide applied in the no-herbicide treatment.

[x]Means within a column followed by the same letter do not differ significantly according to Fisher's least significant difference ($P \leq 0.05$).

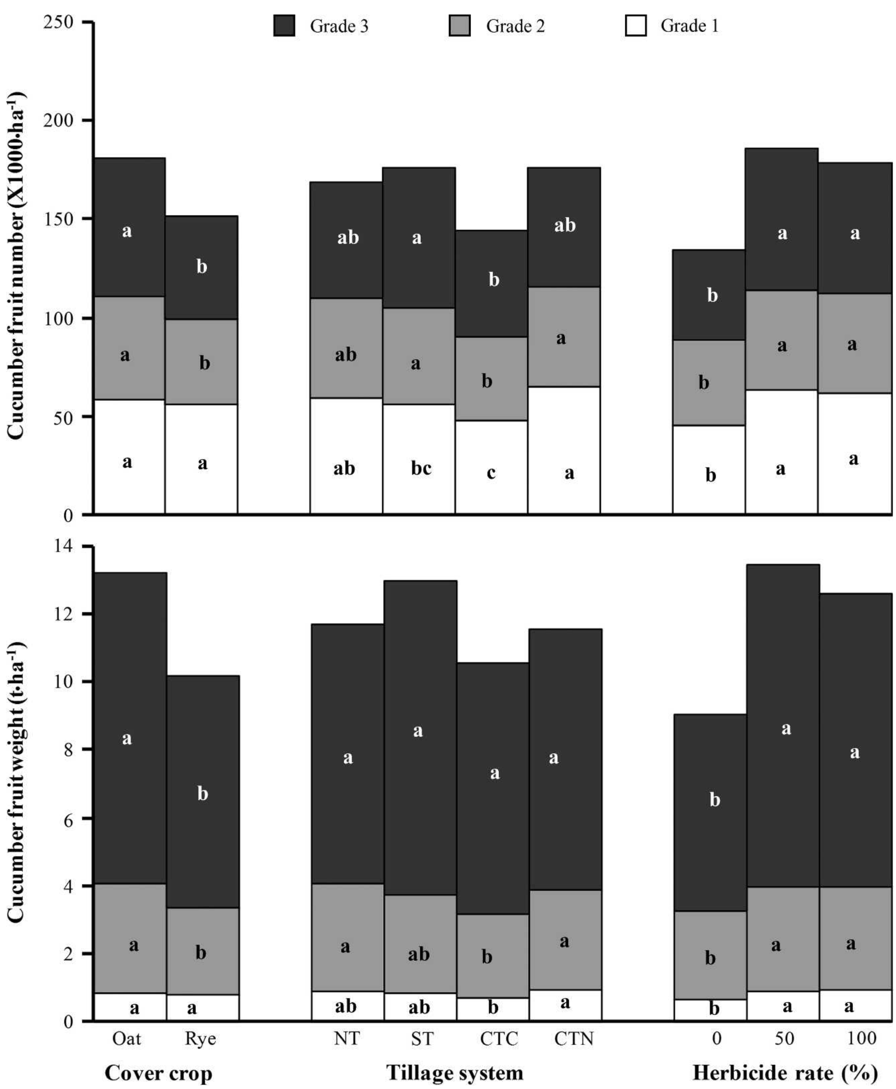

Fig. 2. Machine-harvested pickling cucumber marketable fruit number and fresh weight by grades as affected by cover crop (oat and cereal rye), tillage system (NT, ST, CTC, and CTN), and herbicide rate [no herbicide (0%), half rate (50%), and full rate (100%)] in East Lansing, MI, in the 2005 and 2006 growing seasons. The tillage systems were NT (no-till with cereal rye or oat cover crops), ST (strip tillage with a 20- to 25-cm band tilled in cereal rye or oat residue), CTC (conventional tillage with cover crop incorporated into the soil), and CTN (conventional tillage without cover crop). The full rate of herbicide received 840 $g \cdot ha^{-1}$ a.i. of ethalfluralin plus 270 $g \cdot ha^{-1}$ a.i. of clomazone. The half-rate treatment received 420 $g \cdot ha^{-1}$ a.i. of ethalfluralin plus 135 $g \cdot ha^{-1}$ a.i. of clomazone, and there was no herbicide applied in the no-herbicide treatment. Marketable cucumber fruit includes grade 1, 2, and 3 with diameter of 0 to 27, 28 to 39, and 39 to 51 mm, respectively. Fruit greater than 51 cm (oversize) were considered unmarketable and discarded. For each grade, bars within a system (cover crop, tillage, and herbicide) with the same letter are not significantly different according to Fisher's least significant difference ($P \leq 0.05$).

compared with 2005 because of rainfall and windy conditions that were not favorable for glyphosate application. The large biomass in 2006 was also the result of a better rainfall distribution, especially early in the season (Fig. 1). Cover crop residue acts as a sink or a source for plant-available nutrients. In 2005 when cover crop biomass was small (young plants) and was given enough time to decompose, cucumber leaf chlorophyll content was unaffected at most sampling dates. In 2006, when more cover crop biomass was added to the soil and oat cover crop was given a shorter time to decompose, cucumber leaf chlorophyll was reduced in the cover crop treatments compared with conventional tillage system with no cover crop. Therefore, it is necessary to adjust management practices when cover crops are used. Because the growth cycle of pickling cucumber is short (40 to 55 d), allowing more time for cover crop residue to decompose before crop planting would help improve nutrient availability. Although lower leaf chlorophyll content tended to slow down the vegetative growth of cucumber, fruit production was unaffected in this study. The slower vegetative growth, but equivalent yield of NT and CTN, is consistent with results obtained by Lonsbary et al. (2004). With the density and cultivar used in this study (once-over harvest cucumber), each cucumber plant produces only one to two fruit (Ngouajio et al., 2006). Once individual plant size is large enough to support two fruit, the addition of new leaves will not change the final yield (Lonsbary et al., 2004). Therefore, NT plots had equivalent yield, although the vegetative growth was slower.

In this study, NT treatments had the lowest weed density and biomass but the largest weed size. There were 2 to 3 weeks (except oat cover crop plots in 2006) between glyphosate application and cucumber sowing. All emerged weeds were killed by cultivation in the CTN and CTC treatments. In the NT or ST treatments, however, some weed seedlings were protected by cover crop residue and probably escaped herbicide application. This partially contributed to larger weed size in conservation tillage treatments compared with CTN. Plots treated with the half rate of the herbicide also had larger weed size, probably as a result of earlier weed emergence, compared with plots receiving a full rate of the herbicide. However, marketable yield was similar with full or half rate of the herbicide. This indicates that cucumber yield can be maintained while reducing the amount of pre-emergence herbicide applied by 50%.

Inconsistent results have been reported by other investigators on the effects of conservation tillage on cucumber stand establishment. Beste (1973) and Lonsbary et al. (2004) found that cucumber stand was unaffected by conservation tillage compared with conventional tillage. In contrast, Knavel and Morrison (1977) found that no tillage reduced cucumber stand. In this study, NT reduced cucumber plant number by 14% compared with CTN as a result of poor germination and emergence. However, the low density of cucumber in the NT plots did not produce lower cucumber yield. This may be because cucumber fruit number and fruit weight are relatively stable within a certain range of densities (Ngouajio and Mennan, 2005). Therefore, the change in density by tillage system may not decrease cucumber yield unless planting density is significantly lower than the optimal planting density range. To correct for the reduced stand in the NT system, planting density could be increased slightly to achieve a final plant population equivalent to those in the conventional systems.

Pythium spp. are soilborne pathogens that cause cucumber fruit rot in many production areas in the United States (Holmes, 2000). Conservation tillage systems (NT and ST) significantly reduced the percentage of fruit affected by pythium compared with the conventional tillage systems with or without cover crops (CTC and CTN). There was less soil on cucumber plants and fruit in conservation tillage plots because the cover crop residues reduced soil splash during rains. The same strategy was recommended for control of *Phytophthora capsici* in cucumber and bell pepper to reduce disease dispersal (Ando and Grumet, 2006; Hausbeck and Lamour, 2004; Ristaino and Johnston, 1999; Ristaino et al., 1997).

There was no difference between rye and oat cover crops for weed growth, cucumber establishment, and cucumber leaf chlorophyll content. However, rye reduced cucumber fruit number and fruit weight and increased percentage of cucumber fruit infected by pythium compared with oat. Rye has also been shown to produce lower yield and fruit quality compared with sorghum sudangrass [*Sorghum bicolor* (L.) Moench. × *S. sudanense* (Piper) Stapf.] and hairy vetch (*Vicia villosa* Roth) cover crops (Ngouajio, unpublished data). The processes underlying this effect need to be further studied (Barnes and Putnam, 1987).

Cover crops and conservation tillage are of interest in vegetable production for several reasons, including pressure from the public to reduce pesticide input, growers' interest in soil protection from erosion, and the limited number of herbicides available (Zandstra, 2002; Zandstra et al., 1998). Cover crops and conservation tillage can also serve as components of the "many little hammers" in ecological pest management (Liebman and Gallandt, 1997). All conservation tillage systems (NT and ST) reduced weed pressure and maintained cucumber yield equivalent to the conventional system (CTN). This suggests that the major contributions of conservation tillage in our conditions would be soil quality improvement (reduced erosion and compaction) and weed suppression. In the long term, this could also help reduce fertilizers input through better recycling of nutrients by the cover crops. In this study, when combined with oat cover crop and conservation tillage (NT and ST systems), the half rate of pre-emergence herbicide produced cucumber yield and weed control equivalent to a full rate of herbicide. Reduced herbicide inputs from the integration of cover crops and conservation tillage could offset some of the costs associated with the use of cover crops. Success of the system will depend on environmental conditions (rainfall and temperature) and weed populations. Because conservation tillage involves additional field activities and inputs, an economic analysis of this production system is necessary to assist growers in their decision-making processes.

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