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# Perimeter Cropping As a Means of Reducing Insect Injury and Increasing Crop Yield

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# PERIMETER CROPPING AS A MEANS OF REDUCING INSECT INJURY AND INCREASING CROP YIELD

BY

BRETT L. OWENS

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# PERIMETER CROPPING AS A MEANS OF REDUCING INSECT INJURY AND INCREASING CROP YIELD

This thesis is approved as creditable and independent investigation by a candidate for the Master of Science degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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I wish to dedicate this thesis to all future learners who continue to seek ways to better our earth through horticulture. No idea is ever too small and no challenge is ever too large.

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# ABSTRACT

## PERIMETER CROPPING AS A MEANS OF REDUCING INSECT INJURY AND INCREASING CROP YIELD

BRETT L. OWENS

2017

The squash vine borer, *Melittia cucurbitae* Harris, (Lepidoptera: Sesiidae) is a destructive insect known to injure a broad range of cucurbit crops. Many studies have focused on insecticide management of this insect in squash (*Cucurbita*) and pumpkin (*Cucurbita pepo* Linnaeus) production; however, little work has been documented on organic approaches to reduce or eliminate injury from this pest to these crops in the Midwest. This study used trap cropping and pollinator mixtures to test whether a reduction of squash vine borer could be achieved in a specific cultivar of pumpkins, *Cucurbita pepo* 'Howden'.

The study was conducted during the 2015 growing season and compared plantings of 'Howden' pumpkins with three treatment perimeters. The first perimeter consisted of a wildflower pollination mixture with a common winter squash, *Cucurbita maxima* 'Hubbard' Gregory, known to attract squash vine borer, as the trap crop. The second perimeter contained only the wildflower pollination mixture while the third perimeter for this experiment consisted of bare soil. The presence of squash vine borer injury within the cash crops of 'Howden' pumpkins was reduced when surrounded by a

perimeter crop consisting of a wildflower pollination mixture and a trap crop of ‘Hubbard’ squash.

The pollination/trap treatment provided value in addition to its potential to attract the squash vine borer. The flowers of the wildflower pollination mixture attracted many beneficial insects that helped optimize the pollination process of the cash crop of ‘Howden’ pumpkins.

# CHAPTER 1. INTRODUCTION

## Commercial Cucurbit Production

Commercial cucurbit crop production in the United States generates nearly 150 million metric tons of produce with an estimated value of nearly $2 billion annually (USDA 2013). The most common cucurbit crops in the United States are fresh cucumber, *Cucumis sativus* Linnaeus, cucumbers used in processing, cantaloupe, *Cucumis melo* L., honeydew melon, *Cucumis melo* var. indorus Jacq., pumpkin, *Cucurbita pepo* L., squash, *Cucurbita*) (all varieties are combined) and watermelon, *Citrullus lanatus* Thunberg (Cantliffe et al. 2007).

Of these crops, there has been a steady increase in pumpkin production that can be attributed to its uses for holiday decorations and also health benefits associated with its rich assortment of vital antioxidants and vitamins (USDA National Nutrient Database 2015). The value of this crop continues to increase in the United States (USDA 2013). From 2010-2012, major pumpkin production areas (i.e., Illinois, California, Ohio, Pennsylvania, New York and Michigan) observed increases in production area (19,020 to 20,639 hectares), volume (0.49 to 0.59 billion kilograms), and revenue ($113 million to $150 million) (USDA 2013). The largest increases in revenue were from the sales of miniature orange pumpkins that are used for decoration and also pumpkins that are used pie production (USDA 2013). Consumer demand for pumpkin products in the United States continues to rise with a 79% increase in pumpkin products since 2011 (Nielsen 2015).

The recognized nutritional value of pumpkin has been a major factor for the increased demand for pumpkin products. Kundu et al. (2012) found that adding 5% pumpkin powder to wheat flour resulted in increased fiber, ash, calcium, and β-carotene in wheat flour based food products. In another study, Nwokolo and Sim (1986) found defatted pumpkin seeds contain more than 66% protein and higher levels of essential amino acids (with the exception of lysine) when compared to soybean meal. Zdunczyk et al. (1999) note that pumpkin seed cake contains 598.0 g/kg of crude protein compared to 474.2 g/kg crude protein in soybean meal. The protein efficiency ratio in human diets (weight gain divided by intake of food protein) is higher with a 1:1 pumpkin seed cake (powdered, meal form) protein and soybean meal mixture than with soybean meal alone (Zdunczyk et al. 1999). Pumpkin seeds in both the meal and concentrate form are rich in minerals such as calcium, potassium, phosphorus, magnesium, iron and zinc (Mansour et al. 1992). Pumpkin seeds, when ground into meal form, provide an excellent source of Vitamin B (Mansour et al. 1992).

## MAJOR INSECT PESTS

### Squash Vine Borer - *Melittia cucurbitae* (Harris) (Lepidoptera: Sesiidae)

The squash vine borer has long been considered a major insect pest by cucurbit growers. However, increased pumpkin production over the past 15 to 20 years has elevated the need to address the severity of injury caused to the pumpkin plant by the squash vine borer larvae and decrease the pest’s impact to pumpkin crop production (Brust 2010).

The squash vine borer is native to the western hemisphere from Canada to Argentina, although it is rarely observed west of the Rocky Mountains (Pleasant 1996). Recent reports have indicated that there is an increased distribution through the eastern United States, southeastern Canada and eastern Mexico, stretching to Guatemala (Jackson et al. 2005, Krinski 2014). The larvae of the squash vine borer colonize the vines of pumpkin plants and feed on the phloem and xylem tissues. This reduces the flow of water and nutrients that would otherwise flow through the plant. This feeding injury results in severe wilt or plant mortality if left untreated. Three to four larvae per plant can lead to a 20% reduction in yield. Plant mortality is observed when there are six or more larvae on a single plant (Brust 2010).

The adult squash vine borer belongs to the family Sesiidae, which have characteristic clear wings. Squash vine borer adults are often misidentified as wasps or bees due to their wings and orange abdomen that have black spots on each abdominal segment. The forewings of the borer in the adult are metallic green, while the back wings are clear. The female squash vine borer oviposits her eggs on the underside of cucurbit stems. The eggs are flat and usually brown or reddish in color and are often laid at the base of the cucurbit plant in early summer (Chittenden 1899). They hatch in six to 10 days and the young larvae immediately bore into the stems to feed (Brust 2010).

There is only one generation of squash vine borer per year in the north-central part of the Midwestern United States. Two generations of this pest have been reported in regions with warmer weather and longer growing seasons (Pavuk 2009).

Due to squash vine borer egg placement on the underside of cucurbit stems and leaves, and the burrowing habit of squash vine borer larva into the stems, insecticide applications for the squash vine borer often fail. The window for effective insecticide management is small so producers often apply too much insecticide. This practice increases input costs, is harmful to beneficial organisms, and contributes to other ecological concerns (Tyler 2007). Non-pesticide programs for the management of squash vine borer have been used successfully in the last 10 years. The use of nematodes (*Steinernema riobrave* TX Cabanillas, Poinar and Raulston) as a biological management tool for squash vine borer resulted in an 80% mortality of the larvae in one study (Canhilal and Carner 2006). Organic production of summer squash, *Cucurbita pepo* L., in Iowa indicates an 11.9% reduction of squash vine borer damage when using row covers for insect management (Tillman and Nair 2015). The success in recent years of non-pesticide programs to manage insects is a key reason for the interest in this experiment to study perimeter trap cropping as a pest management tool.

## PERIMETER TRAP CROPPING

Many insect pests immigrate to cash crops from the surrounding landscape. This immigration behavior can be exploited to promote the movement of the pest populations to a host that is more attractive than the cash trap. These more attractive alternative hosts are referred to as trap crops, and are often planted so that they completely encircle the main cash crop (Boucher and Durgy 2004). The effectiveness of this technique can be increased by adding additional perimeter defenses, such as border sprays, biological, mechanical and/or cultural controls as a pest management system (Boucher and Durgy 2004). The use of perimeter trap cropping systems can benefit producers by reducing insect feeding to their crops while also reducing the amount of insecticides that are used (Hokkanen 1991).

Perimeter trap cropping serves as a pest migration interceptor. Pests will become concentrated in the border areas of the field where they can be more easily managed. A "pulling" approach can be used where the specified insect is less attracted (hence "pulled") away from a cash crop and redirected to a more desirable target or trap crop (Cook et al. 2007). Insects will recognize the more attractive plant through key volatiles present in particular or specific ratios (Bruce et al. 2005). The intent of the trap crop is to provide a semiochemical diversion away from the cash crop (Hassanali et al. 2008). This technique, also referred to a directed host orientation (Cook et al. 2007), can use particular host odors, sex and aggregation pheromones, or naturally occurring gustatory and oviposition stimulants as well as visual stimulants (fruit or flower color). All of these methods are intended to keep insect pest populations in the trap crop area while conserving natural enemies and reducing insecticide use within the cash crop area. Additional value can be found if the trapped pest is also a vector of a disease that could cause further yield loss in the cash crop (Boucher and Durgy 2004).

Experiments using perimeter trap cropping have been conducted in the past 20 years with great results. Aluja et al. (1997) successfully used perimeter trap cropping to reduce the papaya fruit fly, *Toxotrypana curvicauda* Gerstaecker, in papaya *Carica papaya* L., groves. The mean percent of puncture damage from the papaya fruit fly was 8.5% within the papaya cash crop and 22% within the papaya trap crop (Aluja et al. 1997). A perimeter trap crop of a double row of collards, *Brassica oleracea* L., was used to reduce the diamondback moth, *Plutella xylostella* L., infestation in cabbage, *B.*

*oleracea* var. capitate Winnigstadt (Mitchell et al. 2000). In the two-year study conducted in 1997-98, the diamondback moth larvae found in the cabbage never exceeded the action threshold of 0.3 larvae/plant. In eight of nine fields used during the two-year period, diamondback moth larvae did exceed the action threshold of 0.3 larvae/plant in the collard trap crop. This proved to be an effective tactic in managing the insect (Mitchell et al. 2000).

Trap crops have been demonstrated to be important for other crops with increasing demand. For example, the increased demand of canola, *Brassica napus* L., for biodiesel production and food oil has prompted producers to increase production levels of the crop in the United States (Sangireddy et al. 2015). Production of canola in northern Alabama faces the economic challenge of insect damage from the cabbage seedpod weevil, *Ceutorhynchus obstrictus* Marsham. In the early spring, the overwintering cabbage seedpod weevil adults immigrate to canola fields when plants begin to flower and bud. The female adults lay their eggs on flowers and immature pods and the newly hatched larvae feed on seeds. Late instar larvae then feed through the pods of canola plant causing further damage before falling to the soil for pupation (Dosdall and Dolinski 2001). The large immigration of the cabbage seedpod weevil during the bud and flowering stages of canola development can cause compelling economic loss at different stages of canola development (Dosdall and Moisey 2004). McCaffrey et al. (1986) reported canola yield losses of 35% due to cabbage seedpod weevil feeding. Yield losses of 20.2%, 38.1% and 52.2% were reported with infestations of one, two or three larvae per pod respectively (Buntin 1999). A study conducted at Alabama A&M University during the 2006-08 growing seasons used an early-maturing line (EML) of canola as a trap crop for the cabbage seedpod weevil. A significant number of adult cabbage seedpod weevils were collected during the bud and flowering stages in the EML trap crop while relatively low infestations were collected in the conventional canola crop (Sangireddy et al. 2015).

Another example of the success of trap crops is the management of the spotted stem borer, *Chilo sacchariphagus* (Bojer). The spotted stem borer has long been a pest of economic significance to sugarcane, *Saccharum* spp., crops in along the Indian Ocean Island region in Asia (Bleszynski 1970, Nibouche et al. 2012). The presence and subsequent injury to plants the spotted stem borer has done to the sugar industry in Australia represents a major threat (Goebel and Sallam 2011). Simultaneous studies conducted from the 2006-2009 growing seasons at the Industrie Sucriere de Bourbon and Société Adrien Bélier in France evaluated the use of sweetcane, *Erianthus arundinaceus* Retz., as a trap crop for the spotted stem borer. Results of field trials in this study showed a significant reduction in damage to the sugarcane crop, resulting in a 21.7% yield increase (Nibouche et al. 2012).

In North Carolina, Boucher and Durgy (2004) reported that a perimeter trap crop of hot cherry peppers, *Capsicum annum* L., surrounding a cash crop of bell peppers, *Capsicum annum* L., was an effective management tool for reducing infestations of the pepper maggot, *Zonosemata electa* Say, in the cash crop (e.g., 12% mean pepper maggot damage in cash crop using pesticides without perimeter trap crop and less than 1% pepper maggot damage in cash crop without pesticides and use of perimeter trap crop). Pepper producers participating in this study said using perimeter trap cropping as an insect management tool was simple to manage and that time and money were saved compared to previous conventional methods that had been implemented (Boucher and Durgy 2004). Several studies conducted in Connecticut, evaluated the perimeter trap crop of ‘Blue Hubbard’ squash, *Cucurbita maxima* ‘Blue Hubbard’ Gregory, for a cash crop of summer squash to reduce the population of cucumber beetle, *Diabrotica undecimpunctata* Mannerheim (Boucher and Durgy 2004). The studies determined that there was a 93% reduction in the cucumber beetle population found in the cash crop of summer squash when compared to the trap crop of ‘Blue Hubbard’ squash.

The administration of an effective trap cropping system within a production system relies heavily on the characteristics of the trap crop itself, as well those of the cash crop. Equally vital are the spatial and temporal characteristics of each crop, understanding the movement patterns of the insect pests that travel between them, and the agronomic and economic requirements of the production system (Shelton and Badenes-Perez 2006). Effective use of trap cropping requires greater study in the growth dynamics and biology of cash and trap crops, as well as a better understanding of insect biology and behavior. Trap cropping systems can be classified into one or more categories: conventional, dead-end, or genetically engineered (Shelton and Badenes-Perez 2006).

Conventional trap cropping is best defined as a crop planted next to a higher value crop, to serve as a naturally greater attractant for a pest, as an oviposition or feeding site, than that of the higher value, or cash crop. The intent is to reduce or eliminate the likelihood of having the pest presence within the cash crop by drawing it into the trap crop where it can be easily and more economically managed. This particular form of trap cropping is widely practiced throughout the world in agricultural programs from developing countries to large-scale farming in industrialized nations. One of the forerunners and most successful examples of conventional trap cropping was the deployment of alfalfa, *Medicago sativa* L., as a trap crop for lygus bugs, *Lygus hesperus* Knight, in cotton fields in the central valley of California during the 1960s (Stern 1969, Godfrey and Leigh 1994). The implementation of this method of pest control was so successful it remains in use today.

The dead-end method trap cropping is defined as a crop that proves to be highly attractive to the intended pest, but on which their offspring will not be able to survive (Shelton and Nault 2004). This type of trap crop acts as a population sink for targeted insects, and as a result reduces their movement later in the season. As noted earlier, the Nibouche et al. (2012) study conducted during the 2006-2009 growing seasons at the Société Adrien Bélier and Industrie Sucriere de Bourbon (France) tested the effectiveness of using sweetcane as a dead-end trap crop for spotted stem borer. The study, which addressed increased spotted stem borer injury in sugarcane, found the number of egg masses oviposited on sweetcane stalks were 1.8 fold higher than on sugarcane and survival of the spotted stem borer larvae was reduced by 4.8 to 7.5 fold when oviposited on the terminal green leaves of the sweetcane plant (Nibouche et al. 2012). Using sweetcane as a dead-end trap crop for the spotted stem borer in this study increased sugarcane yields by 21.7% (Nibouche et al. 2012).

It is vitally important to understand the phenology of the targeted insects and to realize which host plants offer attractiveness for egg-laying while delaying or eliminating the advancement of growth. The dead-end trap cropping technique has also proved very effective when combined with low levels of insecticide on the trap crop, or with advanced genetic engineering.

When considering the developmental relationships between an insect and its host, it is often necessary to employ a method known as sequential trap cropping. With this strategy, one or more host crops are planted earlier and/or later than the cash crop to enhance the attractiveness of the trap crop to the targeted pest. A good example of sequential trap cropping is using Indian mustard, *Brassica juncea* (L.) Czern., as a host crop to trap the diamondback moth, *Plutella xylostella* L., on cabbage. Indian mustard has a relatively short life cycle compared with cabbage and thus may require two to three plantings throughout the growing season to be effective (Srinivasan and Moorthy 1991, Pawar and Lawande 1995).

A more complicated method of pest management is multiple trap cropping. This concept requires planting several different species of plants simultaneously as trap crops to manage a plethora of insect pests or enhance the management of one particular pest whose life cycle stages may be attracted to various plant development stages. An example of multiple trap cropping is the use of corn, *Zea mays* L., and potato, *Solanum tuberosum* L., plants to discourage wireworm infestations (*Coleoptera: Elateridae*) in Georgia sweet potato, *Ipomoea batatas* (L.) Lam., plantings (Seal et al. 1992). When considering this method of trap cropping, it is important to determine whether the expected harvest value of the cash crop will be greater than the value of the trap crop. As with the Georgia sweet potatoes, the overall value of the cash crop was expected to exceed the value of corn and potatoes as a trap crop (Seal et al. 1992).

Trap cropping in a variety of forms has become a substantial component of integrated pest management strategies for today’s agriculture. As research continues to unlock the mysteries of the insect/plant relationship, the effectiveness of trap cropping will continue to improve. However, there is an increasing need for alternative pest management strategies in horticulture specialty crops such as pumpkins.

As previously stated, pumpkin production in the Midwest has been steadily increasing, and this is especially true for the 'Howden' variety. Originally marketed as the 'Howden Field', this pumpkin variety is well adapted to South Dakota growing conditions. It is grown commercially and in private gardens for its traits as an iconic symbol of Halloween. However, the value of this crop can be destroyed by the stem colonization of the squash vine borer.

## POLLINATION

### Introduction and Terminology

The ratio of a plant's flowers that flourish into mature fruit or seeds is defined as fruit set (Garibaldi et al. 2013). The fruit set of crops requiring insect pollination may increase in part to the abundance of pollinating insects, their species population (richness), the even distribution of those pollinating insects within a crop or a combination of these factors (Garibaldi et al. 2013). The lack of commonly accepted terminology across scientific fields to assess a particular insect species' pollination effectiveness has resulted in a barrier that prevents the comparison among different fields of study (Ne'eman et al. 2009). To eliminate any misinterpretation of definition across various fields, the term "pollinator performance" is used in this document to describe the overall effectiveness of a pollinating insect (species and/or group of species) in the pollination process of crop plants (Ne'eman et al. 2009).

Agronomists, horticulturists, and plant breeders have long been interested in the comparison of pollinator performance as related to specific floral characteristics. Floral characteristics are believed to have evolved over time based on pollinator performance and how it best contributes to a specific plant's reproductive success (Stebbins 1970, Grant 1971, Wilson and Thompson 1991, Olsen 1997). A more detailed explanation of the relationship between pollinator performance and the significance in pumpkin crops is covered in the following section.

Plant pollination through animal contact is central for maintaining plant diversity (Ollerton et al. 2011). Approximately 70% of the major crop species in the world rely on animal pollination for seed set or approximately one-third of the world's food production (Klein et al. 2007, Nicholls and Altieri 2012, Gonzalez-Varo et al. 2013). The economic value of insect pollination on United States food production has increased dramatically over the last decade from an estimated value of $3.07 billion annually to more than $24 billion as reported in 2014 (Losey and Vaughan 2006, White House Office of the Press Secretary 2014).

Ecological issues brought on by environmental change that include habitat loss, changing patterns of reactive nitrogen from the atmosphere to the biosphere, rising levels of carbon dioxide in the atmosphere and changes in overall climate are affecting physiological responses of plants (Sala et al. 2000, Hoover et al. 2012). Environmental changes may have negative impacts on the insect species that interact (including pollination abilities) with plants (Tylianakis et al. 2008, Hoover et al. 2012). Modern agricultural practices, including how the land is farmed and some pesticide usage, also impact the relationship between insect pollinators and plants (Nicholls and Altieri 2012). Intrusions to the ecosystem through some methods of current farming practice have created environments that are non-conducive for insect pollinator habitat, but the number of crops requiring pollination on a global scale continues to increase (Feltham et al. 2015). The mutualism plants and insect pollinators share can be disrupted by changes in the environmental patterns which reduce insect pollinator diversity or by altering their ability to find and pollinate plants (Biesmeijer et al. 2006, Potts et al. 2010, Hoover et al., 2012). Brosi and Biggs (2013) use the term "floral fidelity" to explain insect pollinator's forage patterns related to a particular plant species. Floral fidelity is a crucial part of the insect pollinator-plant relationship as the transfer of species specific pollen must take place in order for fertilization to occur (Brosi and Briggs 2013).

Insect pollinator populations are declining and as a result the ability to understand the impacts of a particular insect pollinator species on plant population (including production) is especially important (Biesmeijer et al. 2006, Potts et al. 2010, Brosi and Briggs 2013). The issue of pollinator decline has become so important that strategies have been developed by the United States Environmental Protection Agency (EPA) and the United States Department of Agriculture, by request of President Barrack Obama (Obama Presidential Memorandum 2014), to address pollinator decline. One method of countering the decrease of certain native insect pollinators from a given area (those beneficial to certain crops) is the addition or re-introduction of wildflower plant species in or around cash crops to increase insect pollinator diversity (Korpela et al. 2013). The integration of wildflower pollination strips increases the populations of numerous insect groups due to the increased available flowers and plant diversity (Haaland et al. 2011).

The success and effectiveness of adding wildflower pollination strips as a method of a crop management plan depends, in part, on a pair of key factors. The appropriate diversity of introduced plant species in the wildflower pollination strip must improve habitat quality for the intended insect pollinator (Kleijn et al. 2011) and the mixture must provide attraction to insect pollinators who have a preference for plant diversity across the landscape (Dixon 2009, Isaacs et al. 2009).

Research that that demonstrates the benefits of introducing wildflower pollinator strips within a crop management program has been conducted using a broad range of crops. The studies have observed increased populations of insect pollinators and diversity as well as increases in the cash crop yield (i.e., larger return on investment). Wildflower pollination strips have also been studied as a method for reducing pest insect impacts on cash crops by including plant species within the pollination mixture that trap or attract insect pests. Wildflower pollination strips containing perennial forage sources and plant species that reduce the amount of yield loss that occurs to cash crop through trapping can provide long-term and stable habitats for the natural enemy community of the insect pests while providing an annual attractant of pollen and nectar for insect pollinators (Pfiffner and Wyss 2004, Wäckers and van Rijn 2008).

The benefits of wildflower pollination strips for pollinators and natural enemies are attributed to greater flower abundance, plant diversity and improved plant structure (Haaland et al., 2011). The effectiveness of a good wildflower pollination strip lies in the creation of wildflower mixtures that are attractive and provide suitable nectar sources to invite insect pollinators who will promote pollination across the landscape (Dixon 2009, Isaacs et al. 2009). The response to the quality of wildflower pollination strips as a habitat for insect pollinators is largely dependent on the structure of the landscape surrounding it (Batary et al. 2010, Kleijn et al. 2011). Considering the reductions in pollinator diversity, landscapes undergoing intensive cultivation typically have a shortage of habitat opportunities in which native pollinators can colonize and survive long-term (Kleijn et al. 2011). The introduction of wildflower strips can provide the necessary ecosystem service that is required for generalist pollinators such as *Bombus* spp. (Forup et al. 2008).

Feltham et al. (2015) observed that wildflower pollination strips in strawberry (*Fragaria x* L.) production resulted in a mean increase of 25% insect pollinator populations (range 22-33%). Researchers provided six local *Fragaria x* producers (production qualifications included a minimum of 10 polytunnels with a double cropping system) 600g of mixed annual and perennial flower seed known for high levels of pollen production and nectar rewards (Supporting Supplemental Table 1.1) planted in 6 x 50 m strips approximately 20 m (minimum of 500 m for control) from the *Fragaria x* crop. Test and control crops were provided with commercial bumble bee, *Bombus* Latreille, nests at a density of one nest per 100 m tunnel. Pollinators were counted approximately every 7 days using a modified standard line transect method (Pollard, 1977). Results from this study reported a mean of 8.57 ± 0.55 pollinating insects per 100 m of control and 11.10 ± 0.61 pollinating insects per 100 m of test crop. Two-thirds of the pollinator insect populations observed on control and test crops belonged to the genus *Bombus* (58% *B. terrestris* L. and *B. locorum* L., 4% *B. lapidarius* L., 3% *B. pratorum* L. and 2% *B. pascurorum* Scopoli). The range of remaining insect populations included Honey bees, *Apis* mellifera L., native solitary bees, *Anthophila* L., and hoverflies (Diptera: Syrphidae) (Feltham et al., 2015).

Field experiments were conducted in Switzerland to test the effect of wildflower pollination strips near winter wheat, *Triticum aestivum* L., as both a deterrent for cereal leaf beetles, *Oulema melanopus* L., and cash crop *T. aestivum* yield (Tschumi et al., 2016). Cereal leaf beetles are a major cereal crop pest in Europe, Asia and parts of North America (Olfert and Weiss 2006, Ihrig et al. 2001, Evans et al., 2013). Cereal leaf beetle larvae feed on cereal plant leaves (including *T. aestivum*) limiting the plant's ability to photosynthesize for growth and grain development (Haynes and Cage 1981, Buntin et al. 2009, Reay-Jones 2010). A Swiss government initiative promoting biodiversity and ecosystem services has compensated Swiss producers for the establishment of perennial wildflower strips over the past decade. Tschumi et al. (2016) utilized these pre-established wildflower strips (mean 3.9 years ± 0.7 years) of approximately 189 m x 19 m in area, which contained 1 of 4 mixtures of 24-41 plant species (Supporting Supplemental Table 1.2). Twenty wheat fields (mean size of 1.31h a ± 0.14 ha each) were selected in pairs based on analogous management practices, common landscape composition, no previous pesticide application and no history of established flower-heavy habitats (outside of previously established sown wildflower strips). Wheat test fields were placed in close proximity to an established perennial wildflower strip while the wheat control fields were planted no less than 393 m from perennial wildflower strip.

Cereal leaf beetle egg and larval presence was recorded twice at peak periods through observation of sets of 25 wheat tillers at distances of 5 m and 10 m from the edge of the field closest to the perennial wildflower pollination strip. Second generation adult cereal leaf beetles were collected and counted twice through sweep netting. Injury to the wheat crop was assessed by calculating the percentage of the flag leaf casualty on the same sets of wheat tillers egg and larval activity was found. The results of this study indicated a 40% reduction of cereal leaf beetle injury to wheat crops due to wildflower pollination strips. A 10% increase of wheat population was reported in the test fields by measuring the density and height in 1 $m^2$ sections where cereal leaf beetle egg and larval activity was found (Tschumi et al. 2016).

### Pumpkin, *Cucurbita pepo L.*, Pollination

Pumpkin is a monoecious (i.e., having both male and female reproductive parts) cross-pollinated crop from the Cucurbitaceae family (Petersen et al. 2013). The production of pumpkins relies heavily on pollination from insects that are either purposefully released or wild pollinator populations (Phillips and Gardiner 2015). For favorable pollination and fruit production, insects must transport pollen from the male flower to the female flower (Delaplane and Mayer 2000).

The supplementation of insect pollinators, particularly the honey bee to pumpkin crops is a common practice (Free 1993, Thompson, 2003). However, the decline of honey bee populations paired with the greater demand for pollination services across all crops have led researchers to identify and evaluate the competence of other insect pollinators including the common eastern bumble bee (*Bombus impatiens* Cresson) (National Research Council 2007, Feltham et al. 2015). The eastern bumble bee has been found to be a very effective pollinator of *Cucurbitae* crops in general and specifically pumpkin

(Stanghellini et al. 1998, Artz et al. 2011, Artz and Nault 2011). The squash bee, *Peponapis pruinosa* Say, honey bee and eastern bumble bee are the most commonly found bee species in pumpkin crops and may have the largest impact production (Artz et al. 2011, Cane et al. 2011).

The introduction of managed populations of insect pollinators may not always increase flower visitation or fruit yields in pumpkin crops. Petersen et al. (2013) conducted a two-year study examining the effect that supplemented populations of honey bee and eastern bumble bee had on pumpkin fruit yield in commercial fields when compared to fields that did not supplementation. Previous research determined that the eastern bumble bee is a more productive pollenating insect than the honey bee for individual flowers so a second part of the experiment was to determine if the eastern bumble bee visitation frequency to pumpkin flowers would result in increased pumpkin yields (Artz and Nault 2011, Petersen et al. 2013). The experiment was conducted in 23 pumpkin fields in 2011 and 19 in 2012 (0.5 to 13 ha range) and one of three treatments were applied, honey bee supplementation (2011: n=10, 2012: n=7), eastern bumble bee supplementation (2011: n=6, 2012: n=5) or no supplementation (2011: n=7, 2012: n=7). For fruit yield comparisons, the pumpkin variety ‘Gladiator’ transplants (started in greenhouse) were planted directly into production fields. ‘Gladiator’ was selected due to its proclivity for producing one large fruit per plant rather than several fruits that would compete for plant resources. Surrounding pumpkin varieties varied in participating producer fields, but it is known cross-pollination occurs (Delaplane and Mayer 2000). Results of this experiment indicated a majority of the flower visits were from the squash bee (2011: n=1382, 2012: n=1274), a bee not released as part of the managed insect pollination experiment. Flower visits for the honey bee were significantly lower (2011: n=695, 2012: n=765) while instances of the eastern bumble bee visitation were lower (2011: n=241, 2012: n=628) (Petersen et al. 2013).

Several research projects evaluated the use of wildflower pollination strips as a benefit to many varieties of fruits in the Cucurbitae family, however little could be found to specifically evaluate the benefits of a wildflower pollination strip specifically for pumpkins. Pumpkin production and revenue continues to rise for many of the available varieties and an examination into wildflower pollination mixtures designed for this crop are warranted (USDA 2013). The inclusion of trap cropping plant material within the wildflower pollination mixture is also worthy of further exploration. The mutualism of providing a habitat and forage source for beneficial insect pollinators while deterring or trapping unwanted insect pests would prove useful to pumpkin producers.

## RESEARCH OBJECTIVES

1) Determine the effectiveness of perimeter trap cropping as a defense against squash vine borer.
2) Evaluate the impact of flower strips near pumpkin on both natural enemies and pollinators.

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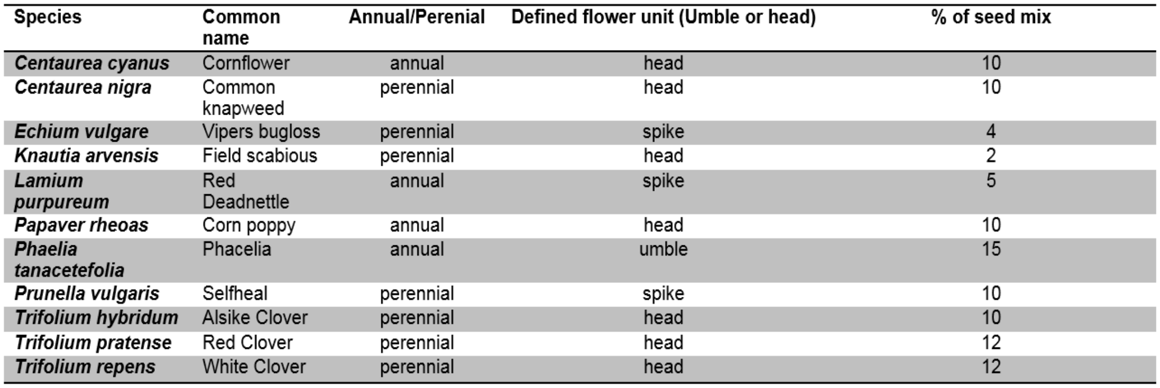
## SUPPLEMENTAL TABLES (SUPPORTING INFORMATION)

**Table 1.1** (Feltham et al. 2015)



| Species | Common name | Annual/Perenial | Defined flower unit (Umble or head) | % of seed mix |
|---|---|---|---|---|
| ***Centaurea cyanus*** | Cornflower | annual | head | 10 |
| ***Centaurea nigra*** | Common knapweed | perennial | head | 10 |
| ***Echium vulgare*** | Vipers bugloss | perennial | spike | 4 |
| ***Knautia arvensis*** | Field scabious | perennial | head | 2 |
| ***Lamium purpureum*** | Red Deadnettle | annual | spike | 5 |
| ***Papaver rheoas*** | Corn poppy | annual | head | 10 |
| ***Phaelia tanacetefolia*** | Phacelia | annual | umble | 15 |
| ***Prunella vulgaris*** | Selfheal | perennial | spike | 10 |
| ***Trifolium hybridum*** | Alsike Clover | perennial | head | 10 |
| ***Trifolium pratense*** | Red Clover | perennial | head | 12 |
| ***Trifolium repens*** | White Clover | perennial | head | 12 |

**Table 1.2** (Tschumi et al., 2016)

| Plant species | Mixture 1 | Mixture 2 | Mixture 3 | Mixture 4 |
|---|---|---|---|---|
| **Annual** | | | | |
| *Agrostemma githago* L. | X | X | | |
| *Anchusa arvensis* L. | | X | | |
| *Buglossoides arvensis* L. | | X | | |
| *Camelina sativa* L. | | X | | |
| *Centaurea cyanus* L. | X | X | X | X |
| *Consolida regalis* Gray | | X | | |
| *Fagopyrum esculentum* Moench | X | X | | |
| *Legousia speculum-veneris* L. Chaix | X | X | | |
| *Misopates orontium* L. Rafin. | | X | | |
| *Nigella arvensis* L. | | X | | |
| *Papaver dubium* L. | | X | | |
| *Papaver rhoeas* L. | X | X | X | |
| *Silene noctiflora* L. | | X | | |
| *Stachys annua* L. | | X | | |
| *Vaccaria hispanica* Mill. Rauschert | | X | | |
| *Valerianella rimosa* Bast. | | X | | |
| **Biennial** | | | | |
| *Alliaria petiolata* (M.B.) Cavara et Grande | | | | X |
| *Cichorium intybus* L. | X | X | X | |
| *Daucus carota* L. | X | X | X | |
| *Dipsacus fullonum* L. | X | X | | |
| *Echium vulgare* L. | X | X | X | |
| *Malva sylvestris* L. | X | X | X | |
| *Melilotus albus* Med. | X | X | X | |
| *Pastinaca sativa* L. s.l. | X | X | X | |

| | | | | |
|---|---|---|---|---|
| *Reseda lutea* L. | | X | X | |
| *Silene alba* Rafn. Godr. | X | X | X | |
| *Silene dioica* L. Clairv. | | | X | X |
| *Tragopogon orientalis* L. s.l. | | X | | |
| *Verbascum densiflorum* Bertol. | X | X | X | |
| *Verbascum lychnitis* L. | X | X | | |
| **Perennial** | | | | |
| *Achillea millefolium* agg. | X | X | X | |
| *Agrostis gigantean* Roth | | | | X |
| *Anthemis tinctoria* L. | X | X | | |
| **Perennial (Continued)** | | | | |
| *Arrhenatherum elatius* L. Presl | | | X | |
| *Artemisia vulgaris* L. | | | X | |
| *Bromus erectus* Hudson s.l. | | | X | |
| *Campanula trachelium* L. | | | X | X |
| *Carex flacca* Schreb. | | | | X |
| *Centaurea jacea* L. s.l. | X | X | X | X |
| *Cirsium oleraceum* L. Scop. | | | | X |
| *Clinopodium vulgare* L. | | | X | X |
| *Eupatorium cannabinum* L. | | | | X |
| *Festuca pratensis* Hudson s.l. | | | X | X |
| *Festuca rubra rubra* L. agg. | | | X | X |
| *Filipendula ulmaria* L. Maxim. | | | | X |
| *Galium mollugo* agg. | | | X | |
| *Galium verum* L. s.l. | | | X | X |
| *Geum rivale* L. | | | | X |
| *Hypericum hirsutum* L. | | | | X |
| *Hypericum perforatum* L. | X | X | X | |
| *Knautia arvensis* L. Coulter | | | X | |
| *Knautia dipsacifolia* Kreutzer | | | | X |
| *Lathyrus pratensis* L. | | | | X |
| *Leucanthemum vulgare* agg. | X | X | X | X |
| *Lolium perenne* L. | | | X | X |
| *Lotus corniculatus* agg. | | | X | |
| *Lotus pedunculatus* Cav. | | | | X |
| *Lycopus europaeus* L. s.l. | | | | X |
| *Lysimachia vulgaris* L. | | | | X |
| *Lythrum salicaria* L. | | | | X |
| *Malva moschata* L. | X | X | X | |
| *Mentha longifolia* L. Huds. | | | | X |
| *Onobrychis viciifolia* Scop. | X | X | | |
| *Ononis spinosa* L. s.l. | | | X | |
| *Origanum vulgare* L. | X | X | X | |
| *Poa pratensis* agg. | | | X | X |
| *Picris hieracioides* L. | | | X | |
| *Pulcaria dysenterica* L. Bernh. | | | | X |
| *Salvia pratensis* L. | | | X | |
| *Saponaria officinalis* L. | | | X | X |
| *Scrophularia nodosa* L. | | | X | X |
| *Silene flos-cuculi* L. Clairv. | | | | X |
| *Solidago virgaurea* L. s.l. | | | X | X |
| *Stachys officinalis* L. Trevisan | | | X | X |
| *Tanacetum vulgare* L. | X | X | X | |

| | | |
|---|---|---|
| *Thalictrum aquilegiifolium* L. | | X |
| *Valeriana officinalis* AGG. | | X |
| *Verbascum nigrum* L. | X | |
| *Vicia cracca* L. S.L. | | X |
| *Vicia sepium* L. | X | X |

# CHAPTER 2. PERIMETER TRAP CROPPING WITH POLLINATORS

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## Abstract

Seasonal fresh market and ornamental use pumpkin production in the United States has seen steady growth since 2005 (USDA Economic Research Service 2015). During the 2015 growing season, 342 billion kg of pumpkins were produced in just the top six producing states, California, Illinois, Michigan, Ohio, Pennsylvania and New York. Pumpkin production occurs in all 50 states with an annual per capita utilization of 1.4 kg per person (USDA Economic Research Service 2015).

Cucurbits are monoecious meaning both male and female reproductive organs appear on the same plant.  The male organs bloom first and only remain on the plant for about one day before falling off.  Female organs bloom approximately one week later while the male blooms continue.  Male flowers produce nectar and pollen while female flowers only produce nectar.  When visited by bees or other beneficial pollinating insects, the sticky granules of pollen on the male flowers attach to the insect and are transferred to the female flower.  Female flowers contain higher levels of nectar.  Hand pollinating is an option for pumpkin crops, but is timely and not as effective.  The quality of the fruit is improved through the activity of pollinator insects.

The concept of building a perimeter crop of attractive flowers around a cash crop of pumpkins to aid in drawing in “workers” to pollinate the pumpkin crop is not new. Developing a perimeter crop that combines the use of an effective trap crop for harmful pests while providing a habitat that attracts beneficial pollinating insects; however, is still

in the research stage. This experiment was conducted to measure the effects of pollination and production when combining a wildflower pollination mixture with a trap crop of ‘Hubbard’ squash to attract the squash vine borer thus limiting insect injury to the cash crop of ‘Howden’ pumpkins.

## INTRODUCTION

Production of pumpkin crops have rapidly expanded in the United States since the early 1980s. The USDA Census of Agriculture (2007) reports less than 7000 farms reported pumpkin acreage in 1982. The number of farms reporting pumpkin acreage in 2007 more than doubled to over 14,000 farms and by 2015, approximately 23,000 farms reported pumpkin production (USDA Economic Research Service 2015).

The rise of the pumpkin market can be attributed to several factors. Relative ease of growth, increased understanding of nutritional value and varied marketability options (Harper and Orzolek 2012) have all played roles in increased production and consumer demand.

The greatest insect risk to cucurbit (including pumpkin) production in the United States is plant injury from squash vine borer larvae (Brust 2010). Squash vine borer larvae feed on the xylem and phloem tissues within the vines of the pumpkin plant damaging the flow of vital nutrients and water needs for growth and fruit production. Just a few larvae on one plant can lead to 20% reduction in yield and plant death can occur with injury inflicted by six or more larvae per plant (Brust 2010). One method of this study was to incorporate a trap crop of ‘Hubbard’ squash in a perimeter around the cash crop of ‘Howden’ pumpkins. By providing a more attractive option for the squash vine borer to deposit their eggs, squash vine borer larvae injury was reduced in the cash crop of ‘Howden’ pumpkins.

Successful natural pollination of healthy pumpkin crops is critical to seed set, fruit set and yield (Walters and Taylor 2006). Twenty years ago farmers were spending more than $110 billion annually on pollination services in agriculture and on rangeland in the United States (Costanza et al. 1997). The cost of pollination services has steadily increased, due in part to the dramatic loss of the honey bee, *Apis mellifera* L. (Hymenoptera: Apidae), populations due to colony collapse disorder (Cox-Foster et al. 2007). Dr. Amanda Bachmann, South Dakota State University Extension Pesticide Education and Urban Entomology Field Specialist, reports (2016) that the United States managed honey bee colony loss was 44.1% for the 2015-16 season, an increase of the 40.6% loss during the 2014-15 season. Honey bee colony loss was under 30% in 2011-12 (Bachmann 2016). In a report provided by the United States Department of Agriculture’s National Agricultural Statistics Survey in 2007 and reposted on the website EcoWatch in 2016, the number of US honey producing colonies has dropped from over 5.5 million hives in 1950 to less than 3 million hives in 2007.

It has been extremely important to determine whether native bees can provide adequate pollination to support sufficient yields. Most cucurbit varieties require pollination to produce fruit (Kemp and Bosch 2001). Honey bees, as pollinators to cucurbit crops, can increase fruit weight by 70% when added as part of a pollination program (Walters and Taylor 2006). However, traditional insect management methods for many of the cucurbit crops, due to their strong attractiveness to insects, utilize multiple applications of foliar broad-spectrum insecticides that have negative impacts on the insect pests as well as pollinators (Howell et al. 2004, Brust and Foster 1995).

Adler and Hazzard (2009) conducted a study to test the effectiveness of ‘Blue Hubbard’ squash as a trap crop for the striped cucumber beetle, *Acalymma vittatum* L., when bordering a cash crop of butternut squash, *Cucurbita moschata* Duch. ex Poir. The experiment compared other cucurbit trap crops against the ‘Blue Hubbard’ including zucchini, *Cucurbita pepo* ‘Embassy’ Paris, buttercup squash, *Cucurbita maxima* ‘Burgess’, wild gourd, *Cucurbita pepo ssp. texana*, mixed with zucchini, *Cucurbita pepo* ‘Elite’, in a 2:3 ratio, and butternut squash, *Cucurbita moschata* ‘Waltham’, as a control. The purpose of the study was to evaluate these treatments for their effectiveness for managing striped cucumber beetle populations in the butternut squash crop and also the impact that they had on pollination. Most overall cotyledon and leaf damage was found in the ‘Blue Hubbard’ trap crops although collection of live beetles were higher in buttercup and zucchini trap crops. The results showed no significant difference between pollination in the zucchini and wild gourd/zucchini mix trap crops; however, pollination within the cash crop containing ‘Blue Hubbard’ squash was significantly increased. Butternut squash that was surrounded by ‘Blue Hubbard’ and buttercup squash trap crops produced 12.5% by weight and 8% more fruit by number than plots surrounded by trap crops of zucchini, gourd/zucchini mix or butternut squash (Adler and Hazzard 2009).

It has been shown that perimeter trap crops aid in insect management and provide improved pollination potential in fruit and vegetable crops. It has also been shown that improved pollination in fruit and vegetable crops leads to larger yields. The utilization of perimeter trap cropping has not been studied extensively. The objective of this study was to determine if perimeter trap cropping was effective at reducing squash vine borer injury to pumpkins. A second objective of this study was to determine if a pollinator perimeter increases the yield of pumpkins.

## MATERIALS AND METHODS

### Experimental Design

For this experiment, pumpkins were grown using a randomized complete block design with three treatments. The treatments included a pollinator perimeter with trap crop (PPT), pollinator perimeter (PP) and a no perimeter planting (NP) control (i.e., bare soil) (Figure 2.1). These treatments were selected to evaluate the impact that perimeter plantings have on pollinators as well as the squash vine borer in regards to pumpkin yield. In 2015, the study included four complete blocks of the three treatments at the N.E. Hansen Research Site in Brookings, SD, and two complete blocks of each treatment at Berndt Farms, a private farm near White, SD. The cash crop, PP and PPT treatments were planted at the N.E. Hansen Research Site during 20-22 May 2015. The cash crop, PP and PPT treatments at the Berndt Farm location were planted on 23 May 2015. No irrigation or fertilization was used for this study.

The cash crop in each treatment was a 9.1 $m^2$ area of ‘Howden’ pumpkins that were planted in four rows of four hills (16 hills, two seeds each). The perimeter cropping systems consisted of a 3 m perimeter border containing PPT, PP or NP treatments. Each block was separated by a minimum of 15 m of bare soil that was maintained by frequent tilling (Figure 2.2). The wildflower pollinator mixture (Table 2.1) was spread using a rotating hand-held seed spreader opened to its maximum output. Once the pollination mixture was laid, the perimeter area was lightly raked with a commercial grade landscape rake. One row of ‘Hubbard’ squash seed (Everwilde Farms, Sand Creek, WI) was hand planted approximately 1.8 m apart along the outer edge of each perimeter (0.6 m from the outer edge), while a second row was planted approximately 1.8 m apart along the inner edge of the perimeter (0.6 m from the inner edge).

Blocks 1 and 2 at N.E. Hansen Research Site [Hansen (1) and Hansen (2)] were located in the east field and separated by a minimum of 15 m of bare soil while blocks 3 and 4 [Hansen (3) and Hansen (4)] were located in the west (approximately 360 m from east field) field and were also separated by a minimum of 15 m of bare soil (Appendix A-1). Blocks 1 and 2 at Berndt Farms [Berndt (1) and Berndt (2)] were separated by 15 m of bare soil.

### Trap Crop and Pollination Crop Mixtures

The wildflower mixture for the PPT and PP treatments (Table 2.1) was developed with the guidance of Dr. Jonathan Lundgren, previous research entomologist with the United States Department of Agriculture’s Agricultural Research Service and mixed by Millborn Seeds (Brookings, SD). The wildflower mixture used in the pollination strip for this project represents a diversity of plant species designed to attract and provide a habitat and forage for pollinating insects beneficial to pumpkin crops. The range of floral diversity in the designed mixture also provides an excellent foraging habitat for insect pollinators by providing a wide range of plant species that flower throughout the growing season (Mogren et al. 2014).

### Squash Vine Borer Presence in Pumpkins

We hypothesized that the implementation of the PPT and PP treatments would reduce squash vine borer infestations in pumpkin. To determine this, the presence or absence of squash vine borer larvae was monitored on individual ‘Howden’ pumpkin plants only through visual monitoring for wilting, frass or entry holes in vines. Data was collected on a two-day rotating basis (day one at N.E. Hansen Research Site, day two at Berndt Farms, day three back at N.E. Hansen Research Site, etc.) in all replicates from 15 June through 24 July 2015 (Figure 2.3). Monitoring continued after 24 July 2015, but no further signs of squash vine borer presence or injury was observed.

### Natural Enemy and Pollinator Species Present in Native Flower Strips and Pumpkins

We hypothesized that the presence of the PPT and PP plantings would increase the abundance of pollinators present in pumpkin that were surrounded by these treatments. To determine this sweep nets were used to sample the diversity of insects found in the pollination strip perimeters of the PPT, PP and NP replicates from 15 June through 20 August 2015. The sweeping process involved using a funnel shaped net attached to a long handled frame that was swept along the base of the plant material in a 180 degree arc with a pendulum style motion while walking along the perimeter areas of each replicate. Upon completion of each collection, insect samples were carefully bagged and sealed in clear plastic bags, labeled with date and replicate information then placed in cold storage for later identification. This method of collection was used to document insects attracted to the perimeter areas in an effort to determine pollinator populations.

Insect identification from the sweeps was conducted using microscopes and magnifying lenses as necessary. Insects were identified to the family taxonomic level.

### Impact of Perimeter Trap Crop and Pollinator Strips on Pumpkin Yield

We hypothesized that the PPT and PP treatments would increase pumpkin yield through a reduction in squash vine borer populations and an increase in pollinator populations. All fruit was harvested between mid-September and early October 2015 and individual fruit weights were recorded. Fruit from N.E. Hansen Research Site 1 and 2 were the first to mature and fruit from Berndt Farms 1 and 2 were the last to mature. All fruit was harvested from each replicate at the same time. Fruit was weighed twice upon collection to ensure accuracy and the scale was calibrated weekly throughout the fruiting period per the manufacturer's guidelines to maintain continued accuracy.

## STATISTICAL ANALYSIS

Data collected for this project included the actual number of squash vine borer larvae collected (found while scouting for potential squash vine borer damage such as plant wilt, frass, or entry holes on the plant which may indicate presence of squash vine borer larvae), fruit weights and fruit numbers for each treatment in each block. The data were analyzed using Statistical Analysis Software Version 9.4 (SAS International Inc. 2016).

The Generalized Linear Mixed Model (GLIMMIX) procedure was used to analyze squash vine borer count data. This model fits data where variability may be inconsistent and responses are not necessarily normally distributed. To fit data into this model, Poisson Regression was utilized for response distribution as there were a high number of zero counts among the treatments in the squash vine borer data. Tukey-Kramer was utilized in this analysis to modify t-statistics (used to obtain p-values when determining significance between location and treatment).

The Mixed Procedure Model was used in SAS for analyzing fruit count and fruit weight that utilized Restricted Maximum Likelihood Estimation (REML) to estimate variance components and generalize least squares estimates of fixed effects parameters. When using fruit weight or fruit count as the dependent variable in this model, results for significance ($P < 0.05$) on location (N.E. Hansen Research Site, Berndt Farm or combined) as a random factor could be generated through a test of fixed effect. When comparing location and treatment type effects (PPT, PP or NP), *p-values* were adjusted using Tukey-Kramer which modifies the t-statistic (used to obtain the *p-value*) as the replicate numbers were not equal for location effect. Tukey-Kramer HSD (honestly significant difference) shows a test size for all differences among the means (SAS International Inc. 2016).

The Generalized Linear Mixed Model (GLIMMIX) procedure was used in the SAS software to analyze insect population data. This model fits data where variability may be inconsistent and responses are not necessarily normally distributed. This model was appropriate to best fit inconsistencies in insect numbers collected across different locations.

## RESULTS

### Squash Vine Borer Presence in Pumpkins

We confirmed our hypothesis that the PPT perimeter plantings would reduce the infestation of squash vine borers in pumpkins. However, this was not confirmed for the

PP treatment. This was determined by analyzing the squash vine borer data for the fixed effect treatment, which was significant ($F$ = 5.89; df = 2, 10; $P$ < 0.0204). This indicated there were significant differences among the tested treatments. We next analyzed the data by treatment.

There were significantly greater squash vine borer populations observed on the NP ($t$ = 3.40; df =1, 10; $P$ < 0.0169) and PP ($t$ = 3.14; df = 1, 10; $P$ < 0.0261) treatments when compared to the PPT treatment. There were no significant differences between the NP and PP treatment. These results indicate that the presence of the trap crop in the PPT treatment was likely the reason for the lower presence of squash vine borer larvae. Without the 'Hubbard' squash trap crop as a part of the perimeter (PP) there was no statistical difference from the NP treatment.

The squash vine borers were first detected on 21 June 2015, on 'Howden' pumpkins in a PP replicate at the N.E. Hansen Research Site location (Appendix A-1). The last sighting of squash vine borer for the season was found on 24 July 2015. A total of 51 squash vine borer larvae were found in the cash crop plantings of 'Howden' pumpkins at both sites during the season. The mean (± SEM) populations of squash vine borer larvae was calculated for each site and treatment (Table 2.2).

Using a linear contrast test, we can test the hypothesis $H_0\colon \mu_{NP} \geq \frac{1}{2}(\mu_{PT} + \mu_{PP})$ versus $H_1\colon \mu_{NP} \leq \frac{1}{2}(\mu_{PT} + \mu_{PP})$. The calculated t-statistic is *-2.74 which is less than the suggested one-winged critical value of -1.81 at the 5% level of significance.* Therefore, we reject $H_0$ thus indicating there were on average significantly fewer squash vine borers found in the cash crop of 'Howden' pumpkins when surrounded by a PPT treatment than by PP or NP treatments. The results of this study support the hypothesis.

### Pollinator Species Present in Native Flower Strips and Pumpkins

A total of 349 insects representing six orders (Coleoptera, Diptera, Hemiptera, Hymenoptera, Neuroptera and Orthoptera) were collected through sweeping the PPT, PP, and NP treatments in this study. Abundance population were determined within each order and treatment. The largest group of insects collected belonged to the Order Hemiptera (Table 2.3).

The presence or absence of pollinating insects and/or insects with other beneficial qualities is certainly important in an experiment of this nature. Due to the nature of this particular experiment and the relationship of populations of insects relative to the particular recipe of the wildflower pollination strip used in this experiment, it is difficult to state precise levels of effectiveness of each insect in each treatment type. It should be noted the results for this section are stated in terms of presence or absence only. The presence of insects collected in this experiment within the orders Neuroptera and Orthoptera were too few to converge any statistical data.

Significant location effects, regardless of treatment type, existed for insects collected with the orders Coleoptera ($p=0.0154, \alpha=0.05$), Hemiptera ($p=0.0003, \alpha=0.05$), and Diptera ($p=0.0013, \alpha=0.05$). This would suggest location did not seem to be a factor. A fair amount of insects from these orders were collected at both the N.E. Hansen Research Site and Berndt Farms. Location was a factor, in this experiment, for insects from the order Hymenoptera as indicated with a non-significant p-value ($p=0.0821, \alpha=0.05$).

There was no significance found in analyzing insects collected from the orders Coleoptera or Hymenoptera as related to any specific treatment type (NP, PP or PPT) or any combination of treatment types. That would suggest, in this experiment, treatment type was likely not a factor relative to the presence of insects from these orders.

A noticeable pattern began to emerge when studying the number of insects from the order Hemiptera. An extremely high level of significance was apparent for both PP and PPT ($p<.0001, \alpha=0.05$ each) treatments while a non-significant p-value ($p=0.0798, \alpha=0.05$) existed within NP treatments. This suggested there is a likelihood a relationship exists with the presence of insects from the order Hemiptera and the lack of any type of treatment (NP). The same could be said for insects from the order Diptera. Low p-values ($p=0.0003, \alpha=0.05$ in PP and $p<0.0001, \alpha=0.05$ in PPT) would likely suggest fewer observations of these insects in PP and PPT treatments. A very high p-value ($p=0.8697, \alpha=0.05$) in NP treatments likely suggests a higher number of insects collected in areas with no treatment (NP).

Individual plants were not observed in this study for specific populations. Direct observation was not made as to which insects were responsible for pollination of the 'Howden' pumpkins. However, a combination of both predator and pollinator insects were found at both locations (Table 2.4). Total PPT treated replicates contained 47.28% of all insects collected and all PP treated replicates contained 45.86% of all insects collected. A total of 6.88% of the insects collected were found in replicates treated with NP.

### Impact of Perimeter Trap Crop and Pollinator Strips on Pumpkin Yield

We confirmed our hypothesis that the presence of the PPT or PP planting would significantly increase pumpkin yields. This was observed by analyzing the total pumpkin harvested weight data for the fixed effect treatment ($F = 6.48$; df = 1, 10; $P < 0.0157$).

The fixed effect location had no significant impact on yield. Data were next analyzed by treatment. Fruit was collected from PPT, PP and NP treatments and measured for weight and yield. The comparative mean (± SEM) analysis of fruit data can be found on Table 2.5.

When comparing the three treatments, we observed that the PPT had significantly higher total weight than the NP treatment (t = 3.56; df = 1, 10; P < 0.0130). There were no significant differences observed among either the NP and PP treatments or the PP and PPT treatments. These data would suggest the presence of a treatment containing a pollination mixture and trap crop (PPT) increased fruit weights. The analysis of total fruit counts (using Generalized Linear Mixed Effects Model) showed just having any type treatment (NP, PP or PPT) was not significant in looking at the total number of fruit produced. Because the treatment effect was nearly significant (F = 3.91; df = 1,10; P = 0.0555) data were analyzed by treatment.

The comparison of means for each treatment type against each other with the Tukey-Kramer adjustment revealed that there were no significant differences among the treatments. The PPT treatment had marginally more fruit produced when compared to the NP treatment (*t* = 2.74; df = 1, 10; *P = 0.0504*). No other differences were observed among the treatments. This indicates that although not significant the use of the PPT treatment may improve pumpkin fruit set when compared to the NP treatment.

## DISCUSSION

The results of this experiment found less squash vine borer damage in cash crops of ‘Howden’ pumpkins surrounded by a perimeter trap crop (PPT) of ‘Hubbard’ squash than in cash crops of ‘Howden’ pumpkins not surrounded by a trap crop (PP and NP). This is consistent with a similar experiment which studied using ‘Hubbard’ squash as a trap crop for cucurbit pests (Boucher and Durgy 2004) and appears to support evidence in Adam’s (2006) study which indicate the largest amount of squash vine borer injury is found in crops of ‘Hubbard’ squash. This is important information for small pumpkin producers who are looking for an inexpensive and non-chemical option to protect their pumpkin crops from squash vine borer larvae damage.

More fruit was harvested in five of six replicates of a cash crop of ‘Howden’ pumpkins surrounded with pollinator treatments than in crops of ‘Howden’ pumpkins treated with NP in this trial. Pumpkin production relies heavily on the pollination activities of pollinating insects (Phillips and Gardiner 2015). This indicates it is quite likely the addition of a pollination perimeter, mixed with a trap crop or on its own, around ‘Howden’ pumpkin crops did a better job in drawing in beneficial pollination insects which successfully pollinate more flowers than ‘Howden’ pumpkin crops not benefited with the addition of a pollination perimeter.

The difference in the number of fruit produced; however, was not great enough to support the hypothesis that PPT or PP treatment is responsible for the increase. There was no significant difference in fruit weight between PPT and PP in this study, however, there were observed differences between the PPT and the NP treatments. This may indicate that the PPT treatment had some benefit. Further study is warranted to determine how to synchronize cash crop and wildflower pollination mixture flowering time. Fruit totals between replicates treated with PPT, PP or NP were significantly different which indicates the use of a wildflower pollination mixture appears to promote increased fruit production, which is consistent with similar research experiments (Stanghellini et al. 1998, Artz et al. 2011, Artz and Nault 2011).

Across both locations (N.E. Hansen Research Site and Berndt Farms), the PPT treatment had fewer squash vine borers in the ‘Howden’ pumpkins. A total of 51 squash vine borer larvae were found in this study and of that total, only four were found in areas with PPT treatments. The results indicate a strong likelihood in the value of using PPT as a treatment for squash vine borer management versus PP or NP treatments.

The implementation of a pest management plan using ‘Hubbard’ squash as a trap crop in commercial operations requires further study. Its effectiveness beyond a 9.1 m squared area requires continued research into trap cropping methodologies, including large scale perimeters and row trapping. A more in depth analysis of insect ecologies and populations within pollination strips would need to be conducted to fully understand pollination methods. Developing an understanding of an individualized wildflower pollination strips as a long-term habitat and perennial forage source for insect pollinators relative to cucurbit crops would be necessary to properly measure its effectiveness.

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## TABLES

**Table 2.1.** Wildflower Pollinator Mixture for PP and PPT treatments.

| Species | Percent of Mixture by Weight | Pounds per Acre |
|---|---|---|
| Phacelia (*Phacelia tanacetifolia*) | 10 | 0.70 |
| Safflower (*Carthamus tinctorius*) | 10 | 3.00 |
| Buckwheat (*Fagopyrum esculentum*) | 20 | 10.0 |
| Sunflower (*Helianthus annum*) | 10 | 1.00 |
| Partridge Pea (*Chamaecrista fasciculate*) | 3 | 0.60 |
| Mustard (*Sinapis*) | 5 | 0.25 |
| Alfalfa (*Medicago sativa*) | 10 | 1.50 |
| Sainfoin (*Onobrychis*) | 5 | 2.50 |
| Alsike Clover (*Trifolium hybridum*) | 10 | 0.60 |
| Ladino Clover (*Trifolium repens*) | 10 | 0.25 |
| Black-Eyed Susan (*Redbeckia hirta*) | 2 | 0.05 |
| Red Clover (*Trifolium pretense*) | 5 | 0.25 |
| **TOTALS** | **100** | **20.70** |

**Table 2.2.** Mean (± SEM) Squash vine borer larvae population by location and treatment.

| Factors | N.E. Hansen Research Site | Berndt Farms | Combined Locations |
|---|---|---|---|
| **Mean (± SEM) SVB by Location** | 10.0 ± 1.87 | 5.50 ± 0.50 | 8.50 ± 1.82 |
| | **PPT** | **PP** | **NP** |
| **Mean (± SEM) SVB by Treatment** | 0.67 ± 0.33 | 3.67 ± 0.92 | 4.17 ± 0.54 |

*SEM = standard error of means*

**Table 2.3.** Abundance distribution of insects in PPT, PP and NP treatments by Order.

| | Treatment | | |
|---|---|---|---|
| **Order** | **PPT** | **PP** | **NP** |
| Coleoptera | 22 | 27 | 3 |
| Diptera | 54 | 31 | 7 |
| Hemiptera | 63 | 84 | 11 |
| Hymenoptera | 11 | 15 | 3 |
| Neuroptera | 1 | 1 | 0 |
| Orthoptera | 4 | 2 | 0 |
| Totals | 155 | 160 | 24 |

*n= 4 replicates in each treatment*

**Table 2.4.** Abundance of natural enemy and pollinator populations by family.

| Insect | PPT | PP | NP |
|---|---|---|---|
| **Natural enemies** | | | |
| *Coleoptera* | | | |
| Cantharidae (Solider Beetle) | 5 | 21 | 2 |
| Coccinelidae Larvae (Lady Beetle) | 0 | 2 | 0 |
| Coccinelidae Adults (Lady Beetle) | 1 | 0 | 0 |
| *Diptera* | | | |
| Asilidae (Robber Fly) | 1 | 2 | 1 |
| Dolichopodidae (Long-Legged Fly) | 6 | 3 | 2 |
| *Syrphidae (Hover Fly) | 3 | 2 | 0 |
| *Hemiptera* | | | |
| Nabidae (Damsel Bug) | 2 | 3 | 0 |
| *Hymenoptera* | | | |
| Braconidae (Parasitoid Wasp) | 8 | 1 | 1 |
| Chalicididae (Chalcid Wasp) | 0 | 1 | 1 |
| Ichneumonidae (Ichneumon Wasp) | 0 | 1 | 0 |
| *Neuroptera* | | | |
| Chrysopidae (Green Lacewings) | 1 | 1 | 0 |
| **Total** | **27** | **37** | **7** |
| | | | |
| **Pollinators** | | | |
| *Diptera* | | | |
| Syrphidae (Hover Fly) | 3 | 2 | 0 |
| *Hymenoptera* | | | |
| Apidae (Small Bee) | 1 | 4 | 0 |
| Halictidae (Sweat Bees) | 0 | 1 | 0 |
| **Total** | **4** | **7** | **0** |

*n= 4 replicates in each treatment*
**Larval*

**Table 2.5.** Comparative mean (±SEM) analysis of fruit data.

| | Treatments | | |
|---|---|---|---|
| **Mean Individual (± SEM) Fruit Weight per Treatment (kg)** | **PPT** | **PP** | **NP** |
| N.E. Hansen Research Site | 8.54 ± 0.89 | 9.80 ± 0.38 | 8.58 ± 0.33 |
| Berndt Farms | 9.46 ± 0.35 | 9.41 ± 0.26 | 7.35 ± 1.21 |
| **Mean Total (± SEM) Fruit Weight per Treatment (kg)** | **PPT** | **PP** | **NP** |
| N.E. Hansen Research Site | 138.05 ± 28.54 | 132.81 ± 35.76 | 87.66 ± 24.85 |
| Berndt Farms | 164.70 ± 50.94 | 102.65 ± 25.26 | 71.85 ± 20.59 |
| **Mean (± SEM) Fruit Yield (#) per Treatment** | **PPT** | **PP** | **NP** |
| N.E. Hansen Research Site | 16.00 ± 2.08 | 13.50 ± 3.52 | 10.00 ± 2.74 |
| Berndt Farms | 17.00 ± 5.00 | 11.00 ± 3.00 | 11.50 ± 3.50 |
| Combined Locations | 16.33 ± 1.86 | 12.67 ± 2.42 | 10.50 ± 1.98 |

*SEM = standard error of means*

# FIGURES

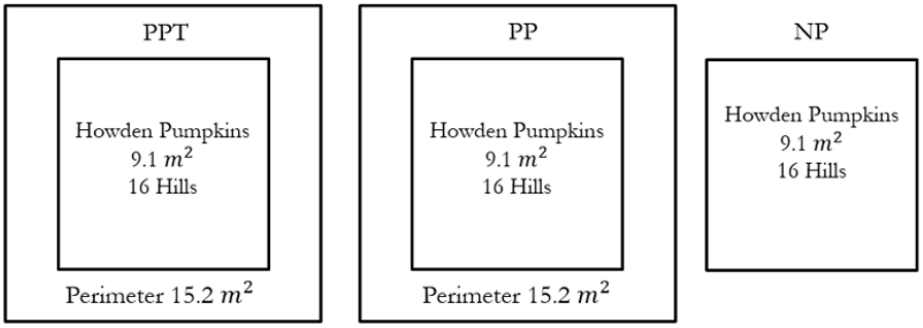


Figure 2.1. The plot layout that was used for the project. The pumpkin cultivar Howden was used for this experiment. Spaces in between perimeters represents bare soil.

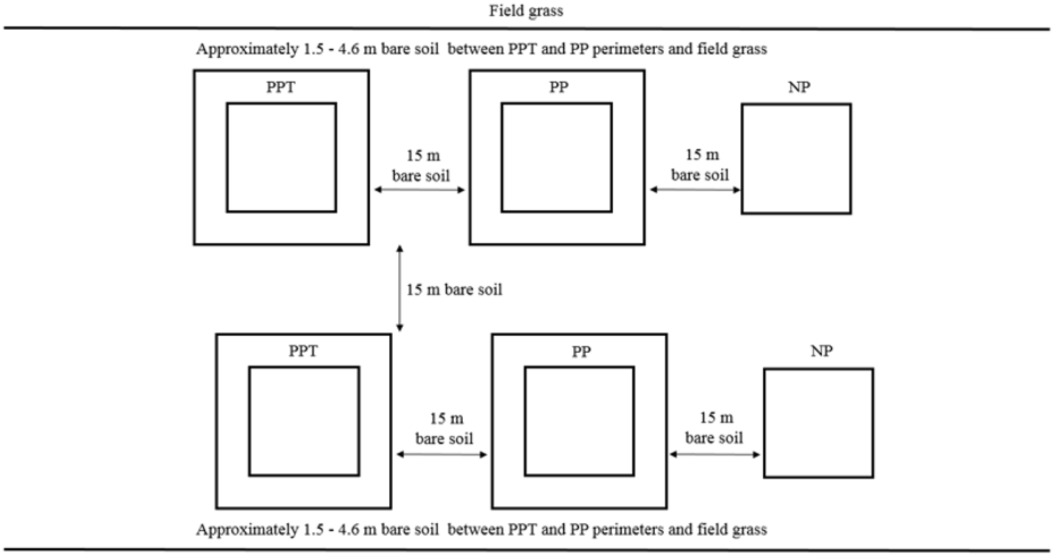
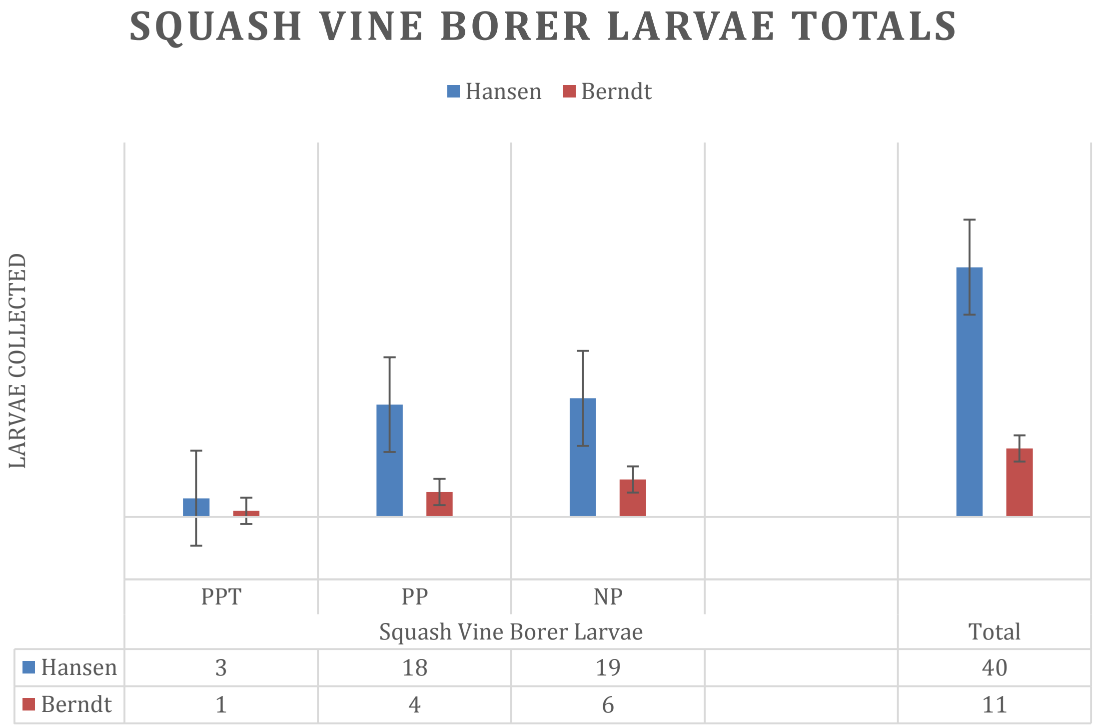


**Figure 2.2:** 2015 Study Layout Example. Distance between planting soil and field grass varied by location due to field shapes.



| | PPT | PP | NP | | Total |
|---|---|---|---|---|---|
| 🟦 Hansen | 3 | 18 | 19 | | 40 |
| 🟥 Berndt | 1 | 4 | 6 | | 11 |

Figure 2.3: The total squash vine borer larvae count by treatment and location.

# CHAPTER 3. SUMMARY

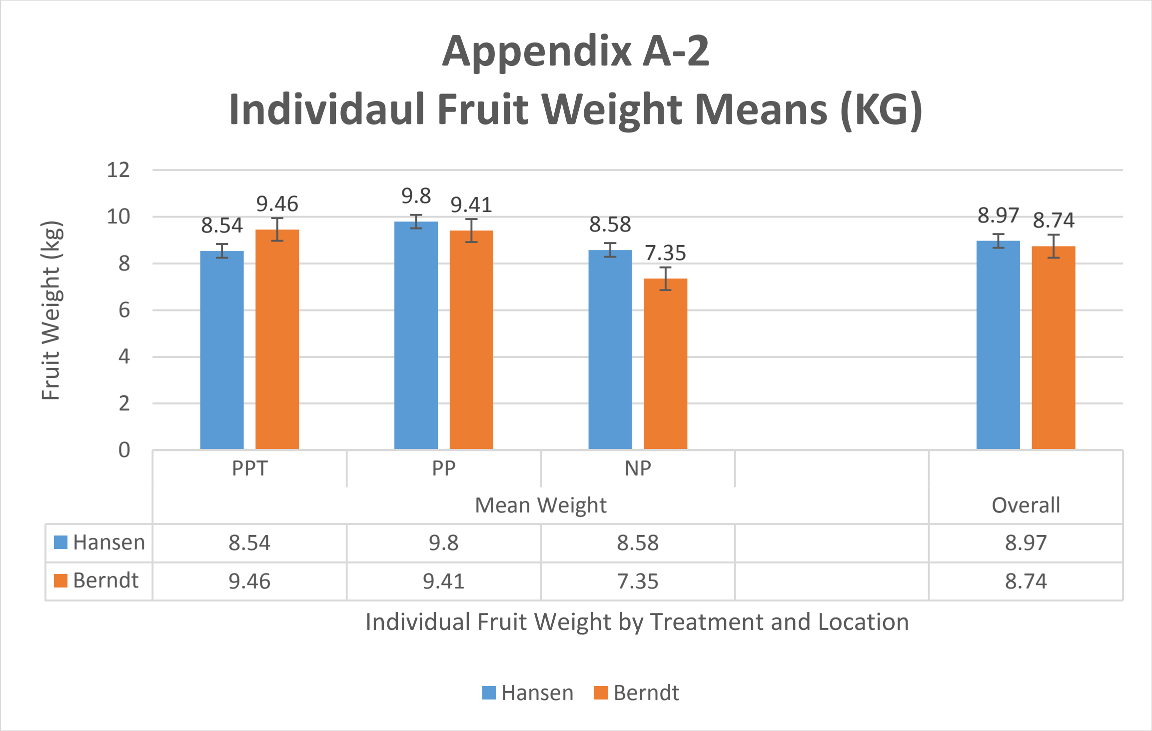
The squash vine borer is known to cause damage to cucurbit crops that can often have an economic impact. The rise in consumer demand for fruits and vegetables with fewer chemicals applied has prompted producers to find new methods of pest management. One of the objectives of this study was to determine whether perimeter trap cropping with ‘Hubbard’ squash was an effective management practice for reducing squash vine borer damage to pumpkins. Results of this particular study found that using perimeter trap cropping reduced squash vine borer presence and also significantly impact yield. This information will prove beneficial to small cucurbit producers, including home gardeners, interested in pumpkin production. The techniques applied in this study are not limited to the production of the ‘Howden’ variety of pumpkin. Producers will likely find success using this method with most medium sized pumpkins, summer squash or other crops affected by squash vine borer.

A second objective of this study was to determine whether the use of a wildflower pollination mixture as a perimeter would result in an increase in fruit yield. Understanding the relationship between the cash crop, pollination mixture, phenology of insects, and the environment is crucial to the success of using a pollination program. A higher fruit yield was achieved during this study in replicates surrounded by a wildflower pollination mixture treatment than replicates surrounded by a bare soil treatment, but the difference in fruit produced was not great enough to show overall economic value for pumpkin patches the size of those used for this study. The ratio of fruit produced in this study (8:5 PPT vs. NP), would indicate the possibility exists for a greater economic impact in large scale pumpkin patches. However, further research would have to be conducted to determine the effectiveness of trap crop location in relation to the cash crop. Additional studies into using the same methodology of trap cropping used in this study with the modification of trap strips in rows within a large pumpkin patch would be warranted. Further, there was no discernable increase of fruit weight found for the pumpkins with wildflower pollination mixture perimeters. To fully understand the measurement of this wildflower pollination strip as an overall benefit to pollination of the crash crop ‘Howden’ pumpkins, greater analysis of insects collected should be considered, e.g., habitat stability, foraging habits and relationships between insect and plant should be explored.

The interest in the health benefits of pumpkin have risen considerably in recent years. This increase in consumer demand goes hand in hand with the desire for more organically-produced, locally-grown produce. In the Midwest, many pumpkins are still grown at small production levels and methods of this study can be applied to reduce the number of crop damaging squash vine borers. With fewer squash vine borers in their crops, producers will likely experience less plant mortality, thus increasing fruit yields within their fields.

# APPENDIX

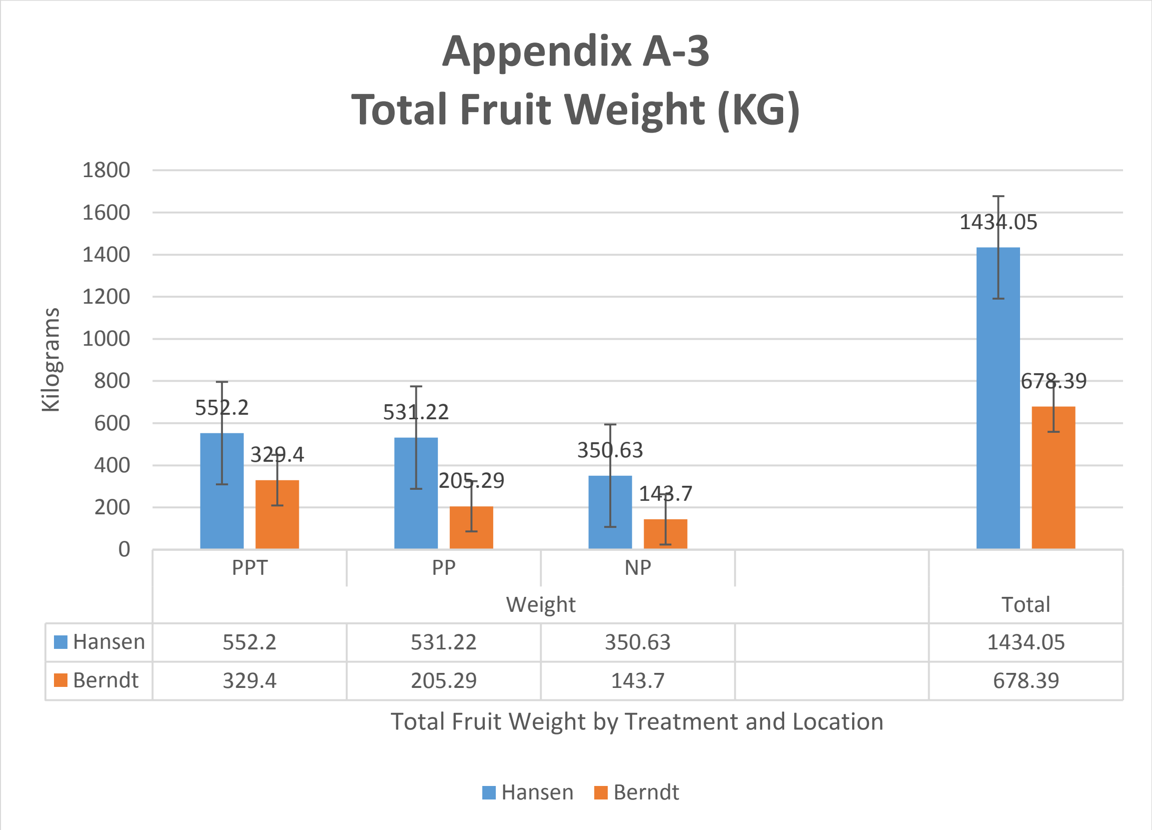
**Appendix A-1**: N.E. Hansen Research Site, Brookings County, SD. White and blue arrows indicate PPT and PP design. *Photo courtesy of Google Maps 2015*.



## Appendix A-2
## Individaul Fruit Weight Means (KG)

| | PPT | PP | NP | | Overall |
|---|---|---|---|---|---|
| | Mean Weight | | | | |
| 🟦 Hansen | 8.54 | 9.8 | 8.58 | | 8.97 |
| 🟧 Berndt | 9.46 | 9.41 | 7.35 | | 8.74 |

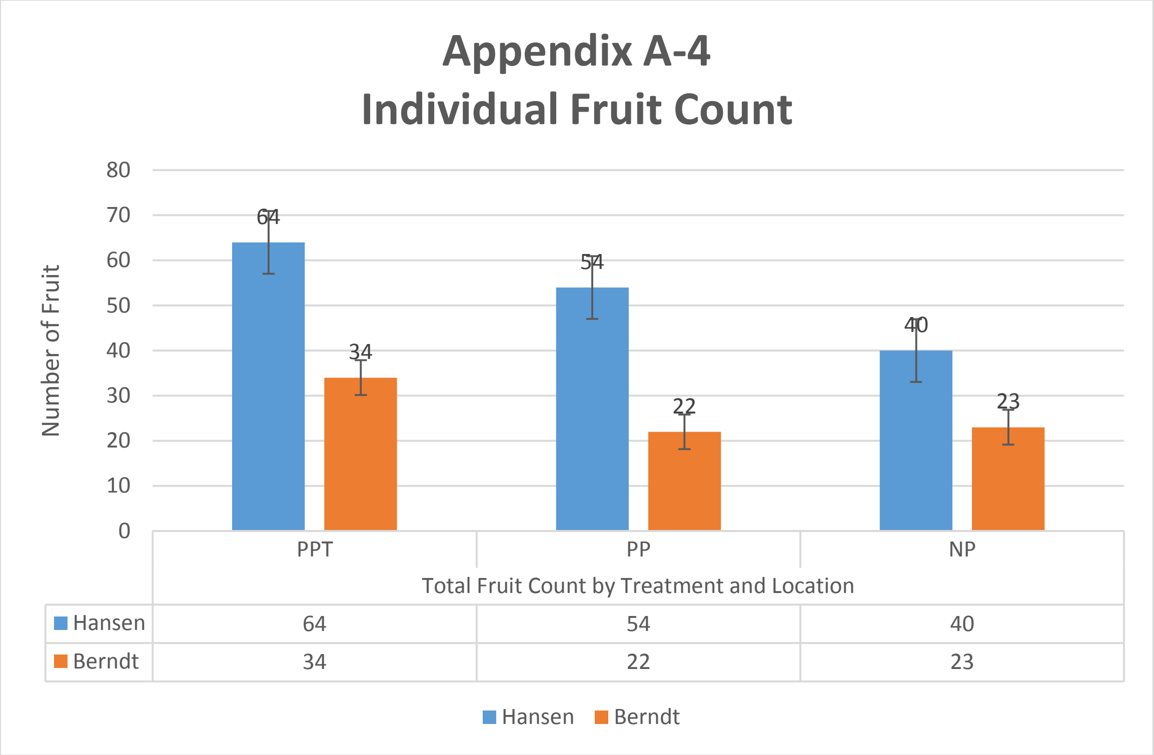
Individual Fruit Weight by Treatment and Location



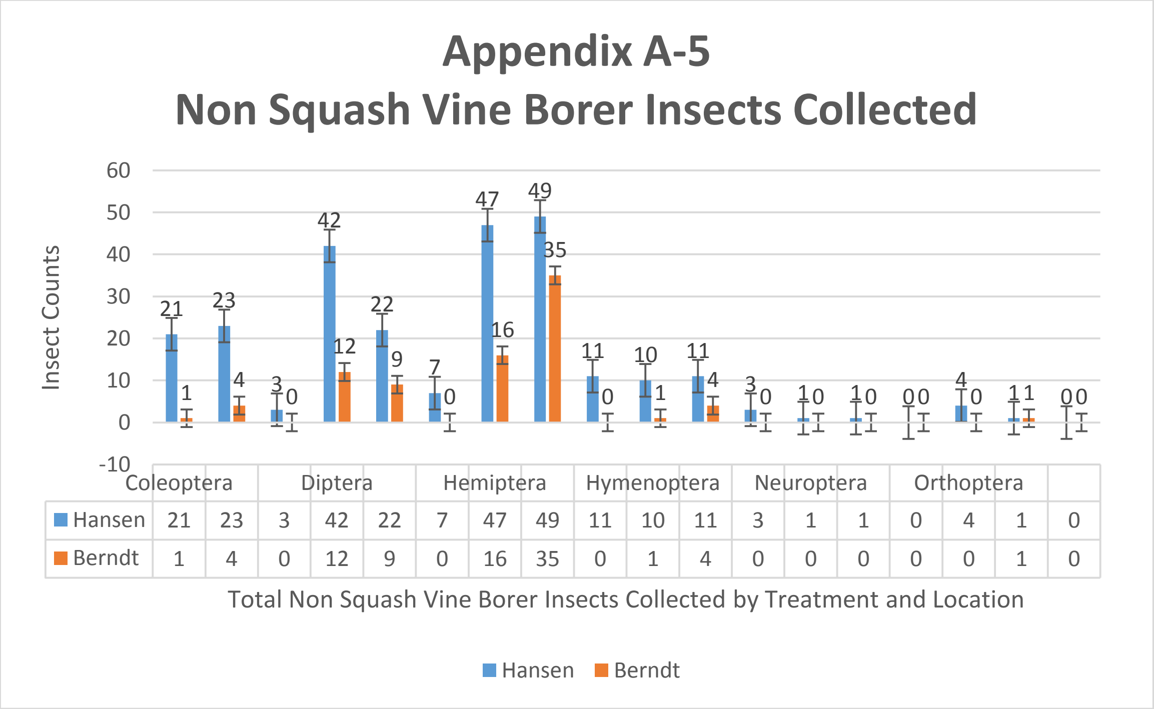
## Appendix A-3
## Total Fruit Weight (KG)

| | PPT | PP | NP | | Total |
|---|---|---|---|---|---|
| | Weight | | | | |
| 🟦 Hansen | 552.2 | 531.22 | 350.63 | | 1434.05 |
| 🟧 Berndt | 329.4 | 205.29 | 143.7 | | 678.39 |

Total Fruit Weight by Treatment and Location



|  | PPT | PP | NP |
|---|---|---|---|
| 🟦 Hansen | 64 | 54 | 40 |
| 🟧 Berndt | 34 | 22 | 23 |



|  | Coleoptera |  | Diptera |  |  | Hemiptera |  |  | Hymenoptera |  |  | Neuroptera |  |  | Orthoptera |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 🟦 Hansen | 21 | 23 | 3 | 42 | 22 | 7 | 47 | 49 | 11 | 10 | 11 | 3 | 1 | 1 | 0 | 4 | 1 | 0 |
| 🟧 Berndt | 1 | 4 | 0 | 12 | 9 | 0 | 16 | 35 | 0 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |