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EVALUATION OF SPRING-PLANTED BRASSICA COVER CROPS FOR USE IN MUSKMELON (*Cucumis melo* L.) AND EGGPLANT (*Solanum melongena* L.) PRODUCTION SYSTEMS

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By

Victoria Joy Ackroyd

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ABSTRACT

EVALUATION OF SPRING-PLANTED BRASSICA COVER CROPS FOR USE IN MUSKMELON (*Cucumis melo* L.) AND EGGPLANT (*Solanum melongena* L.) PRODUCTION SYSTEMS

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Members of the Brassica family produce glucosinolates which upon hydrolysis are reported to impact soilborne pathogen populations. Oilseed radish (*Raphanus sativus* (L.) var. oleiferus Metzg (Stokes)), Oriental mustard (*Brassica juncea* (L.) Czern.), and yellow mustard (*Sinapis alba* L.) are Brassicas that are often used as cover crops. This research evaluated suitability of these species for use as spring-planted cover crops. In one field experiment, cover crops were spring-planted preceding muskmelon (*Cucumis melo* L. Group Reticulatus) and eggplant (*Solanum melongena* L.). In another field experiment, oilseed radish and Oriental mustard were spring-planted, then muskmelon, honeydew (*Cucumis melo* L. Group Inodorous), and cucumber (*Cucumis sativus* L.) were planted at five day intervals after cover crop incorporation to study cover crop phytotoxicity. In the laboratory, lyophilized and non-lyophilized oilseed radish root and shoot extracts were tested on muskmelon, honeydew, and cucumber germination and radicle growth. Results indicate that while these cover crops do aid in nutrient cycling, they do not confer significant protection against soilborne disease caused by *Verticillium dahliae* Kleb. under our field conditions. They should be used with caution due to their ability to inhibit cucurbit seed germination and cash crop growth. Laboratory results further suggest phytotoxic compounds are likely primarily volatile in nature.

Dedicated to Grandma Vicki, 1945 - 2009. Wish you could have seen this.

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CHAPTER 1: Introduction

CHAPTER 1: Introduction

Sustainable agricultural methods have become increasingly popular due to consumer demand, increased input costs, and more stringent regulation of pesticides. "Sustainable" is an amorphous term as there is no set definition, but most definitions account for economics, environment, and social issues (Pannell and Schilizzi 1999). Sustainable practices are viewed as being economically feasible for producers, as environmentally low-impact as possible, and fair to the involved human parties (Pannell and Schilizzi 1999). Different producers may place emphasis on one or more aspects of the definition of sustainability, or consider all equally (Pannell and Schilizzi 1999). In some cases, a single practice can incorporate all three elements: reduced pesticide use saves money while exposing the environment and farm workers to smaller amounts of potentially harmful chemicals. In some cases, a given production method may be sustainable in one way but less so in another (Pannell and Schilizzi 1999). For example, decreased herbicide use, while beneficial to the environment, requires use of more expensive and physically demanding weed management methods such as manual hoeing and/or use of fossil fuels for cultivation.

Producers employ a variety of methods that can be classified as sustainable (Reganold et al. 1990). These practices often result in decreased pesticide use, preservation of the farmland quality, and increased profit margins (Reganold et al. 1990). Depending on the crop and a producer's specific needs/concerns, one or more methods may be used (Reganold et al. 1990). Crop rotation can reduce pest and disease pressure (Reganold et al. 1990). Use of row covers excludes insects

from crops and allows for earlier plant dates. Plastic mulch decreases need for herbicides and maximizes water use. Reduced and no tillage systems prevent erosion and preserve soil structure.

Cover crops provide a variety of benefits; interest in them and use of them has increased (Mutch and Snapp 2003). Programs such as Sustainable Agriculture and Food Systems at Michigan State University actively promote the use of cover crops (SAFS 2009), since they can preserve soil quality, suppress weeds, aid in nutrient cycling, and serve as animal feed (Mutch and Snapp 2003).

Brassica cover crops are of particular interest because they produce glucosinolates. When plants are flailed and tilled into the soil, glucosinolates degrade to biocidal isothiocyanates (ITCs). ITCs impact soilborne pathogens including *Phytopthora spp.* (Dunne et al. 2003) and *Fusarium graminearum* Schwabe, *Rhizoctonia solani* J.G. Kuhn, and *Gaeumannomyces graminis* var. *tritici* J. Walker (Kirkegaard et al. 1996, Sarwar et al. 1998). 2-phenylethyl ITC and propenyl ITC (two common by-products of glucosinolate break down in Brassicas) are more efficient at suppressing fungal pathogens than methyl ITC (a synthetic fumigant) (Sarwar et al. 1998). Studies have also shown ITCs to suppress weed seed germination, a tool which must be used with caution (Norsworthy et al. 2006, Norsworthy and Meehan 2005a, Norsworthy and Meehan 2005b). Haramoto and Gallandt (2005a) found Brassica cover crops decreased cash crop stand count by 23-34% and delayed emergence by roughly 2 days. However, this impact was no different than other short-season cover crops (such as red clover).

Brassica cover crops provide many of the same benefits as other cover crops by improving soil structure and aeration, and aiding in nutrient cycling (potentially reducing fertilizer rates while optimizing yield). Wang et al. (2008) found celery and onion production systems in Michigan benefit from the nutrient cycling properties of Brassica cover crops. Collins et al. (2007) determined 29% of N uptake by a mustard crop was later recycled by the potato cash crop.

There is minimal research on use of Brassica cover crops in Michigan, particularly as spring cover crops. Given interest in cover crops, problems confronting Michigan growers, need for scientific research in sustainable agriculture, and Brassica cover crop potential, it is time this deficiency is addressed. We hypothesize that due to their production of glucosinolates and their nutrient cycling capabilities, Brassica cover crops will reduce impact of soilborne diseases, promote cash crop growth after establishment, improve crop yield, and affect crop germination and establishment in vitro as well as in vivo.

Objectives of this work are to: a) determine effects of Brassica cover crops on verticillium wilt incidence in eggplant and b) determine effects of Brassica cover crops on cucurbit and eggplant establishment, growth, and yield.

CHAPTER 2: Literature Review

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Cash Crops

Michigan ranks second to California in terms of agricultural diversity, contributing 71.3 billion dollars to Michigan's yearly economy (based on estimates using data from 2007) (Holton 2009). Two crops contributing to this diversity are eggplant (*Solanum melongena* L.) and muskmelon (*Cucumis melo* L. Group Reticulatus). In 2005 about 223 ha (550 A) of muskmelon worth $2.4 million were harvested; in the same year, 85 ha (210 A) of eggplant worth $1.11 million were harvested (MDA 2006).

Eggplant and muskmelon are warm season crops requiring a long season to produce fruit (days to maturity vary by cultivar and climate conditions and range from 80-120). Transplants are set in the field as soon as temperatures reliably stay above 13° C (55° F) (about the first week of June). Both crops favor well drained, sandy to loamy soils with a pH of 6.0-6.8 (Kemble 1996, Kemble et al. 1998, OVG 2010). Eggplant are heavy feeders; general recommendations are to apply 128 kg/ha (114 lb/A) N and 128 kg/ha (114 lb/A) each of P_2O_5 and K_2O before installing plastic mulch (OVG 2010). General recommendations are to apply 56 kg/ha (50 lb/A) N, 56-112 kg/ha (50-100 lb/A) P_2O_5, and 112-168 kg/ha (100-150 lb/A) K_2O before laying plastic mulch, if using fertigation (OVG 2010). Soil tests to determine the amount of P and K needed are advisable (OVG 2010). Under favorable weather conditions, eggplant are picked twice a week starting early August and ending late September; muskmelons are harvested three to four times

starting mid July and ending mid September though in hot weather they may require picking every other day (OVG 2010).

Both crops are prone to disease and insect infestation. Aphids, Colorado beetles (eggplant) and cucumber beetles (muskmelon), flea beetles, and mites may infest eggplant and muskmelon (Kemble 1998 et al., Kemble 1996, OVG 2010). According to Kemble (1996), aphids are best controlled through weed eradication along field edges and reflective mulches while the Ohio Vegetable Production Guide (OVG) (2010) states cucumber beetles may be controlled via insecticides. Mites can be controlled by scouting and spot-applications of miticides; flea beetles are best controlled through use of row covers (in small and/or organic operations) (Kemble 1996) and insecticides (OVG 2010). Muskmelon is prone to bacterial wilt (*Erwinia tracheiphilia* Smith), powdery mildew (*Ersiphe cichoreacearum* D.C.), downy mildew (*Pseudoperonospora cubensis* Berk. & M.A. Curtis), anthracnose (*Colletotrichum lagenarium* (Pass.) Ellis & Halst.), fusarium wilt (*Fusarium oxysporum* f. sp. *melonis* W.C. Snyder & H.N. Hansen), alternaria leaf spot (*Alternaria cucumerina* (Ellis & Everh.) J.A. Elliott), and damping-off (*Pythium spp.*) (Kemble 1996, OVG 2010). These diseases are controlled through a combination of plant resistance, crop rotation, fungicides, weed control, and careful fertilization (Kemble 1996, OVG 2010). Fusarium wilt is the soilborne disease of most concern in Michigan muskmelon production (Hausbeck, personal communication). Common eggplant diseases include alternaria leaf spot (*Alternaria solani* Sorauer), anthracnose (*Colleotrichum lagenarium* (Pass.) Ellis & Halst.), and verticillium wilt (*Verticillium dahliae* Kleb.) (OVG 2010). These diseases are controlled through

crop rotation, fungicides, and choosing well-drained sites (OVG 2010). Verticillium wilt is of particular concern in eggplant production in Michigan due to the difficulty of controlling it without methyl bromide (Ngouajio, personal communication).

Verticillium dahliae is a fungal pathogen with a simple life cycle. It thrives under temperatures of 25-28° C (Agrios 2005). It produces short-lived conidia as well microsclerotia; the microsclerotia are its resting structure (Agrios 2005). *Verticillium dahliae* overwinters via microsclerotia in the soil and mycelia in infected plant debris (Agrios 2005). Symptoms develop slowly and first appear on lower/outer parts of the plant; leaves develop chlorotic lesions that turn necrotic and then drop off, while upper leaves may wilt (Agrios 2005) (Figures 2.1 and 2.2). Verticillium wilt gradually becomes more severe and virulent as inoculum accumulates over the years (Agrios 2005). It is controlled through crop rotation, use of resistant cultivars and disease-free plants, soil fumigation, and soil solarization (Agrios 2005).

Methyl Bromide

Methyl bromide (MB) is a preplant soil fumigant and a post-harvest commodities fumigant (Carpenter et al. 2000; Ristaino and Thomas 1997). It has been used to control weeds, soilborne pests such as nematodes, and plant pathogens including fungi and bacteria (Carpenter et al. 2000; EPA 2009c). Methyl bromide is of particular value in controlling verticillium wilt (Wilhelm 1980). Methyl bromide historically has been used primarily on strawberries, peppers,

ornamentals, tobacco, grapes, and melons (Ristaino and Thomas 1997). California and Florida growers relied most heavily on it (Carpenter et al. 2000). Methyl bromide is reported to be harmful to the ozone layer; for this reason, provisions were made in the 1992 Montreal Protocol on Substances that Deplete the Ozone Layer and the 1991 U.S. Clean Air Act to phase out MB (Carpenter et al. 2000; EPA 2009b). Today it can only be used with a special exemption; Michigan, among other states, has an exemption to control soilborne diseases in muskmelon and eggplant production (EPA 2009a). Methyl bromide is becoming increasingly expensive and its use is highly restricted, making the search for alternatives of paramount importance (Ngouajio, personal communication).

Researchers have been searching for years for viable alternatives to MB; as yet their success has been varied. Hausbeck (2007) has stated finding alternatives is vital for growers of crops in the Solanaceae (eggplant family) and Cucurbitaceae (squash and melon family). The most viable alternatives to MB will likely be combinations of several methods (including development/use of disease resistant cultivars and use of cover crops) which decrease soilborne pathogen levels while encouraging plant growth (Carpenter et al. 2000; Martin 2003; Ristaino and Thomas 1997). Martin (2003) also notes past reliance on MB has indirectly led to a dearth of information on specific pathogens and how they interact with their hosts (as well as pathogen control methods other than MB), and remedying this situation will likely lead to new production practices. Suitable alternatives to MB will probably vary by crop and region (Carpenter et al. 2000; Martin 2003). The current regulatory climate is such that chemical based fumigants will likely be

highly restricted, and restrictions (e.g. buffer zones) will make use difficult (Duniway 2002).

According to Duniway (2002), there are no alternatives to MB that are as effective, multi-spectrum (against pathogens, weeds, and nematodes), and easy to apply. Currently registered MB alternatives include chloropicrin (CP), telone (1,3-D), methyl isothiocyanate (MITC) generators like metam sodium and dazomet, methyl iodide, and propylene oxide; potential MB fumigant alternatives which are undergoing EPA registration include sodium azide, propargyl bromide, and dimethyl disulfide (EPA 2009c). Methyl bromide alternatives are not likely to be used separately, but rather would be mixed together or applied sequentially (Duniway 2002). Such MB alternatives are not themselves without hazards. All synthetic fumigants create concerns in regards to groundwater contamination, worker exposure, and chronic exposure (Duniway 2002). Only chloropicrin, 1,3-D, and metam sodium are broad spectrum enough to be considered likely replacement candidates (Duniway 2002). Methyl bromide is currently applied in conjunction with CP (in addition to its pest suppressive capacities, CP is an easily detectable chemical that serves as an indicator of MB presence/exposure; MB is odorless and lethal). However, CP alone is not likely to be a complete alternative as it is not effective against nematodes and some weeds (Ristaino and Thomas 1997). Metam sodium is viewed as unreliable due to application difficulty; it does not move easily through soil (Duniway 2002). Duniway (2002) states, however, that its efficacy could be optimized. Metam sodium does not mix well with other fumigants but could be applied after other fumigants (sequentially) to increase

weed and pathogen control (Duniway 2002). Dazomet can also be difficult to apply; care must be taken to avoid phytotoxicity (Duniway 2002). Methyl iodide when combined with CP (50:50 ratio) works as well as MB:CP to destroy *V. dahliae* Kleb inoculum (Duniway 2002). The type and application method of MB alternative used will depend on the crop and system (Duniway 2002).

Cover Crops

One avenue of inquiry in the search for MB alternatives involves use of cover crops, which provide a number of benefits. Cover crops help prevent erosion, increase nutrient cycling, and add soil organic matter. According to Snapp et al. (2005), routinely incorporating cover crops into a production system leads to an increase in soil organic matter content, which improves soil physical aspects such as water and nutrient holding capacities and aeration; these benefits often lead to increased cash crop yields. Collins et al. (2007) found 29% of the N uptake by a mustard crop was later recycled by the potato cash crop, meaning the cover crop can reduce amount of N fertilizer that needs to be used on even a heavy feeding crop like potatoes. Oilseed radish (*Raphanus sativus* (L.) var. oleiferus Metzg (Stokes)) is an efficient scavenger of N; the Daikon cultivar has been shown to recycle more than 22 kg/ha (20 lb/A) N in two months on a muck soil (Ngouajio and Mutch 2004).

A variety of cover crops, including Brassicas, are grown in Michigan (Mutch and Snapp 2003). Brassica cover crops are cool-season annuals characterized by deep taproots, broad leaves, and small seeds; they originated in the Mediterranean (Snapp et al. 2006). They can germinate in soils as cool as 4°C (40° F), grow to

heights of 76–102 cm (30-45 in.) with roots 31-91 cm (1–3 ft) long, and mature in 4–6 weeks (Snapp et al. 2006). Two broad categories of Brassicas are typically grown as cover crops in Michigan: mustards (*Brassica juncea* (L.) Czern., *B. nigra* (L.) W.D.J. Koch, *B. napus* L., and *B. hirta* Moench) (Snapp et al. 2006) and oilseed radish (Ngouajio and Mutch 2004). Mustards prefer well-drained, neutral to slightly acidic or basic soil and large amounts of moisture (Snapp et al. 2006); oilseed radish tolerates moderate drought (Ngouajio and Mutch 2004). Mustards are generally sown at 10-17 kg/ha (9 – 15 lb/A) (Snapp et al. 2006) while oilseed radish is sown at 11-22 kg/ha (10 – 20 lb/A) (Ngouajio and Mutch 2004). If soil tests reveal the need for fertilizer, N can be applied at 112 kg/ha (100 lb/A); it is also advisable to add sulfur (6:1 N:S ratio), given the crucial role this element plays in production of biocidal compounds (Snapp et al. 2006). When grown as a cover crop, Brassicas do not suffer from diseases or pests severely enough to warrant control methods, other than growing them in rotation with non-Brassica crops (Ngouajio and Mutch 2004, Snapp et al. 2006).

Brassicas are quantitative long day flowerers (long days hasten flowering), though carbohydrate supply plays a role (plants can be induced to flower under short day conditions with addition of sucrose to the growth medium) (Friend et al. 1984). Some mustard species are highly sensitive to long days, making them difficult as a spring crop due to flowering occurring before peak biomass production has occurred (Snapp et al. 2006). *Brassica juncea* (L.) Czern. 'Pacific Gold' can produce 2,240 kg/ha (2,000 lb/A) of biomass as a spring crop, and 3,360-5,600kg/ha (3,000–5,000 lb/A) of biomass as a fall crop (Snapp et al. 2006).

Oilseed radish can produce 8,960-11,200 kg/ha (8,000–10,000 lb/A) of dry biomass (Ngouajio and Mutch 2004). While they are a cool season crop, mustards and oilseed radish do not survive hard freezes (air temperatures below -4°C (25° F)), especially once they are past the seedling stage (Ngouajio and Mutch 2004, Snapp et al. 2006). Ideally Brassicas are flailed and tilled in to the soil at full flowering; irrigation should be applied before and after the process to maximize biofumigation (Snapp et al. 2006). Plants should not be allowed to go to seed as they can become weedy (Snapp et al. 2006).

Aside from the general benefits of cover crops, Brassica species are potentially valuable tools because they are allelopathic. The term 'allelopathy' was first used by Molisch (1937) to describe the phenomenon wherein plants influence each other via chemical means. Originally the term encompassed both positive and negative effects, but currently it typically means the 'inhibitory effect of a compound added to the environment' (Choesin and Boerner 1991). Allelochemicals are common in the plant world and include organic acids, alkaloids, alcohols, aldehydes, glycosides, tannins, and terpenes (Szczepanski 1977). A variety of factors dictate levels at which allelochemicals are present in the environment. Such factors include plant species, quantity and type of allelochemical produced, and the environment itself (e.g. soil composition). Crop and weed species vary in susceptibility to allelochemicals (Oleszek 1987).

The allelopathic compounds of interest in Brassicas such as yellow mustard, oilseed radish, and Oriental mustard include glucosinolates. Glucosinolates are sulfur based compounds comprised of a thioglucose group, an R-group (carbon

side chain) which gives each compound its name, and a sulphonated oxime (Mayton et al. 1996). When in the presence of myrosinase enzyme and water they break down to form isothiocyanates (ITCs), organic cyanides, oxazolidinethiones, and ionic thiocyanate (Kirkegaard and Sarwar 1998). The glucosinolates isolated from Brassica species are either aliphatic, aromatic, or indolyl in structure (Brown and Morra 1997; Kirkegaard and Sarwar 1998). Some are highly volatile while others are water soluble (Brown and Morra 1997). Major glucosinolates found in Brassica cover crops include sinigrin (Oriental mustard) and glucosinalbin (yellow mustard) (Kirkegaard and Sarwar 1998), among others (Table 2.1).

These compounds have been shown to exhibit biocidal properties that impact a variety of pathogens in the soil (Brown and Morra 1997; Sarwar et al. 1998) (Table 2.2). Soil characteristics such as water content influence breakdown of glucosinolates into ITCs and help determine how much of an effect addition of cover crops to the soil will have (Brown and Morra 1997, Morra and Kirkegaard 2002). Warm temperatures and microbial activity decrease phytotoxicity while low temperatures lead to higher phytotoxicity (Mason-Sedun and Jessop 1986). Mason-Sedun and Jessop (1986) determined rate of phytotoxicity decrease is greatest at 24° C and least at 0° C. Some glucosinolates are more potent than others. According to Bialy et al. (1990), allyl and 2-phenethyl ITCs are highly active compounds. ITC quantities matter, as well; the more residue present, the greater the phytotoxic effects (Mason-Sedun and Jessop 1986). Turk and Tawaha (2002, 2003) demonstrated as concentrations of *B. nigra* aqueous extracts increased,

germination rates of lentil (*Lens culinaris* Medik.) and wild oat (*Avena fatua* L.) decreased.

Cover Crops and Soilborne Pathogens

Brassica cover crops are of interest because of their potential to decrease soilborne pathogen populations via volatile and water soluble compounds. Volatile compounds disperse completely through the soil, making them effective potential anti-pathogen compounds (Mayton et al. 1996).

Brassica cover crops can impact soilborne pathogen populations (Table 2.2) and decrease disease incidence/severity. Broccoli residues were found to decrease *V. dahliae* microsclerotia, as well as decrease incidence and severity of verticillium wilt in cauliflower by 50% (Xiao et al. 1998). According to Mayton (1996), *B. juncea* L. and *B. nigra* L. inhibited *Fusarium sambucinum* Fuckel. Dunne et al. (2003) determined *B. juncea* suppressed fungi more effectively than *B. napus*, and suppression was generally due to the fungicidal properties of compounds contained in cover crop residues. Sarwar et al. (1998) demonstrated ITCs were more effective than synthetic chemicals on some fungal species.

The literature does not conclusively support the notion that use of Brassica cover crops results solely in a decrease in pathogen populations or disease levels. Bensen et al. (2009) discovered that while *B. juncea* and *S. alba* cover crops decreased disease in lettuce in the short term, with long term use there was no significant decrease in disease. *Brassica napus* was found to encourage pathogen growth: in an experiment by Mayton et al. (1996), *B. napus* increased *F.*

sambucinum growth. Mazzola et al. (2001) determined high-glucosinolate *B. napus* seed meal did not consistently suppress *Pythium spp.* in apple orchard soil. Njoroge et al. (2008) discovered *Pythium* spp. populations increased in some plots in which Brassica cover crops were used as a green manure compared to an untreated control (though plots planted with Brassicas had higher levels of *Pythium* spp. compared to unplanted plots to begin with). In another experiment, *B. napus, B. juncea,* and *S. alba* did not affect *V. dahliae* or *Fusarium spp.* population levels, nor did they suppress disease in the following processing tomato crop (Hartz et al. 2005). Wiggins and Kinkel (2005) found *B. napus* failed to decrease verticillium wilt and potato scab disease (when disease pressure was medium-high). *Brassica napus* is also ineffective against *Pythium spp., R. solani,* and nematodes (Johnson et al. 1992). *Brassica juncea* and *S. alba* failed to decrease *Sclerotinia minor* Jagger soil sclerotia levels (Bensen et al. 2009). Sometimes the results from Brassica cover crop use are mixed. While a broccoli (*Brassica oleracea* var. italica Plenck) green manure failed to decrease *V. dahliae* infection of potato, a decrease in inoculum levels and disease severity was observed (Ochiai et al. 2007). Pinkerton et al. (2000) discovered *B. napus* decreased *Phytophthora cinnamomi* Rands and *V. dahliae* populations somewhat, but did not decrease incidence of verticillium wilt.

A number of factors determine how effective Brassica cover crops are at decreasing pathogen populations and may help explain contradictory findings. Levels and composition of glucosinolates play a role: higher levels of biofumigants tend to be more effective (Blok et al. 2000; Dunne et al. 2003). Mayton et al. (1996) attributed failure of *B. napus* to decrease *F. sambucinum* growth to its lack of allyl

ITC production. Furthermore, Brassica cover crops produce less active compounds than would be used to treat a field if they were synthetic fumigants (Hartz et al. 2005). Glucosinolate degradation is highly inefficient under field conditions, meaning it is possible insufficient levels of ITCs result (Hartz et al. 2005, Morra and Kirkegaard 2002). Different cover crops produce different levels of key compounds, as do the same cultivars at different sites (Hartz et al. 2005): Njoroge et al. (2008) found *B. juncea* produced more glucosinolates per m^2 than *B. napus*. Sarwar et al. (1998) showed different ITCs have different degrees of toxicity; in general, the shorter the ITC chain the greater the toxicity. Sarwar et al. (1998) also demonstrated ITC toxicity is partially dependent on application method (in vitro, ITCs applied to the headspace of the container resulted in different toxicity levels than those mixed with the plating medium). Innate susceptibility of each pathogen is a factor. Dunne et al. (2003) determined *Phytophthora spp.* had differing levels of susceptibility, and a pathogen may be susceptible to one Brassica cover crop but tolerant of others. Another consideration is pathogen structure being tested, since 'fungal biotypes' differ in sensitivity to ITCs (Sarwar et al. 1998). Some pathogens, such as *Sclerotinia sclerotiorum* (Lib.) de Bary, can adapt to the presence of ITCs, diminishing ITC efficacy (Rahmanpour et al. 2009). Soil type may play a role, as soils with high cation exchange capacities (CECs) may be prone to binding to ITCs and thus decreasing ITC activity (Goldy, personal communication). Finally, Blok et al. (2000) postulate that in cases where the cover crop is tilled under and then covered with air-tight plastic, glucosinolates play a secondary role while it is

primarily fermentation and creation of anaerobic conditions that decreases pathogen populations.

The literature is divided over the notion that glucosinolates alone are responsible for Brassica cover crop impacts on pathogens (Larkin and Griffin 2006; Mazzola et al. 2001). Cohen and Mazzola (2006) have demonstrated low-glucosinolate Brassica seed meal can change composition of soil microbe communities, leading to increases in *Pythium* spp. population. Total bacterial and actinomycete populations (including *Pythium spp.*) increased in soil treated with *B. napus* seed meal (Mazzola et al. 2001). Hoagland et al. (2008) found low-glucosinolate *B. napus* and *S. alba* seed meal amendments also lead to an increase in *Pythium spp.* populations. The ways in which Brassica biomass can impact microbial communities are diverse and intricate; one such way is by serving as a carbohydrate source for sufficiently opportunistic organisms (Cohen and Mazzola 2006). Furthermore, Brassica species are themselves vulnerable to pathogens: one such pathogen is *Alternaria* spp. (Ishimoto et al. 2000). Lu et al. (2010) determined that when a susceptible Brassica cover crop cultivar was grown, *F. oxysporum* (varying races) populations increased; when a resistant Brassica cover crop was grown, populations decreased (Lu et al. 2010).

Cover Crops and Seed Germination

Studies have tested impact of the active chemical components in Brassica cover crops on weed seed germination and weed density and biomass production. Norsworthy and Meehan (2005a) found low ITC levels stimulate weed emergence

while at the highest concentrations they suppress weed seed emergence by at least 37%. According to Norsworthy et al. (2006), susceptibility varies across weed species: they found purple nutsedge is more easily suppressed by ITCs than yellow nutsedge. In some cases, the effect can be thorough: ITCs were found to decrease emergence of Texas panicum by 98%, while emergence of large crabgrass was reduced 98%-100% (Norsworthy and Meehan 2005a). Different forms of ITCs have differing levels of impact; in general, the two most effective ITCs are the phenyl and 3-methylthiopropyl forms (Norsworthy and Meehan 2005b). Norsworthy and Meehan (2005a) also determined application techniques help determine efficacy: loss of volatilized compounds needs to be minimized. Even though weed emergence may be reduced, without competition weed biomass may not be reduced (Norsworthy and Meehan 2005a). Wang et al. (2008) reported Brassica cover crops reduce weed density (compared to the cover crop-less control) and affect composition of weed communities that do become established, but also indicated additional methods were still needed to achieve adequate weed control.

Brassica cover crops can impact cash crop germination and growth. Haramoto and Gallandt (2005a) found these cover crops decreased average stand count of bioassay species by 23-34% and delayed emergence by roughly 2 days under field conditions. They also found, however, that Brassica cover crops did not significantly differ from other short season cover crops (such as red clover) in impact on cash crop establishment.

Multiple laboratory experiments have shown that compounds produced by Brassicas can impact germination and growth. Turk and Tawaha (2002) found *B. nigra* aqueous extracts decreased lentil germination and inhibited lentil seedling growth. They determined plant radicles are more sensitive to extracts than hypocotyls (2002, 2003). Turk and Tawaha (2003) found *B. nigra* aqueous extracts negatively impacted wild oat germination and seedling growth. According to Brown and Morra (1996), the types of glucosinolates present (not just glucosinolate concentration) determine level of seed germination inhibition. Bialy et al. (1990) found concentrations of 500 ppm of allyl, benzyl, and 2-phenethyl ITCs would lead to 30, 10, and 100% wheat (*Triticum aestivum* Songle) seed germination inhibition. At 300 ppm 2-phenethyl ITC inhibited wheat seed germination by 40% (Bialy et al. 1990). Bialy et al. (1990) found 300 ppm of 2 phenethyl ITC retarded wheat root growth by 97% and wheat coleoptile growth by 96%. According to Oleszek (1987), *B. nigra* and *B. juncea* volatiles caused the most damage of several Brassica species tested on wheat, barnyard grass (*Echinochloa crus-galli* (L.) P. Beauv.), and lettuce (*Lactuca sativa* L.). Oleszek (1987) determined Cruciferous volatile compounds severely inhibit lettuce germination. Water soluble compounds from *B. napus* also inhibit lettuce germination (Brown and Morra 1996). The plant part the compounds are derived from can impact germination and growth. Brown and Morra (1996) determined volatile compounds from *B. napus* roots inhibited lettuce germination more than those from stems or leaves. Turk and Tawaha found *B. nigra* leaf extracts tend to be more toxic than extracts from other plant parts such as roots and stems (2002,

2003). Brown and Morra (1996) also determined water soluble compounds from *B. napus* roots delayed lettuce germination, whereas those from leaves and stems completely inhibited it. Turk and Tawaha (2003) postulate *B. nigra*'s allelopathic effects are short term and mainly impact germination.

Not all studies support the conclusion that glucosinolate byproducts are phytotoxic in the field. Choesin and Boerner (1991) found *B. napus* appears not to be allelopathic – allyl ITCs applied at the levels typically found in soil had no impact on 'target plants' (*Medicago sativa* L.). Further, different *B. napus* genotypes producing differing levels of allyl ITC had no difference in their impact on *M. sativa* (Choesin and Boerner 1991). Green bean (*Phaseolus vulgaris* L.) growth and yield were not affected by Brassica cover crop incorporation (Haramoto and Gallandt 2005b). Brassica impacts on germination and growth are dependent on both Brassica species and weed/crop species (Oleszek 1987), perhaps explaining why *M. sativa* and green bean showed no response. Some cash crops may benefit from allelochemicals: evidence indicates that at low levels, Brassica residues can stimulate plant growth (Mason-Sedun and Jessop 1986).

A variety of factors impact effect of Brassica cover crops on seed germination besides compound type and concentration. Soil type is one such factor. Mason-Sedun and Jessop (1986) found Brassica residues incorporated in to a sandy soil have a greater impact (delayed emergence, reduced growth/yield) on wheat than those incorporated in to a clay soil.

Allelopathy alone may not explain impact of Brassica cover crops on other plants; cover crop interactions with microbes also likely play a role. Cohen and Mazzola (2006) found *Pythium* infections were greatest when seedlings were planted immediately after Brassica seed meal incorporation; a delay of 4 weeks greatly decreased infection rates. This differs from a study by Mazzola et al. (2001) in which *B. napus* L. seed meal was found to be phytotoxic to apple seedlings, even 12 weeks after soil incorporation. Mazzola et al. (2001) state glucosinolate by-products alone are unlikely to be the cause. Hoagland et al. (2008) postulated the observed increase in *Pythium* populations was at least partly the cause of observed decreases in weed and wheat seed germination and increases in seedling mortality. Treatments in the Hoagland experiments (2008) with *B. juncea* seed meal suppressed *Pythium* (likely due to the nature of its ITCs), resulting in less severe decreases in germination and increases in seedling mortality. Damage observed by the authors was attributed to the ITCs.

Need for this Work and Objectives

Scientists have been searching for alternatives to MB since the early 1990s (Carpenter et al. 2000). Many of them are investigating chemical fumigants; this is understandable, given chemicals generally provide rapid, obvious, consistent results. However, some authors argue chemicals are only a stop gap solution (Ngouajio, personal communication). If effective, biological alternatives may offer benefits above and beyond control of one specific problem, and may be one of the long term solutions growers need. Brassica cover crops are potentially one such biological alternative and therefore warrant further investigation, especially in

relation to how they impact cash crop seed germination and growth. Compounds from plants in the Brassica family impact cash crop germination and growth in the laboratory (Bialy et al. 1990; Brown and Morra 1996; Mason-Sedun and Jessop 1988; Oleszek 1987; Turk and Tawaha 2002); less work has been done in the field. A fair amount of research has been done in vitro and in the greenhouse; there is a need to verify these results are valid under field conditions. Different geographical and climatic regions may require different solutions. Results obtained in other states may not apply in Michigan. Brassica cover crops need to be evaluated in our climate and geographic location. They also need to be evaluated in terms of the system in which they are used. Little research has been done with respect to Brassica cover crops grown immediately prior to the cash crop in the same growing season (Ngouajio, personal communication). Brassica cover crops also need to be evaluated in terms of which (if any) of them is most effective for addressing specific problems (e.g. soilborne diseases, weed infestations, or unfavorable soil chemical/biological/physical properties).

Table 2.1. Glucosinolates found in Brassica cover crops.

Class	ITC Chemical Name	Glucosinolate Precursor's Common Name	Major Cover Crop Source	Citation
Aliphatic	3-Methylsulphinylpropyl	Glucoiberin	*Brassica (B.) napus*	Daun 1986
			B. oleraceae	Birch et al. 1992; Hansen et al. 1995
	2-Propenyl	Sinigrin	*B. juncea* (L.) Czern.	Hanley et al. 1983; Sang et al. 1984; Kirkegaard and Sarwar 1998
			B. carinata A. Braun	Nastruzzi et al. 1996; Robbelen and Thies 1980
			B. nigra	Kirkegaard and Sarwar 1998
			B. napus	Birch et al. 1992; Elfakir et al. 1992
	4-Methylthiobutyl	Glucoerucin	*Sinapis alba*	Brown and Morra, unpub. data (from Brown and Morra 1997)
			Raphanus sativus	Kjaer et al. 1978
			B. oleraceae	Birch et al. 1992; Minchinton et al. 1982
			B. napus	Birch et al. 1992; Sang et al. 1984
	3-Butenyl	Gluconapin	*B. napus*	Birch et al. 1992; Elfakir et al. 1992; Koristsas et al. 1989; Sang et al. 1984; Sarwar et al. 1998
			B. campestris	Carlson et al. 1987; Hanley et al. 1983

Table 2.1. cont.

Class	ITC Chemical Name	Glucosinolate Precursor's Common Name	Major Cover Crop Source	Citation
Aliphatic	3-Butenyl	Gluconapin	*B. oleraceae*	Birch et al. 1992; Minchinton et al. 1982; Shaw et al. 1989
			B. napobrassica	Birch et al 1992; Shaw et al. 1989
	2-Hydroxy-3-butenyl	Progoitrin	*B. napus*	Birch et al. 1992; Daun 1986; Koritsas et al. 1989; Quinsac et al. 1991; Sang et al. 1984
			B. oleraceae	Birch et al. 1992; Minchinton et al. 1982; Shaw et al. 1989
			B. campestris	Carlson et al. 1987; Sosulski and Dabrowski 1984
	4-Pentenyl	Glucobrassicanapin	*B. napus*	Birch et al. 1992; Koritsas et al. 1989; Quinsac et al. 1991; Sang et al. 1984; Sarwar et al. 1998
			B. campestris	Carlson et al. 1987
			B. oleraceae	Minchinton et al. 1982
	2-Hydroxy-4-pentenyl	Gluconapoleiferin	*B. oleraceae*	Birch et al. 1992
			B. napus	Birch et al. 1992; Elfakir et al. 1992; Koritsas et al. 1989; Sang et al. 1984
Aromatic	2-Phenylethyl	Gluconasturtiin	*B. campestris*	Carlson et al. 1987; Sarwar et al. 1998
			B. juncea	Sang et al. 1984
			B. oleraceae	Birch et al. 1992; Minchinton et al. 1982

Table 2.1. cont.

Class	ITC Chemical Name	Glucosinolate Precursor's Common Name	Major Cover Crop Source	Citation
Aromatic	2-Phenylethyl	Gluconasturtiin	*B. napus*	Birch et al. 1992; Elfakir et al. 1992; Koritsas et al. 1989; Sang et al. 1984
			Sinapis alba	Brown and Morra, unpub. (via Brown and Morra 1997)
	Benzyl	Glucotropaeolin	*Sinapis* spp.	Sarwar et al. 1998c
	p-Hydroxybenzyl	Glucosinalbin	*Sinapis alba*	Kirkegaard and Sarwar 1998; Minchinton et al. 1982; Nastuzzi et al. 1996
			Sinapis arvensis	Al-Shbaz and Al-Shammary 1987
			B. napus	Elfakir et al. 1992; Quinsac et al. 1991
Indolyl	3-Indolylmethyl	Glucobrassicin	*B. campestris*	Carlson et al. 1987; Hansen et al. 1995; Sosulski and Dabrowski 1984
			B. napus	Birch et al. 1992; Macfarlane-Smith et al. 1991; Quinsac et al. 1991; Sang et al. 1984
			B. oleraceae	Birch et al. 1992; Hanley et al. 1983
			B. napobrassica	Shaw et al. 1989
			Raphanus sativus	Sang et al. 1984

Table 2.1. cont.

Class	ITC Chemical Name	Glucosinolate Precursor's Common Name	Major Cover Crop Source	Citation
Indolyl	4-Hydroxy-3-indolylmethyl	4-Hydroxyglucobrassicin	*B. napobrassica*	Shaw et al. 1989
			B. napus	Birch et al. 1992; Quinsac et al. 1991; Sang et al. 1984
			B. oleraceae	Birch et al. 1992; Shaw et al. 1989
	4-Methoxy-3-indolylmethyl	4-Methoxyglucobrassicin	*B. napobrassica*	Shaw et al. 1989
			B. napus	Birch et al. 1992; Koritsas et al. 1989; Sang et al. 1984
			B. oleraceae	Birch et al. 1992; Shaw et al. 1989
	1-Methoxy-3-indolylmethyl	Neoglucobrassicin	*B. oleracea* sv. cymosa	Kirkegaard and Sarwar 1998
				Sang et al. 1984
			B. campestris	Sosulski and Dabrowski 1984
			B. napobrassica	Truscott et al. 1983
			B. napus	Birch et al. 1992; Elfakir et al. 1992; Macfarlane-Smith et al. 1991
			B. oleraceae	Birch et al. 1992; Shaw et al. 1989

Table 2.2. Soilborne pathogens reported to be susceptible to green manures. Susceptibility alone does not imply a reduction in disease in the field.

Binomial Name	Common Name	Pathogen	Disease Name	Citation
Avena sativum L. cv.'Troy'	Oat	*Aphanomyces euteiches* Drechsler	Seedling blight and root rot of legumes	Williams-Woodward et al. (1997);
Brassica juncea (L.) Czern.	Oriental mustard	*Fusarium sambucinum* Fuckel	Fusarium wilt	Larkin and Griffin 2006; Mayton et al. 1996
		Gaeumannomyces graminis (Sacc.) Arx and Oliver var.*tritici*	Take-all of wheat	Angus et al. 1994
		Phytophthora erythroseptica Pethybr.		Larkin and Griffin 2006
		Pythium ultimum Trow	Damping-off	Charron and Sams 1999; Larkin and Griffin 2006; Snapp et al. (2007)
		Rhizoctonia solani J.G. Kuhn	Alternaria leaf spot	Charron and Sams 1999; Larkin and Griffin 2006; Snapp et al. (2007)
		Sclerotinia sclerotiorum (Lib.) de Bary		Larkin and Griffin 2006
		Spongospora subterranean Tomlinson	Powdery scab of potato	Larkin and Griffin 2006

Table 2.2. cont.

Binomial Name	Common Name	Pathogen	Disease Name	Citation
Brassica napus	Canola	*Aphanomyces euteiches* Drechsler	Seedling blight and root rot of legumes	Williams-Woodward et al. (1997)
	Canola	*Gaeumannomyces graminis* (Sacc.) Arx and Oliver var.*tritici*	Take-all of wheat	Angus et al. 1994
		Phytophthora cinnamomi Rands	Root rot	Pinkerton et al. 2000
		Rhizoctonia spp.	Apple replant disease	Mazzola et al. 2001
		Verticillium dahliae Kleb.	Verticillium wilt	Pinkerton et al. 2000
Brassica nigra	Black mustard	*Fusarium sambucinum* Fuckel	Fusarium wilt	Mayton et al. 1996
Brassica oleraceae var. *capitata*	Cabbage	*Aphanomyces euteiches* Drechsler	Seedling blight and root rot of legumes	Lewis and Papavizas 1971
		Rhizoctonia solani J.G. Kuhn	Damping-off, blight and rot of Solanaceous crops	Lewis and Papavizas 1974
Brassica oleraceae var. *italica*	Broccoli	*Fusarium oxysporum* Schltdl. f. sp. *asparagi*	Asparagus root rot	Blok et al. 2000

Table 2.2. cont.

Binomial Name	Common Name	Pathogen	Disease Name	Citation
Brassica oleraceae var. *italica*	Broccoli	*Rhizoctonia solani* J.G. Kuhn	Damping-off, blight and rot of Solanaceous crops	Blok et al. 2000
		Sclerotinia minor Jagger	Lettuce drop	Hao and Subbarao 2003
		Vertillium dahliae Kleb.	Verticillium wilt	Blok et al. 2000; Ochiai et al. 2007; Subbarao et al. 1999; Xiao et al. 1998
Cereale secale L.	Rye	*Rhizoctonia solani* J.G. Kuhn	Damping-off, blight and rot of Solanaceous crops	Snapp et al. (2007)
		Pythium ultimum Trow.	Damping-off	Snapp et al. 2007
Hordeum vulgare	Barley	*Fusarium sambucinum* Fuckel	Fusarium wilt	Griffin and Larkin 2006
		Phytophthora erythroseptica Pethybr.	Pink rot of potato	Griffin and Larkin 2006
		Pythium ultimum Trow.	Damping-off	Griffin and Larkin 2006
		Sclerotinia sclerotiorum (Lib.) de Bary	White rot	Griffin and Larkin 2006

Figure 2.1 Eggplant 'Classic' leaf displaying symptoms of verticillium wilt.

Figure 2.2. Eggplant 'Classic' plants displaying symptoms of verticillium wilt.

CHAPTER 3: Field Evaluation of Spring-Planted Brassica Cover Crops for Performance in Muskmelon (*Cucumis melo* L.) and Eggplant (*Solanum melongena* L.) Cropping Systems

CHAPTER 3: Field Evaluation of Spring-Planted Brassica Cover Crops for Performance in Muskmelon (*Cucumis melo* L.) and Eggplant (*Solanum melongena* L.) Cropping Systems

ABSTRACT

A two year field study was conducted in Benton Harbor, MI, to examine impact of oilseed radish (*Raphanus sativus* (L.) var. oleiferus Metzg (Stokes)), Oriental mustard (*Brassica juncea* (L.) Czern.), and yellow mustard (*Sinapis alba* L.) on eggplant (*Solanum melongena* L.) and muskmelon (*Cucumis melo* L.) growth and yield. Additional treatments included a microbial amendment (Terra Clean® plus SoilBuilder™), fallow (- control) and methyl bromide (+ control). The experiment had a randomized complete block design with three replications. Cash crops were rated for vigor, disease presence (eggplant), height (eggplant), yield, and fresh biomass production (eggplant). All three cover crops reduced stand in direct-seeded muskmelon and transplant survival; eggplant transplant survival was not affected. Yellow mustard reduced eggplant growth and plant vigor. Cover crops did not affect verticillium wilt incidence or eggplant yield. The cover crops tested should be used with care, and sufficient time should be allowed between cover crop incorporation and seed planting/cucurbit transplantation.

INTRODUCTION

Only California exceeds Michigan in terms of agricultural diversity; agriculture contributes $71.3 billion annually to Michigan's economy (Holton 2009). Two crops that contribute to Michigan's diversity are eggplant (*Solanum*

melongena L.) and muskmelon (*Cucumis melo* L. Group Reticulatus). Growers harvested about 223 ha (550 A) of muskmelon worth $2.4 million in 2005; in the same year, growers harvested 85 ha (210 A) of eggplant worth $1.11 million (MDA 2006). Both eggplant and muskmelon are warm season crops. Both crops are susceptible to a variety of soilborne diseases. Eggplant is particularly susceptible to verticillium wilt caused by *Verticillium dahliae* Kleb. This is of particular concern given the phase-out of methyl bromide, which for years was used to control soilborne diseases such as verticillium wilt (Wilhelm 1980). While Michigan producers still have exemptions to use methyl bromide for Solanaceous and Cucurbitaceous crops (EPA 2009a), these exemptions will likely also be phased out. Hausbeck (2007) has stated finding alternatives to methyl bromide is of paramount importance for production of these crops.

Martin (2003) determined there is unlikely to be one general panacea to replace methyl bromide; rather, a variety of methods will likely be used in combination. One potential method is use of Brassica cover crops. In addition to aiding in nutrient cycling, preventing erosion, and improving soil structure (Mutch and Snapp 2003), Brassica cover crops produce compounds which are toxic to some soilborne pathogens (Kirkegaard and Sarwar 1998). As an added benefit, these compounds have also been shown to inhibit weed seed germination (Norsworthy et al. 2006, Norsworthy and Meehan 2005a and 2005b).

Given their useful properties, short growth cycle (55-65 days from seed to flowering), and tolerance of cool temperatures, Brassica cover crops such as

yellow mustard (*Sinapis alba* L.), oilseed radish (*Raphanus sativus* (L.) var. oleiferus Metzg (Stokes)), and Oriental mustard (*Brassica juncea* (L.) Czern.) should be investigated in an eggplant/muskmelon short rotation system. Since these cash crops are not transplanted into the field until early June, there is time to grow Brassica cover crops if they are planted in early April. Since eggplant and muskmelon require significant amounts of fertilizer, they would likely benefit from nutrient cycling properties of the cover crops. Given the cash crops' susceptibility to soilborne diseases, any reduction in soil pathogen levels by the tilled-under cover crop would also be beneficial.

There has been minimal research in to use of Brassica cover crops in most vegetable systems; there has been no research in to use of Brassica cover crops as an early spring cover crop before muskmelon and eggplant. The objectives of this study were to determine effects of spring-planted Brassica cover crops on a) verticillium wilt incidence in eggplant production; b) eggplant growth and yield; and c) melon stand establishment, plant growth, and yield.

MATERIALS AND METHODS

Experimental Site and Procedures

Yellow mustard 'Tilney', oilseed radish 'Defender', and Oriental mustard 'Forge' were planted at the Michigan State University South West Michigan Research and Extension Center (SWMREC) in Berrien County, Michigan, on April 4, 2008 and April 1, 2009. Planting rates in 2008 were: oilseed radish, 22.4 kg/ha (20.0 lb/A); Oriental mustard, 8.5 kg/ha (7.6 lb/A); and yellow mustard, 10.4

kg/ha (9.3 lb/A). In 2009 planting rates were: oilseed radish, 11.2 kg/ha (10.0 lb/A); Oriental mustard, 6.7 kg/ha (6.0 lb/A); and yellow mustard, 9.0 kg/ha (8.0 lb/A). Cover crops had been planted in these plots in 2007; treatments remained the same throughout the three years. The soil was an Oakville series fine sand transitioning to loamy sand. This experiment had a randomized complete block design with three replications. Individual plots were 135 m^2. Treatments were Oriental mustard, yellow mustard, oilseed radish, bare soil (- control), methyl bromide (+ control), and microbial amendment. Cover crops were sown using a John Deere 450 drill. Methyl bromide was applied May 19, 2008 and May 21, 2009 (448 kg/ha (400 lb/A), 50:50 mix of methyl bromide and chloropicrin); plastic mulch and drip tape were installed at the same time. In the microbial amendment treatment, Terra-Clean® (BioSafe Systems, 36 Commerce St, Glastonbury CT) (19 L/ha) (2 gal/A) was applied first to disinfest the soil followed two hours later by SoilBuilder™ (Advanced Microbial Solutions, L.L.C., SouthPilot Point, TX) application at the rate of 19 L/ha (2 gal/A) on June 9, 2008 and June 9, 2009. The active ingredient in Terra-Clean® is the oxidizing agent hydrogen dioxide, which hypothetically controls *Phytophthora spp.*, *Pythium spp.*, *Fusarium spp.*, *Rhizoctonia spp.*, *Verticillium spp.*, and *Thielaviopsis spp.* in the soil (BioSafe Systems, L.L.C. 2010). The company also claims it can 'stimulate plant growth, root development, and nutrient uptake' (BioSafe Systems, L.L.C. 2010). Soilbuilder™ contains one million colony-forming units/mL of microbes including *Bacillus spp.*, actinomycetes, cyanobacteria, algae, protozoa, and their fermentation by-products (Advantage Microbial, L.L.C. 2010). The company claims it can restore soil

microbial populations, increase plant nutrient uptake, reduce soil compaction, and improve water retention (Advantage Microbial, LLC 2010). Cover crops were flailed and incorporated into the soil at the flowering stage with a rotovator on June 3, 2008 and June 4, 2009. Care was taken to avoid cross contamination. Beds were then shaped and covered with plastic mulch; irrigation drip tape was also installed. The entire plot was split into two with the eggplant (*Solanum melongena* L. 'Classic') and muskmelon (*Cucumis melo* L. 'Athena') in the north and south side, respectively in 2008. In 2009 the two crops were rotated.

On June 10, 2008 and June 12, 2009, all crops were planted. Eggplant transplants were planted in four rows with two middle ones serving as data rows. In 2008 melon was direct-seeded in four rows as indicated above. In 2009 melon was both direct-seeded (two rows) and transplanted (two rows) to test the effects of treatments on melon transplants. The muskmelons were re-seeded June 25, 2008 and June 25, 2009. In addition to guard rows, there were guard plants at the beginning and end of each row. These were honeydew (*Cucumis melo* L. Group Inodorus 'Earlibrew') in the muskmelon rows and eggplant 'Ghostbuster' in the eggplant rows. In both years eggplants were spaced 0.5 m apart (14 plants per bed; 13,047 plants/ha (5,280 plants/A)) while muskmelons were spaced 1 m apart (7 plants per bed; 6,523 plants/ha (2,640 plants/A)); both years two muskmelon seeds were seeded per hole, were thinned to 7 plants per bed.

Two weeks after planting, eggplants were staked. Three weeks after planting, fertigation commenced. Plants received 1.1 kg of N/ha (1.0 lb/A) per week in the form of a 4-0-8-2 (Ca) fertilizer through the drip irrigation system; irrigation ran

three times a week, and fertigation occurred once per week. No accounting in the irrigation schedule was made for rain because beds were covered with plastic and no excessively heavy rain events occurred during the growing season. Pesticides were applied as per standard grower practices (Table 3.1). Rows were hoed and beds hand-weeded as necessary.

Data Collection

Prior to cover crop incorporation plant samples were taken from each cover crop treatment, in two areas of 50 cm x 50 cm each. The number of plants in each sample was counted, and samples dried at 60° C for two weeks. Excess soil was shaken off the samples, and they were weighed. Samples consisted of entire plants (roots, stems, leaves, and flowers).

Data collection on eggplants and muskmelons began two weeks after planting, with stand counts. Another stand count was done on the muskmelons two weeks after re-seeding. Eggplant height was taken weekly. Chlorophyll content of the eggplant leaves was measured twice in 2008 and once in 2009 using a SPAD chlorophyll meter. Subjective scores were taken of eggplant plots, also weekly. The subjective score used a scale of 1 to 10, with 1 being 'all plants are dead' and 10 being 'all plants look vigorous, healthy, and productive'. A count of plants showing symptoms of verticillium wilt was taken in each eggplant plot each week in the 2008 and 2009. On July 28, 2008, 2 eggplant plants from the guard rows were harvested and sent to the Michigan State University (MSU) Plant Diagnostics Lab to confirm the presence of verticillium wilt; it was confirmed by isolating *Verticillium dahliae* from symptomatic tissue and culturing it on *Verticillium*-selective medium

(MSU Plant Diagnostics Lab, personal communication). Soil samples were taken every three weeks, on average, using a soil probe and about 20 soil cores per eggplant plot. Soil was stored in plastic bags in a 4° C cooler. Nitrate extraction was performed using the KCl method, and then samples were analyzed for nitrate and ammonia levels by Michigan State University Soil Testing Laboratory.

The first eggplant harvest in 2008 was August 11; in 2009 it was August 6. Harvests continued every two to three weeks until September 28, 2008 and September 24, 2009. Eggplants were separated in to Grade 1 (US No.1), Grade 2 (US No. 2), or cull (Unclassified) (USDA-AMS 1953). They were then counted and weighed. Bird damage was not counted against the fruit. On the last harvest date, all fruits were harvested. Plants were then cut at ground level, and fresh above ground biomass was weighed.

Muskmelon harvests began August 26, 2008 and August 21, 2009. It was not until the September 8, 2008 harvest that a re-seeding mistake was realized. The last harvest date in 2009 was September 24; in that time period melons were harvested almost weekly. They were sorted as either marketable or cull, counted and weighed. Marketable fruits met the definitions for US Grade Fancy - Grade 2; culled fruit did not (USDA-AMS 2008). As with eggplants, bird damage was not counted against muskmelons.

Statistical Analysis

SAS (version 9.2) was used to perform analysis of variance on the data, then means were separated using Fisher's least significant difference at the $P = 0.05$ level when significant differences in means were detected. Data from 2008 and

2009 were combined when there was no year by treatment interaction, except when data varied considerably by year.

RESULTS

Weather

Weather influences crop growth and yield and disease development, so it is an important consideration in any field experiment. Low temperatures at SWMREC during April - September were comparable in 2008 and 2009, but 2009 experienced cooler daily maximum temperatures (Table 3.2). April and July of 2009 experienced particularly decreased highs – the average high in April 2009 was 13.8° C vs. 16.29° C in April 2008 while July 2009 high temperatures averaged 24.8° C compared to the 2008 average of 27.5° C. July 2008's high temperature was on par with the 8 year average July temperature of 27.7° C.

Growing Degree Days (GDD) in 2009 reflect the slightly lower 2009 average temperatures (Table 3.3). There were 1,335.7 GDD in 2009 compared to 1421.4 GDD in 2008 and the 8 year average of 1,509.3 GDD. April, June, July, August, and September 2009 all had fewer GDD than their counterparts in 2008. July 2009 (peak of the growing season) saw 297.1 GDD compared to 368.1 GDD in July 2008. May was the only exception to this trend – there were 166.6 GDD in 2009 compared to 113.1 GDD in 2008.

Both 2008 and 2009 were wetter than average. In 2008 SWMREC received a total of 583.7 mm of rain; in 2009 it was 511.1 mm (Table 3.2). The average is 459.5 mm. While it appears 2008 was rainier than 2009, close to 300 mm of that total came during a heavy rain event in September 2008. Up until September

(during the majority of the growing season), 2009 was wetter than 2008 with a total of 487.2 mm of rain compared to 2009's 290.7 mm of rain. April and June of 2009 received significantly more rain than their 2008 counterparts. Cool weather slows crop growth, while wet weather encourages disease spread.

Cover Crops

Each of the cover crops produced similar amounts of biomass in 2008 and 2009 (Table 3.4). Oilseed radish produced 6,086 kg/ha in 2008 and 4,173 kg/ha in 2009 dry biomass. Oriental mustard produced 3,487 kg/ha dry biomass in 2008 and 2,843 kg/ha biomass in 2009. Yellow mustard values fell in between those of the other two cover crops both years.

There were significant differences among cover crop biomass production in 2008: oilseed radish produced 6,086 kg/ha compared to Oriental mustard and yellow mustard, which produced 3,487 and 3,641 kg/ha, respectively. There were no significant differences among cover crop dry biomass production and stand count in 2009. In 2009, Oriental mustard had a stand of 244 plants/m^2, which was significantly different than the 100.7 and 119.3 plants/m^2 of oilseed radish and yellow mustard.

Soil Nitrogen Levels

The data for 2008 and 2009 were combined as there was no treatment by year interaction. The nitrate levels in oilseed radish plots were significantly higher than those in all other plots (Table 3.5) in June of both years. In July the nitrate levels were significantly higher in Oriental mustard (7.6 ppm) and oilseed radish (7.3 ppm) plots than in other treatment plots, which had nitrate levels ranging

from 4.5 to 5.5 ppm. In September there were no significant differences in nitrate levels, which ranged from 2.3 to 4.1 ppm. There was no significant difference in ammonium levels in 2009 (Table 3.6).

Cash Crop Stand Count and Transplant Survival

There were significant differences in muskmelon stand counts in 2008 and 2009. In 2008, plots in methyl bromide and control treatments had 100% stand count, while those in microbial amendment treatments had 78.6% stand count (Table 3.7). These values differed significantly from those in yellow mustard treatment (40.5%), which in turn differed significantly from those in Oriental mustard (11.9%) and oilseed radish (0%) treatments. In 2009 the pattern was similar. Control and methyl bromide treatments had stand counts of 88.1% and 85.7%; microbial amendment treatment had a stand count of 69.0%, which differed significantly from the control but not from methyl bromide. The oilseed radish, Oriental mustard, and yellow mustard treatments had stand counts of 0%, 1.2%, and 2.4%; these values differed significantly from those in other treatments.

In 2009 plots were also planted with muskmelon transplants. The survival rate in methyl bromide, control, and microbial amendment treatments ranged from 85.7% to 100.0%; this differed significantly from the survival rate in cover crop treatments, which ranged from 45.2% to 50.0% (Table 3.7).

Eggplant transplants were grown and planted each year. There was no significant difference in transplant survival among treatments (Table 3.7).

Eggplant Growth

In 2008 there were significant differences in eggplant fresh biomass production at the end of the season (Table 3.8). Plants in microbial amendment treatment produced the most biomass on average (16.1 kg/plot), while those in yellow mustard treatment produced the least (11.7 kg/plot). There was no significant difference in fresh biomass production in 2009; values ranged from 5.4 to 8.1 kg/plot, less than in 2008.

There were differences in eggplant height during the 2008 growing season. Values were not significantly different for the first date data was taken (June 23, one week after transplanting) but were significantly different for the three following weeks (Table 3.9). Plants in methyl bromide and control treatments were generally taller than those in cover crop treatments, ranging from 18.5 to 19.6 cm on June 30, compared to 15.4 to 16.4 cm for the cover crop treatment plants. Values were not significantly different for the rest of the July data.

There were also differences in eggplant height during the 2009 growing season (Table 3.10), but the pattern differed from that in 2008 (Table 3.9). Not until July 23 and July 30 were there significant differences in eggplant height: plants in the methyl bromide treatment were significantly taller than those in the other treatments.

There was no significant difference in leaf chlorophyll levels for the second data collection dates in 2008 (July 28) and 2009 (August 6). There was a significant difference for the first data collection date in 2008 (July 21): plants in methyl bromide treatment had significantly lower chlorophyll levels than other treatments except Oriental and yellow mustards (Table 3.11). Values ranged from

an average of 42.3 for methyl bromide treatment to 49.2 for control and microbial amendment treatments. Lower chlorophyll levels indicate plants were less stressed/actively growing (Goldy, personal communication).

Cash Crop Health and Vigor

With the exception of stand count, data for muskmelon for the 2008 field season were unusable. Muskmelon subjective scores showed no clear patterns in 2009. In general, direct-seeded muskmelon plots in oilseed radish and Oriental mustard treatments ranked lowest (worst), while those in methyl bromide, control, and microbial amendment treatments ranked highest (best) (Table 3.12). The transplanted muskmelon plots in control and methyl bromide treatments generally ranked highest, especially early in the growing season; those in the yellow mustard treatment ranked lowest (Table 3.13).

Eggplant visual scores also followed no clear patterns. In 2008, plots in methyl bromide treatment had higher scores than those in yellow mustard treatment (on July 7 the methyl bromide plot rating average was 8.3 out of 10 compared to the yellow mustard plot rating average of 4.5; on July 14 the methyl bromide value was 8.3 out of 10 compared to the yellow mustard value of 6.3) (Table 3.14). On September 28, yellow mustard plots had a rating of 6.8 out of 10, significantly less than the rest of the treatments' ratings. For the dates not mentioned, there was no significant difference. In 2009 visual ratings were significantly different at the start of the growing season, but were not at the end (Table 3.15). From mid-July to early August, plots in methyl bromide treatment

scored highest (ranging from 8.2 – 10 out of 10) while those in microbial amendment treatment scored lowest (6.0 – 7.8 out of 10).

There were no clear patterns in verticillium wilt infection in eggplant. In 2008, plots in methyl bromide treatment had higher percentages of symptomatic plants than those in yellow mustard treatment (44.0% compared to 14.3% on July 21, 57.1% compared to 26.2% for July 28) (Table 3.16). In 2008, plants in methyl bromide treatment often had similar percentages of symptomatic plants to those in control treatment. Most of the dates had no significant differences in percentages of symptomatic plants among treatment plots. In 2009, verticillium wilt symptoms did not appear until relatively late – mid-July. Once verticillium wilt symptoms appeared, however, the majority of plants showed symptoms of the disease (Table 3.17). Plants in the methyl bromide treatment in 2009 had the lowest percentages of symptomatic plants (for example, on July 30 100.0% of plants in all treatments except methyl bromide were symptomatic; a significantly different average of 14.3% of plants were symptomatic in methyl bromide treatment). From August – September 2009 there were no significant differences in verticillium wilt symptom percentages among treatments.

Yield

In direct-seeded muskmelon plots in 2009 there were no significant differences in average marketable or total fruit weight per plot (Table 3.18). There were differences in total fruit number produced per plot, though not in marketable fruit number per plot. Plants in methyl bromide and control treatments produced 22.5 and 21.8 fruits on average (with a fruit weight of 15.7 and 14.3 kg/plot),

significantly more than those in other treatments (except microbial amendment treatment) which produced 8.7 – 10.3 fruits per plot (and a fruit weight of 18.1 – 22 kg/plot).

In transplanted muskmelon plots there were significant differences in marketable number, total number, and total weight of fruit produced (Table 3.19). Plants in methyl bromide and oilseed radish plots produced 13.5 and 14.0 marketable fruits per plot on average, while those in yellow mustard and microbial amendment treatments both produced significantly less (9.7 fruits per plot on average). Plants in methyl bromide, oilseed radish, and control plots produced 19.7 to 22.0 fruits total while those in the rest produced 13.7 to 14.7 fruits. There was no significant difference in marketable yields. Plants in oilseed radish treatment produced 40.6 kg total fruit/plot, significantly more than those in other treatments (ranging from 27.1 to 31.4 kg/plot).

In 2008 plants in methyl bromide treatment produced a significantly higher number of marketable eggplant (86.3) than those in other treatments, as well the lowest number of culls (50.2) (Table 3.19). Plants in methyl bromide and control treatments produced a significantly larger mass of eggplant compared to those in yellow mustard treatment (22.8 kg and 23.0 kg compared to 15.9 kg, respectively). Plants in methyl bromide and control treatments produced a significantly lower number of cull fruits (55.7 and 50.2, respectively) compared to those in microbial amendment treatment (70.7). Plants in yellow mustard treatment produced the least number of marketable fruit (58.3) and the least number of total fruit (115.5). There were no significant differences in the weight of fruit produced. Harvest

index I was calculated by dividing the marketable fruit mass produced by the total plant mass (fruit weight plus fresh above ground plant weight); harvest index II was calculated by dividing the total fruit mass produced by the total plant mass. Harvest index II was were significantly different: plants in methyl bromide treatment had a significantly higher harvest index I (0.57) and harvest index II (0.66) than those in microbial amendment (0.47 and 0.58) and oilseed radish (0.50, 0.60) treatments. Harvest indices for plants in methyl bromide and control treatments were similar.

In 2009 plants in oilseed radish treatment produced the highest number of marketable fruit per plot (65.2) while those in the methyl bromide treatment produced the lowest number (40.7) (Table 3.20). Oilseed radish plots produced the most total fruit in terms of number (118.8) compared to methyl bromide plots (79.3). There was no significant difference in amount of fruit weight produced by each plot, except for weight of cull fruit produced. Plants in methyl bromide treatment produced less cull fruit (kg) than those in oilseed radish and microbial amendment treatments. Harvest indices were not significantly different.

DISCUSSION

The cover crops produced roughly equivalent amounts of biomass in 2008 and 2009. Oilseed radish produced more dry biomass than yellow and Oriental mustards in 2008. In general, 2009 was cooler and wetter than 2008, creating sub-optimal growth conditions. These results suggest that none of these three cover crops is consistently superior to the others in terms of biomass production, and thus other criteria should be used to determine which cover crop to plant.

The literature on cover crops suggested plots in oilseed radish and Oriental mustard treatments would have higher levels of nitrates during the growing season, and they did. Dry weights for Oriental mustard and yellow mustard were not significantly different in 2008, suggesting Oriental mustard is a more efficient scavenger of nitrogen than yellow mustard. If nitrogen leaching is of primary concern, Oriental mustard would be the more efficient of the two crops to plant. Collins et al. (2007) showed a mustard (*Brassica hirta* Moench) cover crop can take up and then release a notable amount of nitrogen which the following cash crop can then use. Given the comparatively large amount of biomass produced both years by oilseed radish and the deep taproot of oilseed radish, it follows that plots planted in oilseed radish would have the highest nitrogen levels (as there was more biomass to hold N and then decay). Ngouajio and Mutch (2004) have stated that oilseed radish efficiently recycles nitrogen. That there were no significant differences in plot nitrate levels by September suggests cover crops had thoroughly biodegraded and released their stored N, which was either used by the cash crops or leached away.

In addition to their nutrient-recycling capabilities, cover crops proved problematic in that they reduced muskmelon emergence in both 2008 and 2009. This finding concurs with the literature. Brassica cover crops are allelopathic in laboratory tests (Bialy et al. 1990; Brown and Morra 1996; Mason-Sedun and Jessop 1988; Oleszek 1987; Turk and Tawaha 2002; Turk and Tawaha 2003). They also decrease cash crop and weed stand counts in the field (Haramoto and Gallandt 2005a).

Brassica cover crops can alter soil microbial population levels and structures and encouraging the growth of *Pythium spp.* populations (Mazzola et al. 2001). *Pythium spp.* are a common cause of damping-off, which would also explain the decreased stand counts in the cover crop treatments. Mazzola et al. (2001) postulated the effect on cash crops varies by Brassica species and damage may be attributed to allelopathy, microbial population changes, or a combination of the two depending on the cover crop. Allelopathy and increased *Pythium spp.* populations could also explain decreased survival of transplanted muskmelon; given that eggplant transplants show no such decrease in survival, the cause is more likely allelopathy than *Pythium spp.* population changes. While *Pythium spp.* impacts many crops, plants have been shown to vary in their vulnerability to Brassica cover crops (Norsworthy et al. 2006; Oleszek 1987).

Among the cover crops, yellow mustard seems to have the most deleterious effect on eggplant height and biomass production. In general, plants in methyl bromide and control did better than those in cover crop treatments, suggesting cover crops were negatively impacting cash crop growth. This observation supports laboratory research that has shown cover crops to have a negative impact on cash crop growth (Bialy et al. 1990; Oleszek 1987; Turk and Tawaha 2002). It contradicts field research, however, that has shown Brassica cover crops to have no such impact on a green bean (*Phaseolus vulgaris* L.) crop planted soon after cover crop incorporation in to the soil (Haramoto and Gallandt 2005b).

Brassica cover crops have been shown previously to clearly decrease soilborne pathogen populations in the laboratory (Angus et al. 1994; Dunne et al.

2003; Kirkegaard et al. 1996; Lewis and Papavizas 1971; Lewis and Papavizas 1974; Mazzola et al. 2001; Nastruzzi et al. 1996; Sarwar et al. 1998). Greenhouse and field studies have shown Brassica residues to be capable of decreasing soilborne disease incidence (Blok et al. 2000; Larkin and Griffin 2006; Snapp et al. 2007). Most relevantly to this study, broccoli (*Brassica oleracea* var. italica Plenck) residues decreased verticillium wilt incidence in cauliflower (Subbarao et al. 1999). There was no such clear connection between cover crop use and verticillium wilt incidence in this study, which coincides with research suggesting Brassica cover crops do not control disease in the field (Njoroge et al. 2008). Brassica cover crops did not decrease verticillium wilt incidence in a following cash crop (Hartz et al. 2005; Pinkerton et al. 2000; Wiggins and Kinkel 2005). In one year (2009), yellow mustard decreased the verticillium wilt rating for some data points. In 2008, verticillium wilt likely was not a severe problem in eggplant (methyl bromide and control treatment plots did not significantly differ in disease rating values). In 2009 verticillium wilt did not develop until fairly late in the growing season (mid-July), but it was severe (100% of plants in most plots were symptomatic). Given yellow mustard plots had lower disease ratings in a severe-disease year, it is possible this cover crop can impact verticillium wilt in the field. However, yellow mustard also has one of the clearest impacts on cash crop growth and yield and thus the benefits must be weighed against the costs or losses. Additional studies need to be conducted in controlled environments to clearly test the effect of yellow mustard on verticillium wilt as well as various cash crops.

Furthermore, in terms of muskmelon vigor, the harm the cover crops did to muskmelon stand count directly impacted subjective ratings. The visual impression of plots where plants had to be re-seeded was of decreased vigor.

Brassica cash crops had varying impacts on muskmelon yield parameters. In general, plants in control and methyl bromide treatments produced larger numbers (and heavier weights) of fruit than those in cover crop treatments. Of the three cover crops, oilseed radish was the least harmful: transplanted plants in this treatment produced more marketable fruit than those in non-control and non-methyl bromide treatments and also the largest total fruit weight of any of the treatments. Yellow mustard was arguably the most harmful: plants in this treatment routinely produced the least amount of fruit, both in number and total mass. There was no significant difference in the number or mass of marketable fruit and total fruit mass produced by direct-seeded muskmelon plants. Those in yellow mustard, oilseed radish, and Oriental mustard treatments did produce significantly less total fruit (in terms of number) than those in methyl bromide and control treatments. Taken together, these results suggest that a). spring-planted Brassica cover crops confer no yield advantage on these two cash crops, b). these cover crops can decrease yield, and c). the decrease in yield is likely primarily a result of the cover crops' negative impact on muskmelon stand. Effects on muskmelon yield were likely due to a confluence of two factors. First, the cover crops' impact on cash crop growth meant fewer flower buds, less fruit, and less biomass to sustain the fruit. Second, muskmelons in the cover crop treatments had to be re-seeded or the transplants replaced. In Michigan, the growing season is so

short that some plants may not have had the chance to produce fruit because their plant date was 1 to 2 weeks later than that of most plants in other treatments.

Results were less straightforward with eggplant data. Many harvest parameters with significant differences in 2008 showed no such differences in 2009. As with muskmelon, plants in yellow mustard treatment tended to produce lower numbers and smaller masses of fruit. In 2008, plants in yellow mustard treatment produced less marketable fruit (kg) than those in all other treatments, except oilseed radish and Oriental mustard. Plants in yellow mustard treatment also produced fewer marketable fruit and fewer fruit total than those in control and methyl bromide treatments, while producing larger numbers of cull fruit. In 2009 there was an interesting reversal: plants in methyl bromide treatment produced the smallest number of marketable and total fruit; however, there was no significant difference among treatments in terms of the total mass of fruit produced or the mass of marketable fruit produced, suggesting plants in this treatment produced fewer, larger fruit.

In 2008 there were significant differences in the harvest indices. Plots in the methyl bromide had a higher harvest index I than those in the yellow mustard, oilseed radish, and microbial amendment treatments. Plots in the methyl bromide treatment also had a higher harvest index II than those in the microbial amendment and oilseed radish treatments. For both indices, methyl bromide and control values were similar. In 2009 there were no significant differences among harvest indices.

The general lack of consistent impact on muskmelon and eggplant yield coincides with literature on spring planted Brassica cover crops. Haramoto and Gallandt (2005b) also found no effect on the yield of a green bean crop planted immediately after a Brassica cover crop. This result does, however, contradict the finding of Hartz et al. (2005) that Brassica cover crops increased head lettuce (*Lactuca sativa* L.) yield. It also contradicts the discovery that onion (*Allium cepa* L.) and celery (*Apium graveolens* L.) crops benefit from a preceding Brassica cover crop (Wang et al. 2008, Wang et al. 2010). It should be noted that in the two studies listed above, cover crops were planted in the fall preceding cash crops, and not immediately preceding them. Differing results in the studies noted could thus be due to dissipation of allelochemicals or return of microbial populations to their 'normal' state before the planting of the cash crop. It should also be noted that in the two studies listed above, the crops are considerably different from muskmelon/eggplant.

CONCLUSIONS

Brassica cover crops planted in the spring and incorporated in to soil about two weeks prior to cash crop planting provided some benefits and posed some challenges. Benefits include increased soil nitrate levels during the growing season and some (likely not practically significant) protection against verticillium wilt (in the case of yellow mustard). At the same time, Brassica cover crops can have a severe impact on cash crop stand count when the crops are direct-seeded less than two weeks after cover crop incorporation. An unacceptable stand reduction was

also recorded in muskmelon transplants. Yellow mustard can have a strong negative impact on eggplant growth and subjective vigor scores. Cover crops overall did not increase amount and weight of fruit produced by eggplant or muskmelon, but they did decrease the number of fruit produced (in direct-seeded muskmelon).

More research needs to be done to determine the nature of the impact of Brassica cover crops on muskmelon germination and transplant survival, and to determine if this impact extends to other cucurbits which are commonly direct-seeded in Michigan. If negative effects observed are due to allelochemicals, then a safe plant back period after cover crop incorporation needs to be identified. Such a plant back period would be significantly longer than the 10 to 14 days used in this study. In that case, spring planting of cover crops would not be a viable option for eggplant and cucumber production in Michigan due to the short growing season. Late summer or fall planting of the cover crops could be alternative windows. However, those scenarios need to be tested.

Table 3.1. Pesticide application schedule for eggplant and muskmelon plots in 2008 and 2009.

Application Date	Pesticide(s)	Rate
June 19, 2008	Champ 2F	1 1/3 pt/A
	Maneb 75DF	1 lb/A
July 1, 2008	Champ 2F	1 1/3 pt/A
	Maneb 75DF	1 lb/A
July 10, 2008	Champ 2F	1 1/3 pt/A
	Dithane DF	1 ½ lb/A
	Asana XL	6 oz/A
July 18, 2008	Champ 2F	1 1/3 pt/A
	Dithane DF	2 lb/A
	Thiodan 50	1 lb/A
July 24, 2008	Champ 2F	1 1/3 pt/A
	Dithane DF	2 lb/A
	Thiodan 50	1 lb/A
August 5, 2008	Champ 2F	1 1/3 pt/A
	Dithane DF	2 lb/A
	Thiodan 50	1 lb/A
August 15, 2008	Agrimek	10 oz/A
	Asana XL	8 oz/A
	Champ 2F	1.5 pt/A
	Echo	2 pt/A
August 29, 2008	Agrimek	10 oz/A
	Asana XL	8 oz/A
	Champ 2F	1.5 pt/A
	Echo	2 pt/A
September 10, 2008	Champ 2F	1.5 pt/A
	Echo	2 pt/A
June 26, 2009	Champ	1 1/3 pt/A
	Pencozeb	1.5 lb/A
	Thiodan	15. lb/A
July 8, 2009	Champ	1 1/3 pt/A
	Pencozeb	1.5 lb/A
	Asana XL	6 oz/A
July 17, 2009	Champ	1 1/3 pt/A
	Pencozeb	1.5 lb/A
	Asana XL	6 oz/A

Table 3.1. cont.

Application Date	Pesticide(s)	Rate
July 27, 2009	Asana XL	6 oz/A
	Champ	1 1/3 pt/A
	Equus	2 pts/A
August 4, 2009	Thiodan	1.5 lb/A
	Prevecure	1.2 pts/A
	Champ	1 1/3 pt/A
	Equus	2 pts/A
August 10, 2009	Thiodan	1.5 lb/A
	Prevecure	1.2 pts/A
	Champ	1 1/3 pt/A
	Equus	2 pts/A
August 19, 2009	Champ	1 1/3 pt/A
	Equus	2 pts/A
	Thiodan	1.5 lb/A
	Ranman	2.75 oz/A
August 31, 2009	Champ	1 1/3 pt/A
	Equus	2 pts/A
	Thiodan	1.5 lb/A
	Previcure	1.2 pts/A
September 11, 2009	Champ	1 1/3 pt/A
	Equus	2 pts/A

Table 3.2. Mean monthly and long term (8-year) temperature and precipitation during cover crop growth and melon and eggplant growth in 2008 and 2009 at SWMREC Michigan.*

	Monthly average temperature (C)						Monthly rainfall (mm)		
	2008		2009		8 yr average		2008	2009	8 yr average
Month	Low	High	Low	High	Low	High			
April	3.2	16.3	4.0	13.8	4.0	15.5	45.0	104.6	52.8
May	8.5	18.5	6.4	21.0	10.0	20.3	58.0	52.1	83.3
June	14.2	25.9	14.5	24.8	14.3	25.7	59.2	114.0	59.4
July	14.1	27.5	16.3	24.8	16.7	27.7	92.2	104.0	73.7
August	15.4	26.4	14.8	25.3	16.3	27.0	36.3	112.5	120.7
September	11.9	23.5	13.0	23.3	12.3	23.6	293.1	23.9	69.6
Average/total	11.5	23.0	11.2	22.2	12.1	23.3	583.7	511.1	459.5

* Cover crops were sown on April 4, 2008 and April 1, 2009. Melons and eggplants were planted June 10, 2008 and June 12, 2009.

Table 3.3. Monthly and long term (8-year) growing degree days (GDD) during cover crop growth and melon and eggplant growth in 2008 and 2009 at SWMREC Michigan. Base temperature = 10°C.*

Month	Monthly average GDD		
	2008	2009	8 year average
April	86.5	61.9	81.1
May	113.1	166.6	162.5
June	293.7	280.9	299.4
July	368.1	297.1	374.7
August	328.8	309.8	355.4
September	237.2	219.4	236.3
Total	1421.4	1335.7	1509.3

* Cover crops were sown on April 4, 2008 and April 1, 2009. Melons and eggplants were planted June 10, 2008 and June 12, 2009.

Table 3.4. Brassica cover crop stand count and dry weight biomass prior to soil incorporation.

	Stand (plants m²)		Dry weight kg/ha	
	2008	2009	2008	2009
Treatment				
Oilseed radish	190.7*	100.7 b	6086.5 a	4173.3
Oriental mustard	182.7	244.0 a	3487.5 b	2843.0
Yellow mustard	194.0	119.3 b	3641.5 b	3000.0
$LSD_{0.05}$	NS	91.1	321.7	NS

*Values with different letters are significantly different at the P=0.05 level. NS is not significant at the P=0.05 level.

Table 3.5. Average soil nitrate levels (ppm) as affected by biofumigation with Brassica cover crops and soil treatments. Data for 2008 and 2009 were combined.

	Soil nitrate levels (ppm)		
Treatment	**June**	**July**	**September**
Methyl bromide	5.7 c*	4.5 b	2.3
Oilseed radish	8.2 a	7.6 a	4.3
Oriental mustard	7.4 ab	7.3 a	4.1
Yellow mustard	6.1 c	4.9 b	2.9
Microbial amendment	6.7 bc	5.5 b	3.0
Control	6.4 bc	5.4 b	3.4
$LSD_{0.05}$ =	1.2	1.2	NS

* Means within a column followed by the same letter are not significantly different at the P=0.05 level. NS is not significant at the P=0.05 level.

Table 3.6. Average soil ammonium levels (ppm) in 2009 as affected by biofumigation with Brassica cover crops and soil treatments.

	2009 soil ammonium levels (ppm)		
Treatment	**June**	**July**	**September**
Methyl bromide	0.8*	1.0	0.7
Oilseed radish	0.8	0.8	0.9
Oriental mustard	0.8	0.9	0.9
Yellow mustard	0.9	0.9	0.8
Microbial amendment	0.8	0.9	0.6
Control	0.7	0.9	0.7
$LSD_{0.05}$ =	NS	NS	NS

* NS is not significant at the P=0.05 level.

Table 3.7. Melon 'Athena' and eggplant 'Classic' stand as affected by biofumigation with Brassica cover crops and soil treatments.*

	Muskmelon (%)			Eggplant (%)
	Direct-seed		Transplant	Transplanted
Treatment	2008	2009	2009	2008-2009
Methyl bromide	100.0 a**	85.7 ab	97.6 a	100.0
Oilseed radish	0.0 c	0.0 c	50.0 b	100.0
Oriental mustard	11.9 c	1.2 c	45.2 b	99.3
Yellow mustard	40.5 b	2.4 c	45.2 b	100.0
Microbial amendment	78.6 a	69.0 b	85.7 a	100.0
Control	100.0 a	88.1 a	100.0 a	100.0
$LSD_{0.05}$ =	23.2	17.7	26.6	NS

*Muskmelons were direct-seeded on June 10, 2008 and June 12, 2009 or transplanted on June 12, 2009. Eggplant was transplanted on June 10, 2008 and June 12, 2009. Stand count was taken on June 23, 2008 and June 25, 2009.
**Means within a column followed by the same letter are not significantly different at the P=0.05 level. NS is not significant at the P=0.05 level.

Table 3.8. Eggplant fresh shoot biomass as affected by the previous Brassica cover crops and soil treatments.*

Treatment	2008 (kg/plot)**	2009 (kg/plot)
Methyl bromide	13.0 bc	6.9
Oilseed radish	14.7 ab	8.1
Oriental mustard	12.7 bc	6.7
Yellow mustard	11.7 c	5.4
Microbial amendment	16.1 a	7.3
Control	14.2 ab	7.6
$LSD_{0.05}$ =	2.2	NS

*Biomass was collected on September 28, 2008 and September 24, 2009 at the end of the harvest season.

* *Means within a column followed by the same letter are not significantly different at the P=0.05 level. NS is not significant at the P=0.05 level.

Table 3.9. Effect of cover crops and soil treatments on eggplant 'Classic' height (cm) in 2008.*

Treatment	Jun. 23	Jun. 30	Jul. 7	Jul. 14	Jul. 21	Jul. 28
Methyl bromide	17.6	19.6 a	22.5 a	30.2 a	36.1	44.4
Oilseed radish	14.3	15.4 c	18.8 c	25.7 b	35.8	43.0
Oriental mustard	15.4	16.2 c	19.8 bc	25.5 bc	34.5	45.1
Yellow mustard	15.0	16.4 bc	18.0 c	22.6 c	32.3	40.5
Microbial amendment	17.0	18.5 ab	22.8 a	28.4 ab	36.0	44.5
Control	16.2	18.5 ab	21.5 ab	29.5 a	37.1	43.8
$LSD_{0.05}$ =	NS**	2.3	2.1	3.1	NS	NS

*Eggplants were transplanted on June 10, 2008. Plant spacing was 1.5 m (5.5') between beds and 0.5 m (1.5') inside the rows (13,047 plants/ha) (5,280 plants/A).

** Means within a column followed by the same letter are not significantly different at the P=0.05 level.

Table 3.10. Effect of cover crops and soil treatments on eggplant 'Classic' height (cm) in 2009.*

Treatment	Jun. 25	Jul. 2	Jul. 9	Jul. 16	Jul. 23	Jul. 30
Methyl bromide	18.9*	23.0	28.6	37.9	47.0 a	53.0 a
Oilseed radish	18.5	22.2	26.4	37.8	46.0 ab	49.5 ab
Oriental mustard	18.4	21.2	26.0	36.0	42.0 bcd	46.5 bc
Yellow mustard	17.3	20.8	25.8	34.9	40.5 cd	42.7 c
Microbial amendment	19.0	22.5	26.9	34.5	38.3 d	44.0 c
Control	19.4	22.7	28.7	37.7	43.1 abc	47.1 bc
$LSD_{0.05}$ =	NS	NS	NS	NS	4.7	5.4

*Eggplants were transplanted on June 12, 2009. Plant spacing was 1.5 m (5.5') between beds and 0.5 m (1.5') inside the rows (13,047 plants/ha) (5,280 plants/A).

** Means within a column followed by the same letter are not significantly different at the P=0.05 level.

Table 3.11. Effect of cover crops and soil treatments on eggplant 'Classic' chlorophyll levels.*

	Average SPAD reading**		
Treatment	**July 21, 2008**	**July 28, 2008**	**August 6, 2009**
Methyl bromide	42.3 b***	44.5	51.8
Oilseed radish	49.0 a	46.3	52.0
Oriental mustard	47.7 ab	45.8	53.7
Yellow mustard	47.1 ab	46.4	53.2
Microbial amendment	49.2 a	43.3	52.2
Control	49.2 a	47.5	53.0
$LSD_{0.05}$ =	3.9	NS	NS

*Eggplants were transplanted on June 12, 2009. Plant spacing was 1.5 m (5.5') between beds and 0.5 m (1.5') inside the rows (13,047 plants/ha) (5,280 plants/A).

**Values for 2008 are the average of five readings; values for 2009 are the average of seven readings.

***Means within a column followed by the same letter are not significantly different at the P=0.05 level.

Table 3.12. Visual estimates of direct-seeded melon 'Athena' plot plant vigor as affected by biofumigation with Brassica cover crops and soil treatments in 2009.

Treatment	Jul. 2	Jul. 9	Jul. 16	Jul. 23	Jul. 30	Aug. 6	Aug. 13	Aug. 21
	Average visual estimate*							
Methyl bromide	9.7 a**	9.7 a	9.8 a	9.3 a	8.7 a	8.0 a	7.7 a	8.2 a
Oilseed radish	6.8 c	6.0 c	5.5 c	7.0 c	6.0 b	7.2 bc	7.5 a	7.5 ab
Oriental mustard	6.8 c	6.2 c	5.8 c	6.7 c	6.2 b	6.5 cd	7.8 a	7.5 ab
Yellow mustard	6.8 c	6.0 c	5.7 c	6.2 c	5.8 b	6.3 d	6.3 b	6.8 bc
Microbial amendment	8.5 b	8.0 b	8.3 b	8.0 b	8.0 a	8.0 a	7.0 ab	6.2 c
Control	9.0 ab	8.5 b	8.2 b	9.7 a	8.0 a	7.8 ab	7.5 a	7.5 ab
$LSD_{0.05}$ =	0.8	0.9	0.9	0.9	0.9	0.8	0.9	0.9

*Plots were rated on a scale of 1 to 10, with 1 being 'all plants are dead' and 10 being 'all plants look vigorous'.

**Means within a column followed by the same letter are not significantly different at the P=0.05 level. Plants were direct-seeded on June 12, 2009.

Table 3.13. Visual estimates of transplanted melon 'Athena' plot plant vigor as affected by biofumigation with Brassica cover crops and soil treatments in 2009.

Treatment	Jul. 2	Jul. 9	Jul. 16	Jul. 23	Jul. 30	Aug. 6	Aug. 13	Aug. 21
	Average visual estimate*							
Methyl bromide	9.5 a**	9.5 a	9.7 a	9.3 a	9.0 a	8.7 a	7.7 abc	8.0 a
Oilseed radish	7.3 b	6.3 cd	6.7 bcd	7.5 bcd	8.7 ab	8.3 a	8.8 ab	8.0 a
Oriental mustard	7.3 b	5.7 d	6.2 cd	6.8 cd	8.5 ab	7.7 ab	8.3 a	8.0 a
Yellow mustard	7.2 b	5.3 d	5.8 d	6.5 d	7.2 c	6.2 c	7.0 c	6.8 b
Microbial amendment	8.5 a	7.7 b	7.3 b	7.7 bc	7.8 bc	7.0 bc	7.3 bc	6.3 b
Control	9.2 a	7.5 bc	7.0 bc	8.2 b	7.8 bc	7.0 bc	7.7 abc	7.0 b
$LSD_{0.05}$ =	1.1	1.2	1.1	1.1	0.9	1.2	0.8	0.9

*Plots were rated on a scale of 1 to 10, with 1 being 'all plants are dead' and 10 being 'all plants look vigorous'.

** Means within a column followed by the same letter are not significantly different at the P=0.05 level. Plants were transplanted on June 12, 2009.

Table 3.14. Visual estimates of eggplant plot plant health and vigor as affected by biofumigation with Brassica cover crops and soil treatments in 2008.

Treatment	Jul. 7	Jul. 14	Jul. 21	Jul. 28	Aug. 11	Sep. 8	Sep. 15	Sep. 28
	Visual estimate*							
Methyl bromide	8.3 a**	8.3 a	7.0	7.5	7.3	7.8	6.8	8.0 b
Oilseed radish	7.2 ab	7.8 ab	7.3	7.3	6.8	8.5	7.3	9.0 a
Oriental mustard	6.7 b	7.3 b	8.0	7.3	7.3	7.8	6.8	8.5 ab
Yellow mustard	4.5 c	6.3 c	7.3	7.0	7.7	7.7	6.0	6.8 c
Microbial amendment	8.0 a	7.8 ab	7.7	7.7	7.0	8.7	7.8	9.0 a
Control	9.3 a	8.2 ab	7.7	7.3	7.7	8.5	7.0	8.2 ab
$LSD_{0.05}$ =	1.3	0.8	NS	NS	NS	NS	NS	0.9

*Plots were rated on a scale of 1 to 10, with 1 being 'all plants are dead' and 10 being 'all plants look healthy and vigorous'.

** Means within a column followed by the same letter are not significantly different at the P=0.05 level. NS is not significant at the P=0.05 level. Plants were transplanted June 10, 2008.

Table 3.15. Visual estimates of eggplant plot plant health and vigor as affected by biofumigation with Brassica cover crops and soil treatments in 2009.

Treatment	Jul. 2	Jul. 9	Jul. 16	Jul. 23	Jul. 30	Aug. 6	Aug. 13	Aug. 21
	Visual estimate*							
Methyl bromide	8.2**	8.5 a	8.7 a	9.0 a	10.0 a	8.2 a	7.7	7.7 bc
Oilseed radish	7.5	8.0 ab	8.8 a	7.8 b	8.5 bc	8.2 a	8.8	9.0 a
Oriental mustard	7.2	7.7 bc	8.0 a	7.2 bc	8.7 b	7.8 a	8.3	8.3 abc
Yellow mustard	7.5	7.7 bc	8.2 a	7.5 bc	7.8 c	6.7 bc	7.3	7.2 c
Microbial amendment	6.8	7.2 c	7.0 b	6.0 d	7.8 c	6.5 c	7.7	7.3 abc
Control	7.7	8.2 ab	8.2 a	6.7 cd	8.3 cd	7.7 ab	8.3	8.7 ab
$LSD_{0.05}$ =	NS	0.8	0.8	0.9	0.7	1.0	NS	1.2

*Plots were rated on a scale of 1 to 10, with 1 being 'all plants are dead' and 10 being 'all plants look healthy and vigorous'.
**Means within a column followed by the same letter are not significantly different at the P=0.05 level. NS is not significant at the P=0.05 level. Plants were transplanted June 12, 2009.
***Differences were NS for Aug. 27, Sep.3, Sep.10, Sep. 17, and Sep. 24, 2009.

Table 3.16. Percentage of 'Classic' eggplant with verticillium wilt symptoms as affected by biofumigation with Brassica cover crops and soil treatments in 2008.*

Treatment	Jul. 7	Jul. 14	Jul. 21	Jul. 28	Aug. 11	Sep. 8	Sep. 15	Sep. 28
	% symptomatic plants							
Methyl bromide	10.7 ab**	35.7	44.0 a	57.1 a	60.7	59.5	54.8	73.8
Oilseed radish	3.6 bc	17.9	32.1 ab	48.8 ab	71.4	65.5	56.0	65.5
Oriental mustard	0.0 c	10.7	21.4 bc	33.3 bc	63.1	69.0	59.5	76.2
Yellow mustard	11.9 a	15.5	14.3 c	26.2 c	41.7	67.9	61.9	83.3
Microbial amendment	3.6 bc	21.4	20.2 bc	40.5 abc	65.5	70.2	48.8	63.1
Control	9.5 ab	22.6	39.2 a	56.0 a	67.9	67.9	60.7	79.8
$LSD_{0.05}$ =	7.6	NS	17.8	20.8	NS	NS	NS	NS

*Plants were transplanted June 10, 2008.

** Means within a column followed by the same letter are not significantly different at the P = 0.05 level. NS is not significant at the *P*=0.05 level.

Table 3.17. Percentage of 'Classic' eggplant with verticillium wilt symptoms as affected by biofumigation with Brassica cover crops and soil treatments in 2009.*

Treatment	Jul. 16	Jul. 23	Jul. 30	Aug. 6	Aug. 13	Aug. 21	Aug. 27	Sep. 3	Sep. 10	Sep. 24
	% Symptomatic plants									
Methyl bromide	3.6**	8.3 c	14.3 b	32.1 b	64.3 b	86.9 b	88.1	94.0	95.2	100.0
Oilseed radish	7.1	86.9 ab	100.0 a	100.0 a	91.7 a	100.0 a	100.0	97.6	100.0	100.0
Oriental mustard	14.3	84.5 b	100.0 a	97.6 a	92.9 a	98.8 a	100.0	98.8	100.0	100.0
Yellow mustard	3.6	84.5 b	100.0 a	100.0 a	96.4 a	98.8 a	98.8	98.8	100.0	92.9
Microbial amendment	31.0	100.0 a	98.8 a	98.8 a	89.3 a	100.0 a	100.0	100.0	100.0	100.0
Control	19.0	84.5 b	100.0 a	100.0 a	92.9 a	100.0 a	100.0	100.0	100.0	100.0
$LSD_{0.05}$ =	NS	15.0	4.5	11.1	15.5	8.6	NS	NS	NS	NS

*Plants were transplanted June 12, 2009.

**Means within a column followed by the same letter are not significantly different at the P=0.05 level. NS is not significant at the P=0.05 level.

Table 3.18. Direct-seeded muskmelon 'Athena' marketable and total yield as affected by biofumigation with Brassica cover crops and soil treatments in 2009.*

Treatment	Marketable fruit (no./plot)**	Total fruit (no./plot)	Marketable yield (kg/plot)	Total yield (kg/plot)
Methyl bromide	6.5***	15.7 a	12.2	22.5
Oilseed radish	7.2	10.3 bc	17.4	22.0
Oriental mustard	6.5	10.3 bc	16.4	21.0
Yellow mustard	6.3	8.7 c	14.3	18.1
Microbial amendment	8.3	13.0 ab	17.5	23.0
Control	8.7	14.3 a	17.9	21.8
$LSD_{0.05}$ =	NS	3.0	NS	NS

*Plant spacing was 1.5 m (5.5') between beds and 1.0 m (3.0') inside rows (6,523 plants/ha) (2,640 plants/A). Plants were direct-seeded on June 12, 2009.
**Fruits were sorted in to marketable fruit and fruit which failed to meet the standards (culls) (USDA-AMS 2008).
***Means within a column followed by the same letter are not significantly different at the P=0.05 level. NS is not significant at the P=0.05 level.

Table 3.19. Transplanted muskmelon 'Athena' total yield as affected by biofumigation with Brassica cover crops and soil treatments in 2009.*

Treatment	Marketable fruit (no./plot)**	Total fruit (no./plot)	Marketable yield (kg/plot)	Total yield (kg/plot)
Methyl bromide	13.5 ab***	19.7 a	24.7	31.4 b
Oilseed radish	14.0 a	22.0 a	30.8	40.6 a
Oriental mustard	10.3 bc	13.7 b	23.6	27.4 b
Yellow mustard	9.7 c	14.7 b	20.3	27.4 b
Microbial amendment	9.7 c	14.7 b	20.5	27.1 b
Control	12.2 abc	19.3 a	23.2	30.2 b
$LSD_{0.05}$ =	3.2	4.4	NS	7.3

*Plant spacing was 1.5 m (5.5') between beds and 1.0 m (3.0') inside rows (6,523 plants/ha) (2,640 plants/A). Plants were transplanted on June 12, 2009.

**Fruits were sorted in to marketable fruit and culls fruit which failed to meet the standards (culls) (USDA-AMS 2008).

*** Means within a column followed by the same letter are not significantly different at the P=0.05 level. NS is not significant at the P=0.05 level.

Table 3.20. Eggplant 'Classic' yield in kg/plant, fruit no./plot, and harvest index (fruit weight divided by total plant and fruit weight) as affected by biofumigation with Brassica cover crops and soil treatments in 2008.*

Treatment	-Marketable fruit-**		--------Cull--------		-----Total yield-----		Total plant weight (kg/plot)	Harvest index	
	Yield (kg/plot)	Fruit (no./plot)	Yield (kg/plot)	Fruit (no./plot)	Yield (kg/plot)	Fruit (no./plot)		I***	II
Methyl bromide	22.8 ab****	86.3 a	3.5	50.2 c	26.4 ab	136.5 a	39.4 ab	0.57 a	0.66 a
Oilseed radish	19.0 bc	72.5 b	3.5	67.5 ab	22.5 c	140.0 a	37.2 ab	0.50 bc	0.60 bc
Oriental mustard	19.2 abc	66.2 bc	3.7	59.3 abc	23.0 bc	125.5 ab	35.6 bc	0.54 abc	0.64 ab
Yellow mustard	15.9 c	58.3 c	4.1	57.2 abc	20.0 c	115.5 b	31.7 c	0.50 bc	0.63 ab
Microbial amendment	22.8 ab	70.2 bc	4.3	70.7 a	23.0 bc	140.8 a	39.1 ab	0.47 c	0.58 c
Control	23.0 a	79.5 ab	3.8	55.7 bc	26.8 a	135.2 a	41.0 a	0.56 ab	0.65 a
$LSD_{0.05}$ =	4.0	13.4	NS	13.8	3.7	16.4	4.7	0.06	0.05

*Plant spacing was 1.5 m (5.5') between beds and 0.5 m (1.5') inside rows (13,047 plants/ha) (5280 plants/A). Plants were transplanted on June 10, 2008.

** Fruits were harvested 5 times.

***Harvest index I is the marketable yield divided by the total plant mass (fresh weight vegetative mass plus total fruit weight); harvest index II is the total fruit yield divided by the total plant mass.

****Means within a column followed by the same letter are not significantly different at the P=0.05 level. NS is not significant at the P=0.05 level.

Table 3.21. Eggplant 'Classic' yield in kg/plant, fruit no./plot, and harvest index (fruit weight divided by total plant weight) as affected by biofumigation with Brassica cover crops and soil treatments in 2009.*

Treatment	-Marketable fruit-**		--------Cull--------		-----Total yield-----		Total plant weight (kg/plot)	Harvest index	
	Yield (kg/plot)	Fruit (no./plot)	Yield (kg/plot)	Fruit (no./plot)	Yield (kg/plot)	Fruit (no./plot)		I***	II
Methyl bromide	18.8****	40.7 d	4.1 b	38.7	22.8	79.3 c	29.7	0.56	0.73
Oilseed radish	18.9	65.2 a	6.3 a	53.7	25.2	118.8 a	33.2	0.58	0.76
Oriental mustard	16.8	59.8 ab	5.4 ab	45.2	22.2	105.0 ab	28.9	0.59	0.77
Yellow mustard	12.2	44.8 cd	5.1 ab	47.7	17.4	92.5 bc	23.7	0.53	0.76
Microbial amendment	13.4	49.5 bcd	5.9 a	51.5	19.4	101.0 abc	26.6	0.51	0.73
Control	16.0	57.3 abc	5.7 ab	57.0	21.7	114.3 ab	29.3	0.54	0.74
$LSD_{0.05}$ =	NS	12.7	1.7	NS	NS	23.1	NS	NS	NS

*Plant spacing was 1.5 m (5.5') between beds and 0.5 m (1.5') inside rows (13,047 plants/ha) (5,280 plants/A). Plants were transplanted on June 10, 2008.

**Fruits were harvested 5 times.

***Harvest index I is the marketable yield divided by the total plant mass (fresh weight vegetative mass plus total fruit weight); harvest index II is the total fruit yield divided by the total plant mass.

****Means within a column followed by the same letter are not significantly different at the P=0.05 level. NS is not significant at the P=0.05 level.

CHAPTER 4: Impact of Brassica Cover Crops on Cucurbit Germination and Yield

CHAPTER 4: Impact of Brassica Cover Crops on Cucurbit Germination and Yield

ABSTRACT

There is evidence to suggest Brassica cover crops can be phytotoxic to cash crops, especially when the cash crop is planted too soon after cover crop incorporation. A field experiment was completed in which honeydew (*Cucumis melo* L. Group Inodorus), muskmelon (*Cucumis melo* L. Group Reticulatus), and cucumber (*Cucumis sativus* L.) seeds were planted at 5 d intervals after the incorporation of oilseed radish (*Raphanus sativus* (L.) var. oleiferus Metzg (Stokes)), Oriental mustard (*Brassica juncea* (L.) Czern.), and no cover crops. Cucumber emergence was reduced in oilseed radish treatment for the Day 0 planting. There were no other significant differences in emergence for individual planting dates and cash crops among treatments. At cucumber harvest (50-60 d after planting) there were no significant differences in individual vine weight or marketable fruit mass per vine, though plants in oilseed radish and Oriental mustard treatments produced significantly more total fruit mass per vine than those in the control treatment. There were no significant differences in marketable fruit number per vine, though plants in the oilseed radish treatment produced more culled fruit per vine in the control. Bioassays using both non-lyophilized and lyophilized root and shoot aqueous extracts of oilseed radish were performed in the laboratory on muskmelon, cucumber, and honeydew. Germination rates and radicle elongation measurements showed both extracts impacted all three crops to varying degrees. Germination ranged from 64.4-98.9% at the 0% concentrations to 0–2.2% at the 100% (1kg fresh weight cover crop: 1 L water) concentrations for

non-lyophilized extracts. Muskmelon germination was least sensitive to the extracts, followed by cucumber and then honeydew. Cucumber and muskmelon root growth was equally inhibited by non-lyophilized shoot extract, while honeydew growth was mildly stimulated at 5 and 12.5% concentrations. Honeydew root growth was least inhibited by non-lyophilized root extract, followed by cucumber and then muskmelon. Overall non-lyophilized root extract was more potent than non-lyophilized shoot extract, while the reverse was true of lyophilized extracts. In addition, non-lyophilized extracts were far more inhibitory than lyophilized extracts.

INTRODUCTION

Current economic and regulatory conditions present growers with increasing challenges. Consumers demand environmentally-friendly production practices as local, state, and federal government regulations make pesticide use more difficult. Fertilizer prices increase yearly. Production challenges include maintaining soil quality (high soil fertility and low pest pressure) and using pesticides and fertilizers more efficiently. One tool that may be of use in meeting these challenges is cover crops. Cover crops provide a variety of services in a production system. They decrease erosion, aid nutrient cycling, preserve soil quality, and suppress weeds (Mutch 2009). Cover crops in the Brassica family such as oilseed radish [*Raphanus sativus* (L.) var. oleiferus Metzg (Stokes)], Oriental mustard (*Brassica juncea* (L.) Czern.), and yellow mustard (*Sinapis alba* L.) have also been shown to impact plant pathogen populations in the soil (Sarwar et al. 1998). Given the phase-out of methyl bromide, any practice that is

environmentally-friendly, economically feasible, and which decreases soilborne disease incidence is likely to be well received by growers, consumers, and the government. Use of Brassica cover crops in field rotations could be one such practice.

Our previous field study involving muskmelon (*Cucumis melo* L. Group Reticulatus) and honeydew (*Cucumis melo* L. Group Inodorus) suggested oilseed radish, Oriental mustard, and yellow mustard may be phytotoxic, especially to seed germination and seedling growth. Haramoto and Gallandt (2005a) also determined Brassica cover crops decreased cash crop emergence by 23-34% and delayed germination 2 d (though their impact was similar to that of other short-season cover crops such as red clover). Laboratory experiments have proven compounds produced by Brassicas can inhibit weed seed germination (Norsworthy et al. 2006; Norsworthy and Meehan 2005a and 2005b). Studies with *Brassica nigra* Moench aqueous extracts have shown the extracts to inhibit germination and growth of lentils (*Lens culinaris* Medik.) and wild oats (*Avena fatua* L.) (Turk and Tawaha 2002 and 2003). Wheat (*Triticum aestivum* Songle) germination is likewise inhibited by compounds produced by Brassica cover crops (Bialy et al. 1990). Phytotoxicity would typically be a problem in production systems where the cover crop is tilled under and another crop is immediately planted, as in a muskmelon/eggplant (*Solanum melongena* L.) short rotation wherein the cover crop is planted in April and tilled under in late May.

There are several potential avenues through which Brassica cover crops could be impacting cucurbit germination. Molisch (1937) first coined the word

allelopathy to describe the situation wherein plants interact with each other via chemical compounds. These interactions can be positive or negative, though today the word allelopathy implies negative interactions (Choesin and Boerner 1991). One well-known example would be that of black walnut (*Juglans nigra* L.), which exudes chemicals from its roots that prevent many plants from growing beneath its canopy. Allelochemicals are common throughout the plant world and include (but are not limited to) organic acids, alkaloids, alcohols, aldehydes, glycosides, tannins, and terpenes (Szczepanski 1977). While allelochemicals are common, a variety of factors dictate levels at which they are present in the environment. Such factors include the plant species present, the quantity and type produced, and the environment itself (e.g. soil moisture levels and soil composition). Furthermore, crop and weed species vary in their susceptibility to allelochemicals (Oleszek 1987).

Brassica cover crops produce multiple classes of compounds that are implicated as being allelopathic. The primary class of interest is glucosinolates, which when degraded by hydrolysis produce biologically-active compounds called isothiocyanates (ITCs) (Kirkegaard and Sarwar 1998). Some of these glucosinolate by-products are water-soluble, while some are highly volatile (Brown and Morra 1996). Other compounds from glucosinolate hydrolysis that may be allelopathic are organic cyanides and oxazolidinethione (Brown and Morra 1996).

Allelopathy is not the only mechanism by which Brassica cover crops could impact germination. These cover crops do not solely act by killing pathogens/weed seeds. Cohen and Mazzola (2006) have demonstrated low-glucosinolate Brassica

seed meal can change the composition of soil microbe communities, leading to increases in the *Pythium* spp. population. Hoagland et al. (2008) found low-glucosinolate *Brassica napus* and *Sinapis alba* seed meal amendments also lead to an increase in *Pythium spp.* populations. Njoroge et al. (2008) discovered *Pythium* spp. populations increased in some plots in which Brassica cover crops were used as a green manure compared to an untreated control (though plots planted with Brassicas had higher levels of *Pythium* spp. compared to unplanted plots to begin with). *Pythium* spp. is one of the pathogens that can cause seedling damping-off. Cohen and Mazzola (2006) found *Pythium* infections were greatest when seedlings were planted immediately after seed meal incorporation; a delay of 4 weeks greatly decreased infection rates. The ways in which Brassica biomass can impact microbial communities are diverse and intricate; one such way is by serving as a carbohydrate source for sufficiently opportunistic organisms (Cohen and Mazzola 2006). Hoagland et al. (2008) postulated the observed increase in *Pythium* populations was at least partly the cause of the observed decreases in weed and wheat seed germination and increases in seedling mortality. Treatments in the Hoagland experiments (2008) with *Brassica juncea* (L.) Czern. seed meal suppressed *Pythium* (likely due to the nature of its ITCs), resulting in less severe decreases in germination and increases in seedling mortality. What damage the authors did observe they attributed to ITCs.

One last way in which cover crops could impact seed germination and seedling establishment is by changing soil structure (Cortland, personal communication). Cover crops that have been incorporated but have not yet

decomposed sufficiently could create a situation wherein seeds are planted but are not in good contact with soil/moisture, in cavities created by the decomposed crops.

Brassica cover crops have the potential to be a valuable tool. More information is needed on their impact on cash crops, especially on those which are direct-seeded. Brassica cover crops may be impacting germination directly through allelopathic mechanisms, or indirectly through altering soil microbial community structure or soil structure. Producers need to know how long to wait between cover crop incorporation and cash crop seeding. The objectives of this study are to a) verify that Brassica cover crops impact cucurbit germination in the field; b). determine a safe plant-back period; and c). determine if the cover crops are allelopathic.

MATERIALS AND METHODS

Field Experiment - Site and Procedures

Oilseed radish 'Defender' and Oriental mustard 'Forge' were planted at the Michigan State University Horticulture Teaching and Research Center in Holt, Michigan on May 8, 2009. Monthly temperature and rainfall for the site are presented in Table 4.1 and growing degree days in Table 4.2. The plot previously was fallow for three years. The soil was Thetford loamy sand (sandy, mixed, mesic, Psammaquentic Hapludalfs). The experiment was a split plot design with four replications and two factors (cover crop was the main plot factor while crop planting date was the subplot factor). Cover crop factor included oilseed radish (11 kg/Ha) (10.0 lb/A), Oriental mustard (7 kg/Ha) (6.0 lb/A), and bare ground

control. Cover crops were planted on May 8, 2009 using a Marliss drill. Cover crop plots were 116 m^2 each. Ammonium nitrate fertilizer (22 kg N/Ha) (20 lb N/A) was applied May 27, 2009. Cover crops were sampled for biomass production (Table 4.3) and flail mowed and tilled under June 24, 2009 when most plants were at flowering stage. Black plastic and drip tape were installed immediately afterwards on raised beds.

Each main plot (cover crop) treatment was divided in to seven subplots, each of which was randomly assigned a planting date. The cucurbits were planted at five day intervals after cover crop incorporation (CCI) (D0, D5, D10, D15, D20, D25, and D30). Furthermore, each subplot bed had three rows of holes. Muskmelon 'Athena' was planted in the center row of each bed, while pickling cucumber 'Journey' and honeydew 'Earlibrew' were planted in the outer rows of holes. Two seeds per hole were sown by hand. Rows were 1 m apart, center to center. Holes within each row were 0.5 m apart. Irrigation was applied for 2 – 3 hours after each cucurbit planting, except when soil was damp to a depth of five cm due to previous rainfall. No fertilizer and no other irrigation were applied to the cucurbits due to the amount of rain received over the summer. Plots were hoed once.

Laboratory Experiments – Materials and Methods

Oilseed radish was planted by grower Ron Eding on September 14, 2009 in Hamilton, MI (42° 40' 39" N, 86° 0' 22" W). The soil was a Houghton muck soil with 80% organic matter. A total of 528 plants were harvested from 15 randomly chosen 0.5 m^2 quadrats on November 30, 2009. Plants were 0.3 - 0.6 m tall and

had not yet initiated flower buds. The plants were rinsed in tap water and then in deionized water to remove dirt, air-dried for 1 d, and weighed. Roots were separated from shoots; the two plant parts were processed separately. The biomasses were processed in a commercial grade blender (CB-10; Waring Commercial®, Torrington, CT) with deionized water (1 L to 1 kg biomass) for 90 - 120 sec. The resulting extracts were strained through cheesecloth. Both extracts were then filtered through Whatman #4 filter paper. These extracts will henceforth be referred to as the non-lyophilized extracts. Some of the strained liquids were further centrifuged at 10,000 rpm for 10 minutes (RC5C; Sorvall® Instruments, DuPont, Wilmington, Del.), and then the supernatants were freeze-dried using a lyophilizer. The resulting powders were mixed to allow for uniformity and stored at 4° C until use. Solutions made with these powders will henceforth be referred to as lyophilized extracts.

Experiments testing both extracts were designed as a completely randomized design with three replications. Each experiment was repeated three times. Non-lyophilized extract was diluted to make solutions of 5, 12.5, 25, 50, and 100% strength. Deionized water was the control. For assays using lyophilized extracts, extracts were dissolved in deionized water to create concentrations of 0, 0.25, 0.5, 1, 2, 4, and 8 g/L by serial dilution of a stock solution containing 8 g/L. Crops tested were cucumber 'Journey', muskmelon 'Athena', and honeydew 'Earlibrew'. Ten seeds of each crop were placed in 10 cm Petri dishes on Whatman #4 filter paper, then 3.0 ml of each extract dilution was placed into each Petri dish. Dishes were sealed with parafilm. Seeds were incubated in a Conviron growth

chamber (Controlled Environments, LTD, Winnipeg, Manitoba, Canada) at 21° C in the dark for 6 d.

The EC and pH of the 100% concentration treatments for non-lyophilized extract, the 8 g/L lyophilized extract and deionized water were measured with a Horiba D-24 pH/conductivity meter (Spectrum Technologies, Inc). An experiment was run using deionized water acidified with acetic acid (vinegar) to a pH of 5.48 to determine if the extracts' acidity was a confounding variable. Three milliliters of vinegar solution were placed in each of four Petri dishes containing ten seeds each; deionized water was the control. As with the bioassays, seeds were incubated at 21°C for 6 d. As the ECs of water and extracts were similar, no experiment was run to test the possibility of EC being a confounding variable.

Field Equivalent Concentration Estimates

Field equivalent rates (FER) (extract concentrations that would typically occur under field conditions) were estimated for both types of extracts. For the non-lyophilized sample, FER was calculated based on area harvested, total fresh biomass, and amount of extract obtained (Table 4.7). For lyophilized extracts, FER estimates were based on amount of extract produced and harvested area (Table 4.8). Both estimates rely on the assumptions that 15 cm of cover crop are incorporated, extracted materials are released simultaneously and immediately into the environment, and 3 ml of aqueous extract were added to each Petri dish (equal to 46.88 L per cubic meter of soil). The FER estimation equation for lyophilized extract is as follows (after Hill 2006):

$$FER = E(g) * P(cm^3)/A(cm^2) * D(cm) * W(L)$$

Where *FER* is estimated field equivalent rate, *E* is total extract dry weight, *P* is Petri dish volume (64 cm^3), *A* is area harvested, *D* is assumed depth of cover crop incorporation (15 cm), and *W* is extract volume added to each Petri dish during bioassays (3 ml). Extracts are likely released over time in the field, not simultaneously as assumed. These estimated field rates are thus likely higher than would be found under field conditions.

Data Collection

In the field experiment, two 50 by 50 cm cover crop biomass samples were taken from each plot prior to cover crop incorporation. Samples were dried at 60° C for 14 d. Cucurbit seed emergence was recorded every 5 d. At 30 d after planting, muskmelon and honeydew plants were cut at ground level, counted, and placed in a drier for an average of 21 d at 60° C. One cucumber seedling from each hole containing two seedlings was likewise cut and dried to determine biomass production. Cucumbers were harvested at 50 to 60 d after planting, sorted into USDA Grade 1, 2, 3 or cull fruit, and weighed. At the time of harvest cucumber plants were cut at ground level, counted, and weighed to determine fresh biomass. Fresh cucumber vine weights per bed were divided by number of vines remaining in each bed to eliminate biases resulting from varying germination and survival rates. Cucumber yields were also divided by number of plants remaining in each bed for the same reason.

In laboratory experiments, on day 6 Petri dishes were opened and root length and germination rates were measured. Root length was measured using a digital caliper (Avenger Products, Boulder City, NV, USA). A seed was considered to be germinated if the root was at least 2 mm long.

Statistical Analysis

Field experiment data were analyzed using SAS PROC GLM and ANOVA (SAS v 9.2, SAS Institute, Cary, North Carolina).

Data from the three laboratory experiments using non-lyophilized extracts were combined because there was no experiment by treatment interaction. Data from lyophilized shoot extracts treatments were likewise combined. Data from lyophilized root extracts treatments were not combined due to an experiment by treatment interaction; data from this part of each experiment were analyzed individually. Germination and root length were analyzed using SAS PROC GLM and ANOVA (SAS v 9.2, SAS Institute, Cary, North Carolina).

For all data, means were separated using Fisher's protected LSD. A *P*-value of 0.05 was used to determine significance.

RESULTS

FIELD EXPERIMENT

Weather

Because weather impacts crops, a year with weather extremes may result in skewed data. Temperature, rainfall, and growth degree day (GDD) data were obtained from the Michigan Automated Weather Network (MAWN) for 2009 and

the preceding eight years (Tables 4.1 and 4.2). Low temperatures from May-September in 2009 were similar to those of the eight year average, with the July low being the most different (13.4° C average in 2009 compared to the eight year average of 15.1° C). The average high temperatures for 2009 were likewise similar to average, though July was again slightly cooler than average (24.9° C compared to 27.8° C). The slightly lower temperatures (both for lows and highs) resulted in just under 70 fewer Growing Degree Days (GDD) in 2009 than on average (1263.6 GDD in 2009 compared to an average of 1341.8 GDD). July in particular saw a notable decrease in GDD: 290.2 in 2009 vs. 359.5 on average. Overall lower temperatures (and thus fewer GDD) could slow crop growth, especially those that thrive in the heat such as cucurbits. During the 5 d immediately after the D5 planting, temperatures were especially cool, resulting in extremely low germination rates for all crops and treatments (including the control). To mitigate impact of weather the first 5 d after planting the germination rates in the results tables were determined 10 d after planting.

While 2009 was slightly cooler, on average, it was also slightly rainier. In total HTRC received 424.7 mm of rain from May-September 2009, whereas on average it receives 393.3 mm of precipitation during those months. June and August were notably rainier, with 126.2 and 104.7 mm falling when on average those months receive 80.8 and 59.4 mm, respectively. Slightly wetter weather may encourage the disease proliferation, and 2009 was an especially severe year for downy mildew.

Cover Crop Biomass

The oilseed radish cover crop had fewer plants on average per m^2 quadrat than the Oriental mustard (Table 4.3). This is because oilseed radish seeds are larger than those of Oriental mustard. Oilseed radish produced 4,677 kg/ha compared to 5,250 kg/ha for Oriental mustard. Oriental mustard seemed better adapted to the cool and wet spring than the oilseed radish, which would explain why the mustard was close to full flower when the radish was barely opening its buds. Mustards are also more sensitive to day length than oilseed radish. Under ideal circumstances the two species flower at roughly the same time after planting.

Cash Crop Emergence

There were few significant differences in the cucurbit crop emergence across treatments for each planting date (Table 4.4). Cucumber was impacted by treatments when it was planted immediately after cover crop incorporation (D0). Only 45.8% emerged in oilseed radish treatment compared with 72.9% emergence in the control. Emergence percentage for cucumbers in Oriental mustard treatment was statistically similar to the other two treatments. Across the 30 day planting period, cucumber showed a significant difference in emergence levels: 84.6% of seeds in control emerged, while 79.4% in Oriental mustard treatment and 77.2% in oilseed radish treatment emerged (Table 4.5). Control treatment had a significantly higher overall emergence percentage than oilseed radish treatment, while Oriental mustard treatment emergence rate was not significantly different than that of the other two treatments. Cover crop treatments did not affect muskmelon and honeydew seed emergence.

Cash Crop Growth

Cucumbers were thinned to two plants per hole 30 d after planting and allowed to grow a total of 50–55 d to harvest. At harvest, remaining vines were counted and weighed fresh. There was no significant difference in number of vines remaining among treatments (Table 4.6). On average 9.9–10.3 out of 12 possible vines remained per bed.

There was no significant difference in average individual vine weights; however, all values for control treatment were lowest (Figure 4.1).

Cucumber Yield

There was no significant difference in production of Grades 1, 2, and 3 fruit per vine; there was a significant difference in the average number of culled fruit per vine averaged over the seven plant dates (Figure 4.2). Plants in oilseed radish treatment produced 0.54 culled fruit per vine, significantly differing from those in the control which produced 0.36 culled fruit per vine. There was no significant difference between Oriental mustard treatment and the other two treatments. There was no significant difference in marketable yields per vine among treatments (Figure 4.3). There was a significant difference between treatments in terms of total yield and average yield over all planting dates (Figure 4.4). Averaged over all the planting dates, oilseed radish and Oriental mustard treatment vines produced 230.5 and 198.4 g of fruit mass/vine compared to 142.8 g of fruit mass/vine in the control; the cover crop treatment plants thus produced significantly more total fruit mass/vine than control plants (Figure 4.5).

LABORATORY EXPERIMENT

Extract Yield and Characteristics

Oilseed radish produced roughly three times more shoot tissue than root tissue (Table 4.7). The harvest netted 4.40 kg of root tissue and 12.78 kg of shoot tissue. The large proportion of shoot to root tissue was due to the fact the taproot was not well developed at cover crop sampling. When macerated in a 1:1 ratio of biomass: deionized water and strained through cheesecloth, the results were 5.90 and 13.85 L of root and shoot tissue aqueous extract, respectively. This extract was then filtered through filter paper, for a final total of 3.43 L of non-lyophilized root aqueous extract and 10.07 L of non-lyophilized shoot aqueous extract. Lyophilized root and shoot extracts yielded 110.0 and 181.0 g of dry powder from 2.29 and 5.79 kg of fresh biomass, respectively (Table 4.8). The FER for non-lyophilized extract was 0.20 and 0.67 ml/Petri dish for root and shoot extracts, respectively (Table 4.7). Lyophilized extract FER was 4.00 and 8.88 g/L for root and shoot extracts, respectively (Table 4.8). Specific treatment concentrations for both lyophilized and non-lyophilized extracts are listed in Table 4.9.

The pH of the deionized water was 8.16 while that of root and shoot extracts was 6.02 and 5.80, respectively (Table 4.10). The EC of the deionized water, root extract, and shoot extract was 28.10, 29.50 and 25.38 mv, respectively. An experiment was conducted using an acetic acid solution with a pH of 5.4; germination for muskmelon seeds in this treatment was 97.5% (with a standard deviation of 5) while that of seeds in the deionized water control was 100% (with a standard deviation of 0) (Table 4.11). Average root length in the acetic acid treatment was 35.7 mm, while in the control it was 36.3 mm.

Germination

Both root and shoot non-lyophilized aqueous extracts significantly reduced germination of honeydew, muskmelon, and cucumber (Figures 4.6 and 4.7). As concentration of both extracts increased from 0 to 100%, inhibition became more pronounced. Whereas 64.4-98.9% of seeds germinated at 0% extract concentration, at 100% extract concentration germination rates ranged from 0 to 2.2%.

Shoot lyophilized extract had varying impacts on the crops (Table 4.12). There were no differences in muskmelon germination rates across treatments. As concentration increased, germination of both cucumber and honeydew seeds decreased. At the 0 g/L concentration, 80.0% of honeydew germinated while 20.0% germinated at the 8 g/L concentration; at the 0 g/L concentration, 82.2% of cucumber germinated while at the 8 g/L concentration, 42.2% germinated. The effects were not as pronounced with lyophilized root extract (Table 4.13). Data for the three trials could not be combined due to trial by treatment interaction. For some trials in which the differences were significant, cucumber germination ranged from 86.7% at the 0 g/L concentration to 40.0% at the 8 g/L concentration. The same was true of honeydew: germination ranged from 90.0% at 0 g/L to 60.0% at 8 g/L. Muskmelon germination was not inhibited by lyophilized root extracts.

Crops also varied in their sensitivity to non-lyophilized extracts. Muskmelon germination was most severely impacted at the 50% and 100% non-

lyophilized root extract concentrations and 100% shoot extract concentration while cucumber germination inhibition began at 5% root concentration mark and 12.5% shoot concentration mark (Figures 4.6 and 4.7). Honeydew germination was most sensitive to non-lyophilized extracts and began to be significantly inhibited around 5% concentrations of root and shoot extract.

Radicle Length

Both root and shoot non-lyophilized aqueous extracts of oilseed radish negatively inhibited radicle elongation of cucumber, honeydew, and muskmelon (Figures 4.8 and 4.9). As extract concentration increased, impact on radicle length became more severe. Crop radicle lengths ranged from 22.8 to 37.0 mm at 0% extract concentration to a total growth inhibition at 100% extract concentration. Even at 50% extract concentration radicle lengths ranged only from 0 to 5.7 mm. The one exception was honeydew; at concentrations of 5% and 12.5% both root and shoot non-lyophilized extracts stimulated root growth.

As with germination rates, lyophilized extracts had a less pronounced impact on radical elongation than non-lyophilized extracts (Figures 4.8 and 4.9, Tables 4.14 and 4.15). None of the crops were affected by lyophilized shoot extracts. In lyophilized root extract treatments, however, as concentration increased root length generally decreased (Table 4.15). In Trial 1, for example, average muskmelon root length decreased from 43.4 mm in the 0 g/L treatment to 11.4 mm in the 8 g/L treatment. Similarly, average cucumber root length decreased from 23.1 mm in the 0 g/L treatment to 9.8 mm in the 8 g/L treatment

(Trial 2). Unlike cucumber and muskmelon, honeydew showed no clear association between extract concentration and radical length.

DISCUSSION

FIELD EXPERIMENT

As indicated in Table 4.1, May 2009 was cooler and rainier than average. This undoubtedly slowed cover crop growth and reduced biomass production. Kirkegaard and Sarwar (1998) showed biomass levels determine the amount of glucosinolates (and thus breakdown products like ITCs) present. Decreased biomass means decreased amounts of glucosinolates released in to the environment, and thus potentially decreased impacts on weeds/pathogens/cash crops.

There was no significant Brassica cover crop impact on cucurbit emergence in this field study, except for cucumber emergence on plant date D0. This may be due to a combination of cucumber being more sensitive to cool weather and/or increased sensitivity to chemicals under adverse weather conditions. The overall finding of this field study is in contrast with our previous observations (Chap. 3) and previous research indicates Brassica cover crops and their chemical by-products can impact seed germination. Bialy et al. (1990) found ITCs can inhibit wheat (*Triticum aestivum* Songle) germination, though the effect varies by specific ITC and concentration. Turk and Tawaha (2002, 2003) have demonstrated *Brassica nigra* Moench aqueous extracts can inhibit lentil (*Lens culinaris* Medik.) and wild oat (*Avena fatua* L.) germination. Norsworthy et al. (2006) and Norsworthy and Meehan (2005a and 2005b) have demonstrated ITCs are active

against a wide range of weed seeds. Brown and Morra (1996) found *B. napus* extracts inhibit lettuce (*Lactuca sativa* L.) germination. These and other studies differ from this one in that they were done in the laboratory and/or using pure chemical extracts and/or using smaller types of seeds. Carefully controlled laboratory results do not always translate in to similar field results. A variety of factors including soil structure and composition, weather, and amount of chemicals that actually enter the environment in a given time period may mitigate effects of compounds that otherwise would have an evident impact on germination. Unlike in the laboratory, seeds in the field were not exposed to the entire amount of chemical by-products all at once.

The results from this study are similar to those found by Haramoto and Gallandt (2005a) in a field study, in which cucumber germination was not impacted by a yellow mustard cover crop. The germination of other cash crops in that study, however, was impacted by the Brassica cover crops. Other studies have found Brassica cover crops to impact cash crop germination in the field. *Brassica napus* decreased lettuce (*Lactuca sativa* L.) and spinach (*Spinacia oleracea* L.) germination (Kruidhof et al. 2009). Timing and treatment of the cover crop matter, as well. Kruidhof et al. (2009) found that *B. napus* biomass inhibited lettuce and spinach establishment in the first 2 – 3 weeks when finely macerated, while cut biomass inhibited cash crop establishment after the first 2 – 3 weeks.

The results of this field study differ from those in Ch. 3, where oilseed radish and Oriental mustard in particular inhibited muskmelon seed germination. There are several possibilities as to why the results differ. Hoagland et al. (2008)

found low-glucosinolate *B. napus* seed meal and *Sinapis alba* seed meal amendments increase *Pythium spp.* populations, including those of known-pathogenic *Pythium* species which cause damping-off. They assert that it is a combination of ITCs directly damaging seeds/seedlings and increased *Pythium spp.* populations that causes decreased germination and increased seedling mortality of cash crops and weeds. *Pythium spp.* populations vary by soil type and location (Hoagland et al. 2008). It is possible SWMREC soil is heavily infested with *Pythium spp.* whereas that at HRTC is not. Hoagland et al. (2008) further note *Pythium spp.* do not respond uniformly to treatments, perhaps explaining the inconsistency producers experience when using Brassica cover crops to decrease weed populations and also helping explain why germination at SWMREC was severely inhibited while at HRTC it was not. Differing soil properties are another possible explanation. The soil at SWMREC is sandy, while the soil at HRTC contains more clay. Hoagland et al. (2008) state that clay and organic matter can act as buffers, decreasing amount of cover crop substrate available to *Pythium spp.* and limiting population increases. This same buffering (due to a high cation exchange capacity) could also prevent ITCs from coming in to as much contact with seeds, decreasing any direct effects on germination.

While Brassica cover crops have been shown to impact seed germination and seedling survival, there were no such clear impacts beyond the seedling stage in this study. There were no significant differences in individual vine weights (Figure 4.1) or marketable harvest per vine (Figure 4.3). This concurs with the findings of Haramoto and Gallandt (2005b) that a yellow mustard (*S. alba*) cover

crop neither suppressed nor encouraged green bean growth. While vine weights did decrease over the course of the 30 d planting period, this was most likely due to the increasing severity of downy mildew in the plot. There was a significant difference in total yield per vine: plants in oilseed radish and Oriental mustard treatments produced 230.5 and 198.4 g fruit/vine, which was significantly different than the 142.8 g fruit/vine produced by plants in the control (Figure 4.5). While there was no significant difference in production of Grades 1, 2, and 3 fruit per vine, there was a significant difference in the number of culled fruit per vine (Figure 4.2). Plants in oilseed radish treatment produced 0.54 culled fruit per vine, differing from those in the control which produced 0.36 culled fruit per vine. With 0.45 culled fruit per vine, there was no significant difference between Oriental mustard treatment and the other two treatments. The majority of culled fruit were culls because they were too large, not because they were rotten or badly misshapen.

Cucumbers likely benefited from nutrient cycling and soil improvement capacities of the cover crops; while the values were not statistically significant, Figures 4.1, 4.2, and 4.3 support this assertion. Plants in oilseed radish treatment consistently produced more fresh weight biomass per vine than those in the control (Figure 4.1). Plants in oilseed radish treatment also consistently produced more Grade 1, 2, and 3 fruit per vine than those in the control (Figure 4.2) and also reliably produced more marketable fruit mass per vine than those in the control (Figure 4.3). Finally, over the seven plant dates plants in oilseed radish and Oriental mustard treatments produced more fruit mass per vine than those in the

control (Figure 4.5). The limited yield response of cucumber to the cover crops is typical of most short cycle crops (Ngouajio, personal communication).

LABORATORY EXPERIMENT

Previous research indicates plants in the Brassica family can have an inhibitory effect on seed germination and growth (Brown and Morra 1997; Oleszek 1987; Turk and Tawaha 2002 and 2003). Most of these studies focused on rape (*B. napus*) and black mustard (*B. nigra*). Oleszek (1987) stated the impact of a Brassica species on seed germination and seedling growth would vary depending on both Brassica and crop species. This study allowed us to investigate impact of oilseed radish on seed germination and radicle growth under controlled conditions.

The amount of oilseed radish biomass harvested was not as large as it would have been had the plants been fully mature and beginning to flower (Ngouajio, personal communication). Yield was about 5,866 kg/ha of fresh root tissue and 19,968 kg/ha of fresh shoot tissue. This is important because oilseed radish is usually tilled under after flower initiation but before seed set. For the above reasons, estimated field rates are likely underestimations of what would happen in a normal situation where the cover crop is allowed to grow until the flowering stage. Turk and Tawaha (2002 and 2003) found stronger concentrations of *B. nigra* aqueous extracts were more inhibitory to seed germination and seedling growth. Root tissue estimated field rate (0.2 mL or 6.7% of the non-lyophilized full strength solution) falls between the 5 and 12.5% experimental treatments; at these rates, germination inhibition was observed in cucumber and

honeydew, as was radicle elongation inhibition in muskmelon and cucumber. Shoot tissue estimated field rate (0.7mL or 22.3% of non-lyophilized full solution strength) falls between the 12.5 and 25% treatments; germination inhibition was again observed in honeydew and cucumber at these rates, as was radicle elongation inhibition in cucumber. Therefore, while many of the non-lyophilized extracts treatments were more concentrated than the field rate equivalent, effects were still seen at rates near the field rate equivalent and the stronger concentrations help offset the smaller original biomass harvest (had the harvest been of normal size and at the normal time, the field extract rate would naturally be higher than it was).

The study conditions differ from field conditions in that in the field, organic matter would degrade slowly and water soluble compounds would be released over time. Also, due to soil dynamics, seeds would likely not come into contact with such concentrated volumes of water soluble compounds. Compounds would be mixed in with soil and with other chemicals in the soil, further diluting them and potentially mitigating their impact on seeds. In addition, organic matter and clay in the soil can act as buffers (Hoagland et al. 2008).

The EC of all three substances used in the solutions (root and shoot extract and deionized water) were similar, making it unlikely any effects were due to differences in osmotic potential. The pH of non-lyophilized root and shoot extracts was similar and somewhat acidic (6.0 and 5.8, respectively), as was that of lyophilized root and shoot extracts (6.8 and 5.6, respectively). An experiment was

performed to determine if pH was a potential confounding variable; water was mixed with acetic acid to create a solution with a pH of 5.5. Muskmelon seeds placed in Petri dishes with 3 ml of this solution had similar germination rates and root lengths when compared to those in the control (deionized water) (Table 4.11). In the acetic acid solution, 97.5% of seeds germinated while 100.0% of those in the control germinated; average root length in the acetic acid solution treatment was 35.7 mm (with a standard deviation of 8.7), while in the control it was 36.3 mm (with a standard deviation of 9.9). Given the above information it is likely that the observed results were caused by the treatments and not by differences in extract pH or EC.

In this study both root and shoot non-lyophilized aqueous extracts consistently inhibited germination of all three crops. This finding is in line with the work of Brown and Morra (1996), which determined *B. napus* aqueous extracts inhibit lettuce seed germination. It also coincides with the work of Turk and Tawaha, who discovered *B. nigra* aqueous extracts inhibit germination of lentils (2002) and wild oats (2003). Effects were far more pronounced with non-lyophilized extracts than with lyophilized extracts.

Non-lyophilized root aqueous extract appears to be more inhibitory to germination than shoot aqueous extract whereas lyophilized shoot extract was more consistently inhibitory than the root extract. The observation that non-lyophilized root extracts are more potent than shoot extracts is in contrast with the findings of Brown and Morra (1996) that water soluble compounds from *B.*

napus leaves and stems inhibited lettuce seed germination, whereas those from roots merely delayed germination. It is also in contrast with the work of Turk and Tawaha (2002, 2003), which determined that *B. nigra* leaf extracts tended to be more toxic than those from other plant parts including roots and stems. However, Brown and Morra (1996) determined volatile compounds from *B. napus* roots inhibited lettuce seed germination more than those from stems and leaves. Brassica species vary in their chemical profiles (Kirkegaard and Sarwar 1998) and these chemicals vary in their potency, depending on the crop involved (Brown and Morra 1996).

Non-lyophilized root and shoot aqueous extracts likewise proved inhibitory to radicle elongation. With the exception of the impact of root extract on honeydew, as extract strength increased so did level of inhibition. Honeydew roots were stimulated at 5 and 12.5% extract concentrations. Some previous work has found low rates of Brassica residue stimulate growth (Mason-Sedun and Jessop 1986), perhaps explaining this observation. Oleszek (1987) stated the impact of Brassica cover crops varies depending on the cover crop and the cash crop, perhaps explaining why honeydew growth was stimulated while muskmelon and cucumber growth was inhibited.

As with germination rates, crop root elongation was less sensitive to lyophilized extracts than non-lyophilized extracts. When a significant effect was present, in general, as concentration increased radical length decreased. Differences in potency between lyophilized and non-lyophilized extracts probably

were due to varying levels of volatile versus water soluble compounds. While it is likely that both types of compounds have inhibitory effects, volatile compounds (specifically ITCs) are generally believed to be the major force behind biological activity such as germination inhibition and pathogen disruption. Lyophilized extracts likely contained less of these highly active compounds, and thus were generally less potent.

Even at low concentrations, most of the crops were sensitive to non-lyophilized oilseed radish extracts. Crops were overall far less sensitive to lyophilized extracts, typically beginning to show inhibition at the 2 to 4 g/L concentrations. Cucumber and muskmelon root growth was inhibited at non-lyophilized 5% root extract concentration. This observation coincides with Turk and Tawaha (2002, 2003), who determined roots are particularly sensitive to Brassica aqueous extracts. As with germination rates, radicle sensitivity varied by crop, though differences were less pronounced. Muskmelon was more sensitive to non-lyophilized shoot extract than honeydew and cucumber, while cucumber was less sensitive to that extract than honeydew. Cucumber and honeydew were equally sensitive to non-lyophilized root extract.

CONCLUSIONS

Our field study demonstrates that at these levels of biomass production, oilseed radish and Oriental mustard have limited inhibitory impact on cucurbit germination under our specific field conditions. Differences between the results in

this study and those in Chapter 3 may be due to differing soil physical and microbial properties.

The laboratory study demonstrates Brassica non-lyophilized aqueous extracts can impact cucurbit germination and growth and confirms that oilseed radish contains allelopathic chemicals. Inhibition was demonstrated even at concentrations near the fairly low estimated field rate for non-lyophilized extracts. Root and shoot extracts have varying degrees of toxicity, with non-lyophilized root extract being generally more inhibitory of both germination and radicle elongation. Further, the degree of inhibition varies by cucurbit crop. Muskmelon germination and root growth were both less impacted by extracts than that of honeydew and cucumber.

Lyophilized extracts were less potent than non-lyophilized ones. This suggests the primary compounds involved in germination and growth inhibition could be volatile in nature. More work should be done to identify these compounds.

Laboratory work often provides more consistent results than field work. Discoveries in the laboratory, however, do not always have relevance in the field due to the multitude of variables that can interfere with seemingly simple interactions. Further work needs to be done in the greenhouse/field to determine at what biomass levels Brassica cover crops might begin to impact germination and growth and if this impact is practically significant. More work also needs to be done to determine how much interaction occurs between soil physical properties (such as clay content), soil microbial communities (such as the presence of

Pythium spp.), and Brassica cover crops in the field. Finally, other commonly recommended Brassica cover crops such as yellow mustard should be tested in the laboratory to determine if they are likewise capable of inhibiting germination and growth.

Table 4.1. Mean monthly and long term (8 year) average temperatures and precipitation during cover crop and cucurbit growth in 2009 at HRTC Michigan.*, **

	Monthly average temperature (°C)				Monthly rainfall (mm)	
	2009		8 yr average		2009	8 yr
Month	Low	High	Low	High		average
May	7.9	20.5	7.4	19.9	109	106
June	13.4	24.8	13.4	25.8	126	81
July	13.4	24.9	15.1	27.8	61	70
August	14.9	25.5	14.7	27.0	105	59
September	10.7	23.5	10.5	23.5	24	77
Ave./Total	12.1	23.8	12.2	24.8	425	393

* Cover crops were sown on May 8, 2009. Cucurbits were planted during the period between June 24, 2009 and July 24, 2009.

**Raw data are from the Michigan Automated Weather Network (MAWN).

Table 4.2. Monthly and long term (8 year) average growing degree days (GDD) during cover crop and cucurbit growth in 2009 at HTRC Michigan*. Base temperature = 10°C.**

	Monthly GDD	
Month	**2009**	**8 yr average**
May	163.8	144.6
June	279.0	288.9
July	290.2	359.5
August	314.0	335.7
September	216.6	213.2
Total	1263.6	1341.8

* Cover crops were sown on May 8, 2009. Cucurbits were planted during the period between June 24, 2009 and July 24, 2009.

**Raw data are from the Michigan Automated Weather Network (MAWN).

Table 4.3. Cover crop biomass production (dry weight) for field experiments conducted in 2009 at the Horticulture Teaching and Research Center (HRTC), East Lansing, MI.*

Crop	Ave no. of plants/m2	Dry weight (g/m2)	Estimated kg/ ha
Oilseed radish	68.0 (11.6)	476.8 (82.4)	4,677
Oriental mustard	165.2 (36.8)	525.2 (77.2)	5,250

*Two samples were collected in each treatment using a 0.25 m2 quadrat and final data was converted to 1 m^2. Values in parentheses are standard deviations.

Table 4.4. Emergence percentages of three cucurbit crops planted after oilseed radish, Oriental mustard, or no cover crop. Each percentage is generally the average of four replications, each planted with 24 seeds of each crop. OSR= Oilseed radish, OM=Oriental mustard, CK=control. There was no plant date by cover crop significance at the P=0.05 level with the exception of D0 cucumber.*

Cucurbit	Treat-ment	Day planted (days after cover crop incorporation)						
		0	5	10	15	20	25	30
MM	**CK**	87.5	62.5	70.5	81.3	85.4	96.9	99.8
	OM	77.1	54.2	80.2	82.3	85.4	89.6	96.9
	OSR	94.8	41.7	76.1	87.5	85.4	96.9	99.0
	$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS
HD	**CK**	80.2	64.6	76.0	82.3	76.0	91.7	92.7
	OM	63.5	69.4	82.3	73.0	74.0	90.6	85.4
	OSR	68.8	55.2	76.0	82.3	83.3	90.6	92.7
	$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS
Cuke	**CK**	72.9 a	74.0	87.5	86.1	83.3	89.6	99.0
	OM	73.6 a	74.0	69.8	81.3	80.2	90.6	86.5
	OSR	45.8 b	70.8	81.3	90.6	74.0	91.7	86.5
	$LSD_{0.05}$	18.7	NS	NS	NS	NS	NS	NS

* Within each cucurbit crop and column, means were separated using the LSD at the 5% level of significance. NS is not significant.

Table 4.5. Emergence percentages of three cucurbit crops planted after oilseed radish, Oriental mustard, or no cover crop. Each percentage is the average of seven planting dates, each consisting of four replications wherein each replication was planted with 24 seeds of each crop. OSR= Oilseed radish, OM=Oriental mustard, CK=control.

Cucurbit	Treatment	Average % emergence	$LSD_{0.05}$
Cucumber	**CK**	84.6 a*	
	OM	79.4 ab	
	OSR	77.2 b	5.7
Muskmelon	**CK**	82.8	
	OM	80.8	
	OSR	83.0	NS
Honeydew	**CK**	80.5	
	OM	77.0	
	OSR	78.4	NS

* Means within column and crop followed by the same letter do no differ significantly at the P=0.05 level. NS is not significant.

Table 4.6. Number of remaining vines left at harvest (out of 12) of cucumber planted after oilseed radish, Oriental mustard, or no cover crop. Each value is the average of four replications. OSR= oilseed radish, OM=Oriental mustard, CK=control.

Treatment	Day planted (days after cover crop						
	0	5	10	15	20	25	30
CK	7.3*	9.5	11.0	9.3	11.3	10.8	11.5
OM	7.0	10.0	10.8	9.8	9.5	11.8	10.5
OSR	7.0	10.3	10.5	11.0	9.8	11.5	11.8
LSD	NS	NS	NS	NS	NS	NS	NS

*Within each column (planting date) NS indicates no significant difference at the *p*-level of 0.05 for differences among cover crop treatments.

Table 4.7. Oilseed radish harvest and non-lyophilized aqueous extract data and corresponding field equivalent rates. The ratio of DI water to biomass was 1:1 (L:kg).

Extract source	Area harvested	Total fresh biomass	Fresh weight kg/ha	Total DI water	Extract amount*		Extract field rates**
					Cheesecloth	Filter paper	
	m^2	kg	kg	L	L	L	ml/Petri dish
Roots	7.5	4.4	5,866.7	4.4	5.9	3.4	0.2
Shoots	6.4	12.8	19,968.8	12.8	13.9	10.1	0.7

* Amount obtained after filtration through a cheesecloth or filter paper.

** Field equivalent rate represents the maximum concentration assuming the cover crop is incorporated 15 cm deep and that all allelochemicals are released at the same time.

Table 4.8. Oilseed radish harvest and lyophilized extract data and corresponding field equivalent rates.

Extract source	Area harvested	Total fresh biomass	Extract dry weight	Ratios		Extract field rates*
				Extract/area harvested	Extract/ fresh biomass	
	m^2	kg	g	g/m^2	g/kg	g/L
Roots	3.9	2.3	110.0	28.1	48.0	4.0
Shoots	2.9	5.8	181.0	62.4	31.3	8.9

*Estimated extract field equivalent rate calculation (Eq. [1]) **

** Field equivalent rate represents the maximum concentration assuming the cover crop is incorporated 15 cm deep and that all allelochemicals are released at the same time

Table 4.9. Oilseed radish non-lyophilized and lyophilized aqueous extract treatments. Root and shoot concentrations were the same.*

Non-lyophilized extract concentration %	Amount of non-lyophilized extract per Petri dish (ml)	Lyophilized extract concentrations (g/L)
0.0	0.000	0.00
5.0	0.150	0.25
12.5	0.375	0.50
25.0	0.750	1.00
50.0	1.500	2.00
100.0	3.000	4.00
-	-	8.00

*Each Petri dish received a total of 3 ml of solution.

Table 4.10. Properties of oilseed radish non-lyophilized and lyophilized root and shoot aqueous extracts and deionized water. Values in parentheses are the standard deviations; values are the average of 8 readings. Values are for the full strength concentration (100% and 8 g/L) of extracts.

Property	Extract	Average	
		Non-lyophilized extract	Lyophilized extract
pH	Root	6.0 (0.0)	6.8 (0.0)
	Shoot	5.8 (0.0)	5.6 (0.0)
	Deionized water	8.2 (0.1)	7.8 (0.1)
	Vinegar solution	-	5.5 (0.0)
EC (mv)	Root	30.0 (0.5)	28.0 (0.0)
	Shoot	25.4 (0.7)	25.1 (0.6)
	Deionized water	28.1 (0.6)	28.6 (0.5)
	Vinegar Solution	-	117.0 (0.5)

Table 4.11. Effect of an acetic acid solution on muskmelon seed germination and root length. Numbers in parentheses are standard deviations.

Treatment	pH	Average % germination*	Average root length (mm)
Acetic acid solution	5.5 (0.0)	97.5 (5.0)	35.7 (8.7)
Deionized water	7.8 (0.1)	100.0 (0.0)	36.3 (9.9)

*Each value is the average of four replications consisting of ten seeds each.

Table 4.12. Germination rates of cucurbits exposed to seven concentrations of oilseed radish lyophilized shoot aqueous extract. Each value is the average of three experimental runs, each consisting of three replications of ten seeds each.

	Germination %		
Treatment (g/L)	**Muskmelon**	**Honeydew**	**Cucumber**
0.00	98.9	80.0 a*	82.2 a
0.25	97.8	58.9 bc	88.9 a
0.50	98.9	66.7 ab	88.9 a
1.00	97.8	50.0 c	80.0 a
2.00	98.9	48.9 c	75.6 a
4.00	97.8	53.3 bc	61.1 b
8.00	97.8	20.0 d	42.2 c
$LSD_{0.05}$	NS	14.4	14.0

* Means within a column followed by the same letter do no differ significantly at the P=0.05 level. NS is not significant.

Table 4.13. Germination rates of cucurbits exposed to seven concentrations of oilseed radish lyophilized root aqueous extract. Each value is the average of three experimental runs, each consisting of three replications of ten seeds each. Data could not be combined due to trial by treatment interaction.

	Germination %								
	Muskmelon			Honeydew			Cucumber		
Treatment (g/L)	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
0.00	96.7	100.0	86.7	73.3 a	60.0	90.0 a	90.0	76.7 a	86.7 a
0.25	100.0	100.0	100.0	70.0 ab	53.3	66.7 ab	80.0	90.0 a	93.3 a
0.50	96.7	100.0	93.3	66.7 ab	53.3	63.3 ab	93.3	83.3 a	93.3 a
1.00	100.0	96.7	100.0	46.7 bc	70.0	70.0 ab	73.3	70.0 ab	90.0 a
2.00	100.0	100.0	100.0	56.7 abc	70.0	53.3 bc	66.7	76.7 a	90.0 a
4.00	96.7	100.0	100.0	13.3 d	36.7	53.3 bc	60.0	73.3 a	66.7 b
8.00	96.7	100.0	96.7	33.3 dc	36.7	26.7 c	66.7	50.0 b	40.0 c
$LSD_{0.05}$	NS	NS	NS	26.5	NS	27.8	NS	21.3	19.1

* Means within a column followed by the same letter do no differ significantly at the P=0.05 level. NS is not significant.

Table 4.14. Radicle lengths (mm) of cucurbits exposed to seven concentrations of oilseed radish lyophilized shoot aqueous extract. Each value is the average of three experimental runs, each consisting of three replications of ten seeds each. Averages were calculated using the number of seeds germinated, not the number of seeds tested.

	Root length (mm)		
Treatment (g/L)	**Muskmelon**	**Honeydew**	**Cucumber**
0.00	42.6	27.0	24.2
0.25	60.8	30.4	28.5
0.50	30.2	27.2	26.0
1.00	28.1	29.8	24.9
2.00	28.8	26.2	24.0
4.00	26.3	29.3	23.1
8.00	19.9	21.2	18.6
$LSD_{0.05}$	NS	NS	NS

* Means within a column followed by the same letter do no differ significantly at the P=0.05 level. NS is not significant.

Table 4.15. Radicle lengths (mm) of cucurbits exposed to seven concentrations of oilseed radish lyophilized root aqueous extract. Each value is the average of three experimental runs, each consisting of three replications of ten seeds each. Averages were calculated using the number of seeds germinated, not the number of seeds tested. Data could not be combined due to trial by treatment interaction.

	Root length (mm)								
	Muskmelon			Honeydew			Cucumber		
Treatment (g/L)	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
0.00	43.4 a	37.2 a	37.3 a	28.1	20.1 bc	29.3 a	23.6	23.1 ab	22.4 bc
0.25	29.3 b	3 0.1 b	30.3 b	26.9	26.1 ab	26.4 ab	28.8	25.7 a	28.2 a
0.50	29.8 b	29.2 b	29.0 bc	26.1	27.1 ab	25.5 ab	28.1	25.5 a	26.5 ab
1.00	29.1 b	22.9 c	25.8 cd	30.9	26.6 ab	22.0 bc	32.1	23.6 a	22.9 bc
2.00	23.5 c	25.4 c	23.1d	24.0	27.5 ab	28.0 a	21.0	25.7 a	18 .4 c
4.00	18.3 d	19.2 d	18.1 e	23.6	30.6 a	22.9 abc	20.0	16.3 bc	18.0 c
8.00	11.4 e	9.2 e	8.1 f	16.4	15.4 c	18.0 c	14.2	9.8 c	11.5 d
$LSD_{0.05}$	4.9	3.5	3.9	NS	8.6	6.5	NS	7.0	4.9

*Means within a column followed by the same letter do no differ significantly at the P=0.05 level. NS is not significant.

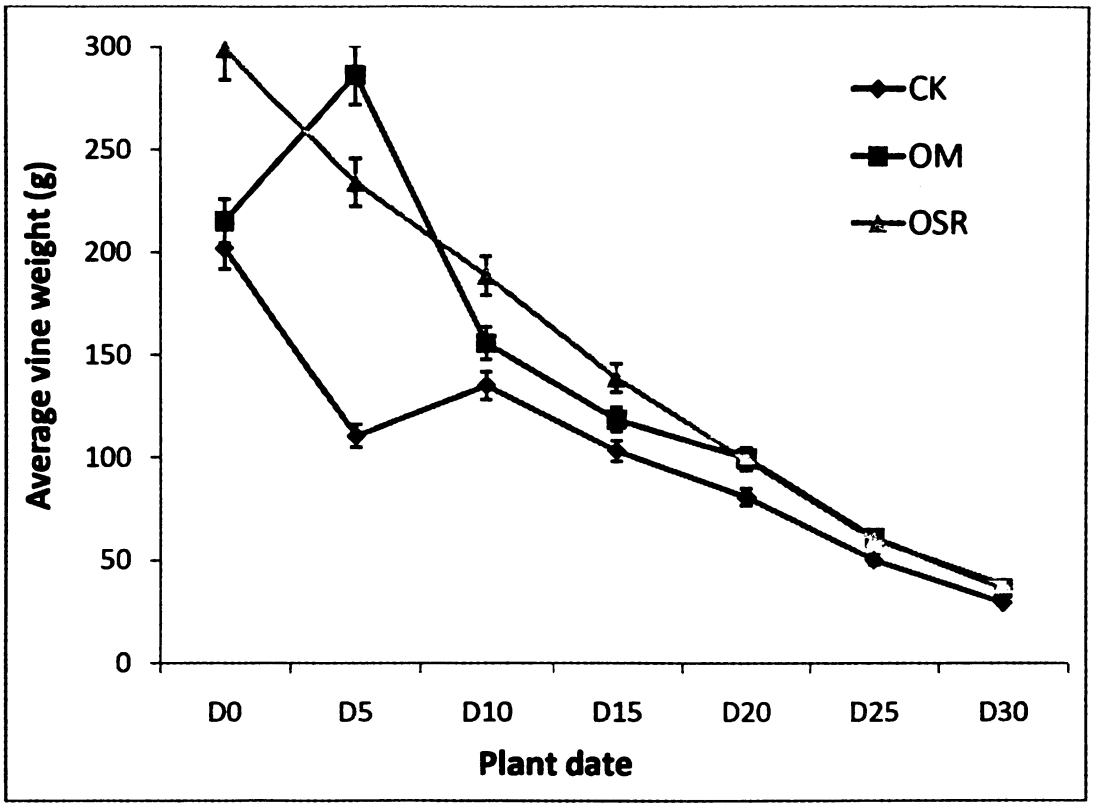

Figure 4.1. Individual fresh vine weights (g) at harvest of cucumber planted after oilseed radish, Oriental mustard, or no cover crop. Each value is the average of four replications. OSR= oilseed radish, OM=Oriental mustard, CK=control. NS (not significant) at the *p*-level of 0.05 for differences among cover crop treatments.

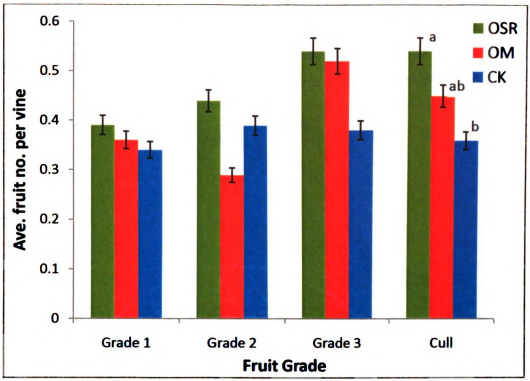

Figure 4.2. Average cucumber fruit produced per plant from seeds planted after oilseed radish, Oriental mustard, or no cover crop. Values are the averages of all seven planting dates. OSR= Oilseed radish, OM=Oriental mustard, CK=control. NS at the P=0.05 level for differences between cover crop treatments with the exception of the cull fruit. Different letters indicate significant difference; Means followed by the same letter do not differ significantly at the P=0.05 level. NS is not significant; $LSD_{0.05}$ = 0.15.

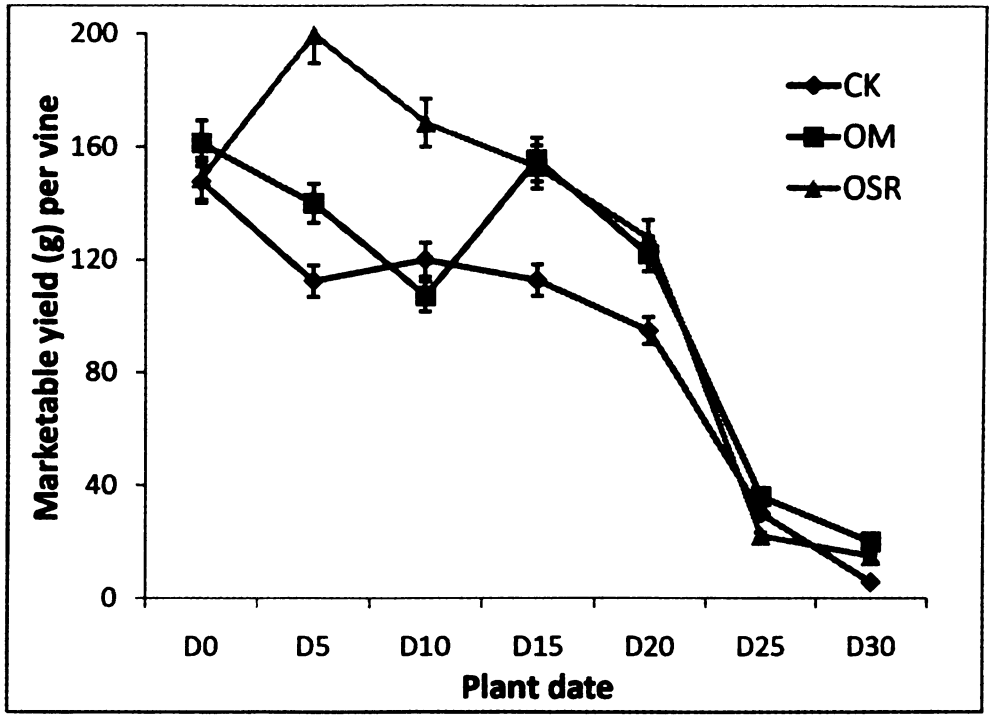

Figure 4.3. Cucumber marketable yield (g) per plant from plants planted after oilseed radish, Oriental mustard, or no cover crop. OSR= Oilseed radish, OM=Oriental mustard, CK=control. NS (not significant) at the *P*=0.05 level for differences between cover crop treatments.

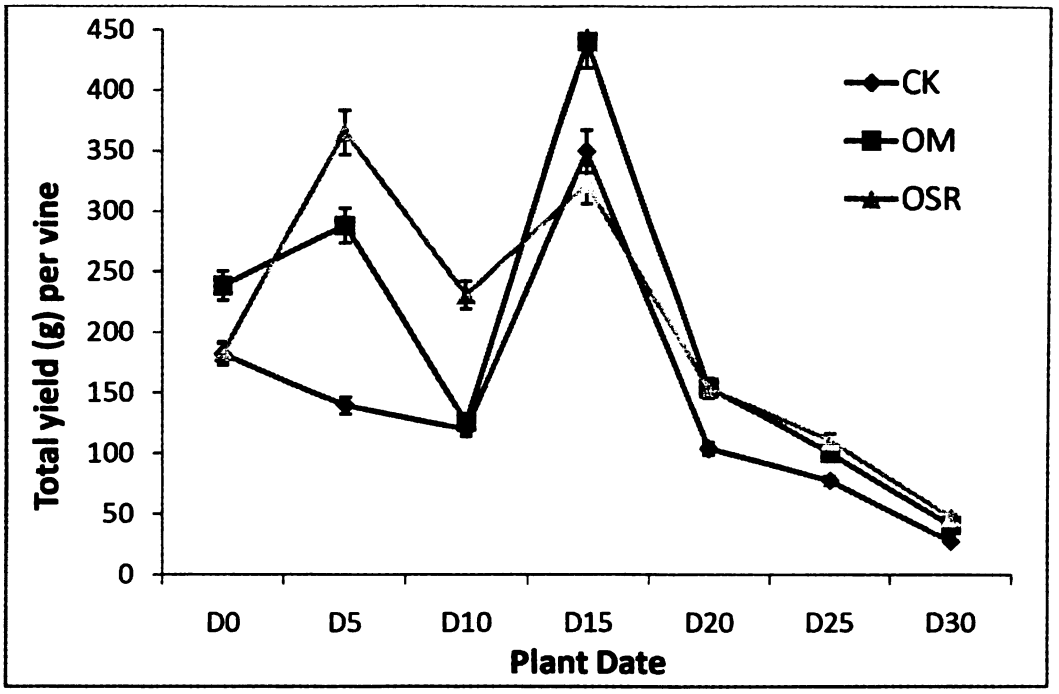

Figure 4.4. Cucumber total yield (g) per plant from plants planted after oilseed radish, Oriental mustard, or no cover crop. OSR= Oilseed radish, OM=Oriental mustard, CK=control. NS (not significant) at the *P*=0.05 level for differences between cover crop treatments.

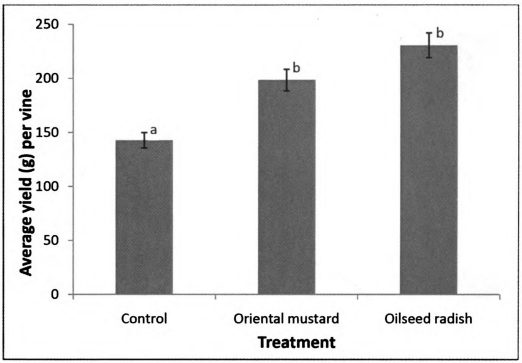

Figure 4.5. Yield (g) per cucumber vine in each treatment averaged over the seven plant dates. Bars with different letters are significantly different at the P=0.05 level. LSD = 43.35. Standard error bars are 5% of each value.

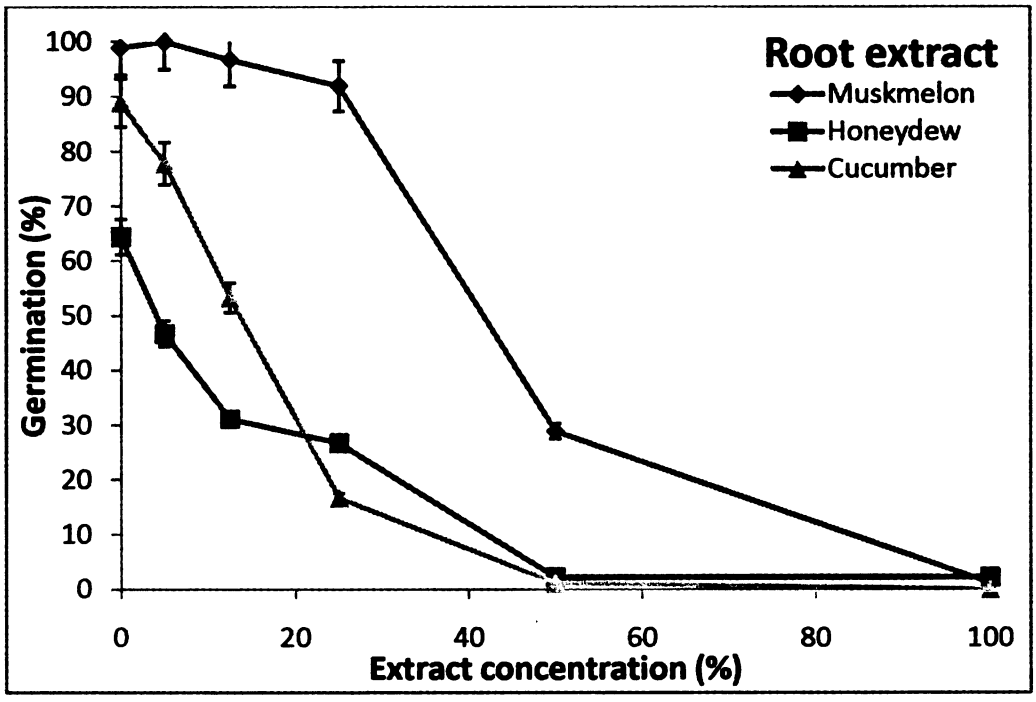

Figure 4.6. Germination percentages of three cucurbit crops exposed to six extract concentrations of non-lyophilized oilseed radish root aqueous extract. Each percentage is the average of three experimental runs, each consisting of three replications of ten seeds each.

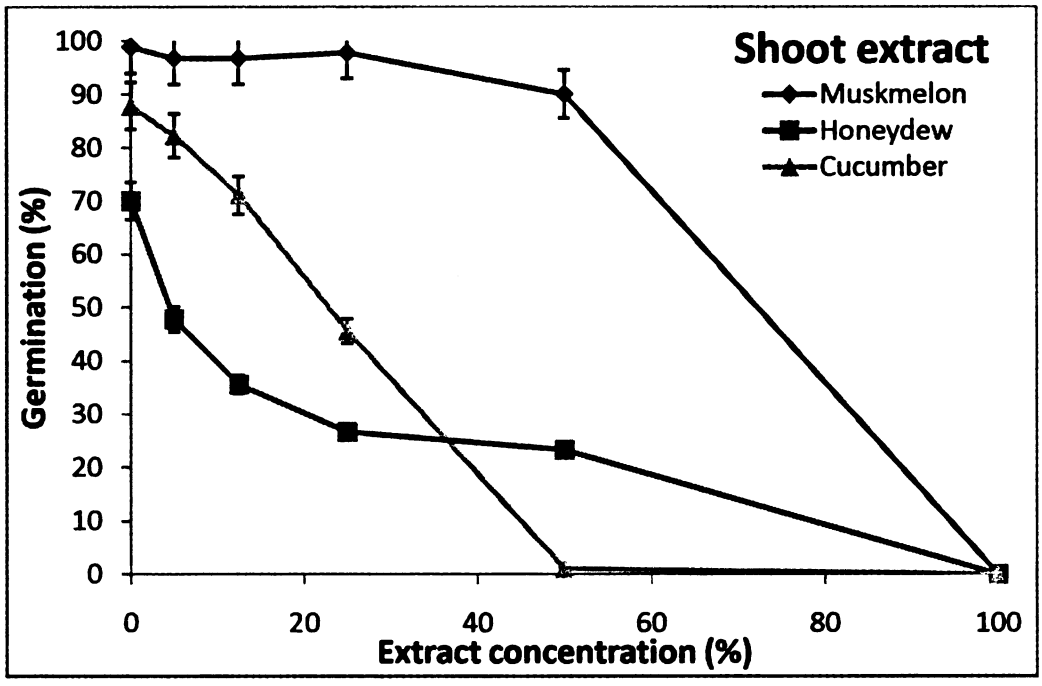

Figure 4.7. Germination percentages of three cucurbit crops exposed to six extract concentrations of oilseed radish non-lyophilized shoot aqueous extract. Each percentage is the average of three experimental runs, each consisting of three replications of ten seeds each.

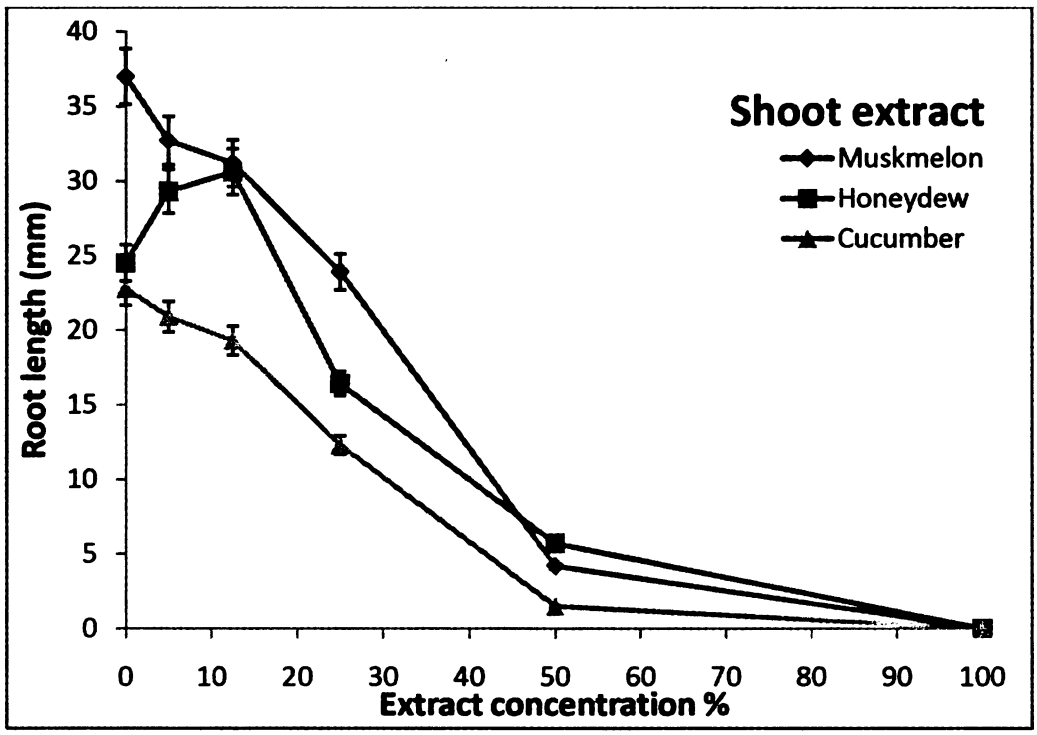

Figure 4.8. Radicle lengths (mm) of cucurbits exposed to six concentrations of oilseed radish non-lyophilized shoot aqueous extract. Each value is the average of three experimental runs, each consisting of three replications of ten seeds each. Averages were calculated using the number of seeds germinated, not the number of seeds tested.

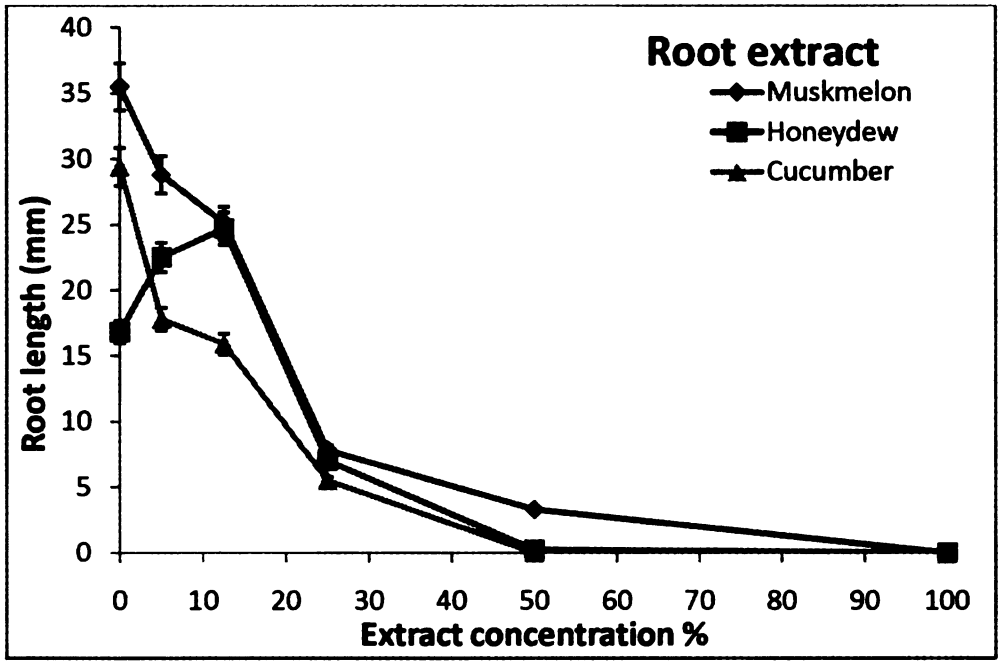

Figure 4.9. Radicle lengths (mm) of cucurbits exposed to six concentrations of oilseed radish non-lyophilized root aqueous extract. Each value is the average of three experimental runs, each consisting of three replications of ten seeds each. Averages were calculated using the number of seeds germinated, not the number of seeds tested.

CHAPTER 5: Conclusions and Further Work

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These studies overall do not support the use of oilseed radish, yellow mustard, or Oriental mustard as spring cover crops in an eggplant/muskmelon short rotation if the cash crops are to be planted within two weeks of cover crop incorporation. Furthermore, these cover crops should be used cautiously, especially in the case of direct-seeded melons. The SWMREC field experiment demonstrated these cover crops can inhibit muskmelon emergence. Although inhibition was less of a problem for the re-seeded melons, the growing season in Michigan is generally short and may not allow re-seeded plants to produce an acceptable yield. Laboratory studies also showed oilseed radish to inhibit muskmelon, honeydew, and pickling cucumber germination and radicle growth. That cucumber germination was not inhibited by oilseed radish and Oriental mustard in the HRTC field experiment suggests impact will vary by location/soil type/microbial populations.

Laboratory experiments suggest impact of oilseed radish on cucurbit germination is due at least partly to allelopathy, and the responsible compounds are likely volatile in nature. Cucurbit germination and radicle elongation were increasingly inhibited as non-lyophilized extract concentration increased. The one exception was honeydew, whose growth was stimulated at low extract concentrations. Inhibition was far less severe when lyophilized extracts were involved. Non-lyophilized aqueous root extracts proved to be more inhibitory to both germination and radicle growth than non-lyophilized shoot extracts, while the opposite was true of lyophilized extracts. Species varied in their sensitivity, as

well: muskmelon was less inhibited than honeydew or cucumber with both types of extracts.

Furthermore, the SWMREC field experiment provides some evidence that these Brassica cover crops may be deleterious to eggplant growth. During the first year of the experiment, plants in cover crop treatments (especially yellow mustard treatment) were shorter on several consecutive data collection dates than those in other treatments, including the fallow control. Eggplants in cover crop treatments produced less fresh above ground biomass than those in other treatments during the first year of the study. Differences were less pronounced/not significant during the second year of the study, perhaps due to decreased cover crop dry biomass production.

The SWMREC study suggests while the Brassica cover crops may have some impact on verticillium wilt incidence, it is not significant in a practical sense and it is not reflected in the yields. Given negative impact on cash crop growth, the costs are not worth the benefits under this production system.

One positive aspect of the use of these Brassica cover crops is the indication in the SWMREC study that they do scavenge N, which is later released in to the soil during decomposition. Oilseed radish and Oriental mustard treatment plots showed significantly higher levels of nitrate during the growing season (June and/or July) than those in other treatments. This finding suggests that Brassica cover crops still have a place in sustainable production systems, just not as spring cover crops immediately before a cash crop.

These studies create more questions than they answer. Possible laboratory and greenhouse research questions might include: do Oriental mustard and yellow mustard also inhibit cucurbit germination; what impact do these cover crops have on soil microbial populations; is the effect on cucurbit germination due to allelopathy, microbial biological interactions, or a combination; what is the nature of the potentially allelopathic chemicals (water soluble, volatile, or both); and what is a safe plant-back period when growing Brassica cover crops? Field research questions might include: do these Brassica cover crops impact germination of other direct-seeded cash crops in Michigan when planted as spring cover crops; how does soil type affect the impact of these cover crops on cash crops; and do higher/lower amounts of Brassica cover crop biomass production have differing impacts on cash crop health, growth, and yield?

Table A1. Number of cucumber, muskmelon, and honeydew vines left 30 d after planting and dry vine weight (g). The maximum number of possible vines left for muskmelon and honeydew was 24; for cucumber it was 12. A weight of 0 means the vine mass was too small for the scale to detect.

			Cucumber		Muskmelon		Honeydew	
Treatment	Plant date	Replication	Vine #	Weight (g)	Vine #	Weight (g)	Vine #	Weight (g)
CK	0	1	7	1.7	22	33.2	18	27.7
OSR	0	1	6	1.8	21	46.0	16	43.0
OM	0	1	1	0.0	17	19.0	13	29.0
CK	0	2	3	6.1	17	43.5	15	57.0
OSR	0	2	1	2.1	22	74.3	14	48.5
OM	0	2	5	11.0	15	50.0	10	38.0
OSR	0	3	7	14.0	22	80.0	16	59.8
OM	0	3	6	9.5	22	57.0	18	60.5
CK	0	3	6	5.0	18	44.1	21	54.5
OSR	0	4	2	3.0	15	32.0	9	23.0
OM	0	4	3	6.8	22	55.0	9	32.5
CK	0	4	4	7.5	15	31.5	16	46.5
CK	5	1	10	6.5	-	-	12	22.6
OSR	5	1	12	11.5	15	34.0	12	25.0
OM	5	1	-	-	18	33.5	-	-
CK	5	2	9	16.5	2	7.5	8	27.0
OSR	5	2	7	16.6	11	29.0	14	43.6
OM	5	2	6	8.0	10	40.2	16	56.7
OSR	5	3	9	12.7	6	16.5	13	32.0
OM	5	3	2	0.0	10	22.5	15	30.5
CK	5	3	2	0.0	2	1.0	14	5.9
OSR	5	4	5	8.1	4	18.6	7	29.4

Appendix A. cont.

Appendix A. cont.

			Cucumber		Muskmelon		Honeydew	
Treatment	Plant date	Replication	Vine #	Weight (g)	Vine #	Weight (g)	Vine #	Weight (g)
OM	5	4	9	15.0	2	6.0	2	1.5
CK	5	4	9	13.3	2	6.0	5	8.7
CK	10	1	8	13.0	11	25.5	15	61.0
OSR	10	1	8	11.5	17	68.0	21	94.5
OM	10	1	8	6.0	16	61.5	18	89.0
CK	10	2	11	30.5	14	70.0	16	83.0
OSR	10	2	10	47.5	17	90.5	21	130.0
OM	10	2	9	44.0	19	104.0	20	120.0
OSR	10	3	9	19.0	18	65.0	12	61.5
OM	10	3	10	8.5	18	53.0	21	59.5
CK	10	3	8	2.5	14	26.0	13	11.5
OSR	10	4	10	31.5	12	44.5	14	81.5
OM	10	4	7	36.0	20	80.5	15	69.0
CK	10	4	10	40.0	20	54.5	16	75.5
CK	15	1	8	4.5	-	-	15	54.4
OSR	15	1	10	22.5	13	49.9	20	72.5
OM	15	1	7	18.5	-	-	15	92.4
CK	15	2	11	42.5	-	-	21	94.4
OSR	15	2	-	-	-	-	17	77.2
OM	15	2	10	49.0	18	96.0	-	-
OSR	15	3	13	45.4	-	-	19	110.3
OM	15	3	-	-	18	92.5	19	100.5
CK	15	3	6	15.5	17	74.1	-	-
OSR	15	4	-	-	21	88.3	15	67.5

Appendix A. cont.

Treatment	Plant date	Replication	Cucumber		Muskmelon		Honeydew	
			Vine #	Weight (g)	Vine #	Weight (g)	Vine #	Weight (g)
OM	15	4	-	-	16	79.0	-	-
CK	15	4	-	-	15	61.1	15	63.5
CK	20	1	-	-	19	80.2	19	82.0
OSR	20	1	10	13.0	16	86.2	17	96.2
OM	20	1	-	-	-	-	6	29.4
CK	20	2	8	20.5	24	92.0	-	-
OSR	20	2	9	28.5	20	70.1	19	65.0
OM	20	2	-	-	-	-	-	-
OSR	20	3	11	45.0	-	-	23	138.4
OM	20	3	9	44.1	21	94.5	21	131.6
CK	20	3	9	30.3	-	-	23	117.0
OSR	20	4	4	6.0	-	-	12	47.8
OM	20	4	9	34.0	20	76.6	18	73.0
CK	20	4	8	33.1	20	64.0	-	-
CK	25	1	10	20.4	22	76.2	22	91.0
OSR	25	1	10	41.6	22	122.1	21	124.2
OM	25	1	12	55.2	24	134.4	22	128.6
CK	25	2	7	3.1	22	101.8	21	92.4
OSR	25	2	7	18.4	23	84.7	15	34.5
OM	25	2	7	13.3	16	50.8	19	66.7
OSR	25	3	10	53.2	24	147.2	22	165.1
OM	25	3	10	36.9	20	96.6	21	172.7
CK	25	3	10	33	24	126.5	19	121.1
OSR	25	4	8	26.5	21	94.0	17	110.3
OM	25	4	11	49.1	23	120.6	23	127.6

Appendix A. cont.

			Cucumber		Muskmelon		Honeydew	
Treatment	Plant date	Replication	Vine #	Weight (g)	Vine #	Weight (g)	Vine #	Weight (g)
CK	25	4	8	27.6	19	74.8	21	97.8
CK	30	1	12	29.9	23	82.6	22	112.0
OSR	30	1	10	45.5	24	124.4	21	129.1
OM	30	1	9	47.7	13	89.2	8	56.0
CK	30	2	10	27.0	24	84.8	20	70.5
OSR	30	2	8	16.8	24	68.6	21	66.5
OM	30	2	12	21.8	23	54.3	21	56.7
OSR	30	3	10	26.6	22	107.3	24	125.1
OM	30	3	6	19.5	23	117.3	21	133.6
CK	30	3	12	14.6	21	76.8	12	47.3
OSR	30	4	11	32.7	23	101.7	22	113.2
OM	30	4	9	37.2	23	98.5	19	101.0
CK	30	4	10	18.0	24	66.7	23	71.4

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